Impact of Time-of-Use Tariff Policies on Electric Vehicle Charging Behavior and Power System Operation in Beijing

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Overview

China is the largest producer and the largest consumer of electric vehicles worldwide. Increasing number of electric vehicles have presented an opportunity to facilitate the integration of renewable energy and accelerate the low-carbon transformation. However, uncontrolled charging of electric vehicles could increase power system costs, lead to increase in emisisons of greenhouse gases and other air pollutants, and even jempodise the stability of power grids, as presented by previous studies focused on developed countries.

This study focuses on evaluating the impact of electric vehicle (EV) charging on the operation of power systems in Beijing, the capital city and the 2nd largest city in China. It investigates the impact of EV charging in three different time periods—the past (2018), the present (2025), and the future (2030)—considering various scenarios involving EV charging behaviors and time-of-use pricing policies. The study employs multiple models to predict the number of EVs and assess the implications of different charging strategies on the load. The research explores the potential benefits of coordinated charging and peak-valley pricing in managing power generation across time.

Methods

The study employs a multi-method approach to assess the impact of electric vehicle (EV) charging behavior on power system operation under peak-valley pricing policies. First, actual EV operation and charging data in 2018 is utilized to model charging behavior considering different levels of behavioral responses. This analysis encompasses the influence of the policy responsiveness on the power system load curve, taking into account factors such as charging start times and daily mileage. Subsequently, the growth of EVs in Beijing is forecasted for the years 2025 and 2030 using Logistic, Bass, and polynomial regression models. These models provide insights into the potential scale of EV impact on the power system. Finally, a power system dispatch model is developed to simulate the cost-minization optimal operation of power systems in Beijing and West Inner Mongolia over an 8760-hour period. This simulation considers different EV charging scenarios to investigate the impacts of varying EV stocks predictions, charging behaviors, and time-varying electricity price policies. We then compare the resulting system-level impacts such as load curves, renewable energy integration, and system costs.

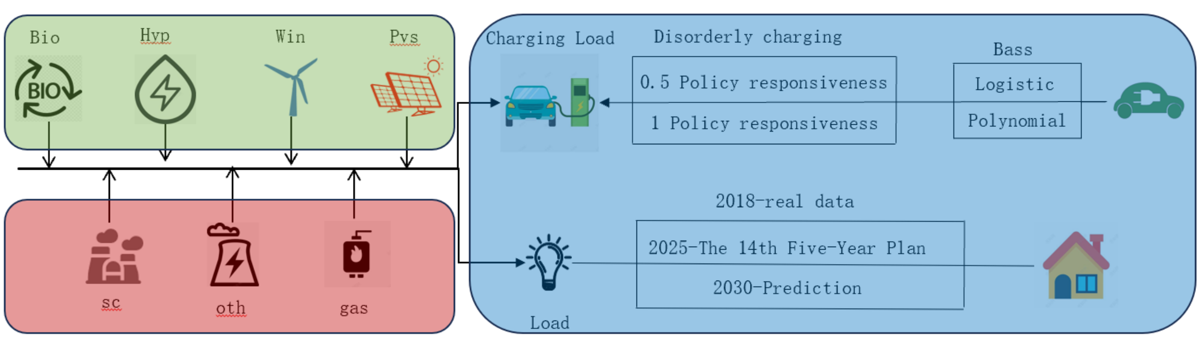

Fig 1. Schematic representation of the EV-grid interconnected systems.

Results

The total EV fleet in Beijing is predicted to reach 2,580,000 by 2030 according to the Logistic Model, with a market saturation point of 4,053,046 vehicles. The Bass Model forecasts the total EV fleet to be 1,850,000 by 2030, while the Polynomial Regression Model projects 6,010,000 by 2030. A linear prediction based on current policy (limited allocation of vehicle licence plates) projects 1,500,000 by 2030.

In Beijing, the peak charging load during the evening hours (20:00 - 24:00) was 41.47 MW without peak-valley pricing, with a valley load of 5.41 MW during the early morning (06:00 - 08:00), resulting in a peak-valley difference of 36.05 MW. With the current peak-valley pricing policy, the peak load during the afternoon (13:00 - 15:00) increases to 31.26 MW, while the evening peak load decreases to 32.59 MW, reducing the overall peak-valley difference to 20.95 MW.

The total power system cost decreased from 52,091 million RMB to 52,067 million RMB with peak-valley pricing in 2018, a reduction of 0.05%. In 2025, costs decrease to 89,852 million RMB (conservative EV growth) and 89,855 million RMB (rapid EV growth), representing reductions of 0.04% and 0.03%, respectively. In 2030, costs decrease to 71,505 million RMB (conservative EV growth) and 72,378 million RMB (rapid EV growth), indicating reductions of 0.02% and 0.01%, respectively.

Peak loads in the power system decreased from 6,061 MW to 6,022 MW in 2018, 8,244 MW to 8,141 MW in 2025, and 9,327 MW to 9,321 MW in 2030 under controlled charging. EV charging during off-peak hours led to a 22.5 billion kWh increase in wind power generation and a 2.8 billion kWh increase in solar power generation. Total operating costs of the power system reduced by 0.13 billion RMB in 2018, 0.28 billion RMB (conservative EV growth) and 0.35 billion RMB (rapid EV growth) in 2025, and 0.69 billion RMB (conservative EV growth) and 1.04 billion RMB (rapid EV growth) in 2030.

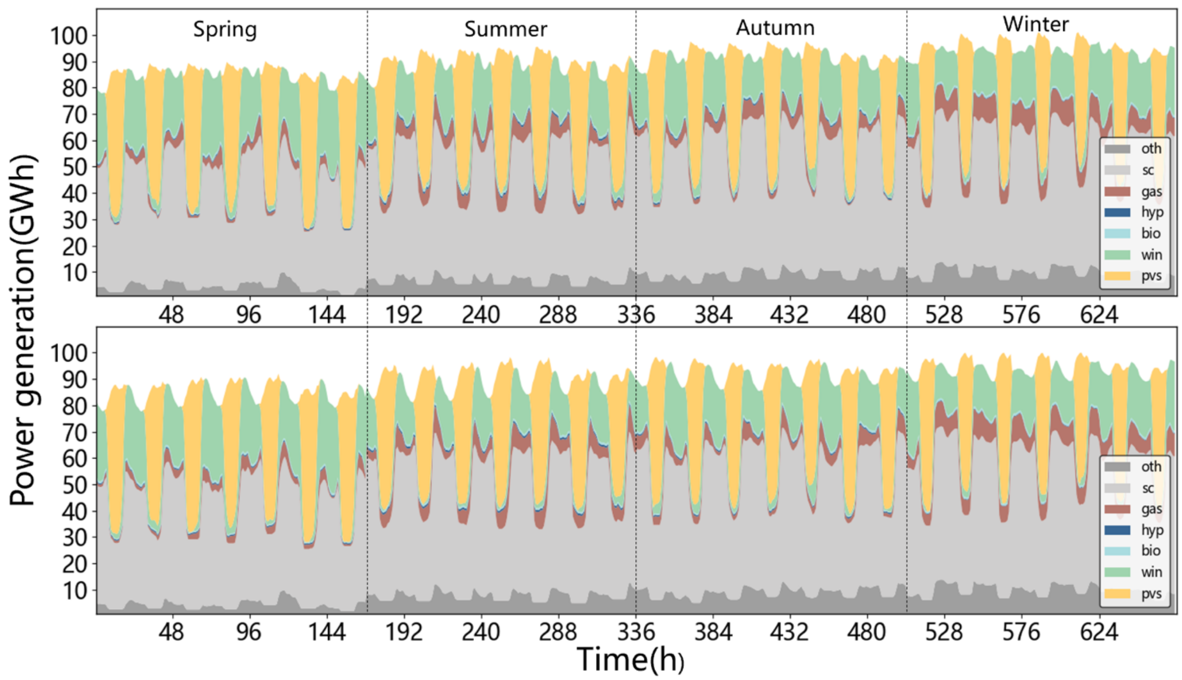

Fig 2. Selected week-long dispatch results of power systems over four seasons in 2030: uncontrolled charging (top panel), controlled charging (bottom panel).

Conclusions

The study finds that peak-valley pricing policies are effective to manage the impact of EVs on power systems. These policies not only reduce peak loads to enhance grid stability but also promote the integration of renewable energy and reduce system costs. The study recommends the implementation of dynamic pricing strategies and the development of smart charging infrastructure to further optimize the integration of EVs into the power system.

References

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