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Quantifying Benefits of EV Smart Charging: Zhejiang as a Representative Chinese Province

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Project Description

This slide deck presents the China section of RAP's global project on quantifying the benefits of EV smart charging. The modeling analysis was supported by Dr. Zhang Shuwei from the Draworld Environment Research Center. Special thanks are extended to Max Dupuy and Julia Hildermeier for their invaluable feedback and comments.

The author assumes full responsibility for any errors or omissions in this presentation.

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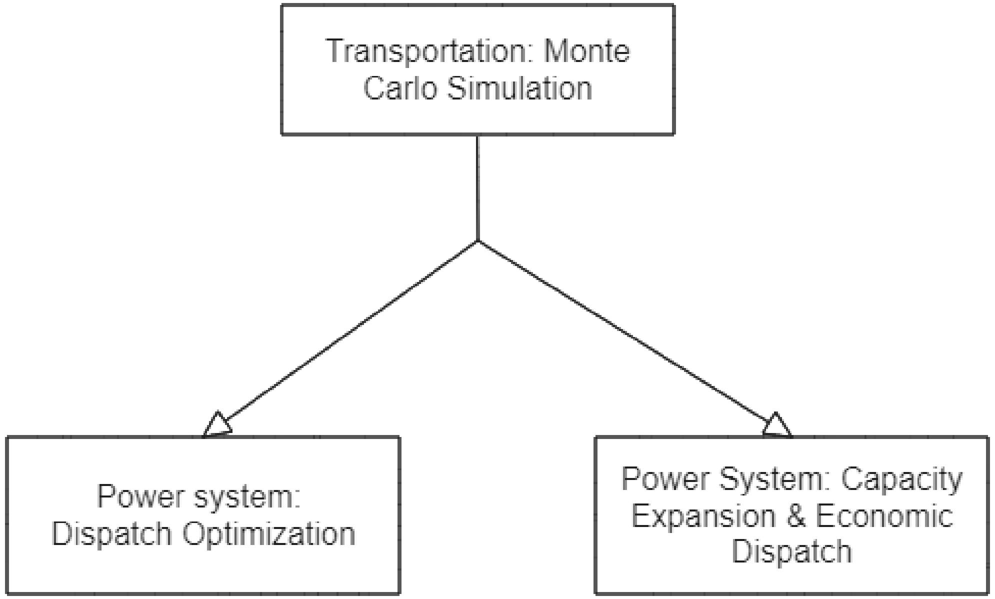
Model Description

High Level Model Components



	Transportation	Power: Dispatch Optimization	Power: Capacity Expansion & ED
Inputs	EV characteristics, Charging behaviors	EV Charging Flexibility Potential, Load Curve	Load Curve, Existing & Future Generation Stock & Costs
Method	Monte Carlo Simulation	Convex Optimization	Capacity Expansion & Economic Dispatch
Objective(s)	EV Charging Flexibility Potential Curves	Load smoothing, Renewable integration	Minimize Total System Costs

Mid-level Model Description

Charging Flexibility Potential Monte Carlo Simulation

Description:

- Utilize an agent-based model to compute EV charging flexibility bounds without compromising charging needs, based on:
  - EV charging behaviors
  - ICCT projections of future stock size
  - EV technology specifications

Steps:

1. Translate inputs into probability distributions.
2. Simulate charging sessions by drawing from these distributions.
3. Derive flexibility from the time window available for charging within each session.
4. Overlay charging sessions to create aggregate charging flexibility.
5. Determine upper and lower bounds of total charging flexibility.

Mid-level Model Description

Dispatch Optimization

Description:

- Optimize electric vehicle charging from system operator/dispatcher's perspective.
- System operator's main concerns include:
  - Reduce peak load
  - Smooth out the load and net load curves

Steps:

- Take cumulative charging boundaries as the main optimization constraints.
- Set optimization goals, which includes:
  - Minimize system ramp rate
  - Minimize system net ramp rate
  - Minimize overall system peak
  - Maximize green electricity share
- Solve the mathematical optimization problem given goals and constraints over the highest-peak day in 2040.

Mid-level Model Description

Capacity Expansion and Economic Dispatch

Description:

- Simulate power system hourly operation of the year 2040.
- Complex model that optimizes power system investment and operation decisions to maximize overall social welfare given capital and marginal costs under grid physical constraints.

Steps:

- Collect data on costs, existing capacity, renewable power endowment and load.
- Constrained by the need to meet load as well as the EV charging flexibility constraints, solve for power system investment decisions and operation decisions to minimize overall system costs.

Capacity Expansion & Economic Dispatch Model Detailed Explanation: Inputs

Projected Inputs:

- Load
- Variable Costs & Fixed Costs
- Existing resource capacity
- Extendability of resources
  - e.g., smaller coal-fired power plants are expected to be phased down in 2040

Status Quo Inputs:

- Capacity expansion limits
- Variable renewable energy capacity factor
- Emission intensity by resource type
- EV charging flexibility boundary

Capacity Expansion & Economic Dispatch Model Detailed Explanation: <u>Constraints</u>

The following must be true for all 8,760 hours:

- Energy balances: electricity supply must match demand.
- EV charging constraints: the cumulative charging curve must stay bounded and is monotonically increasing.
- Generation constraints: comply with capacity expansion and dispatch upper limits.

Capacity Expansion & Economic Dispatch Model Detailed Explanation: <u>Decision Variables</u>

- Hourly EV electricity charged.
- Capacity expanded for each type of resource.
- Hourly electricity generated for each type of resource.

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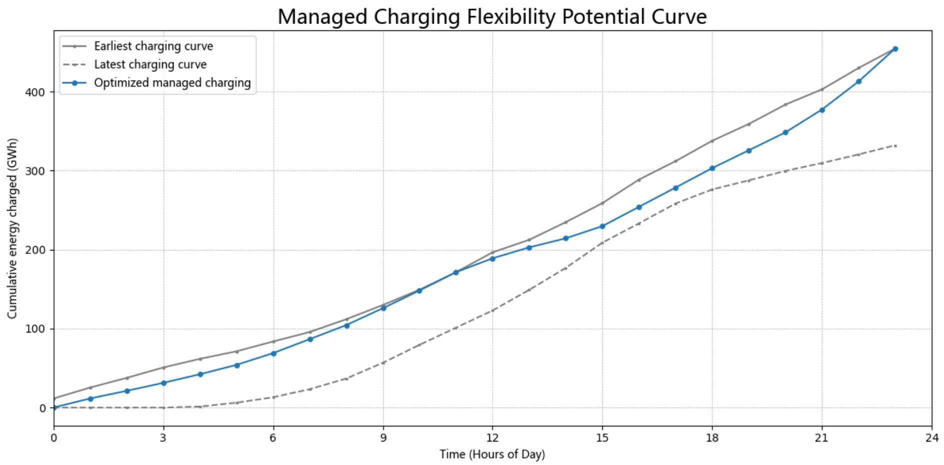
Dispatch Optimization Results

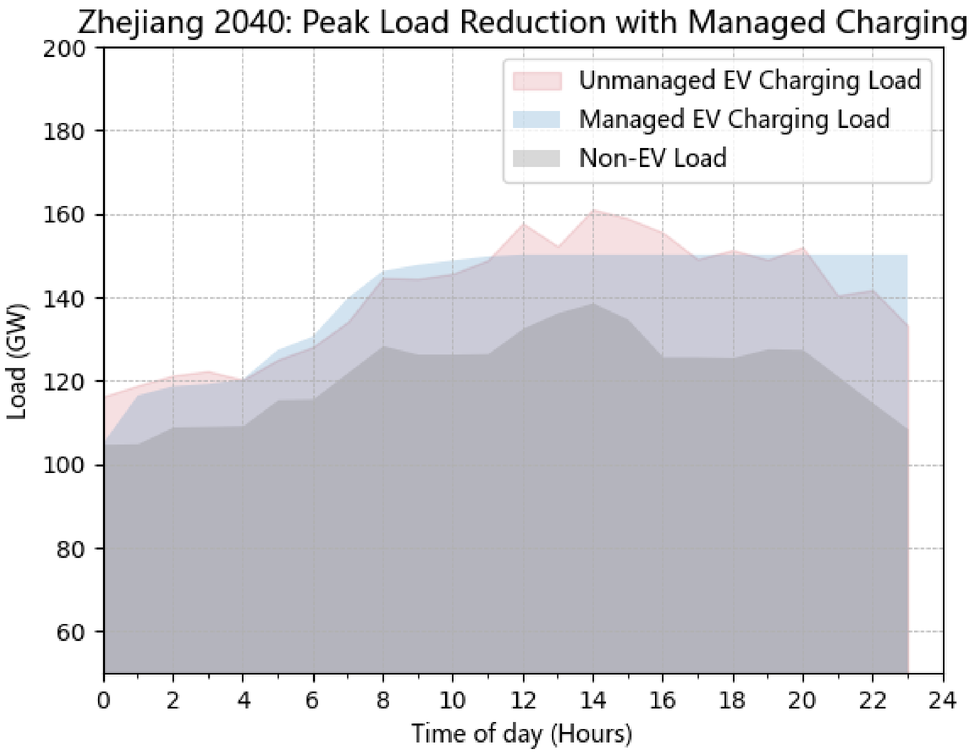
Dispatch Optimization Description

- The dispatch optimization model analyzed the role that managed charging can play from a system operator's perspective. Specifically, the analysis examined the following goals:
  - Ramp Rate Reduction
  - Overall System Peak Reduction
  - Net-load Peak Valley Differences Reduction
- The analysis focused on the projected peak demand day in 2040 in Zhejiang Province. The model optimized each goal independently, constrained by the charging flexibility potential curves.

Reduce Overall System Peak

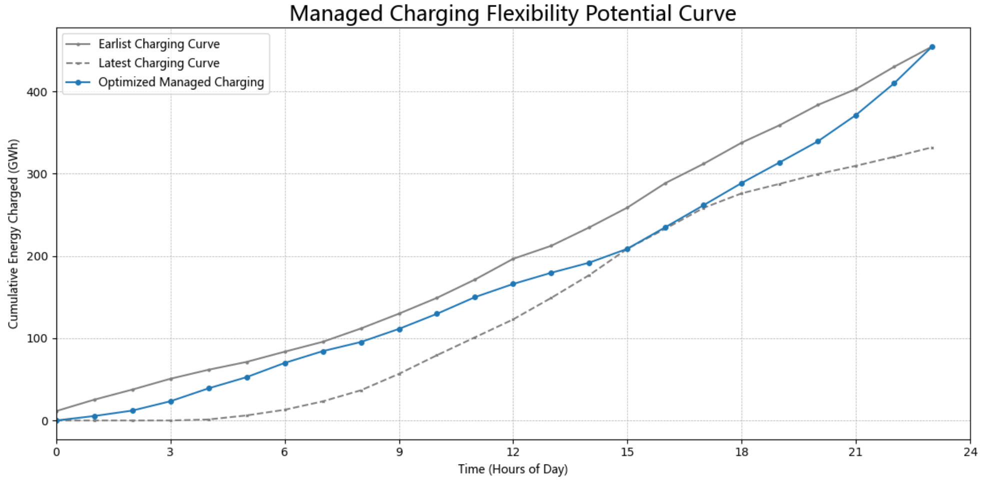
- The system peak represents the highest electricity demand on the grid during a specific time period.
- The top figure illustrates the Monte Carlo charging flexibility potential and cumulative charging load curve for the day with the highest projected demand.
- The bottom graph compares the system load profiles with and without managed EV charging, overlaid on other electricity demands.
- Managed charging **reduces overall system peak by 7%**.

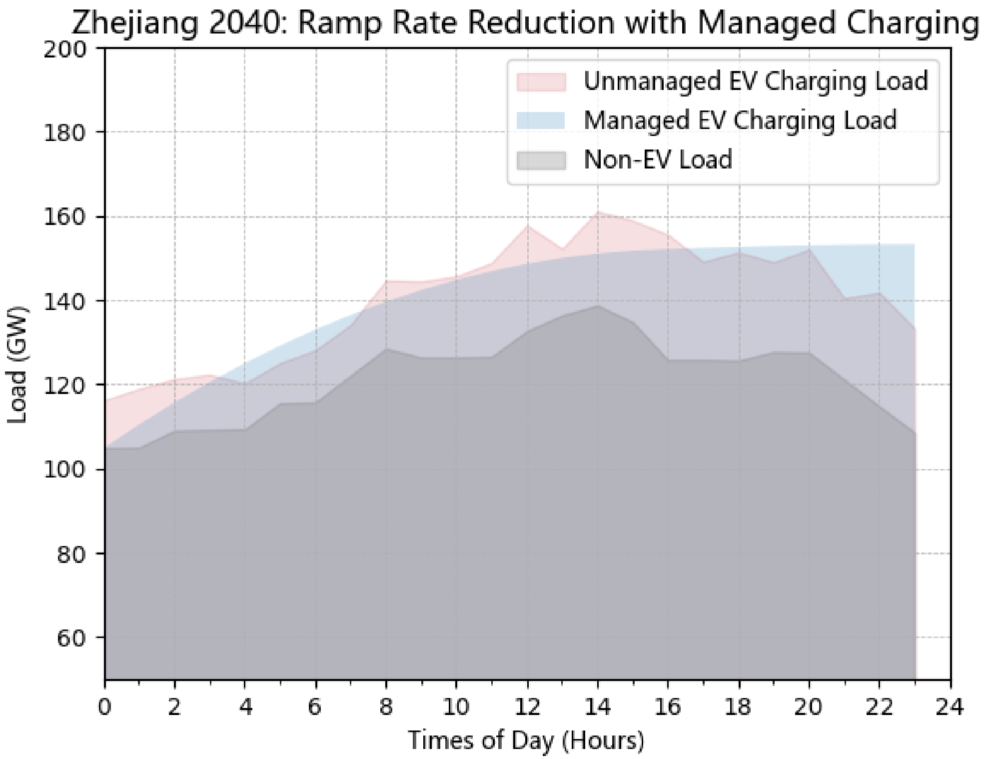




Reduce Ramp Rate

- Ramp rate refers to the speed at which the overall load curve increases or decreases over time.
- The top figure demonstrates the cumulative charging load curve for the peak demand day.
- The bottom graph compares the unmanaged and managed charging load curves, overlaid on top of other power demands.
- Managed charging **reduces the average ramp rate by 55%.**

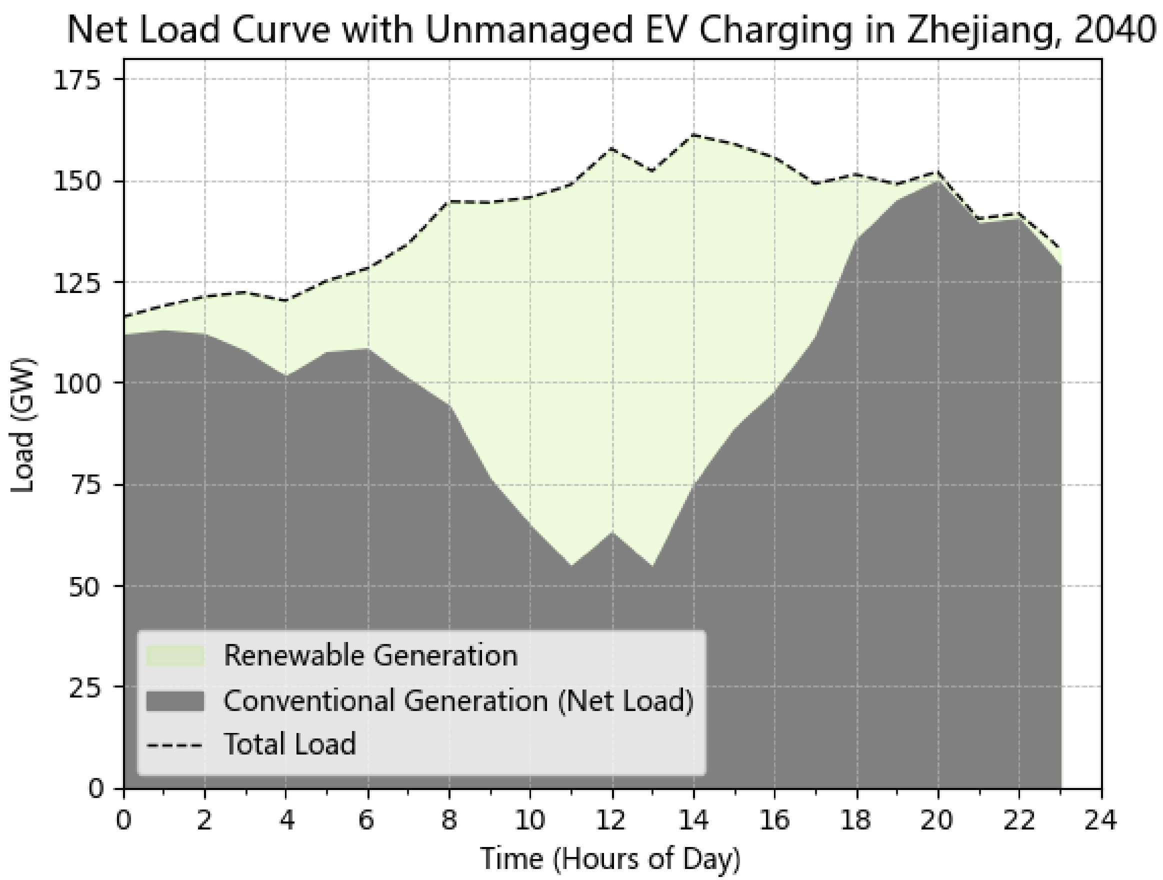


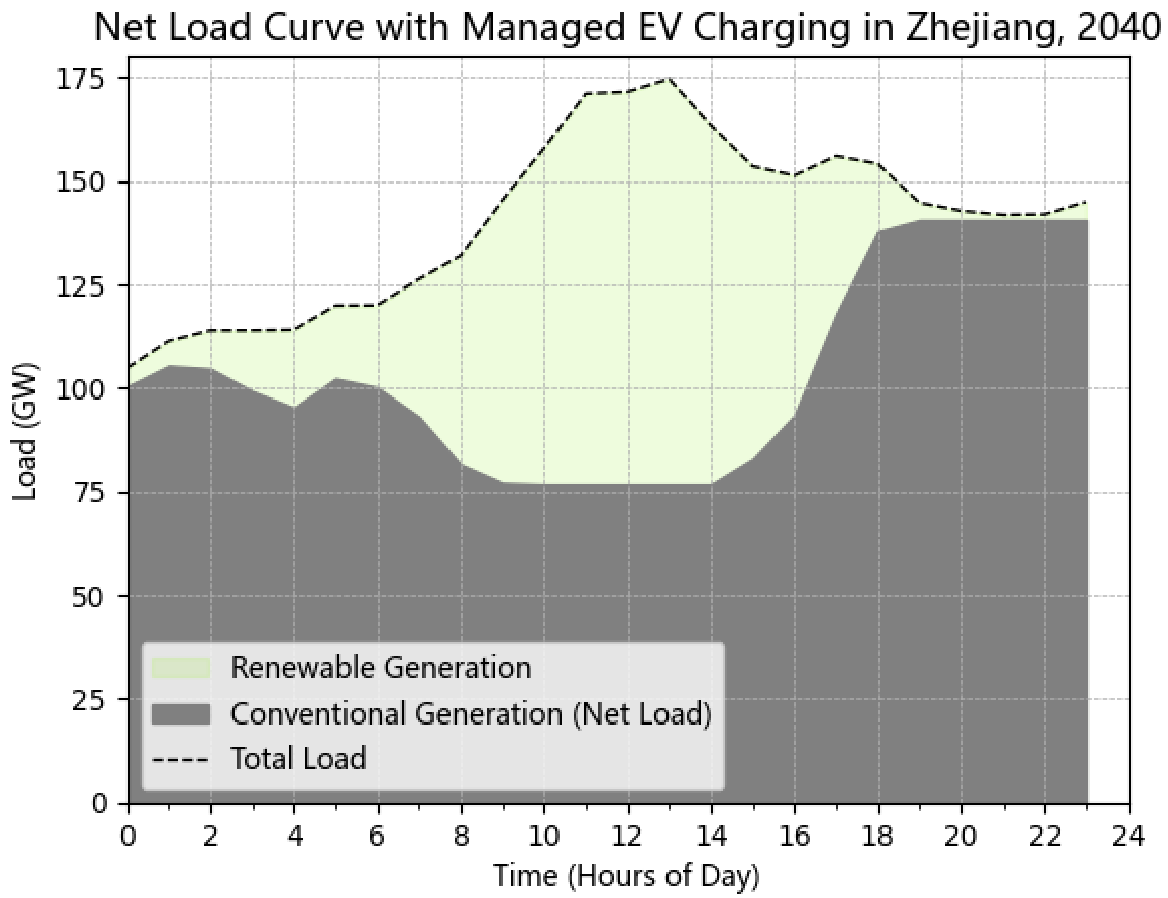


Reduce Peak-to-Trough Net Load

- Peak-to-trough Net Load is the gap between maximum and minimum electricity demand, after subtracting renewable generation. It indicates the demand to be met by other dispatchable resources.
- Managed charging reduces the **peak-to-trough net load by 33%,** resulting in a flatter overall net load profile.

Reduce Peak-to-Trough Net Load Graphics





Summary Table

Optimization Goals \ Outcomes	Peak Load Reduction %	System Average Ramp Rate Reduction %	Peak-to-Trough Net Load Differences %
Minimizes Peak Load	**6.8%**	52.33%	-4.5%
Minimizes System Average Ramp Rate	4.9%	**55.35%**	-1.2%
Minimizes Net Load Peak and Valley Differences	-8.4%	-13.25%	**33.1%**

Takeaways

- From the perspective of a system operator or dispatch center, EV managed charging as a system resource can play a pivotal role in achieving a more stable dispatch pattern. It can help reduce ramping rates, peak load and peak-to-trough net load — all while meeting users' charging needs without compromise.
- To enable these rapid responses, the widespread adoption of smart, automated charging control technologies is essential to fully unlock the flexibility potential of EVs.
- However, while reducing ramping rates and peak load are complementary goals, efforts to minimize net peak-to-valley differences may inadvertently increase both peak load and ramping rates.

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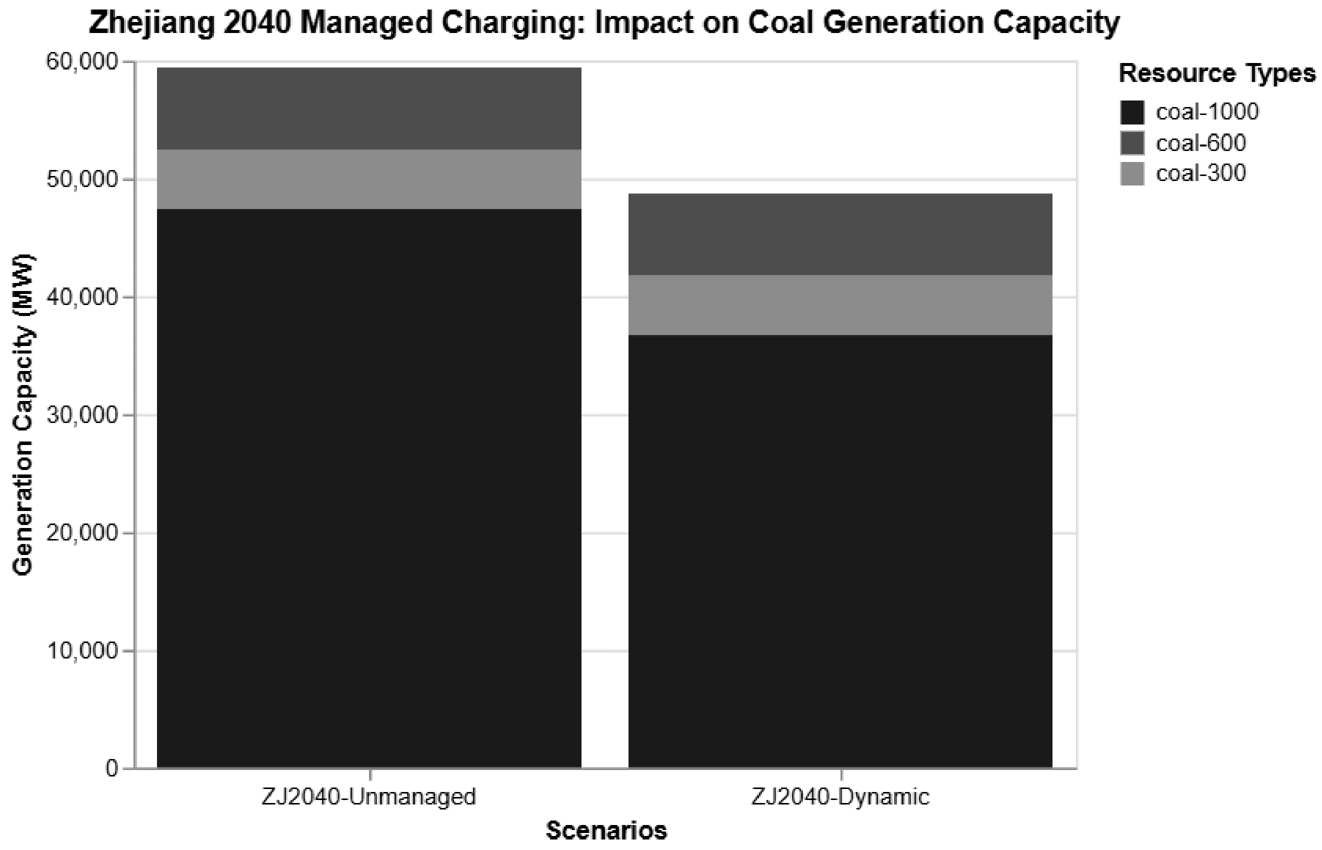
Capacity Expansion & Economic Dispatch Results

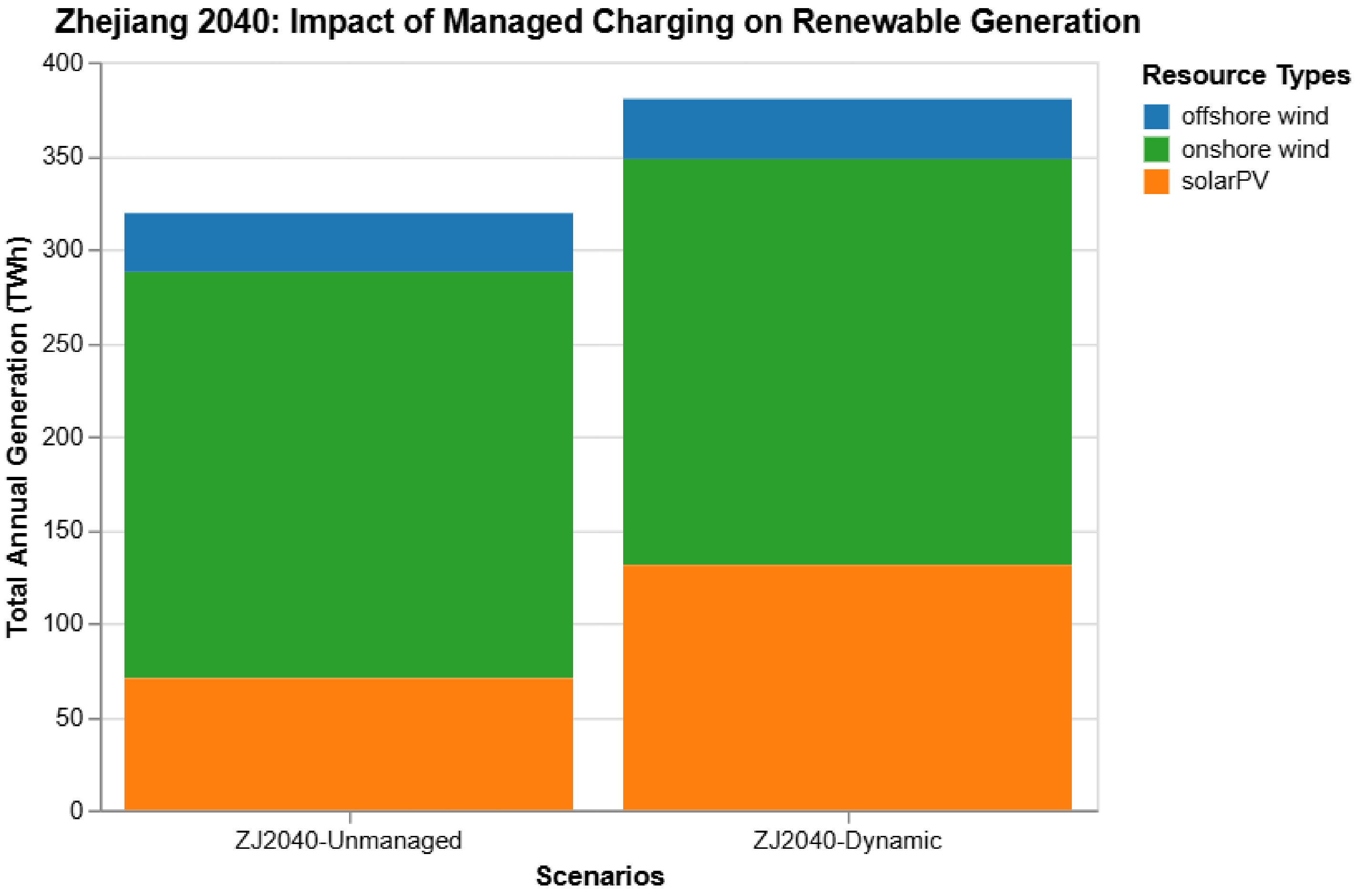
Coal Generation Capacity Reduction

- Managed charging (right) leads to a 17% reduction in coal generation capacity.
- Coal plants are categorized into three representative types based on their rated capacity.
- Reasons for the reduction:
  - Charging is scheduled during hours with more renewable generation, which has no fuel cost.



Renewable Energy Integration

- Managed charging leads to a 19% increase in renewable energy generation.
- Three types of renewable resources are considered: offshore wind, onshore wind and solar. Most of the increase comes from solar generation, and some from wind.
- Explanation: Charging can be coordinated to align with the generation profiles of solar and wind resources to enable more investment.



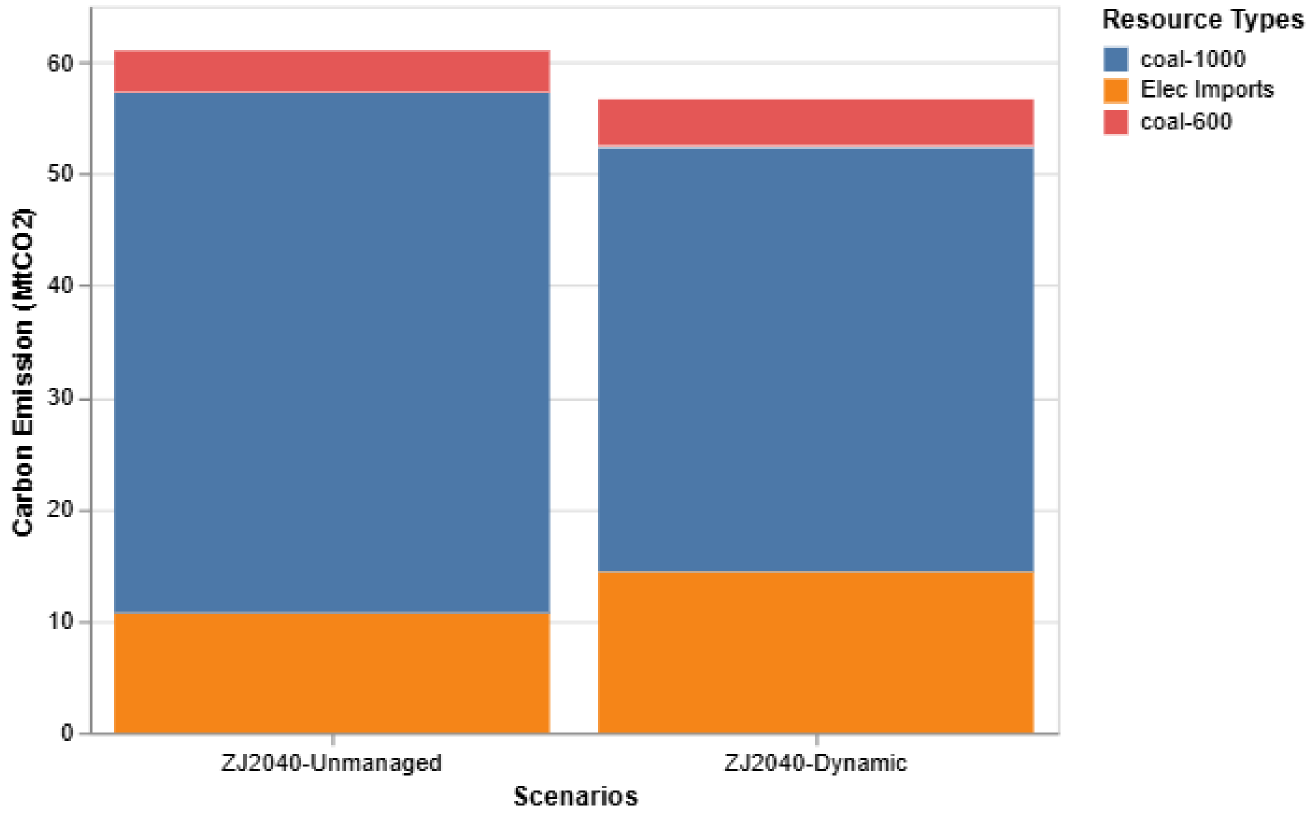
Costs Comparison

- Managed charging results in a total power system cost reduction of 2 billion yuan annually.
- In the managed charging scenario:
  - Higher upfront investment in renewable energy capacity.
  - Lower operational costs for renewable energy sources.
- Overall, the increased capital expenditure is offset by reduced operational expenses, leading to net savings.

	Capacity Expenditure (billion yuan)	Operation Expenditure (billion yuan)
Managed charging	135	139
Unmanaged charging	130	146

Carbon Emission Comparison

- Imported electricity is purchased with an assumed 50% renewable energy mix, as mandated by NEA policy.
- Annual emissions saved: 4.3 million tons, representing a 7% reduction from the unmanaged scenario.
- The emission reduction stems from decreased coal power generation.



Takeaways

- From the system planner's perspective, managed charging is a viable solution that can simultaneously reduce grid costs, complement renewable generation, decrease reliance on coal power, and lower carbon emissions.
- While some policies aim to reduce the impact of EV charging on the grid, the full potential of these "batteries-on-wheels" remains largely unexplored.
- Specifically, they have not been treated as system resources that can provide much-needed flexibility. More dispatch rules and incentive structures need to be established to realize these benefits.