

Virtual Power Plants As Flexibility Providers for Resilient Grid

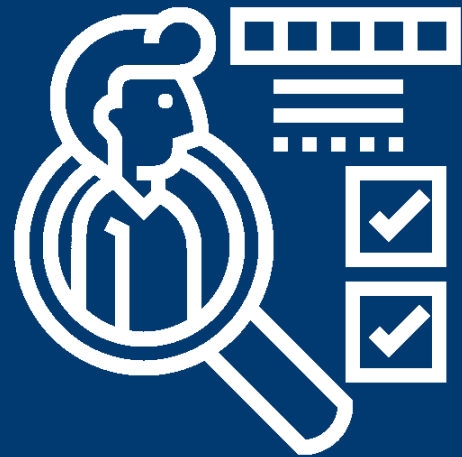
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Dr. Mohammed Qais

July 17, 2026



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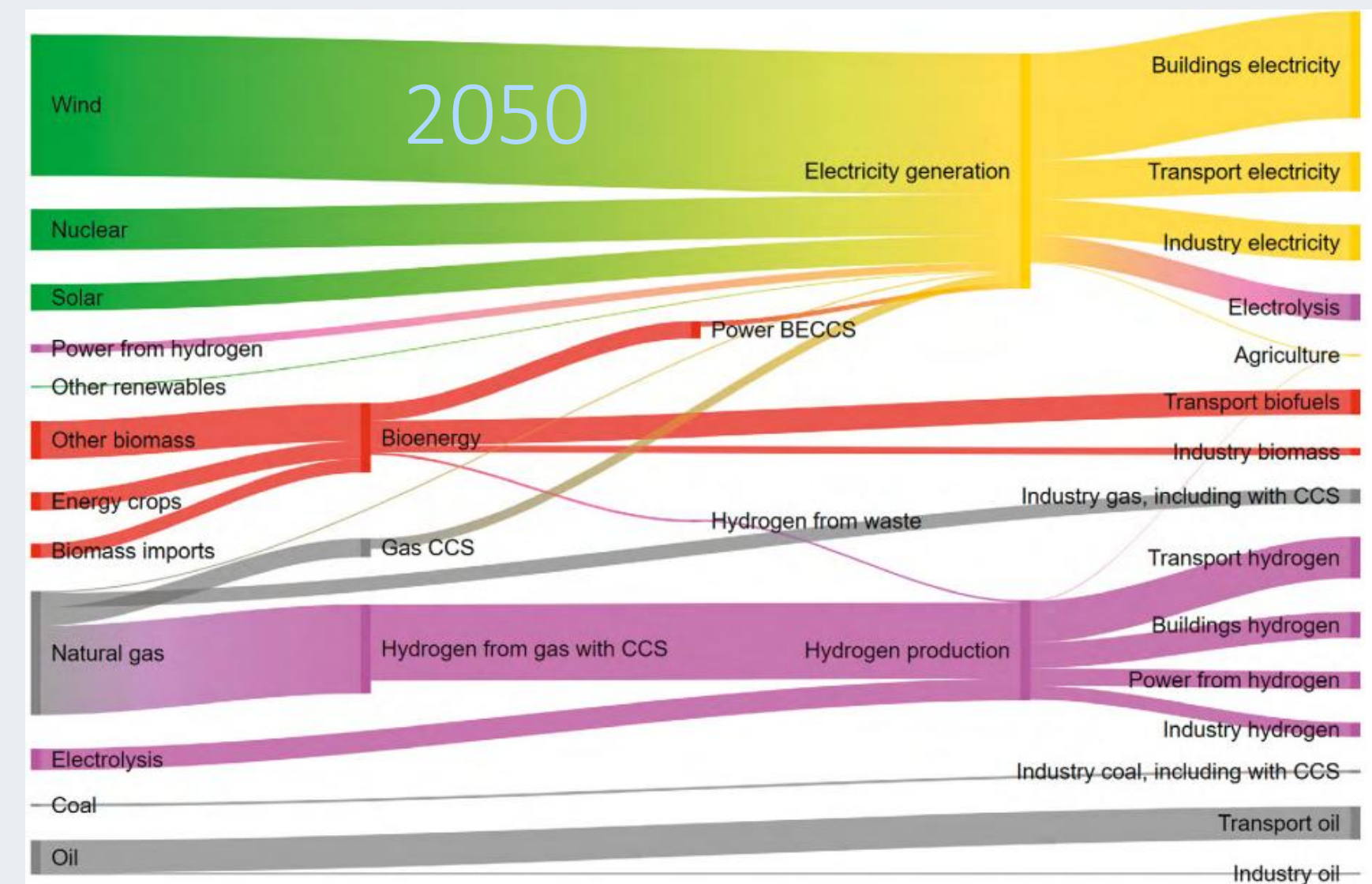
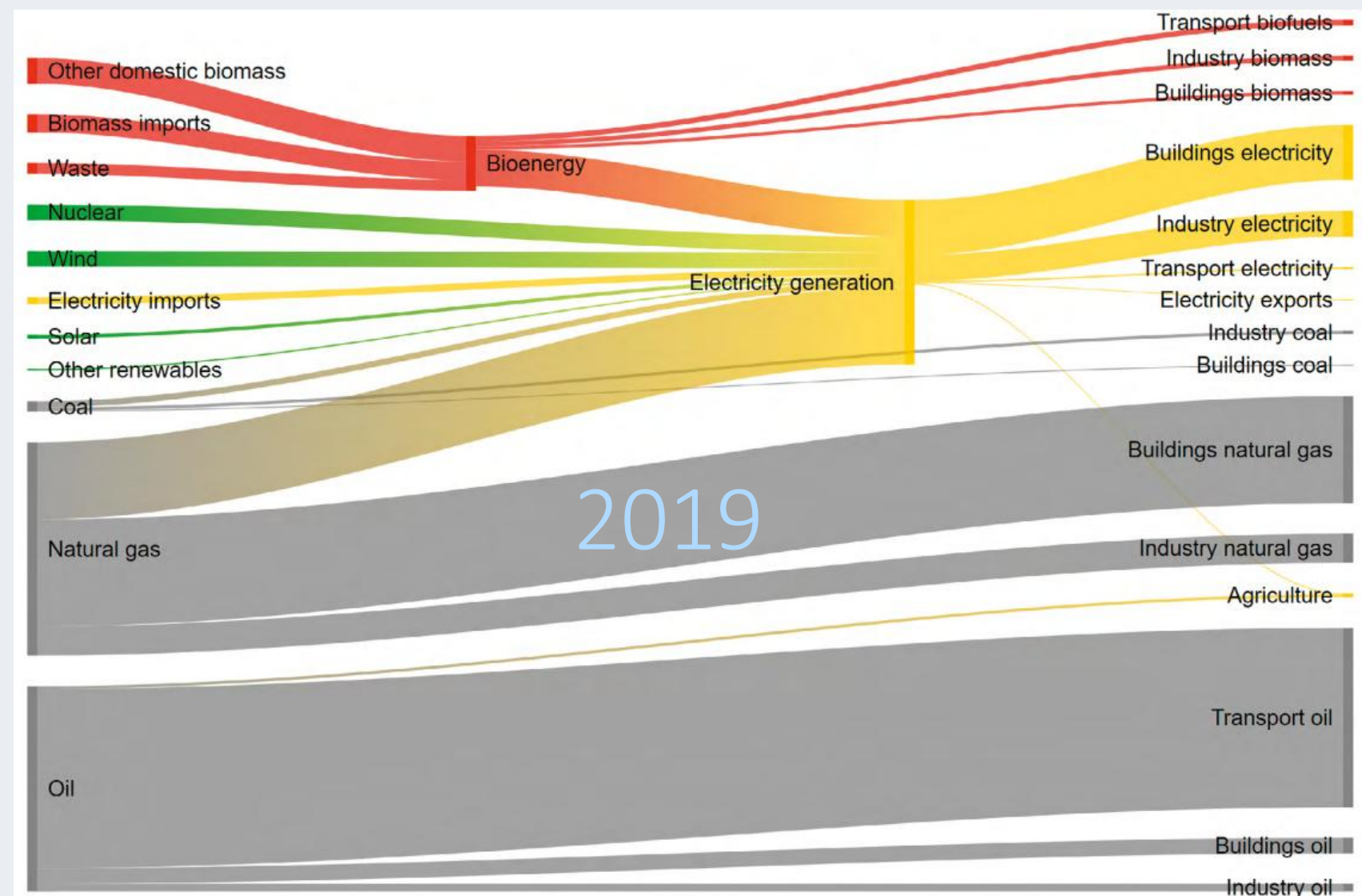
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- UK Net Zero Target by 2050.
- Future Challenges
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- Effects of future EV demand.
- VPP for EV coordination.
- VPP impact: validated results.
- Tesla VPP: A real-world application.

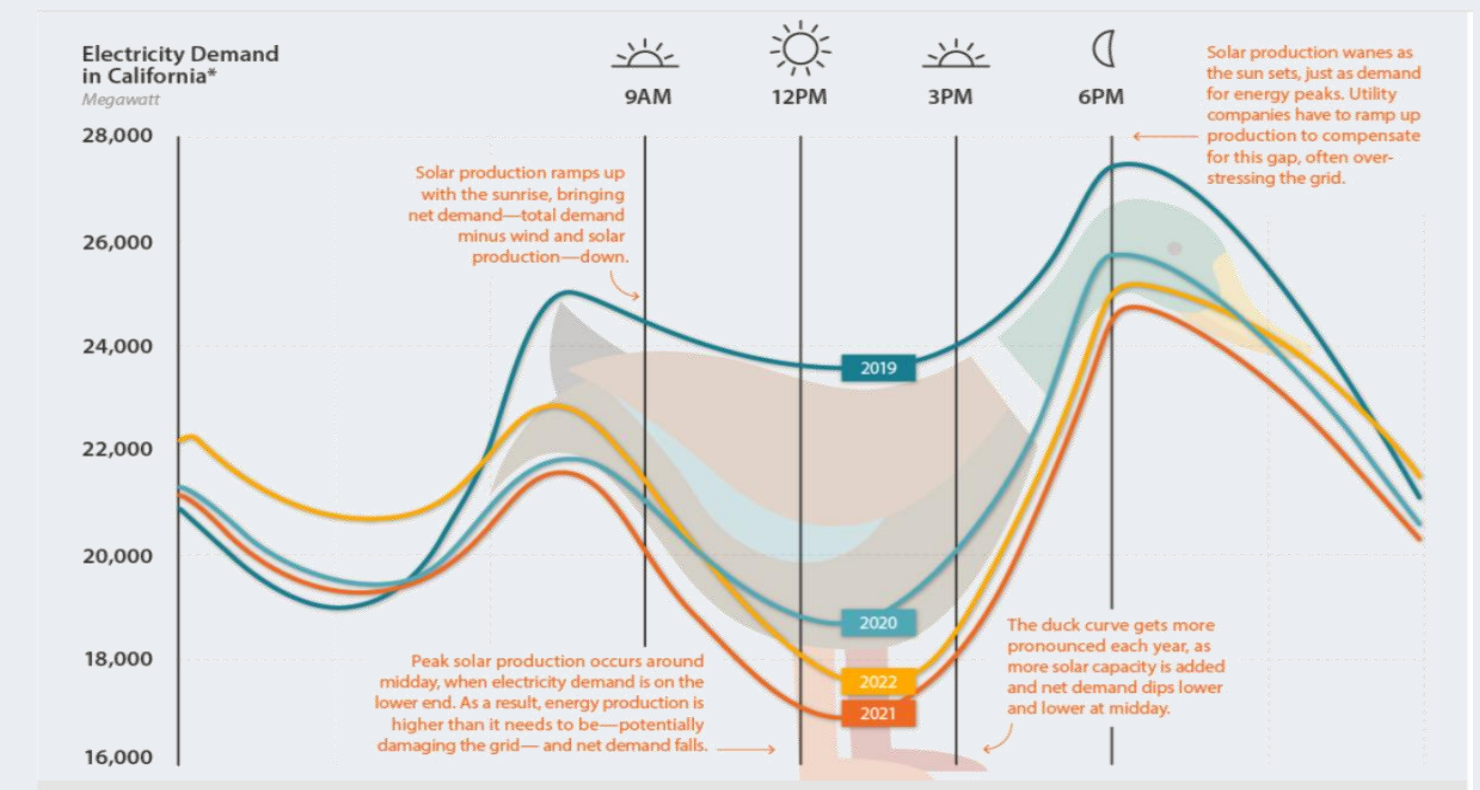
UK Net Zero target by 2050

- Wind and solar resources will be the main resources for electricity generation.
- Electrification of transportation and heating (e.g., EVs and heat pumps)



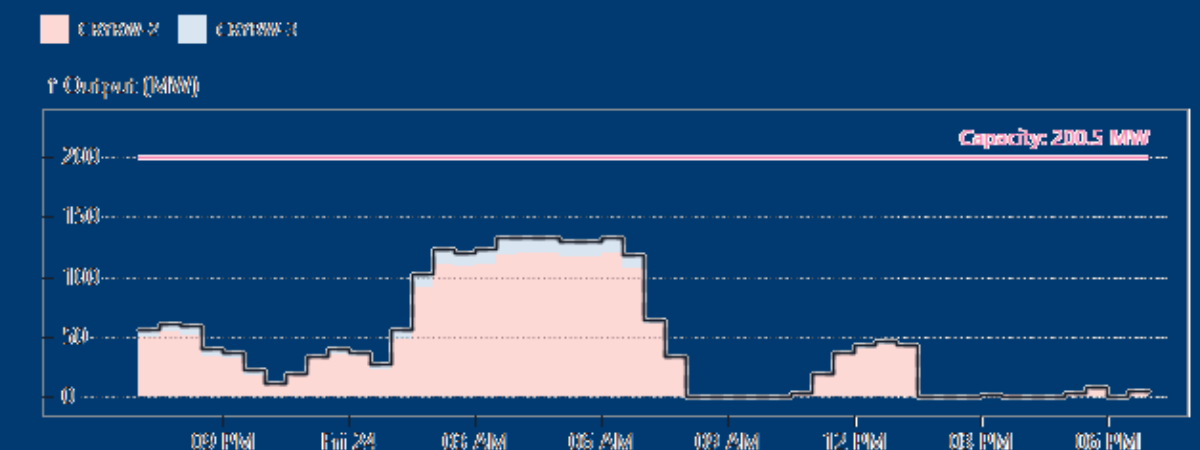
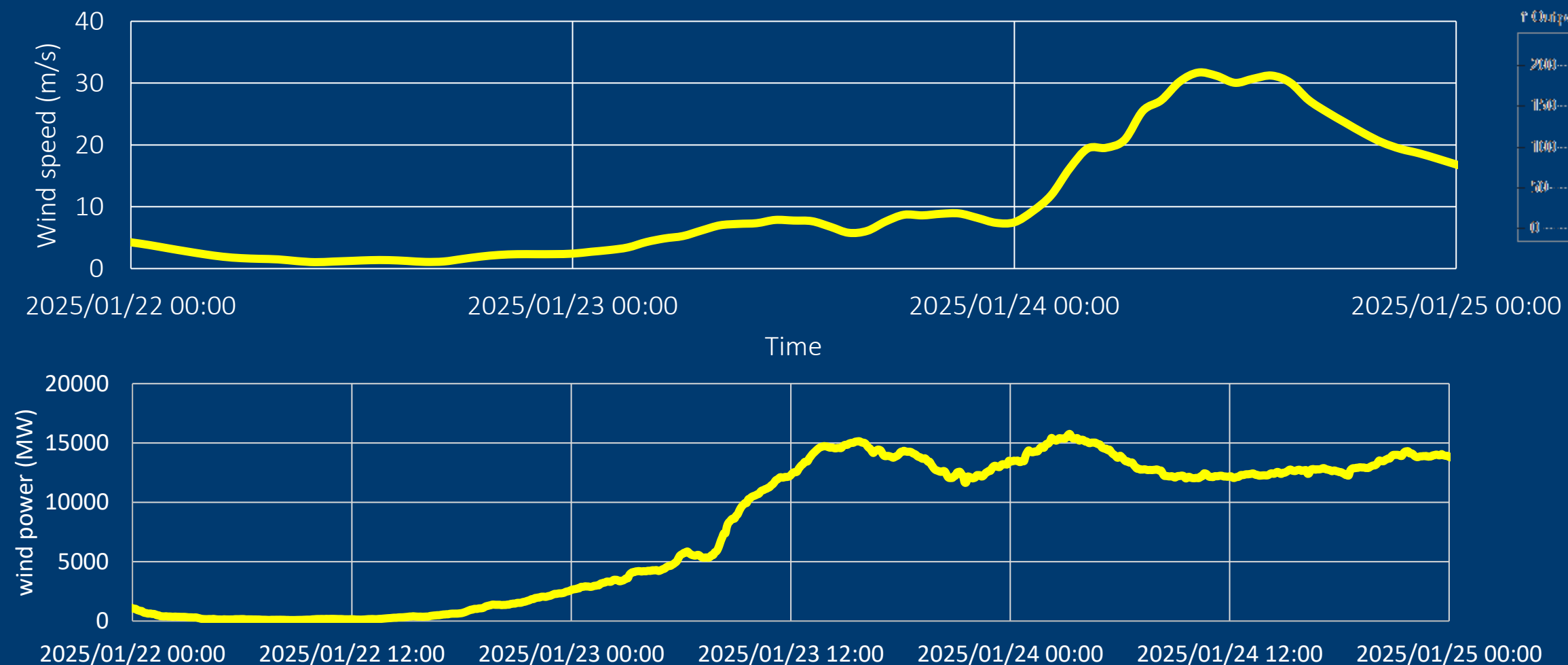
Future Challenges

- High penetrations of DERs in the electrical grid may introduce a variety of detrimental conditions, including voltage swings and reverse power flow, which can cause grid instability.
- The intermittent nature of renewable energy resources, such as solar radiation at daytimes, causes balance complexity between demand and supply (e.g., Duck curve of electricity demand in California)

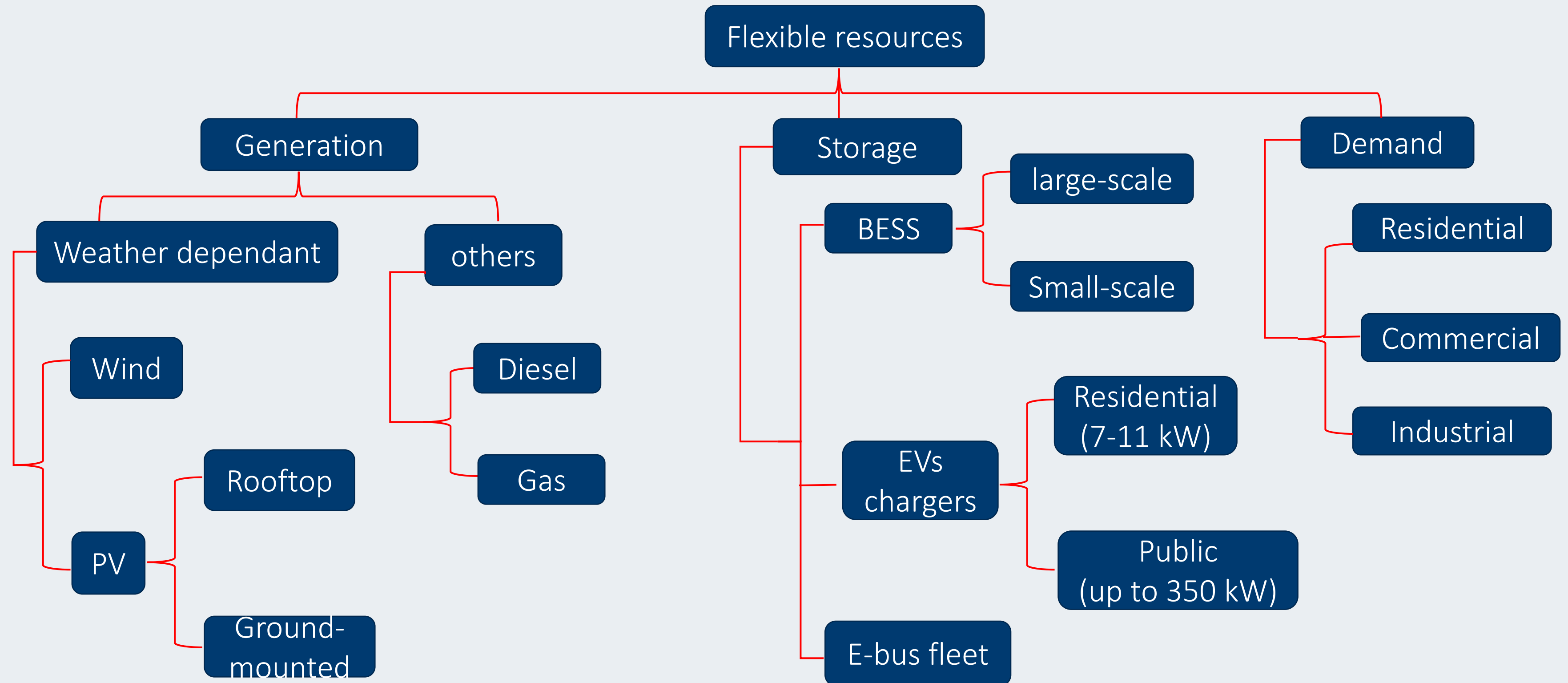


Future Challenges

- Wind farms usually produce electrical power at wind speeds between 4 and 25 m/s.
- In addition to wind power curtailment, Windstorms can damage overhead lines, resulting in power disruptions for clients.
- Recently, storm Éowyn, on 24th January, 2025, caused a power outage to thousands of people in Scotland.



Flexible Assets

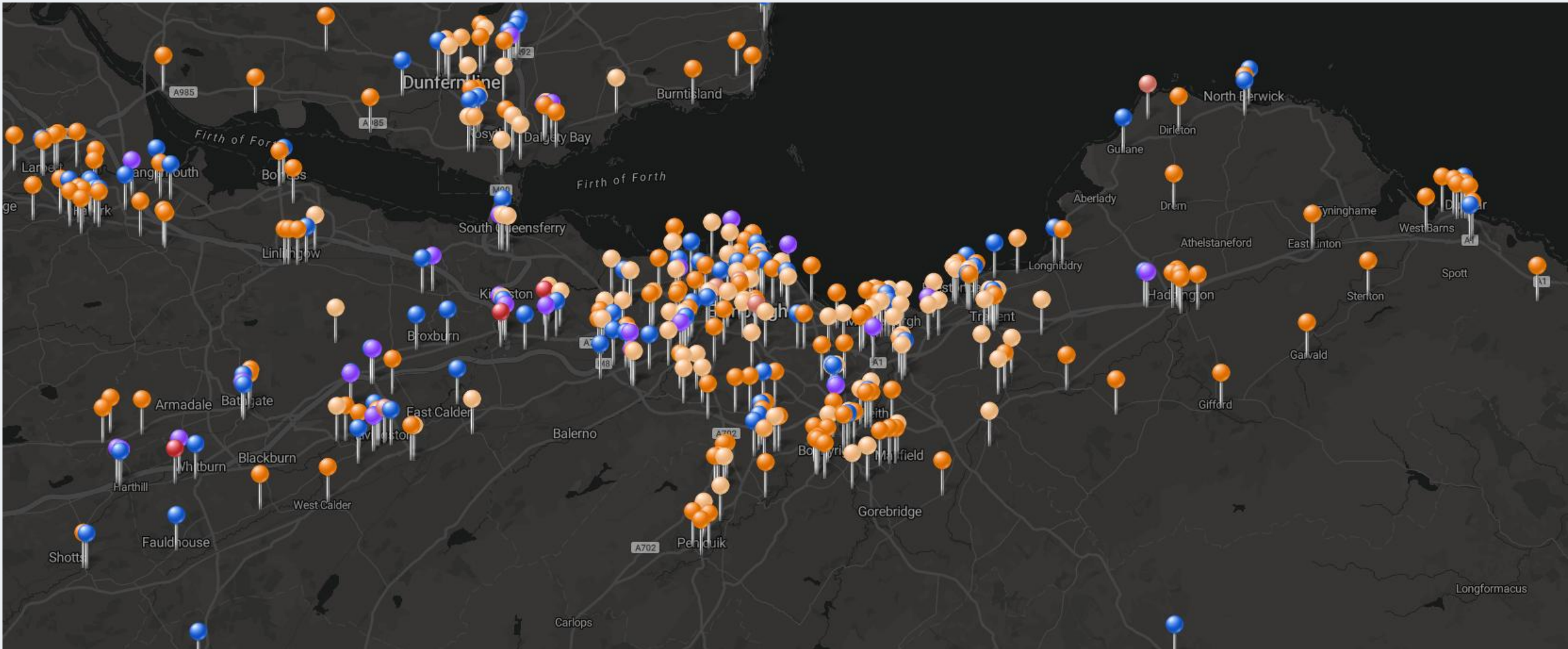


Flexibility Clustering

- **Power flow direction:**
 - › Bidirectional flow: Energy storage systems: EVs, batteries, pumped energy storage ...etc.
 - › Unidirectional flow: Load & Generation (PV, wind, diesel)
- **Flexibility duration:**
 - › Upward ramping rate: includes the response time and the maximum power that can be injected.
 - › Downward ramping: includes the response time and the minimum power that can be injected.
- **Availability time:** such as the solar radiation period, the idle time of EVs.
- **Available capacities:** such as the batteries and EVs.
- **Magnitude of injected power:** how much power can be injected into the grid (i.e., charging and discharging power of EVs vary between 3 kW and 350 kW).
- **Demand side flexibility:** Controlling demand is considered the fastest method for balancing the demand-supply of the power grid.

Charging Points in Edinburgh

Charging Power
150 kW CCS
CHAdeMO 50 kW
7 kW Type 2
22 kW Type 2
50 kW CCS
350 kW CCS
120 kW CCS
300 kW CCS
130 kW Tesla
250 kW CCS
44 kW CCS
CHAdeMO 44 kW
35 kW Type 2



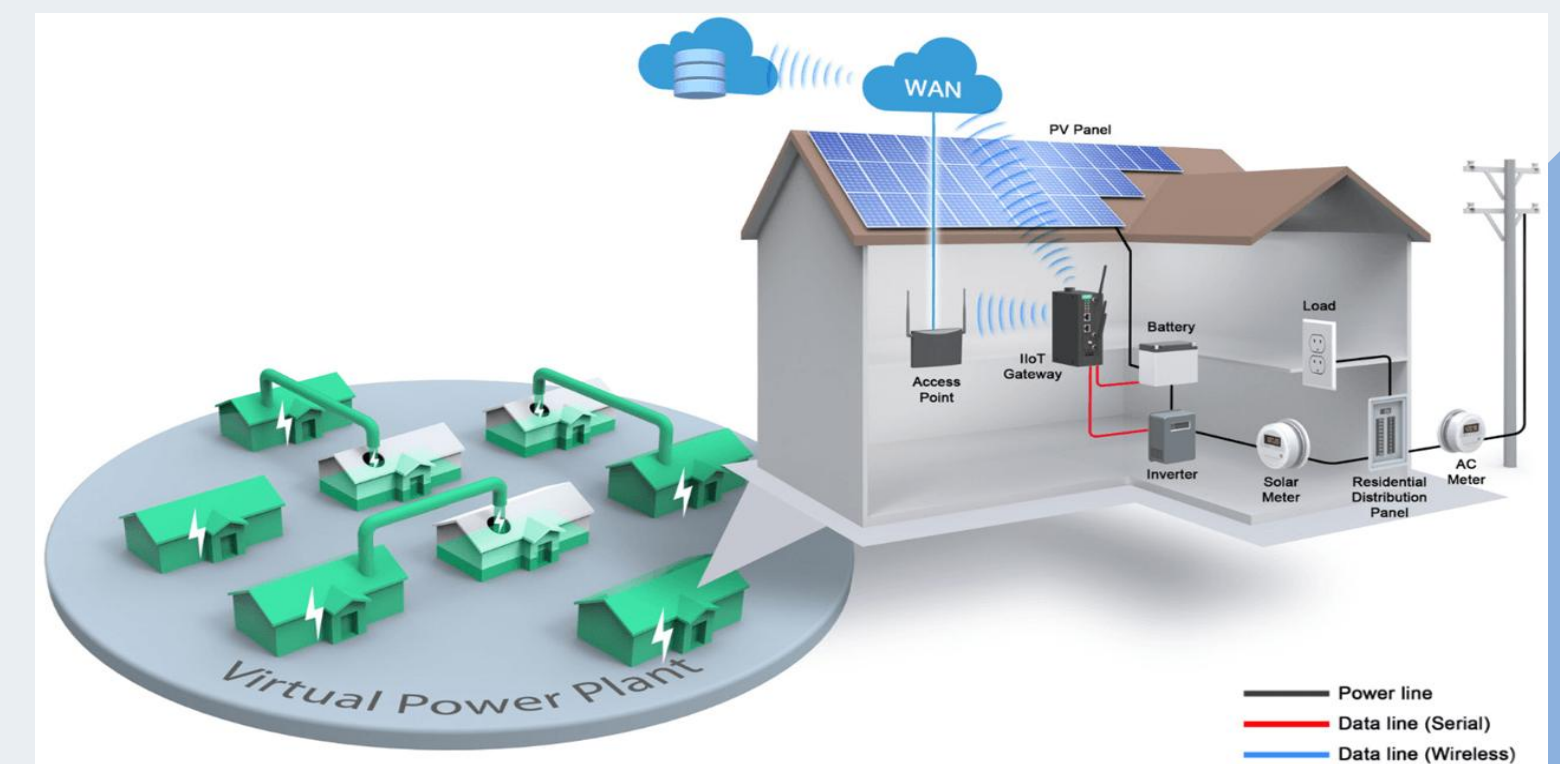
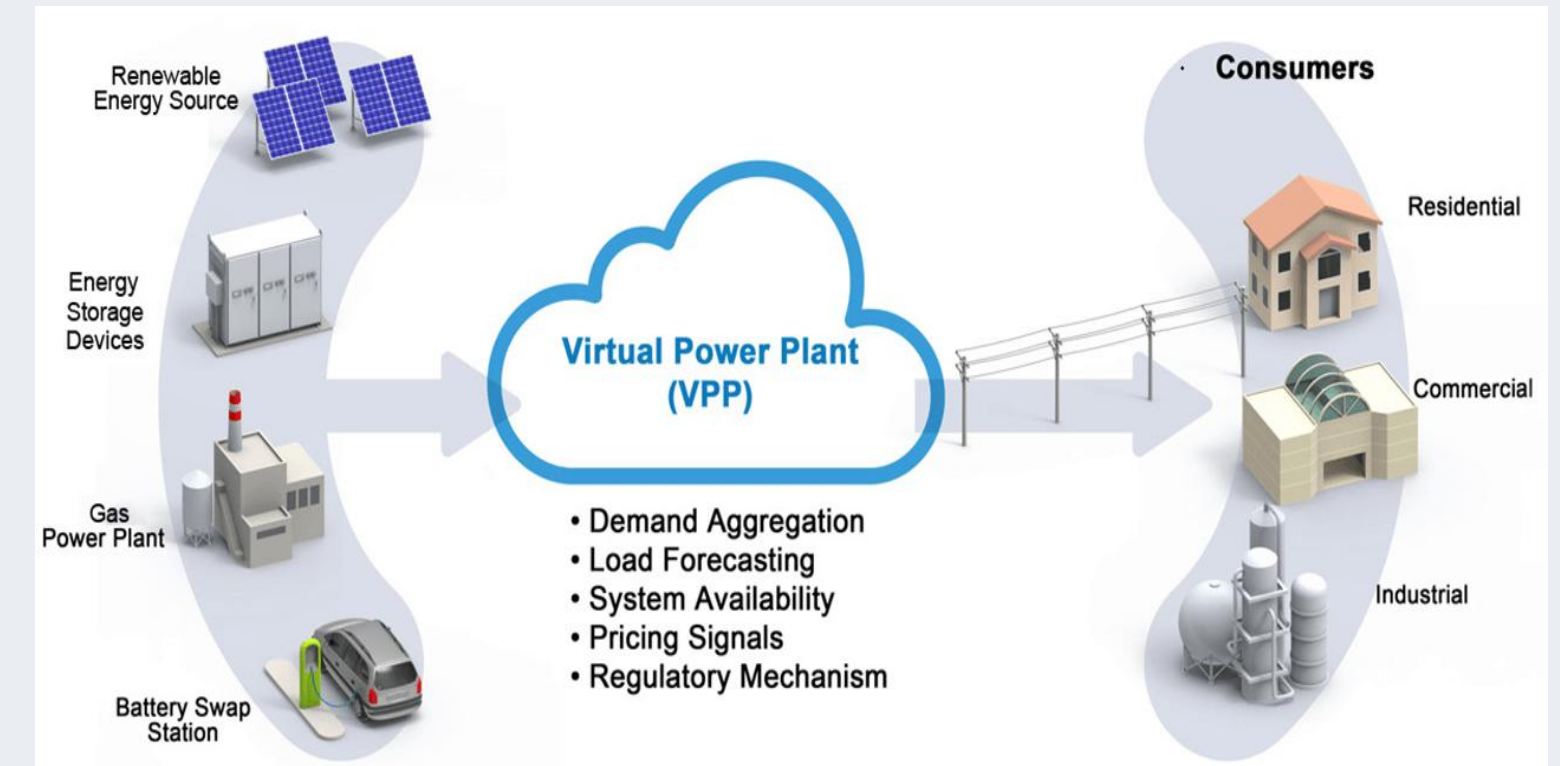
What is VPP?

What is VPP?

A VPP is a cloud-based network of:

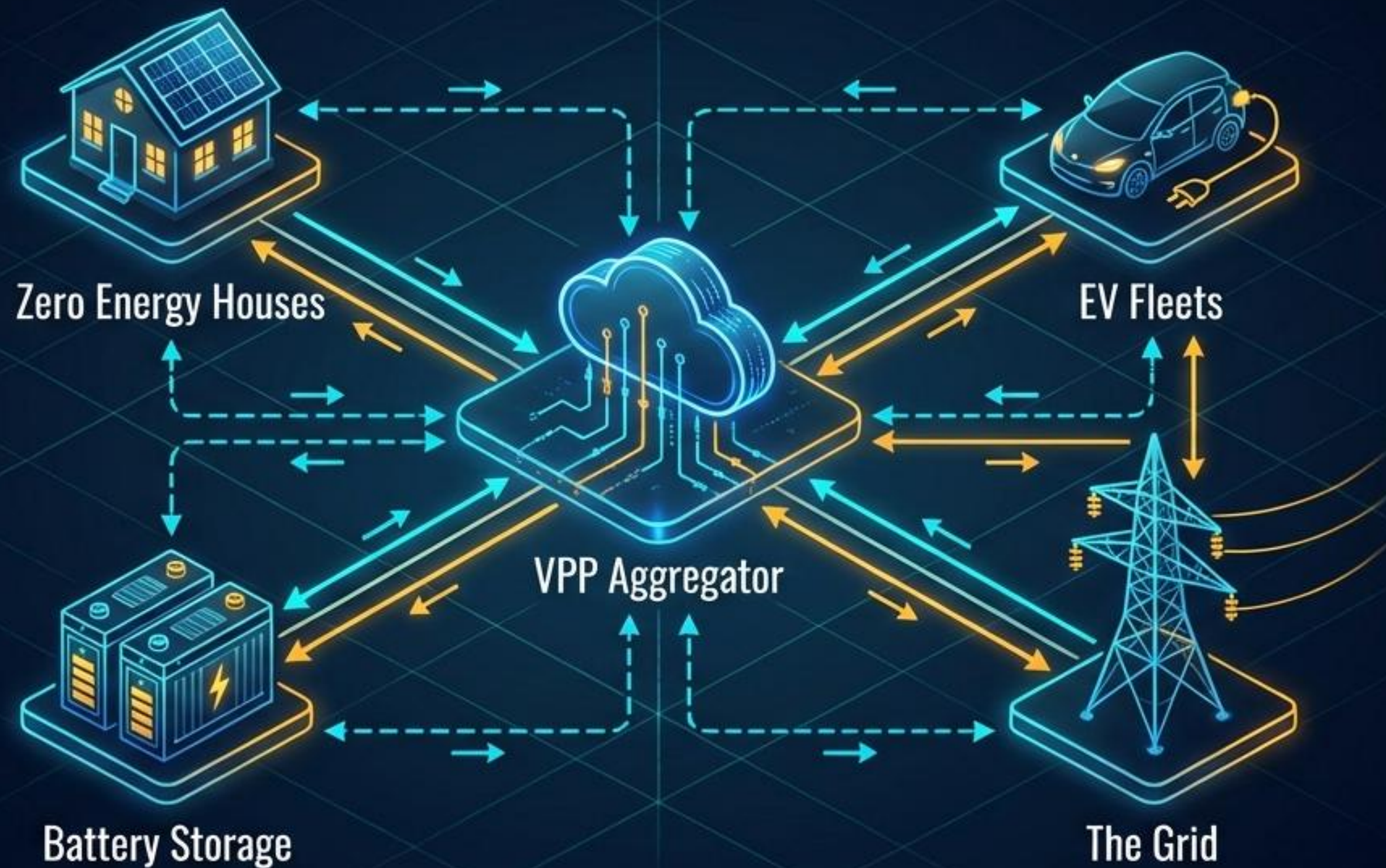
1. Electricity generators (e.g., solar panels).
2. Electricity consumers (e.g., Heat pumps, EVs)
3. Electricity storage systems.

VPPs leverage IoT technology to aggregate and coordinate the supply and demand of distributed energy resources (DERs) and consumers.

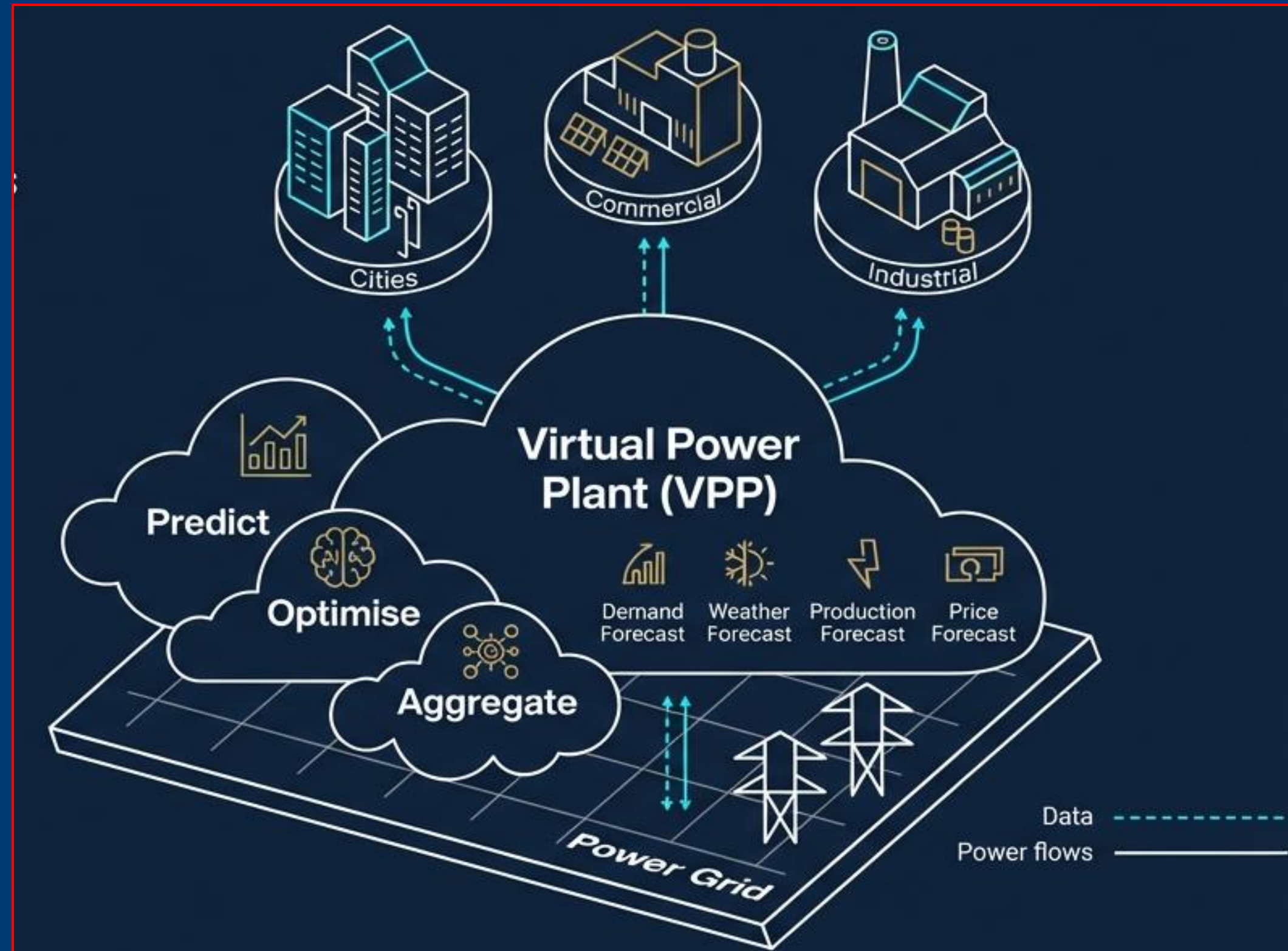


Application of VPP

Residential Virtual Power Plant



VPP operation



Optimization Methodologies for VPPs

1. LINEAR PROGRAMMING (LP)

DETERMINISTIC OPTIMIZATION

USES SIMPLIFIED LINEAR MODELS

Formulas

$$\mathbf{A} \cdot \mathbf{x} \leq \mathbf{b}$$
$$\leq \mathbf{b}$$

FORMULAS



Best for: High-level planning, simple deterministic schedules.

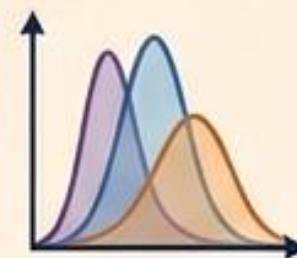
Method: Calculates a static plan for a known future (e.g., day-ahead pricing).

Limitations: Requires linearization of complex grid physics; ignores most uncertainty.

2. STOCHASTIC OPTIMIZATION (SO)

OPTIMIZING OVER MULTIPLE SCENARIOS

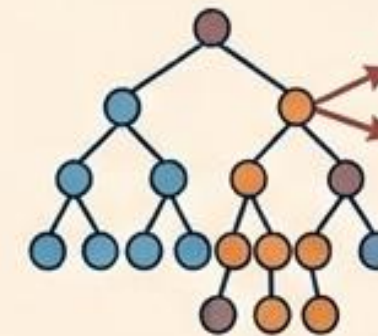
ACCOUNTS FOR PROBABILISTIC UNCERTAINTY



PROBABILITY



DICE



Best for: Chance-constrained and multi-scenario scheduling (weather, loads).

Method: Uses probability distributions and scenario trees for a robust solution.

Limitations: HIGH COMPUTATIONAL COMPLEXITY for large VPPs; difficult to scale with complex non-

3. REINFORCEMENT LEARNING (RL)

DATA-DRIVEN & ADAPTIVE CONTROL

LEARNS OPTIMAL POLICIES THROUGH INTERACTION



RL AGENT



ENVIRONMENT



REWARD

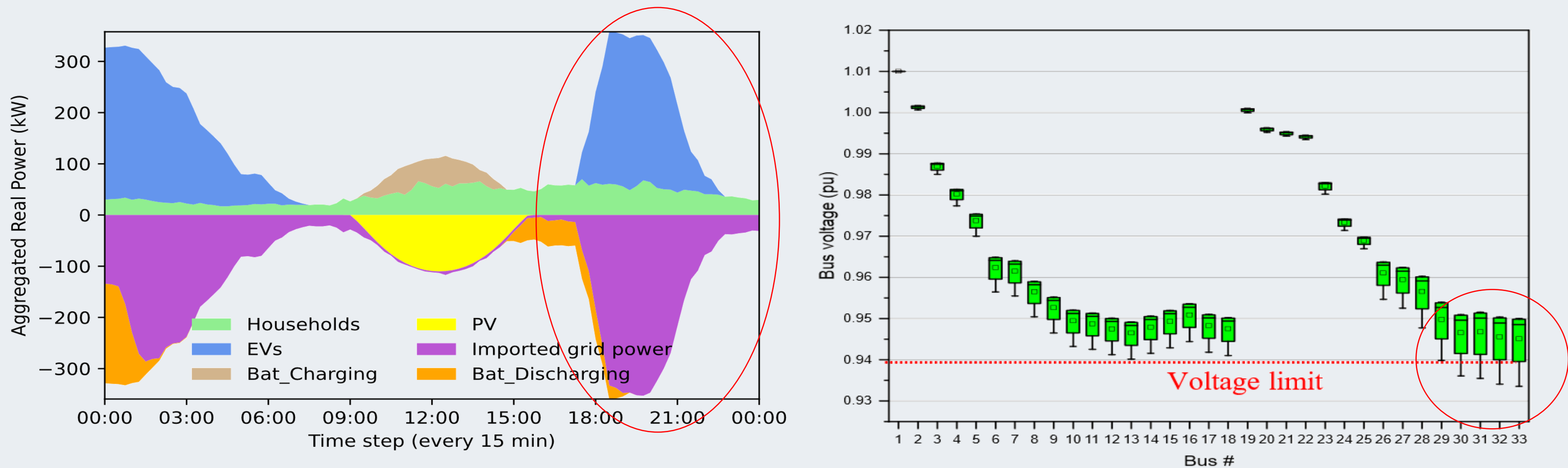
Best for: Real-time, continuous control of thousands of dynamic assets.

Method: Model-free interaction, continuous exploration, and reward signals.

Benefits: SCALABLE TO HIGH-DIMENSIONAL NON-LINEAR SYSTEMS; adapts dynamically to changes.

Effect of Future EV Demand on Distribution Networks

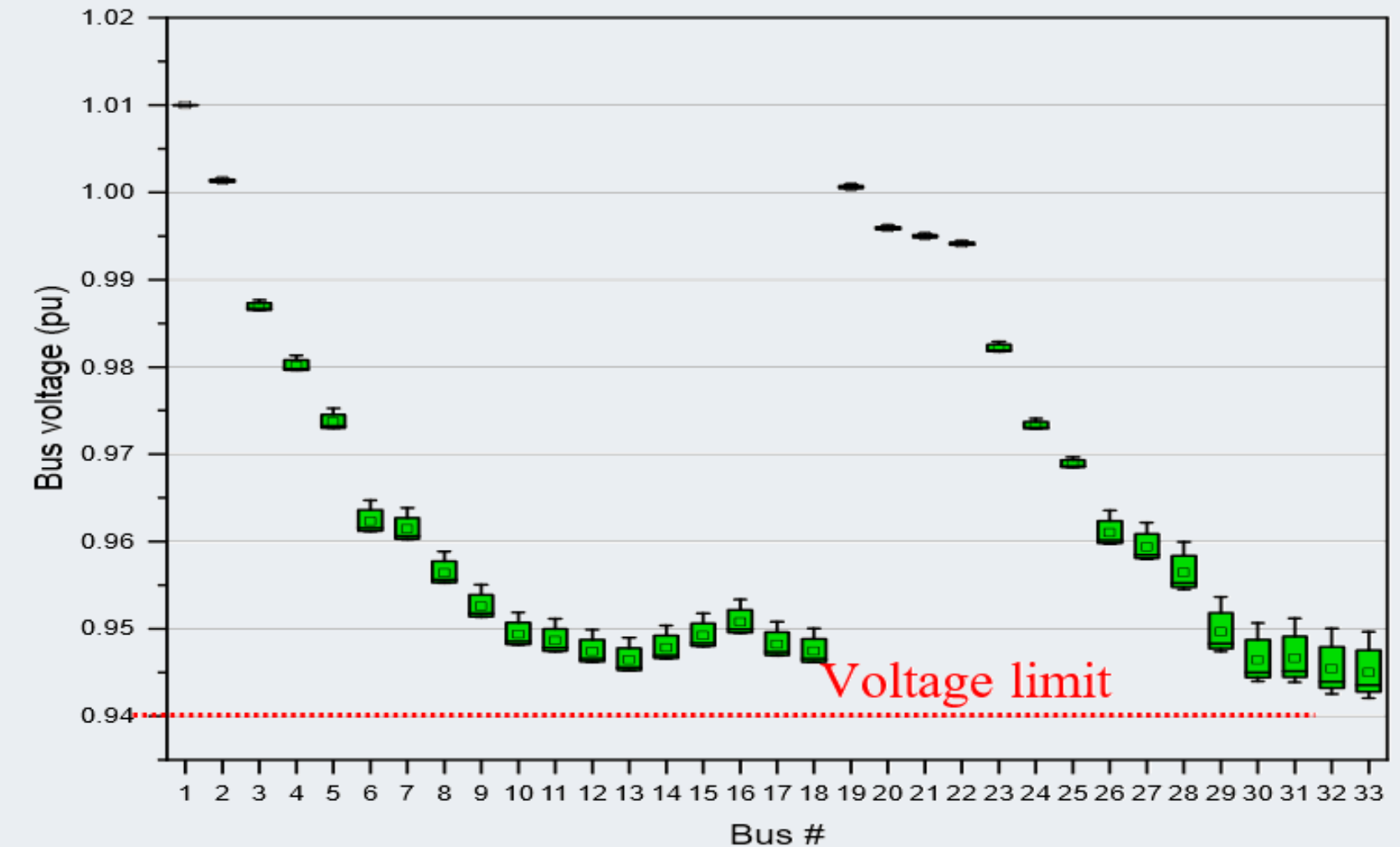
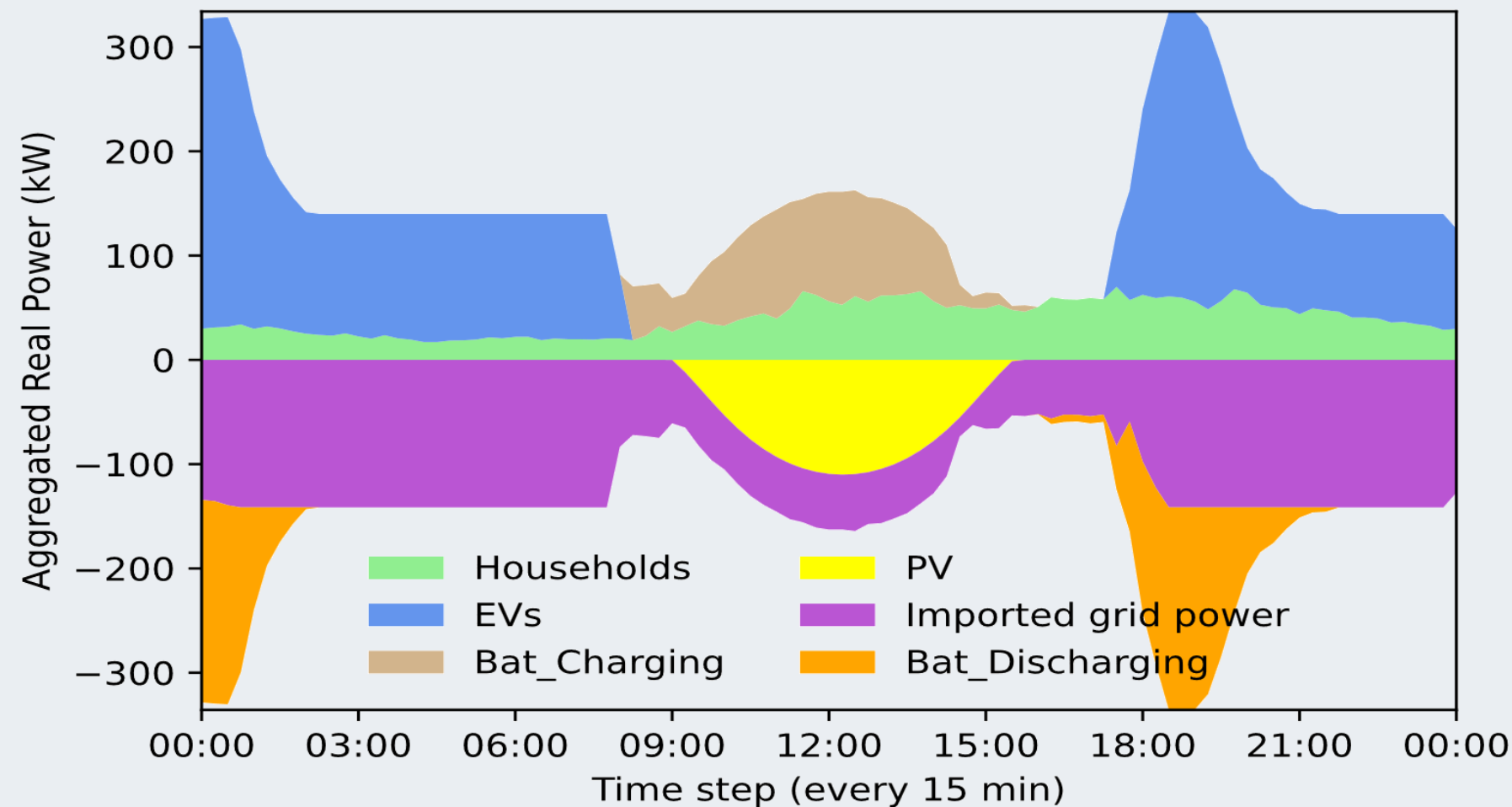
The simultaneous charging of large number of EVs at homes on arrival causes steep power demand from grid and deep voltage drop.



Mohammed Qais, Desen Kirli, Edward Moroshko, Aristides Kiprakis, Sotirios Tsaftaris, A virtual power plant for coordinating batteries and EVs of distributed zero-energy houses considering the distribution system constraints, Journal of Energy Storage, Volume 106, 2025, 114905, <https://doi.org/10.1016/j.est.2024.114905>.

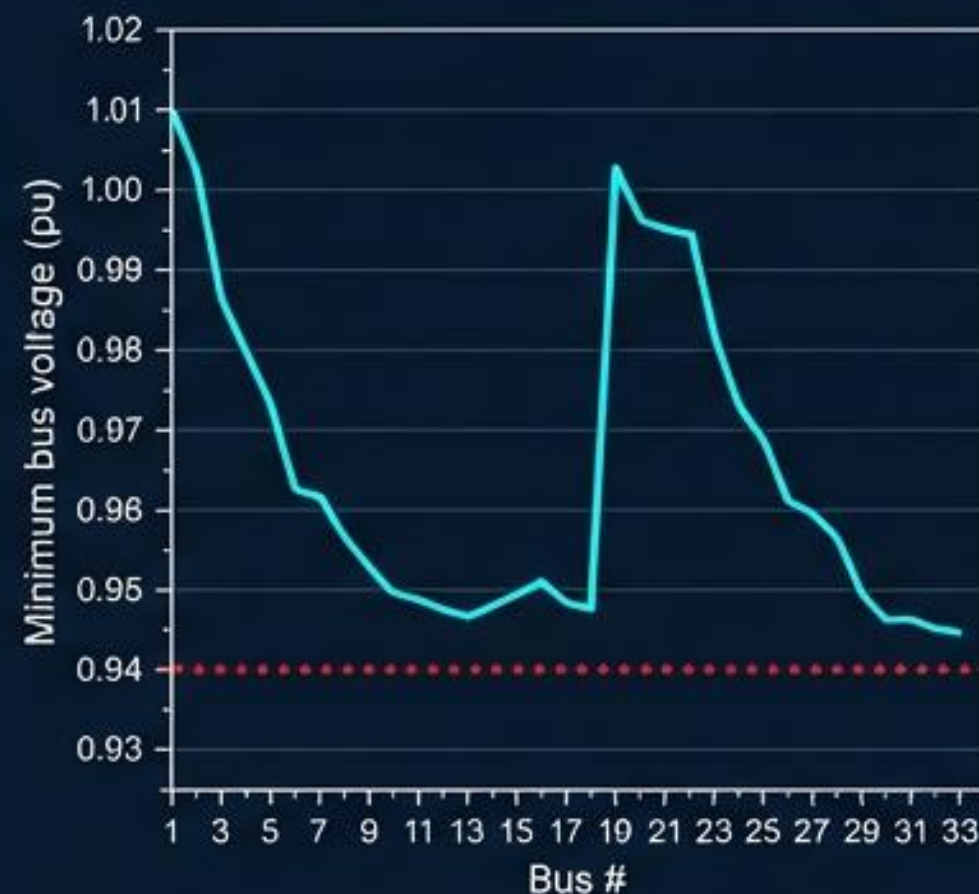
VPP for EVs Coordination

- VPP is applied to aggregate and control the smart chargers of EVs and the installed solar-batteries system at houses.
- VPP utilized the grid power to fully charge the batteries during mid-day time.



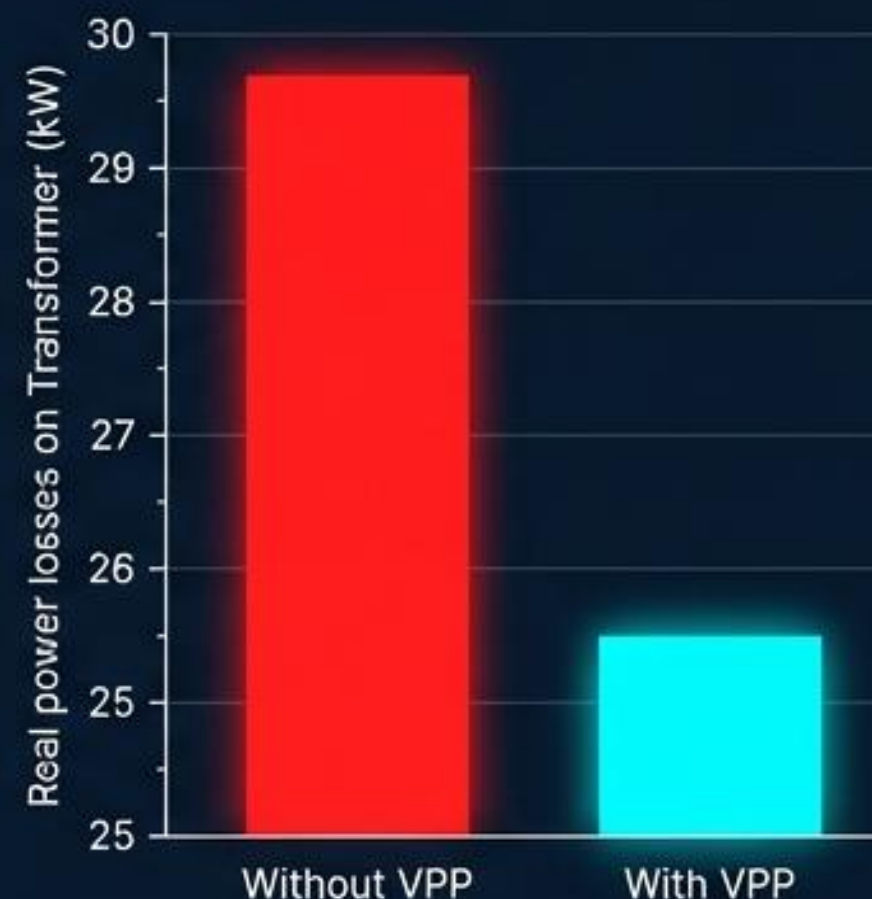
VPP Impact: Validated Results

Grid Compliance



Voltage maintained >0.94 pu
(IEEE 33 Bus System).

Asset Health



Reduced Transformer
Hotspots & Power Losses.

Consumer Benefit

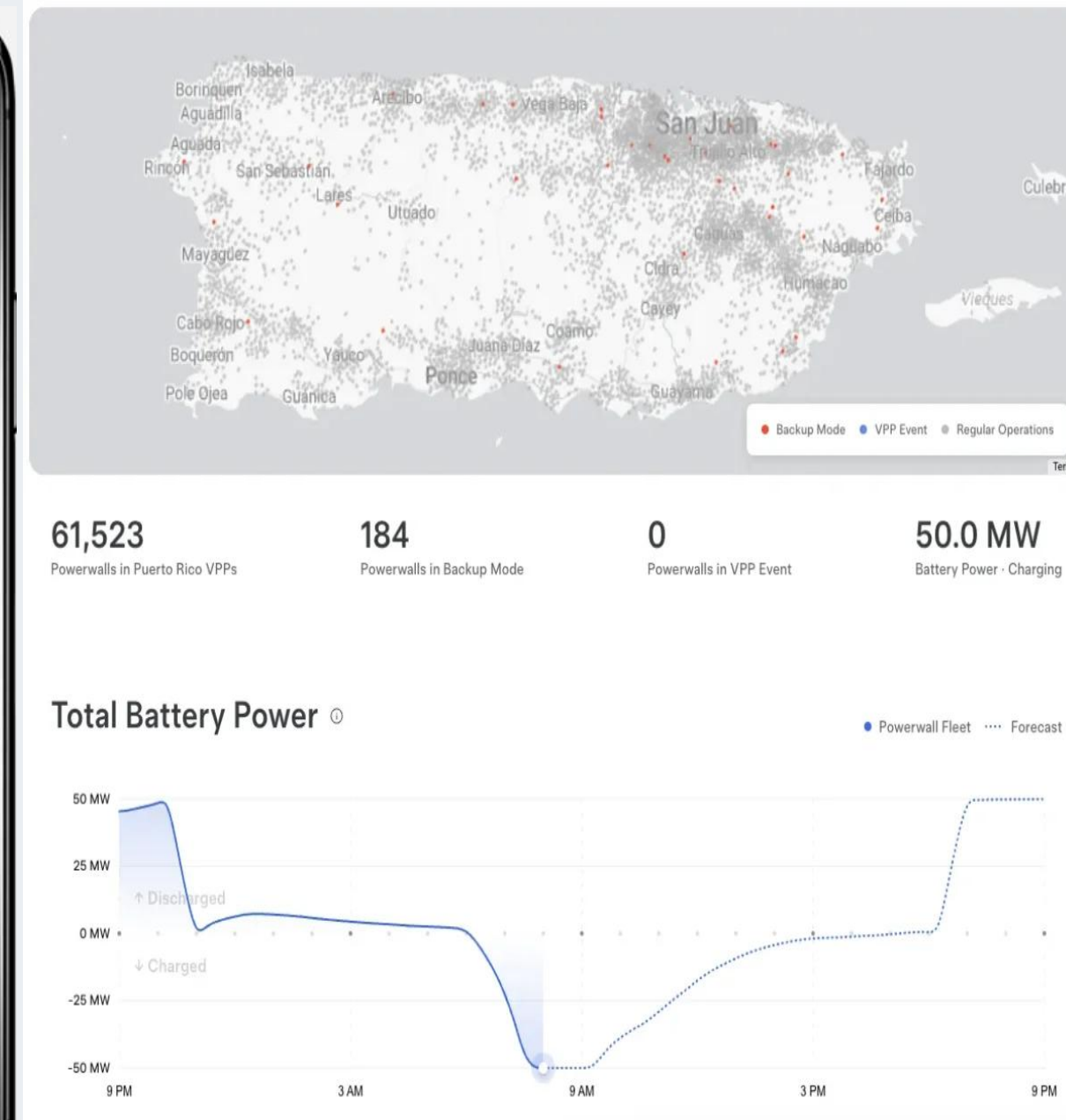
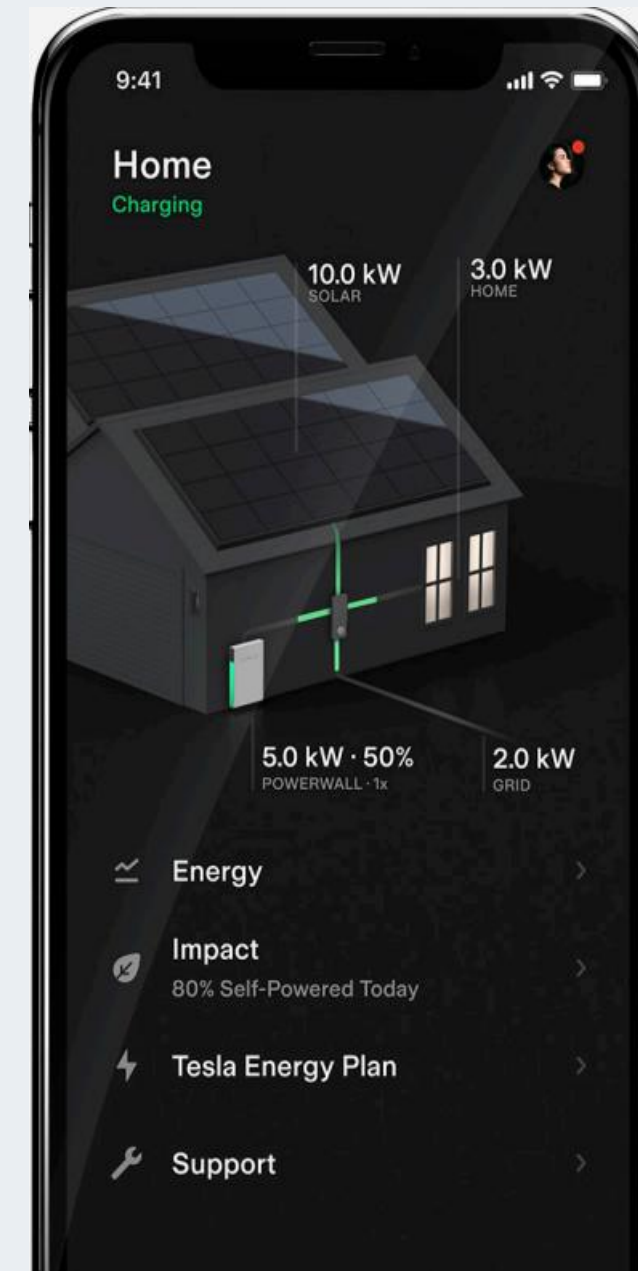


44% Cost Saving with minimal
comfort sacrifice (1°C).

Tesla VPP Program: A Real-World Application

Tesla offers home solar panels and Powerwall systems designed to save on energy costs and sustainably power homes. The Tesla Energy with Tesla VPP system has been applied in different countries:

1. SA VPP¹: South Australia's Virtual Power Plant, a network of potentially 50,000 solar and Tesla Powerwall home battery systems across South Australia forming the world's largest VPP.
2. Puerto Rico VPP²: which now includes over 63,122 participating Powerwall owners.
3. Tesla Electric UK.
4. Tesla VPP in Texas and California.



[1] <https://arena.gov.au/projects/tesla-virtual-power-plant/>

[2] <https://www.notateslaapp.com/news/2899/tesla-launches-live-dashboard-for-puerto-ricos-powerwall-virtual-power-plant-vpp>

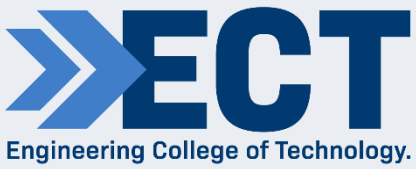
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“Virtual power plants can aggregate small, everyday energy assets and orchestrate their operation to function as a virtual large-scale power plant.”

Thank you so much for listening, and I welcome any questions or thoughts you may have.

Thank You!

Upcoming Programmes



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Bachelor of Engineering (Honours) in Electrical Engineering	September 2026, February 2027
Master of Science (Power System Analysis and Renewable Integration)	October 2026, February 2027
Master of Science (Industrial Automation and Instrumentation Control)	October 2026, February 2027

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