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# VPP Participation Models: What is the Objective?

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*Photo from iStock-627281636*

# Virtual Power Plants as defined by the DOE loan office[1]

"**VPPs are aggregations of distributed energy resources (DERs)** such as rooftop solar with behind-the-meter (BTM) batteries, electric vehicles (EVs) and chargers, electric water heaters, smart buildings and their controls, and flexible commercial and industrial (C&I) loads …. **VPPs enroll DER owners** – including residential, commercial, and industrial electricity consumers – **in a variety of participation models** that offer rewards for contributing to efficient grid operations."

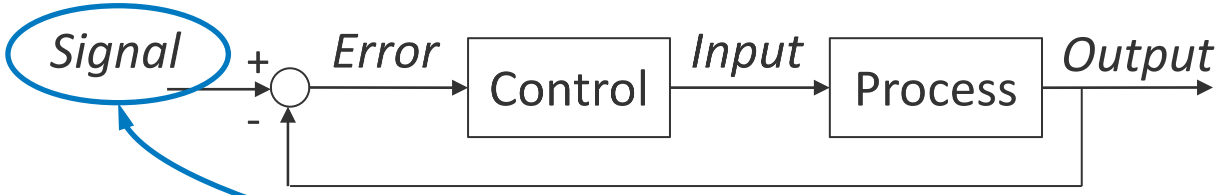
"**VPPs are not new** and have been operating with commercially available technology for years. **Most of the 30-60 GW of VPP capacity today is in demand response programs** that are used when bulk power supply is limited …. However, VPPs have the technical potential to perform a wider array of functions. Example functions of VPPs on the market today include **shifting the timing of EV charging** …, supplying homes with energy from **onsite solar-plus-storage systems** during peak hours …, charging distributed batteries at opportune times … all while **minimizing impact to the DER owner**."

[1]Jennifer Downing et al., "Pathways to Commercial Liftoff: Virtual Power Plants" (U.S. Department of Energy (DOE), September 2023), https://liftoff.energy.gov/vpp/.

# A personal anecdote

Systems Engineering =

Controls + Optimization




$$\min_{x} f(x)$$
$$s.t. \quad g(x) \leq 0$$

***Controls engineers can make distributed energy resources do whatever we want …***

***But what do we want?***

# Electricity systems are more than multi-objective—they are multi-stakeholder

**Independent Power Producer**

- Make sound investments
- Maximize profits

**Independent System Operator**

- Maximize market surplus (value of consumption – production costs)
- Mitigate market power
- Satisfy stakeholders

**Utility Company**

- Maximize shareholder (IOU) or member (Co-op, Muni) value
- Satisfy regulatory requirements

**Aggregator**

- Maximize profits / Be profitable in the long term

**Regulator**

Ensure that electricity systems are:

- Safe
- Adequate
- Reliable
- Affordable
- Economically viable
- Environmentally sustainable
- And meet minimum standards of service

**Consumer**

- **Use energy to meet needs**
- Minimize energy bills
- Align energy use with values
- **Set and forget**

**Consumer with DER**

*General consumer objectives (left) plus:*

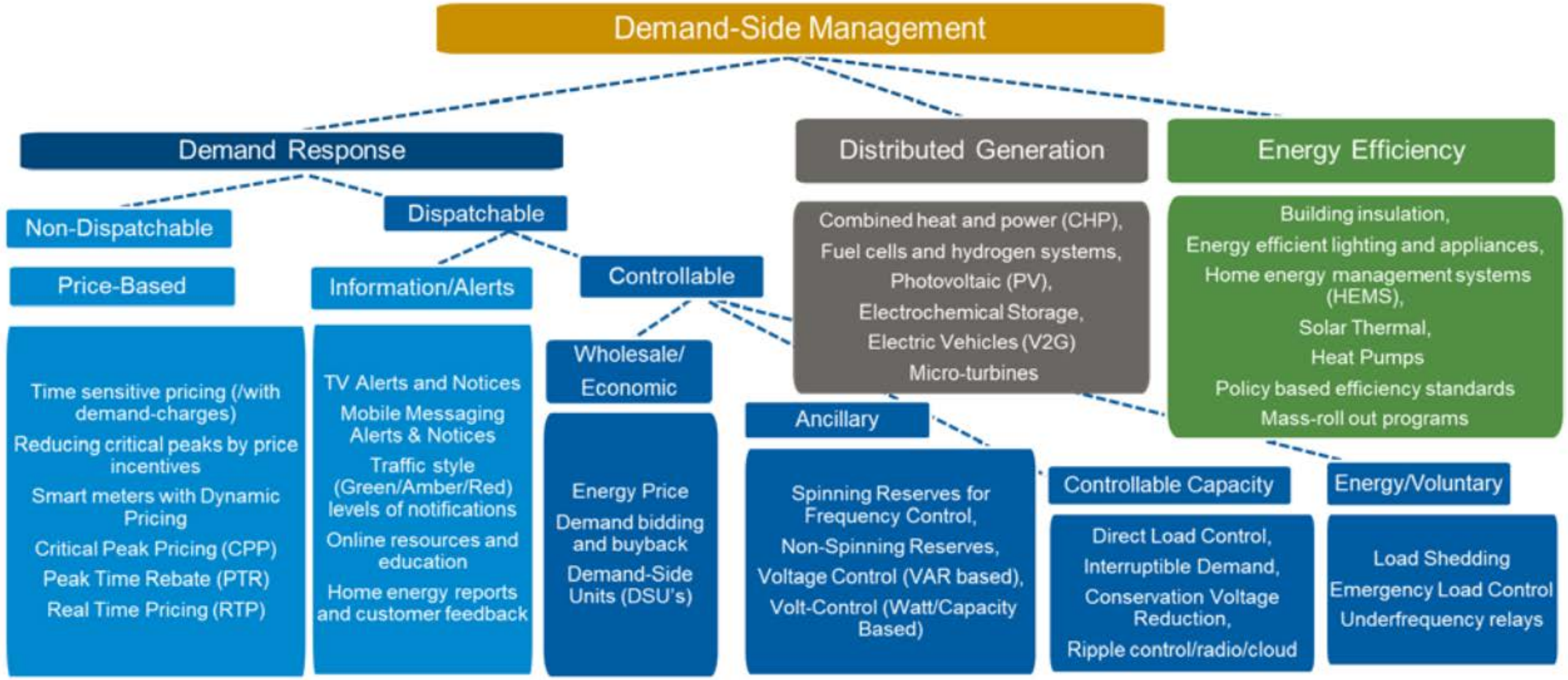
- Make sound DER investments
  - DER provides desired service
  - Positive net present value / acceptable payback time

# To persist, demand participation mechanisms must be acceptable and sustainable by all parties

**Does the strategy**

- Reduce grid costs?
- Reduce customer bills?
- Are costs, e.g.,
  - enablement
  - operations
  - transaction/attentional
  - foregone opportunities

  outweighed by benefits?
- Are all participants, i.e., grid suppliers, customers, and other parties, financially viable?



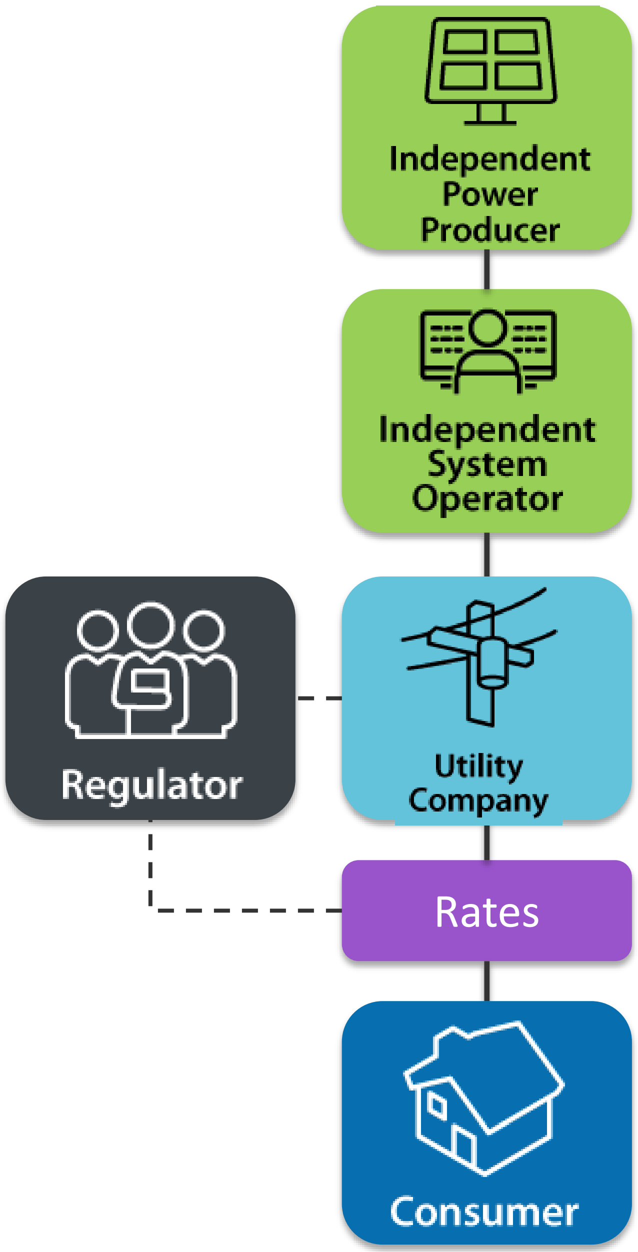

**Source:** Matsuda-Dunn et al. (2024)

Matsuda-Dunn, Reiko, Killian McKenna, Jal Desai, and Peter Mukoma. 2024. "Determining and Unlocking Untapped Demand-Side Management Potential in South Africa: Demand Response at the Grid Edge." NREL/TP-6A40-88042. https://doi.org/10.2172/2290257.

# Part 1

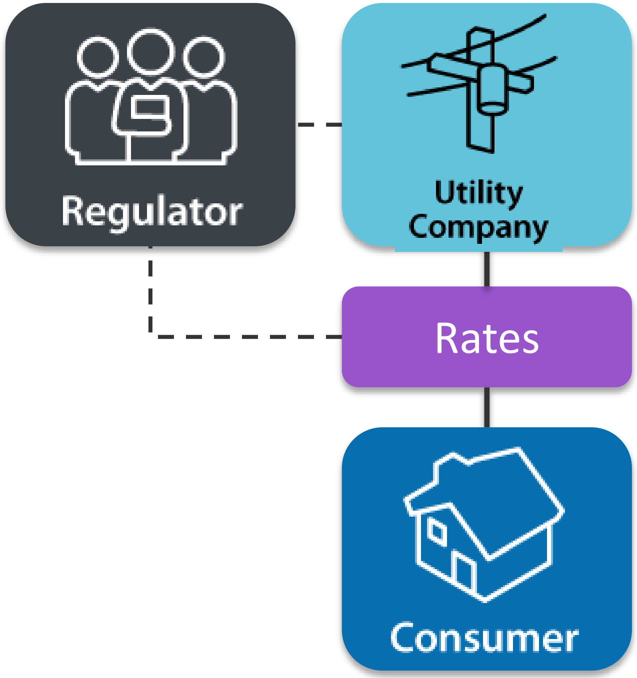
## Traditional Power Systems

# Without distributed energy resources (DERs), and with large thermal and hydropower generators, the electricity system structure is simple



# v1 Demand participation primarily comprised:

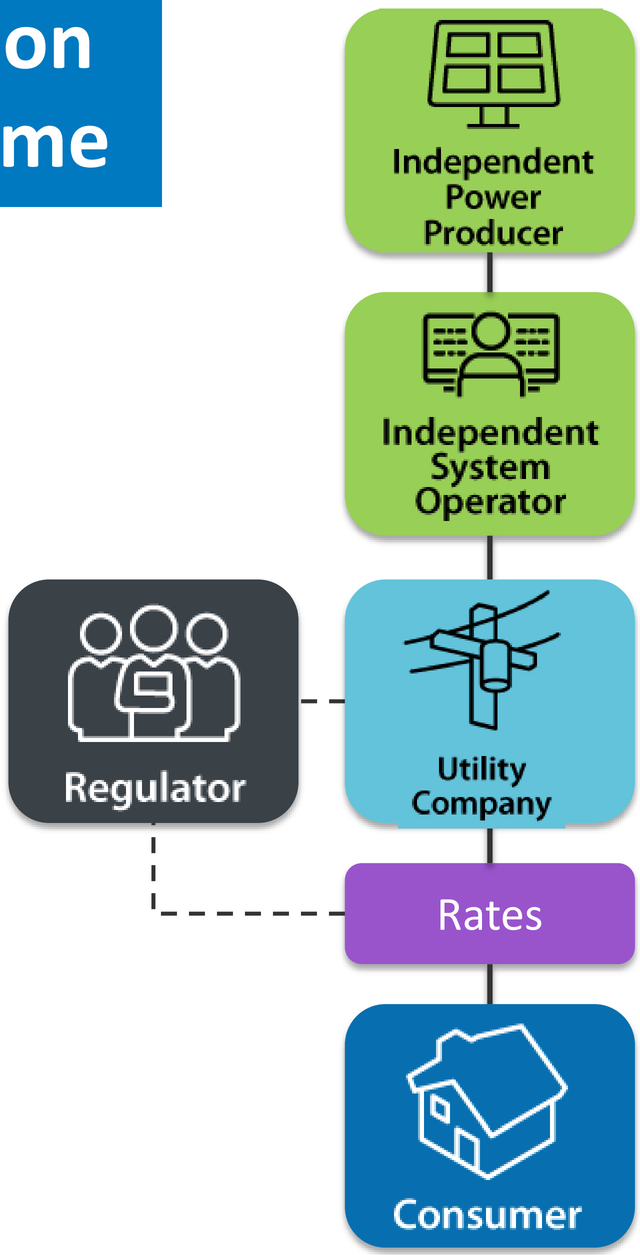
- Energy efficiency
- Peak load reduction




- **Interruptible rates** for large C&I
- **Demand charges** to recover T&D costs
- **Time-of-use rates** favoring overnight and weekend electricity use to make better use of, e.g., nuclear and coal plants

- **Energy efficiency** to reduce energy bills

# v1.1 Demand participation elaborates on the v1 theme




- **Wholesale demand response programs** reduce capacity, energy, and ancillary service costs in restructured markets
- **Energy efficiency programs** incentivize customers to adopt technologies that reduce grid costs
- **Critical peak pricing** and its variants to incentivize peak load reduction from more customers
- **Direct load control** for air conditioners, water heaters, pool pumps, and other end uses


- In some locations, **energy efficiency programs** are delivered by third parties
- Third parties often **facilitate retail and wholesale demand response**

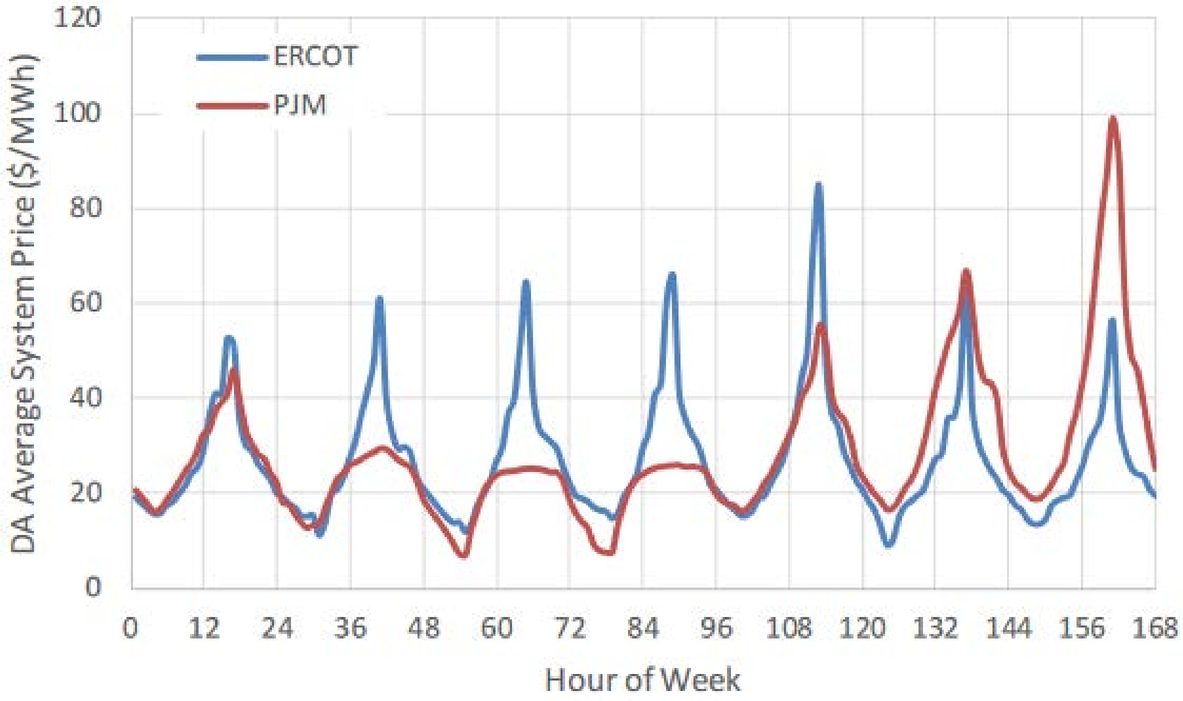
# Participation is limited by how **grid service value** stacks up against demand response availability and cost

Denholm, Sun and Mai (2019) report that for 2016-2017:

- Wholesale capacity prices from $1.81/kW-month to $7.03/kW-month
- Wholesale average energy prices from $0.022/kWh - $0.035/kWh
- Capacity and energy are about 75% of bulk system costs
- Transmission is 20% to 25% of bulk system costs

U.S. EIA on retail electricity prices in 2022:

- $0.125/kWh on average in the U.S.
- 12% for transmission, 26% for distribution, balance for generation



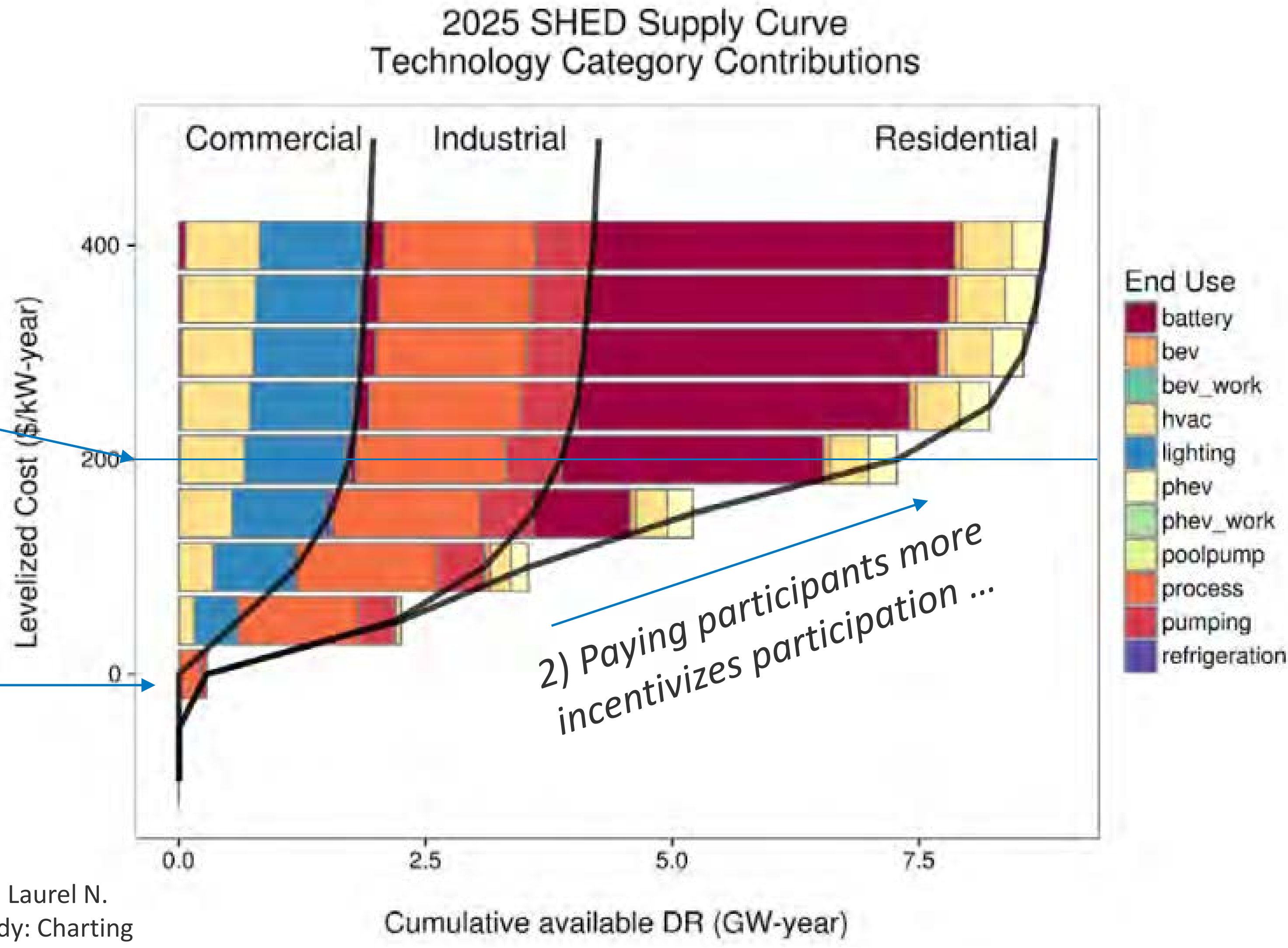

Energy price variation in PJM and ERCOT, July 1-7, 2016
Source: Denholm, Sun and Mai (2019)


Denholm, Paul, Yinong Sun, and Trieu Mai. 2019. “Introduction to Grid Services: Concepts, Technical Requirements, and Provisions from Wind.” NREL/TP-6A20-72578. https://www.nrel.gov/docs/fy19osti/72578.pdf.
U.S. EIA. 2021. “Electricity Explained: Factors Affecting Electricity Prices.” 2022. https://www.eia.gov/energyexplained/electricity/prices-and-factors-affecting-prices.php

# Participation is limited by how grid service value stacks up against **demand response availability and cost**

*3) … but there is a ceiling set by the price at which supply-side resources can deliver the same service*

*1) Some industrial load is low-value, and will not consume electricity at modestly high prices*




Source: Alstone et al. (2017)

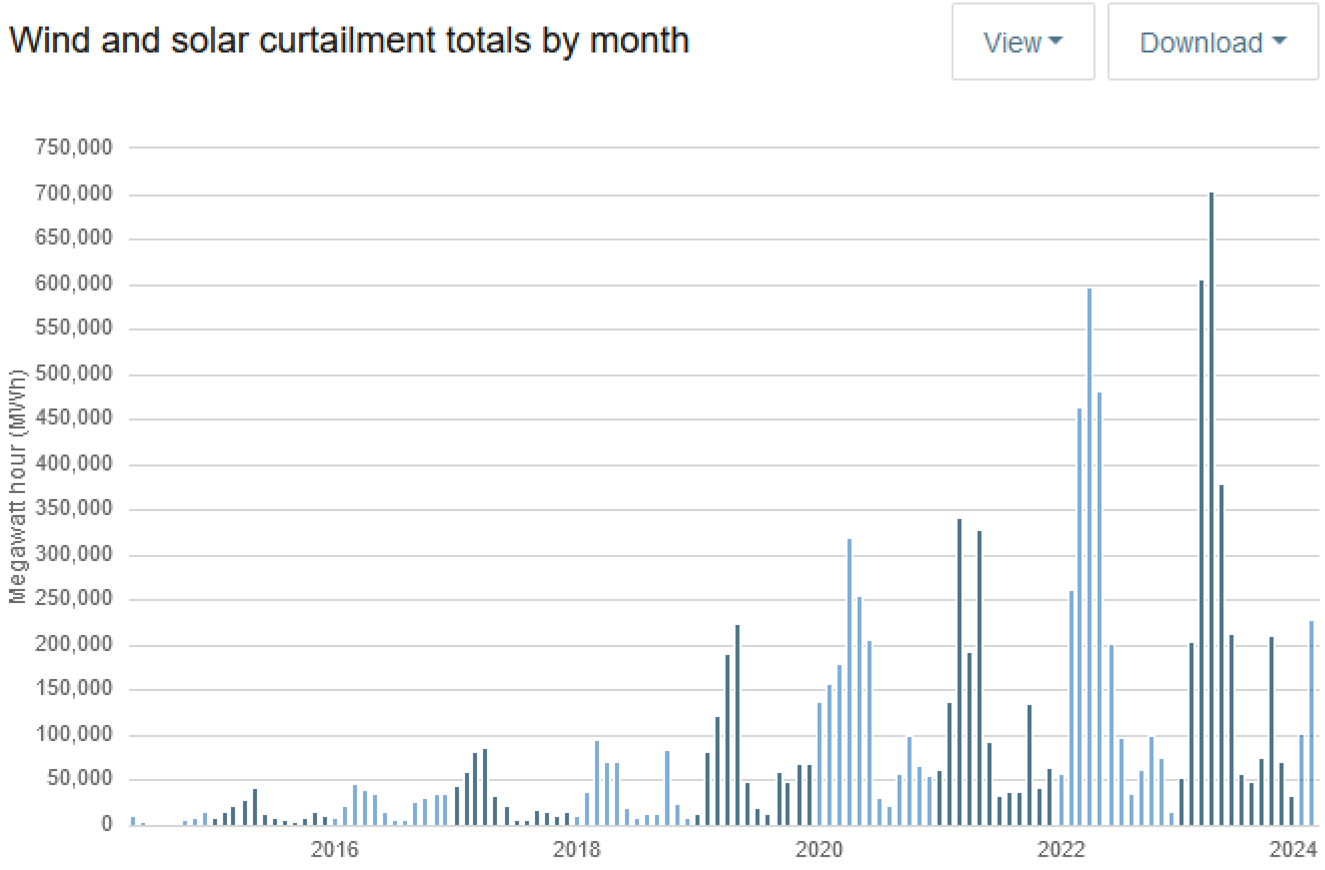
Alstone, Peter, Jennifer Potter, Mary Ann Piette, Peter Schwartz, Michael A. Berger, Laurel N. Dunn, Sarah J. Smith, et al. 2017. "2025 California Demand Response Potential Study: Charting California's Demand Response Future (Phase 2 Appendices A)." Lawrence Berkeley National Laboratory. https://www.cpuc.ca.gov/WorkArea/DownloadAsset.aspx?id=6442452699.

# Part 2

## Future Power Systems

# **Curtailment**, low prices, and anticipated seasonal mismatch present new demand-side opportunities

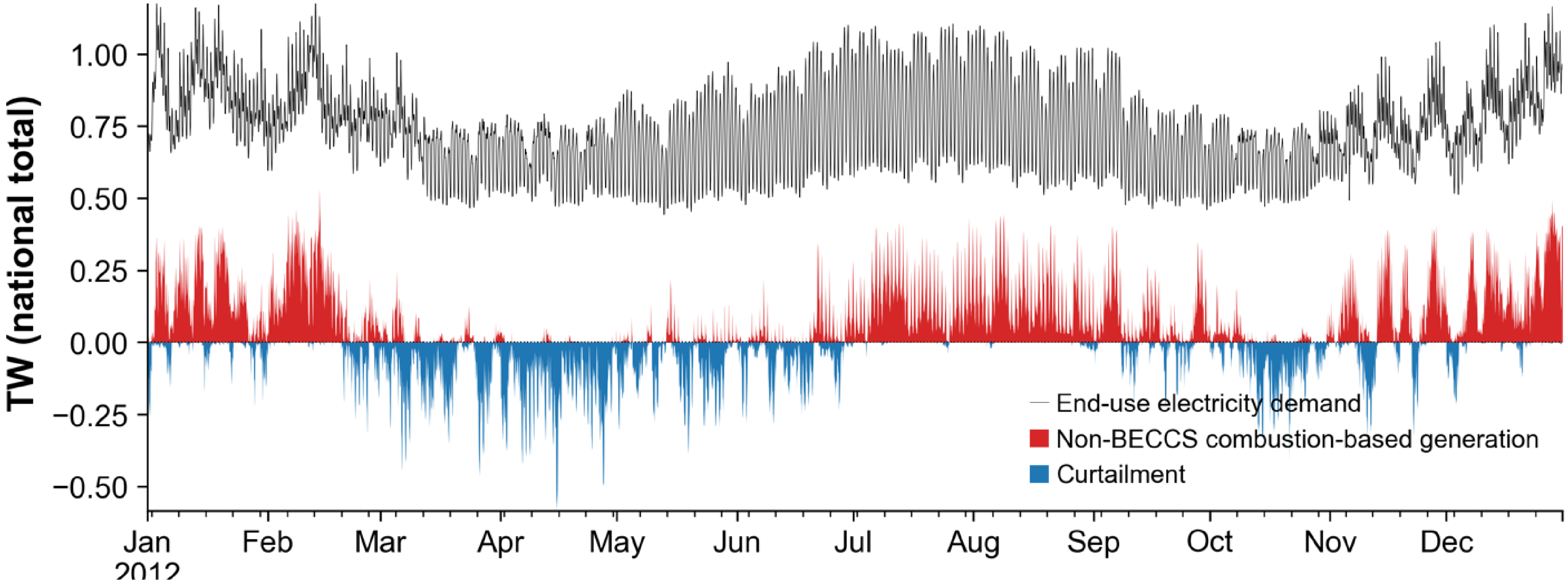
- CAISO historical curtailments to right
- Curtailment is highest in the spring
- 2019 curtailment ranged from an average of 1 GWh/day (summer) to over 5 GWh/day (spring) (Gerke et al. 2020)




Source: http://www.caiso.com/informed/Pages/ManagingOversupply.aspx Updated as of 3/7/2024

Gerke, Brian F., Giulia Gallo, Sarah J. Smith, Jingjing Liu, Peter Alstone, Shuba Raghavan, Peter Schwartz, Mary Ann Piette, Rongxin Yin, and Sofia Stensson. 2020. "The California Demand Response Potential Study, Phase 3: Final Report on the Shift Resource through 2030." Technical Report. Lawrence Berkeley National Laboratory (LBNL). https://buildings.lbl.gov/publications/california-demand-response-potential.

# Curtailment, low prices, and **anticipated seasonal mismatch** present new demand-side opportunities



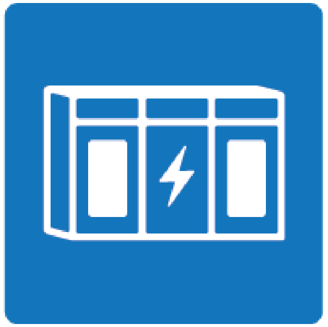

**The seasonal supply/demand balance for the contiguous United States in the All Options scenario (ADE demand case) in 2035 shows the seasonal mismatch challenge (Denholm et al. 2022).**

Demand met by fossil- and hydrogen-fueled resources (red) occurs largely during periods of relatively low wind and solar output, or periods of very high electricity demand. The supply of wind and solar generally exceeds demand resulting in curtailment (blue) in the spring and fall, often for continuous periods.


Denholm, Paul, Patrick Brown, Wesley Cole, Trieu Mai, Brian Sergi, Maxwell Brown, Paige Jadun, et al. 2022. “Examining Supply-Side Options to Achieve 100% Clean Electricity by 2035.” NREL/TP-6A40-81644. National Renewable Energy Lab. (NREL), Golden, CO (United States). https://doi.org/10.2172/1885591.

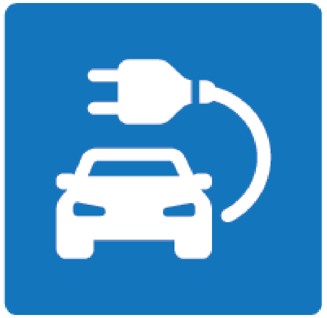
# New demand-side technologies **provide direct value to their owners**, and could also provide grid services

## Solar PV



## Behind-the-Meter Storage

- Power during outages
- Clean energy investment



## EVs

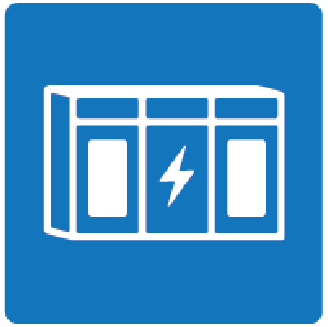
- Transportation services
- Lower operational costs
- Competitive or lower total cost of ownership
- Cleaner energy sources
- No emissions at point of use
- Power during outages (V2X)

## Heat Pumps

- Space heating and cooling
- Cleaner energy sources
- No emissions at point of use

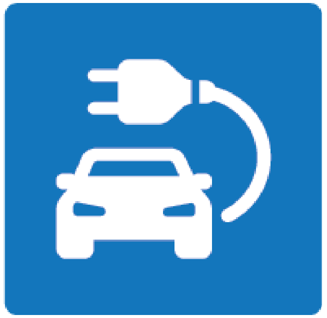
# New demand-side technologies provide direct value to their owners, and could also **provide grid services**

**Solar PV**



**Behind-the-Meter Storage**

- Increase output (discharge storage) during times of peak net-load*
- Reduce output (charge storage) during times of low net-load
- Limit output based on distribution system constraints
- Autonomously manage local voltage and respond to system frequency



**EVs**

- Schedule charging to be counter-cyclical compared to the overall net-load pattern (V1G)
- Discharge vehicle batteries when electricity supply is particularly valuable (V2G)
- Charger can provide some smart inverter services

**Heat Pumps**

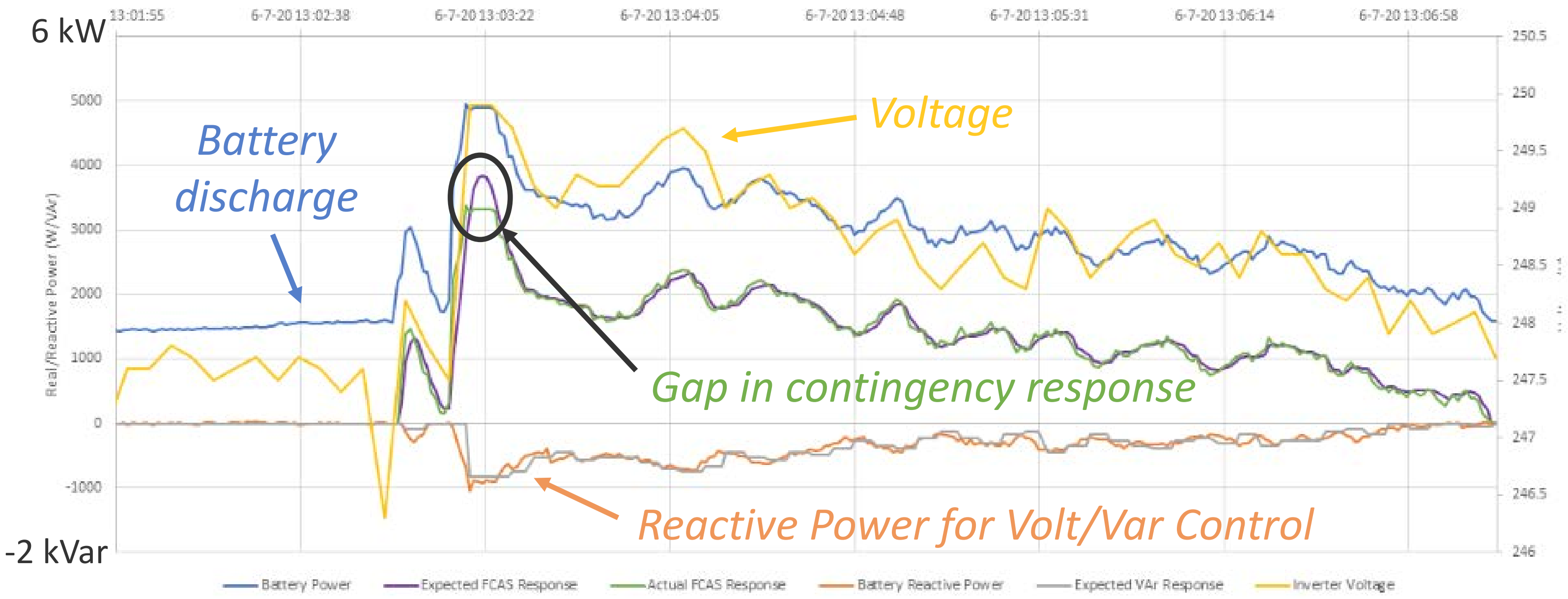
- Reduce load during times of peak net-load

*Net-load is a system's total load minus all variable renewable generation, e.g., wind and solar

# Virtual power plants connect DER owners and grid operators through IT and control infrastructure

**Australian Energy Market Operator (AEMO) VPP Demonstrations** ([link](https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/virtual-power-plant-vpp-demonstrations))

- Final report (2021) documents results of 8 VPP portfolios, 31 MW, and 7,150 participating customers
- All VPPs used PV plus batteries
- Snapshot of technical ability at one point in time
  - Primary service: contingency reserves
  - Could respond to real-time energy prices as unscheduled entity
  - One location included Volt/Var controls
  - VPP forecasting accuracy (~10%) is not yet as good as utility-scale solar plants (~5%)




Source: AEMO (2021)

**Example response from device in a VPP participating in AEMO and distribution operator VPP pilots at the same time shows simultaneous:**

- Volt/var control
- Contingency response
- Battery dispatch for another reason

AEMO. 2021. "AEMO NEM Virtual Power Plant Demonstrations: Knowledge Sharing Report #4." AEMO Virtual Power Plant Demonstrations, Updates to the Australian Renewable Energy Agency (ARENA). Australian Energy Market Operator (AEMO). https://aemo.com.au/en/initiatives/major-programs/nem-distributed-energy-resources-der-program/der-demonstrations/virtual-power-plant-vpp-demonstrations.

# Virtual power plants must navigate regulatory and market conditions

## Tesla VPP in ERCOT

- Tesla as retail electricity provider
- Retail charges peak and off-peak
- Transmission and delivery service provider charges
- Real-time energy sold at market price
- “There may be times when the VPP has made a capacity commitment and is unable to discharge in response to prices above the sellback trigger price ….”

https://www.tesla.com/support/energy/virtual-power-plant/tesla-electric

## Tesla VPP in PG&E

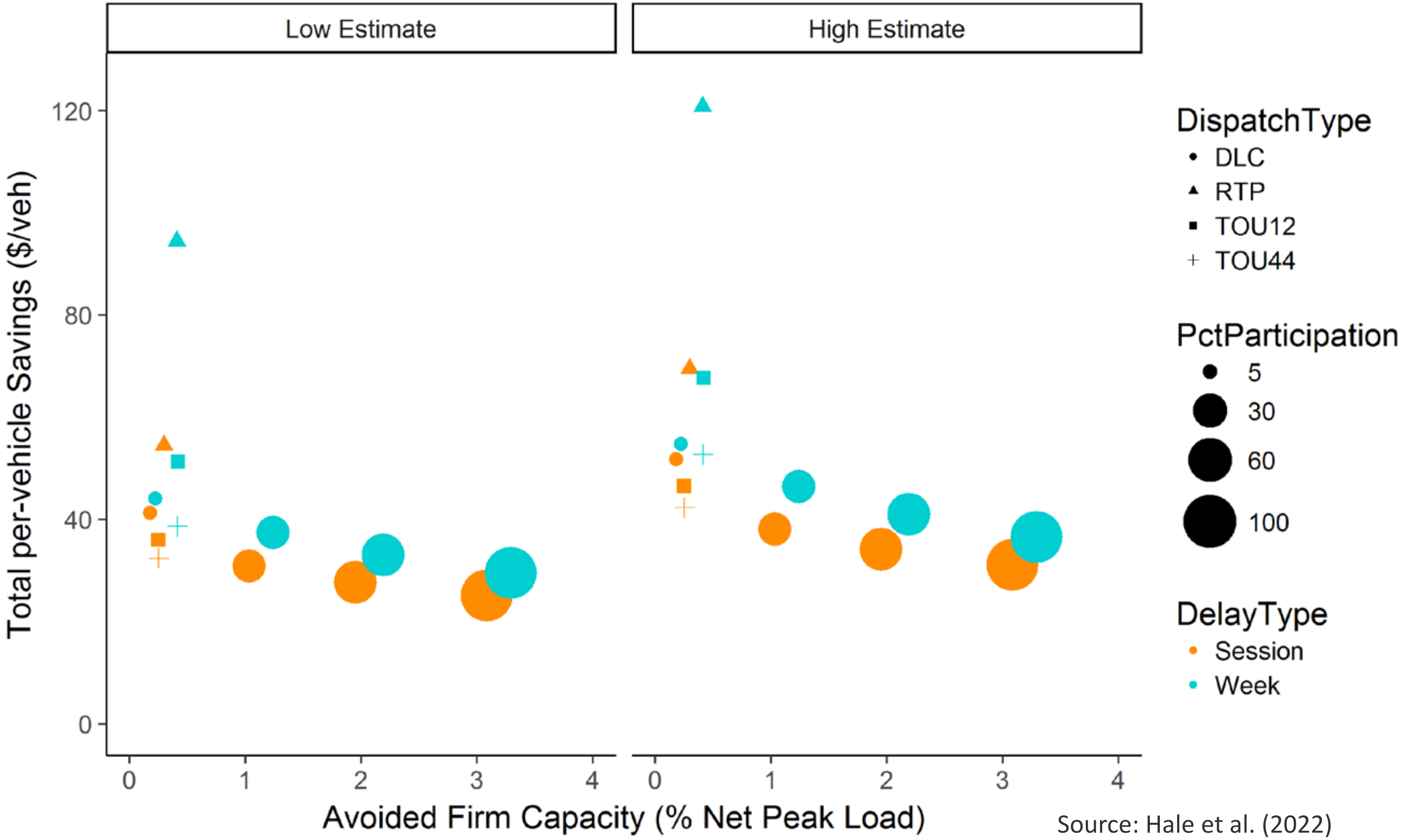
- Emergency Load Reduction Program
- $2/kWh during events

https://www.tesla.com/support/energy/virtual-power-plant/pge

# DER participation mechanisms must balance different stakeholders' benefits and costs

**Electric vehicle managed charging example**

- Maximum bulk system value of $120/vehicle-yr
- Real-time Price (RTP): most value at low participation, but can response be automated?
- Time-of-use (TOU): least costly to implement, but least value
- Direct load control (DLC): most sustained value, but most costly to implement



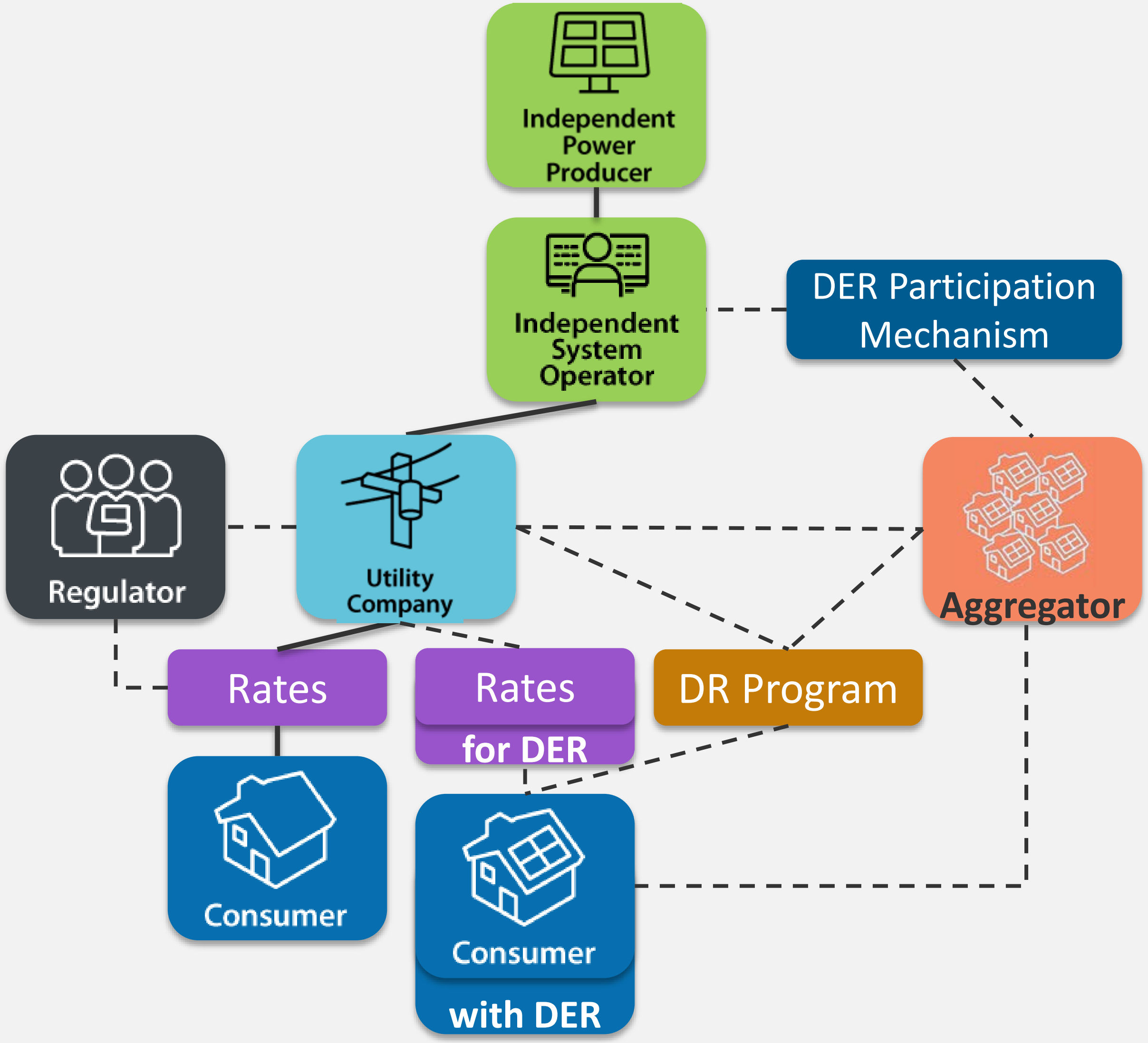

Source: Hale et al. (2022)


Hale, Elaine, Luke Lavin, Arthur Yip, Brady Cowiestoll, Jiazi Zhang, Paige Jadun, and Matteo Muratori. 2022. "Electric Vehicle Managed Charging: Forward-Looking Estimates of Bulk Power System Value." Technical Report NREL/TP-6A40-83404. https://doi.org/10.2172/1890139.

# Conclusion

**Scope**

- DER Scope
  - Residential customers
  - Distributed photovoltaics (PV)
  - Battery energy storage systems (BESS)
  - Electric vehicle (EV) managed charging
- Bulk power scenarios
  - Vertically integrated utilities
  - Independent power producers
- DER participation scenarios
  - Retail tariff only
  - DR program
  - Wholesale participation




**Possible Extensions**

- Distinguish between IOU and non-profit utilities
- Incorporate the value of backup power in storage adoption decisions
- Analyze more retail tariff structures
- Endogenize more DER participation parameters (e.g., incentive levels, incentive types)

*Final analysis summer 2024*

An ongoing project (MARKET Task 2.5.1) is analyzing the impact of different DER participation models, including virtual power plants (VPPs), using a stylistic model of the New England power system, 2025-2035.

# Open Questions

- **Previous slide tackles parts of:** How can behind-the-meter PV plus storage and flexible loads, especially electric vehicles, and heat pumps, contribute to affordable reliability and resilience at different scales (e.g., bulk system, community, home) and considering all relevant markets and other contracts?
- **Other work:** How can industrial demand participation evolve to produce welfare-maximizing outcomes, especially as industry electrifies (e.g., electrochemical processes for hydrogen, ammonia, steel; heat pumps)?

# Open Questions

***What does the demand-side of the grid look like in a fully decarbonized energy system?***

What market designs and regulatory structures, what distributed technology adoption levels and operational modes are **sustainable for all stakeholders**: electricity users with and without DERs, load serving entities, distribution and transmission utilities, grid operators, independent power producers, aggregators, and technology providers?

# Thank you

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