THE UNIVERSITY OF MELBOURNE

Melbourne Energy Institute

MEInetwork21 Energy Systems Seminar Series

Seminar 6

Demand Response and Virtual Power Plants

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The University of Melbourne

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Demand Response and Virtual Power Plants

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MEInetwork21 Seminar

18th November 2021

A changing system and market…

(Images sourced from the internet)

LOW FLEXIBLE AND INFLEXIBLE GENERATION

- NUCLEAR
- COAL

FLEXIBLE GENERATION UNITS

- GAS
- HYDRO
- CCGT
- CHP

MARKET SERVICES

INFLEXIBLE CONSUMPTION

(Images sourced from the internet)

IMPORTED FLEXIBILITY

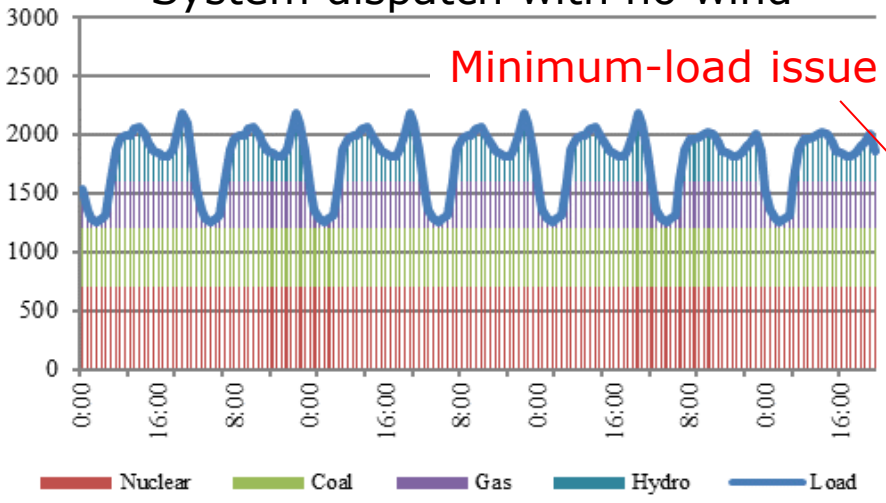
- INTECONNECTIONS
- AC LINES
- HVDC

(Images sourced from the internet)

Courtesy of T. Capuder, University of Zagreb

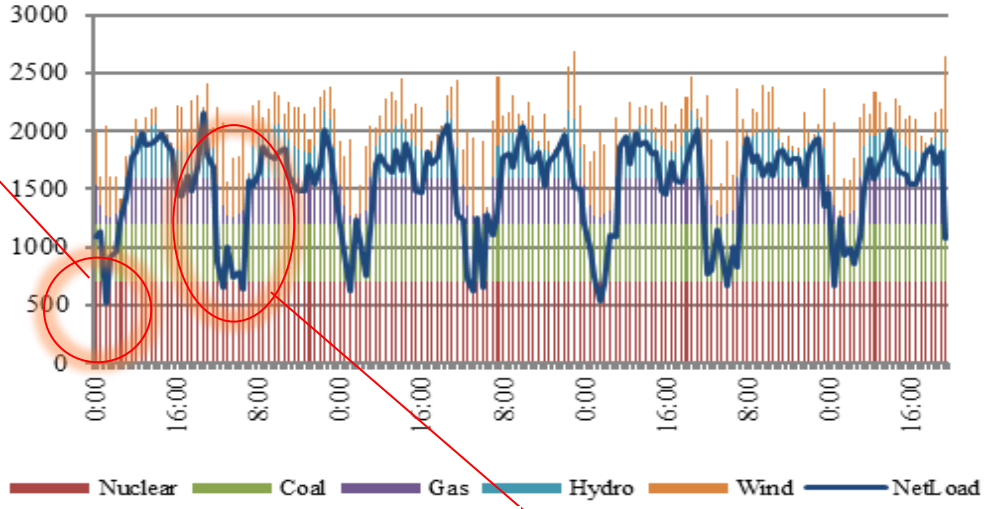
Flexibility challenges

System dispatch with no wind



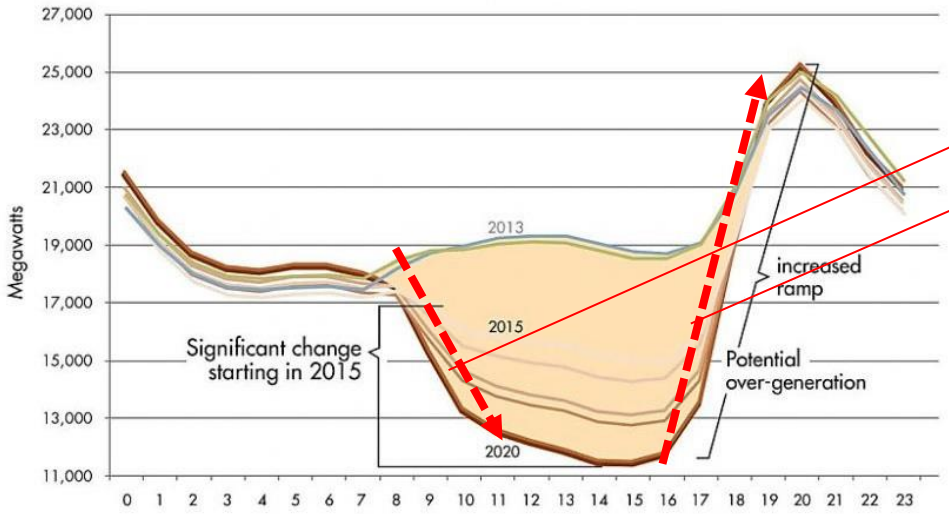
Minimum-load issue

Ideal system dispatch with wind



Courtesy of T. Capuder, University of Zagreb

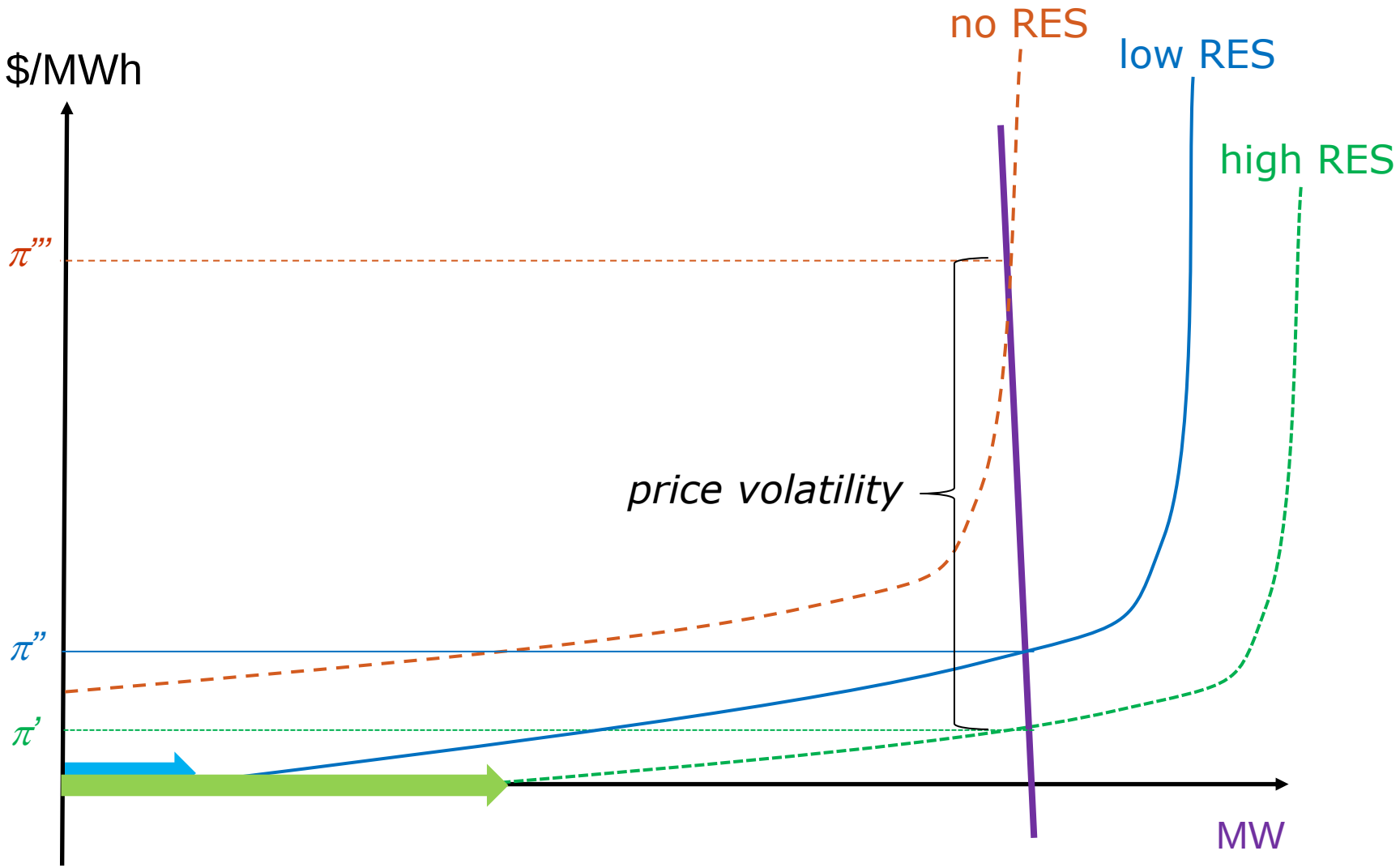
Net load



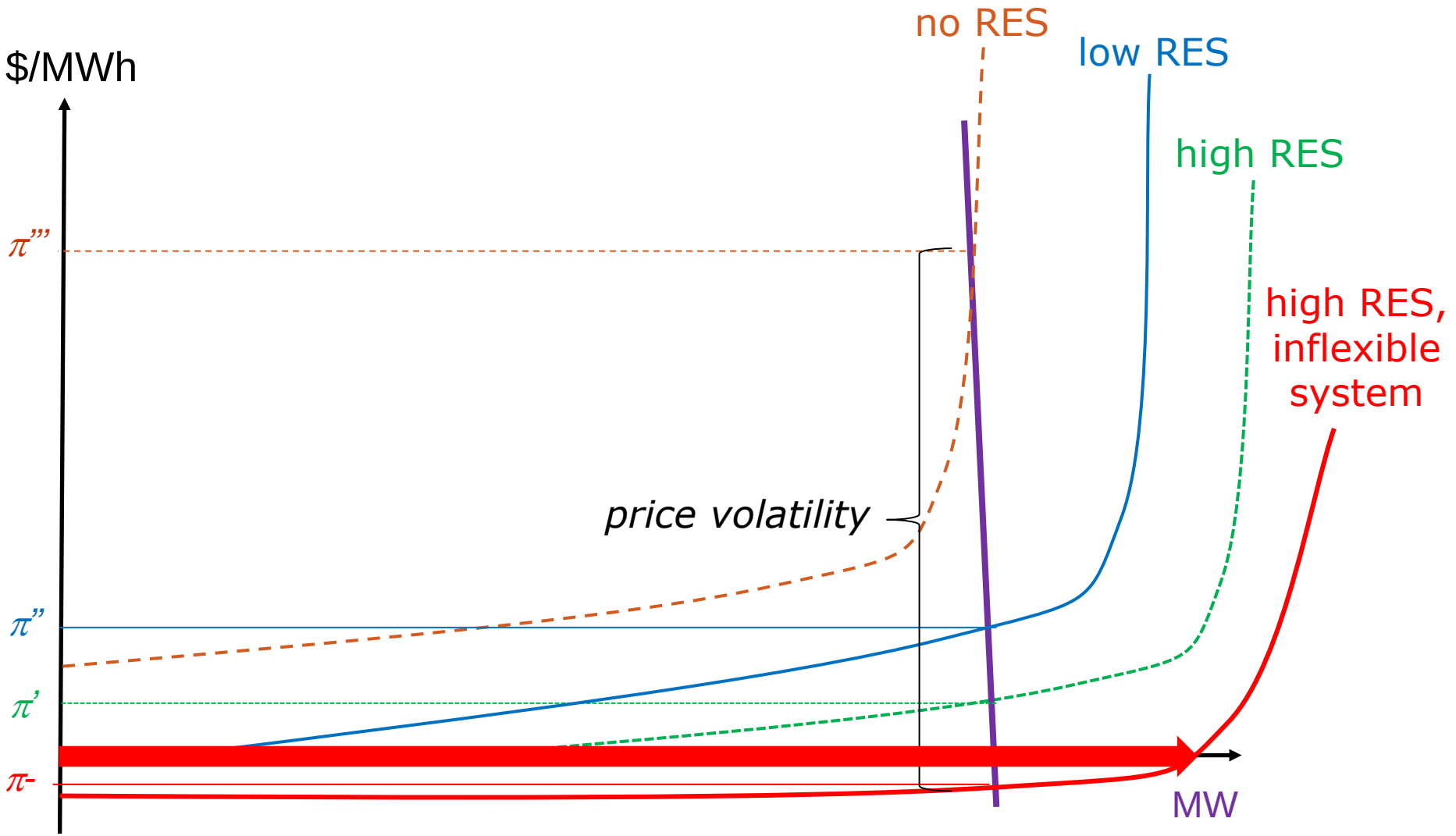
Steep down-ramps and up- ramps

Source: CAISO

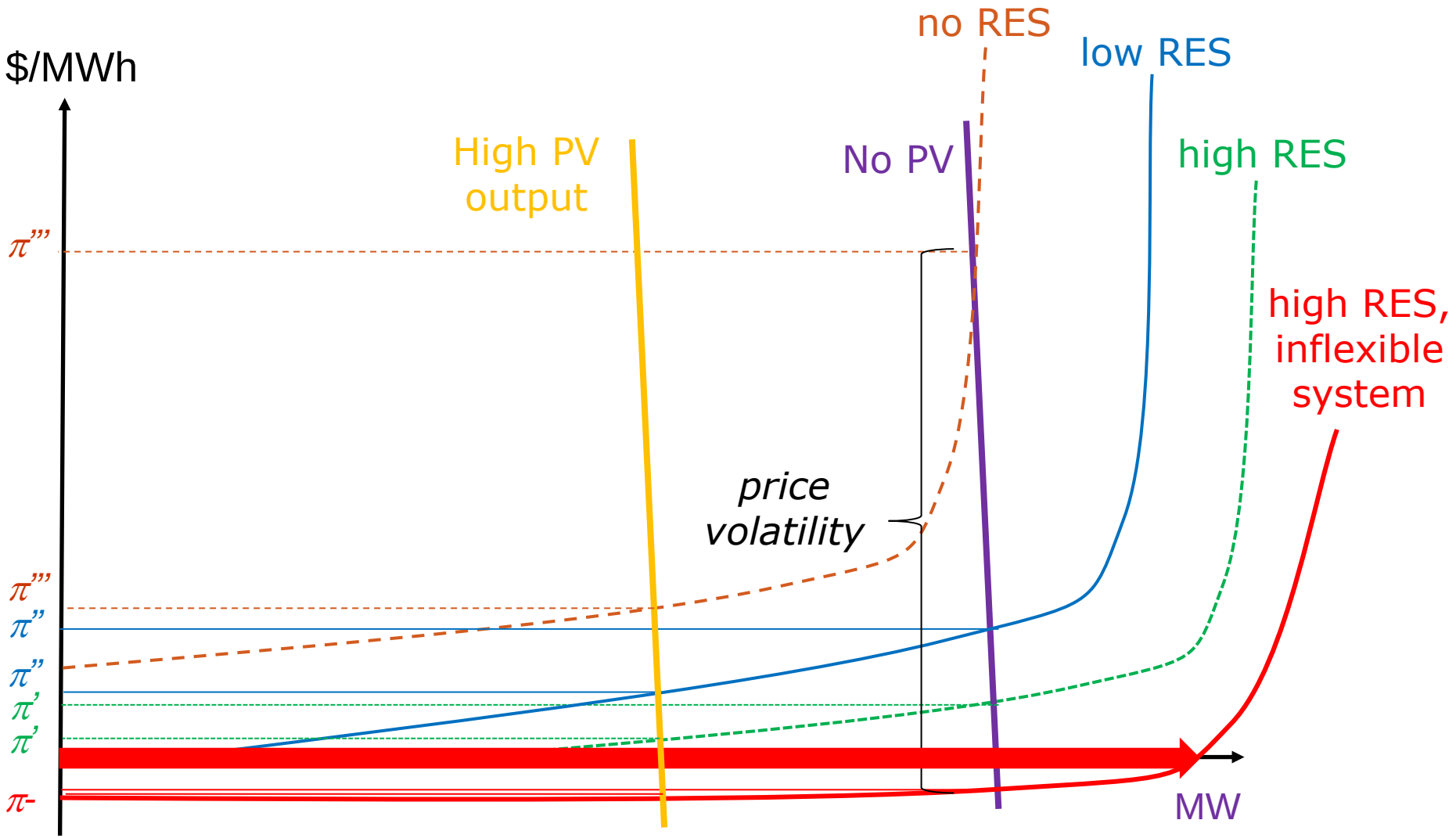
Price volatility…



… negative prices, …



… and off-market distributed PV



A changing system and market…

LOW FLEXIBLE AND INFLEXIBLE GENERATION

- NUCLEAR
- [redacted]

What next?

MARKET SERVICES

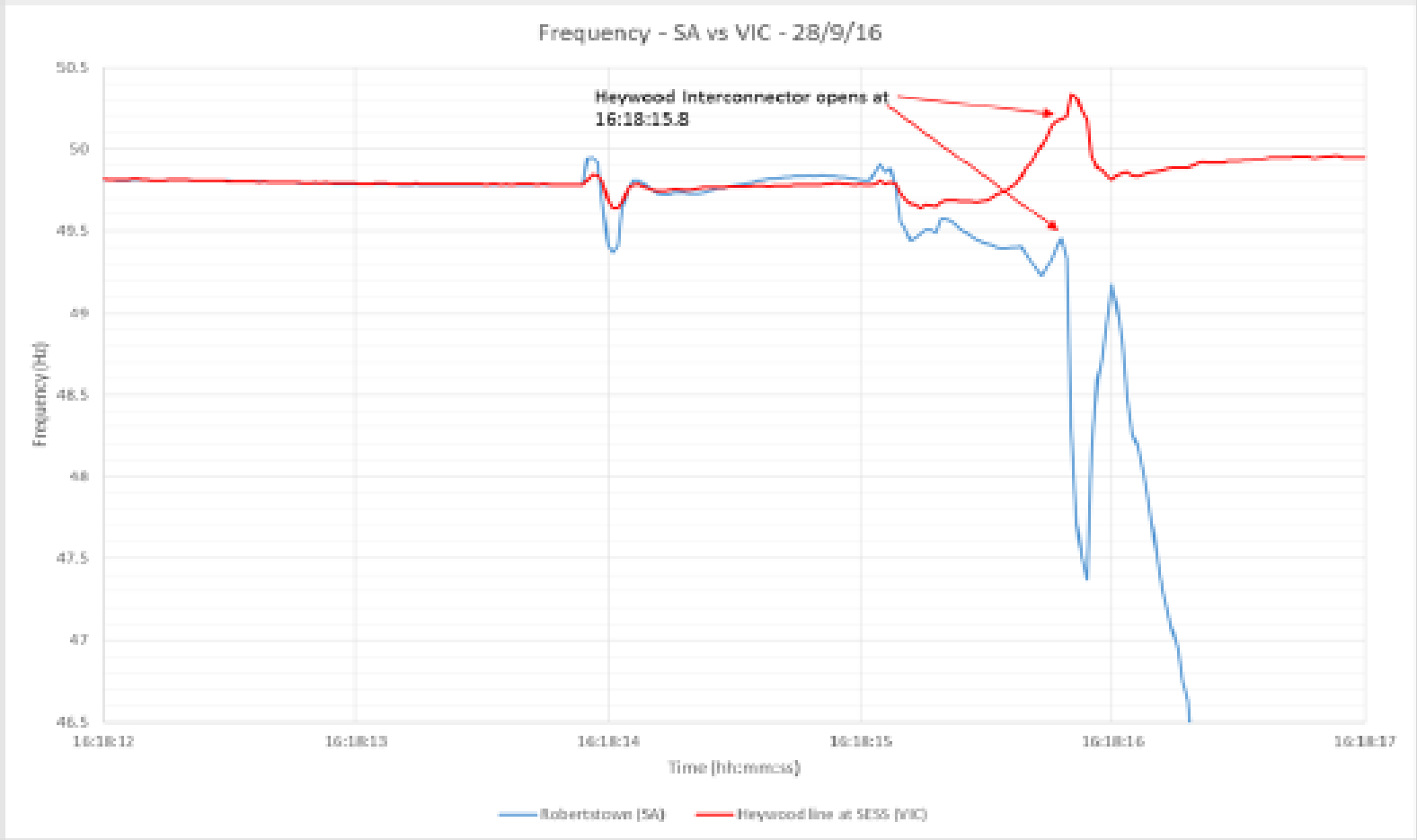
INFLEXIBLE CONSUMPTION

IMPORTED FLEXIBILITY

- INTECONNECTIONS
- AC LINES
- HVDC

Is it a far future?

Figure 5 SA frequency compared to Victoria during event

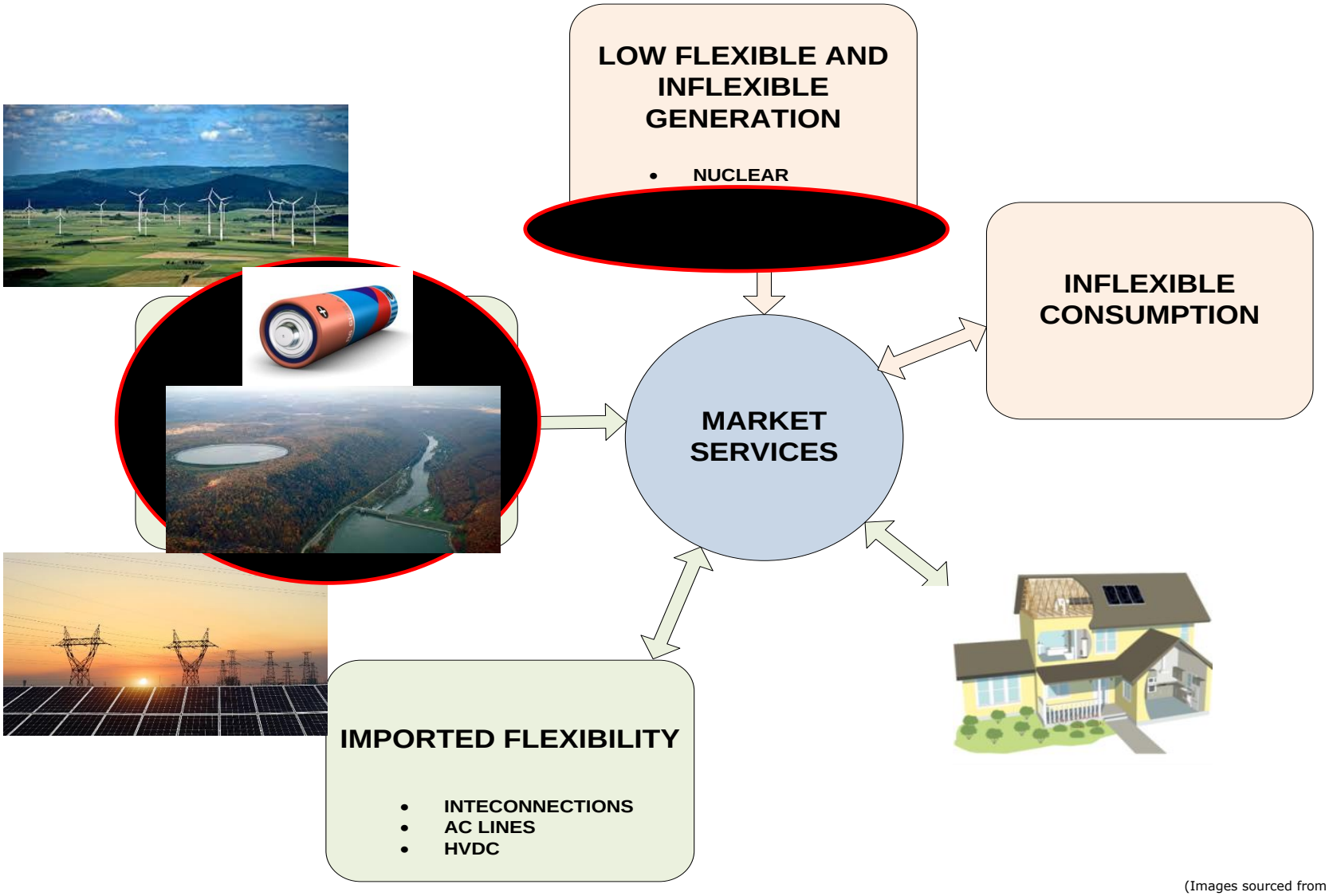


Source: AEMO

"Engineering", aka…
Where there's a problem there's a solution!

(Images sourced from the internet)

Flexibility and security services during the transition



(Images sourced from the internet)

And in the future?

LOW FLEXIBLE AND INFLEXIBLE GENERATION

- NUCLEAR

INFLEXIBLE CONSUMPTION

MARKET SERVICES

IMPORTED FLEXIBILITY

- INTECONNECTIONS
- AC LINES
- HVDC

(Images sourced from the internet)

And in the future?

LOW FLEXIBLE AND INFLEXIBLE GENERATION

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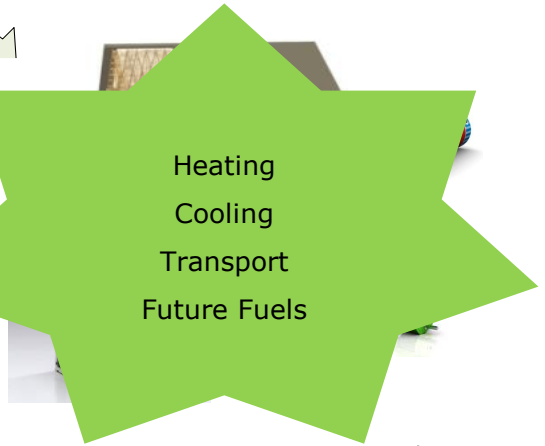
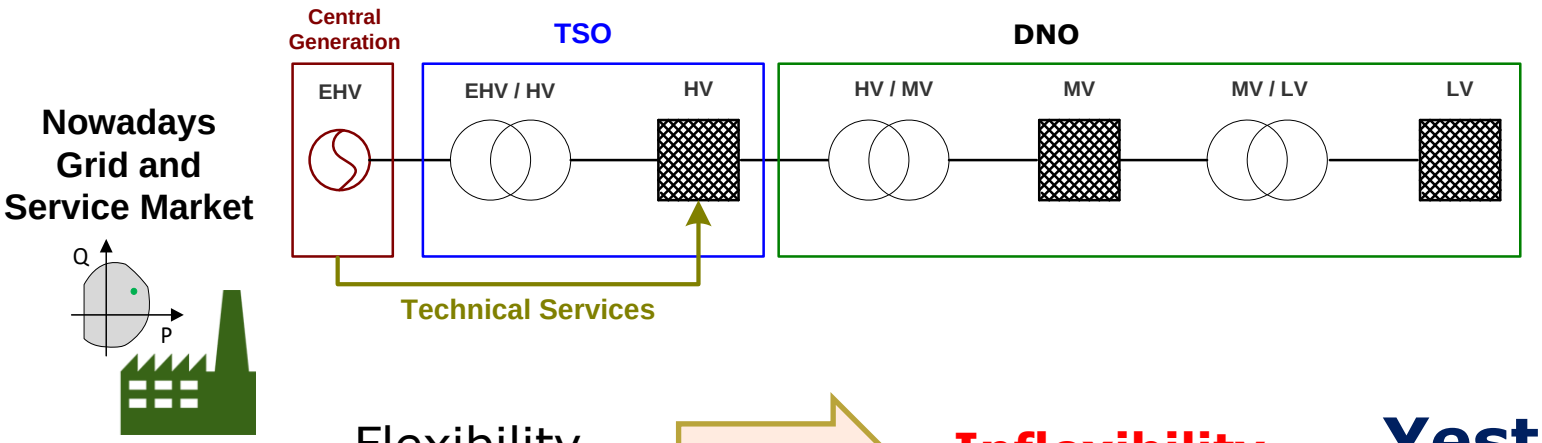


(Images sourced from the internet)

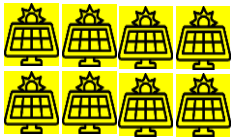
Flexibility, DER and demand response

- In order to address the emerging challenges from renewables integration, **more flexibility** is required
- **New sources of flexibility** will also be needed
- **Distributed energy resources (DER)** on the demand-side can represent major forms of flexibility
  - **Storage**
  - Flexible consumption in the form of **Demand Response** (DR)
- Integrate perfectly with **embedded generation** (e.g., rooftop solar)
- Facilitated by new generation, storage and control technologies (the "smart grid")

Direction of flexibility



Flexibility → **Inflexibility** — **Yesterday**



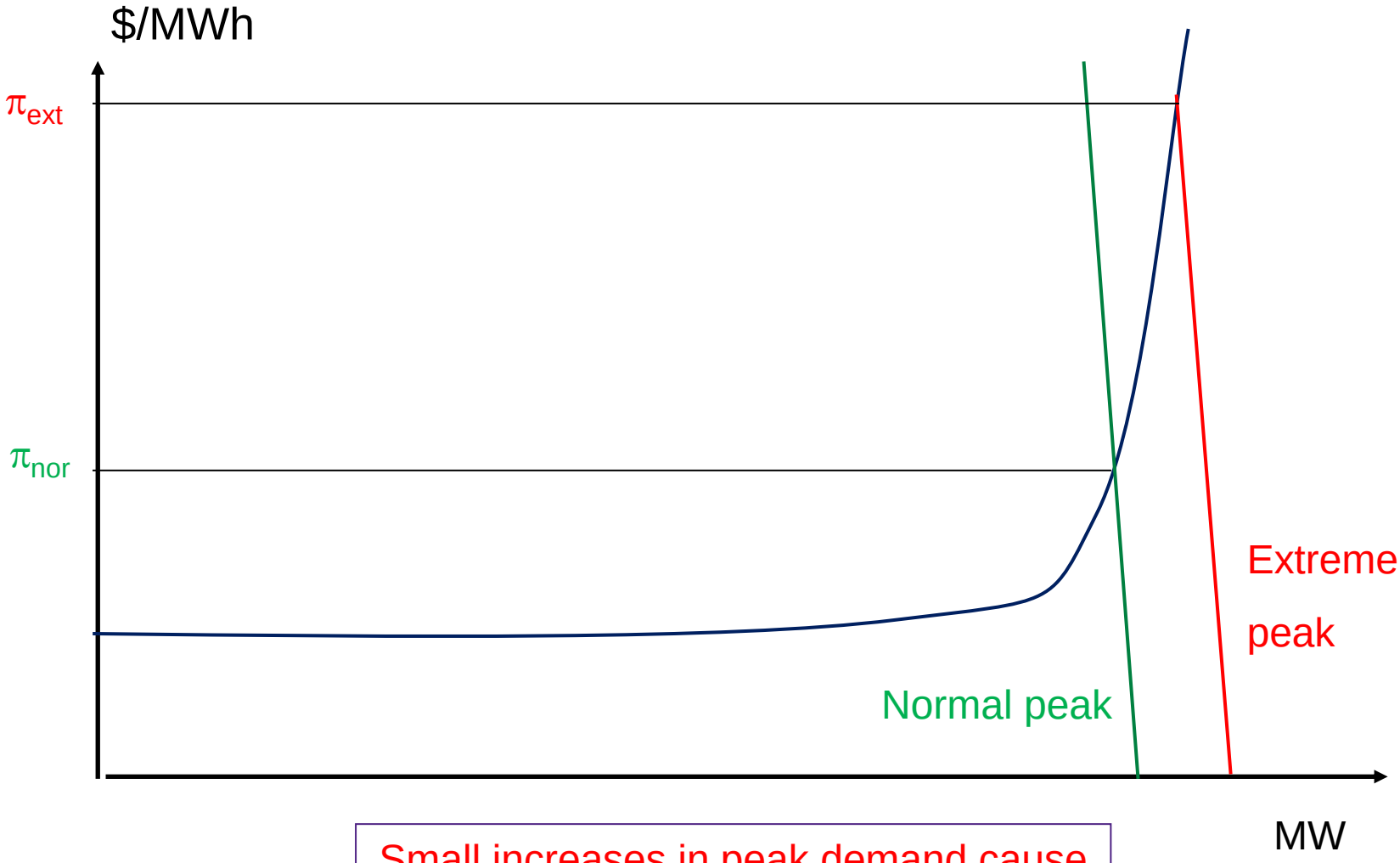
Flexibility ← — **Tomorrow**

(Images sourced from the internet)

What is demand response (DR)

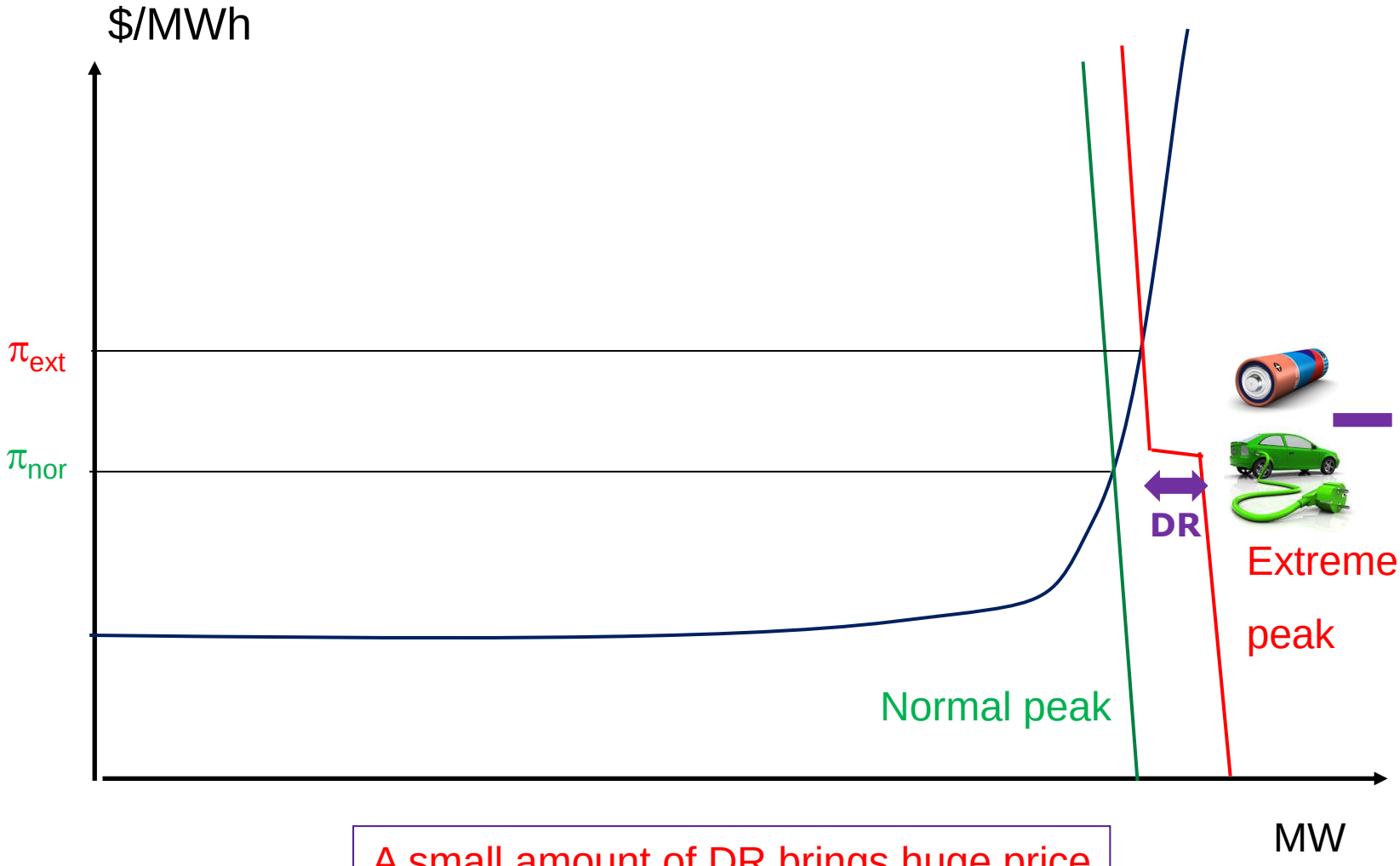
- Customer *adapting* their **consumption** to dynamic (or time varying) electricity prices or other signals
  - Water heaters as typical examples
  - In the close future, EVs
- More generally, in the presence of local generation (e.g., PV) and storage (batteries, EVs in V2G mode):
  - Customers become ***prosumers***
  - They could adapt ***both consumption and production*** to prices or other signals

DR and energy markets: A very hot summer day…



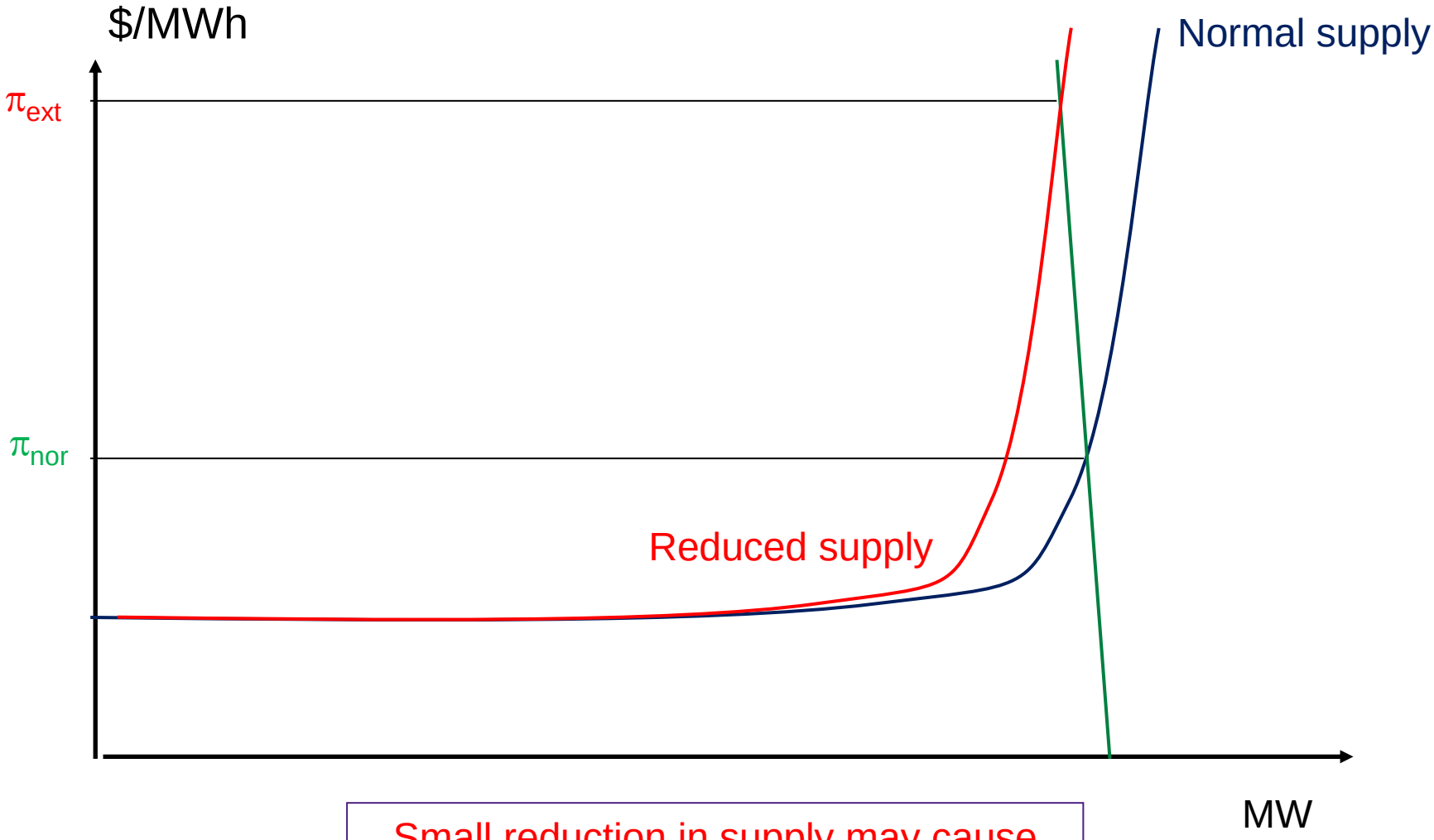
Small increases in peak demand cause large changes in prices

DR and energy markets: A very hot summer day…



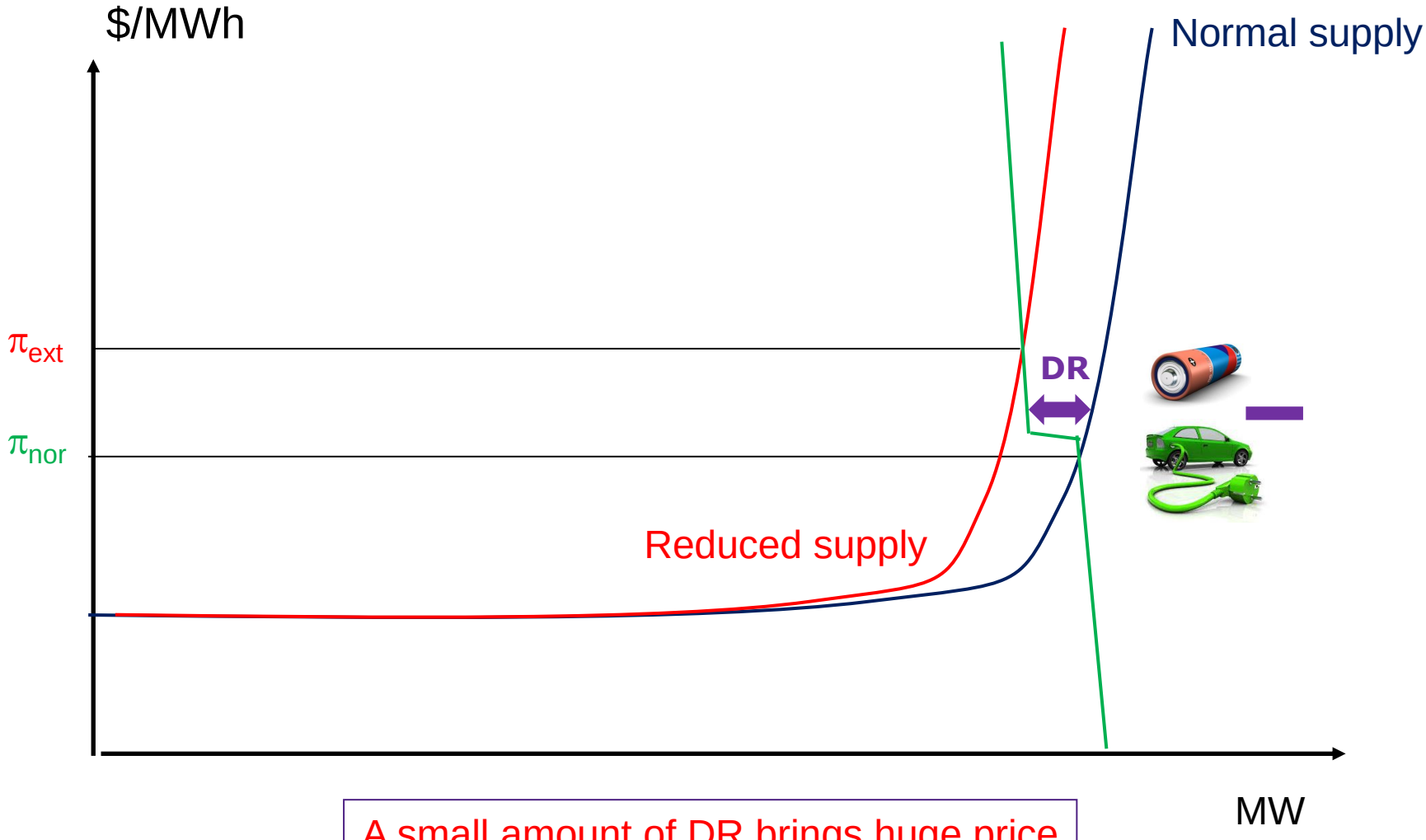
A small amount of DR brings huge price benefits to the system!

DR and energy markets: Unplanned outages



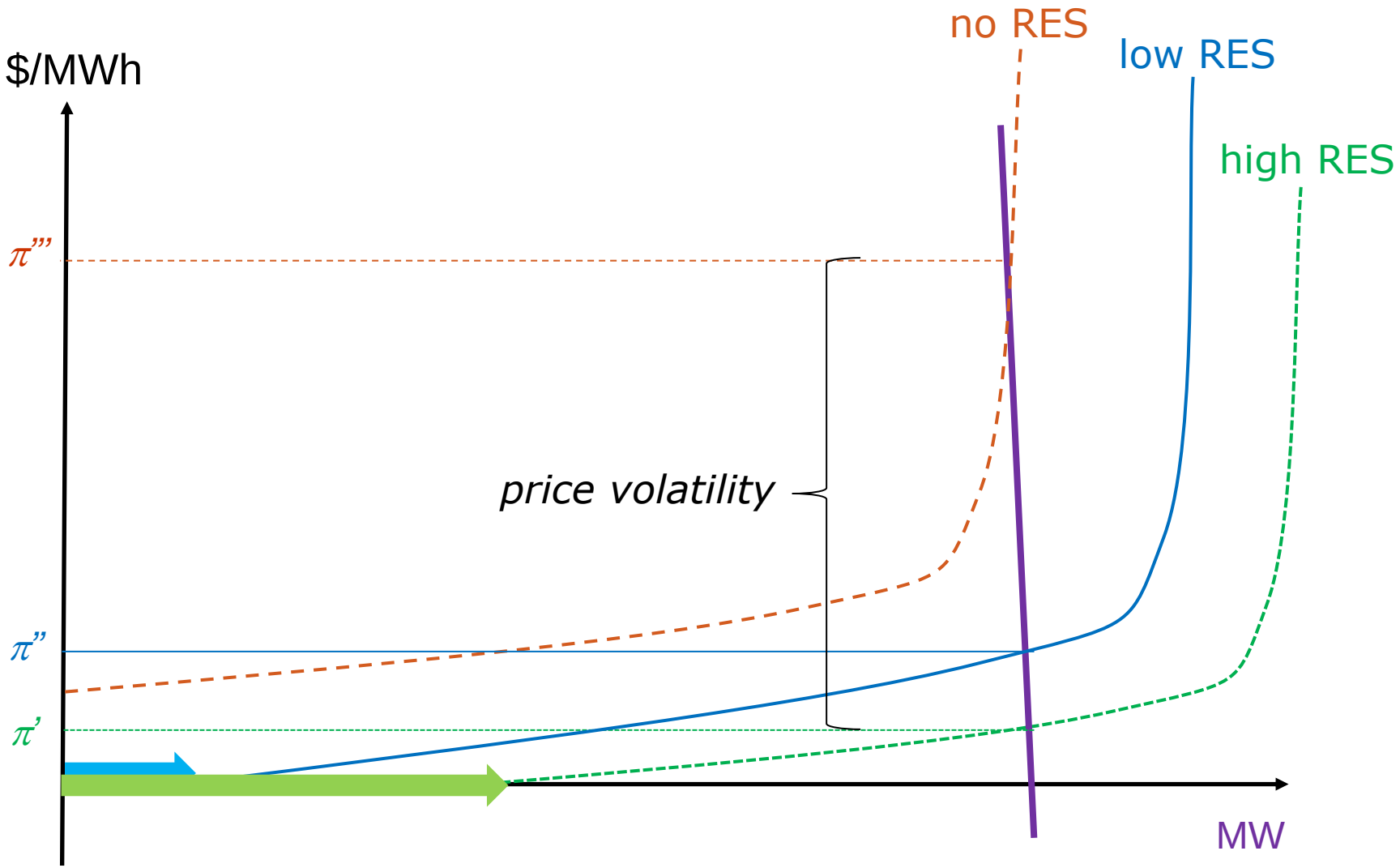
Small reduction in supply may cause large changes in prices

DR and energy markets: Unplanned outages

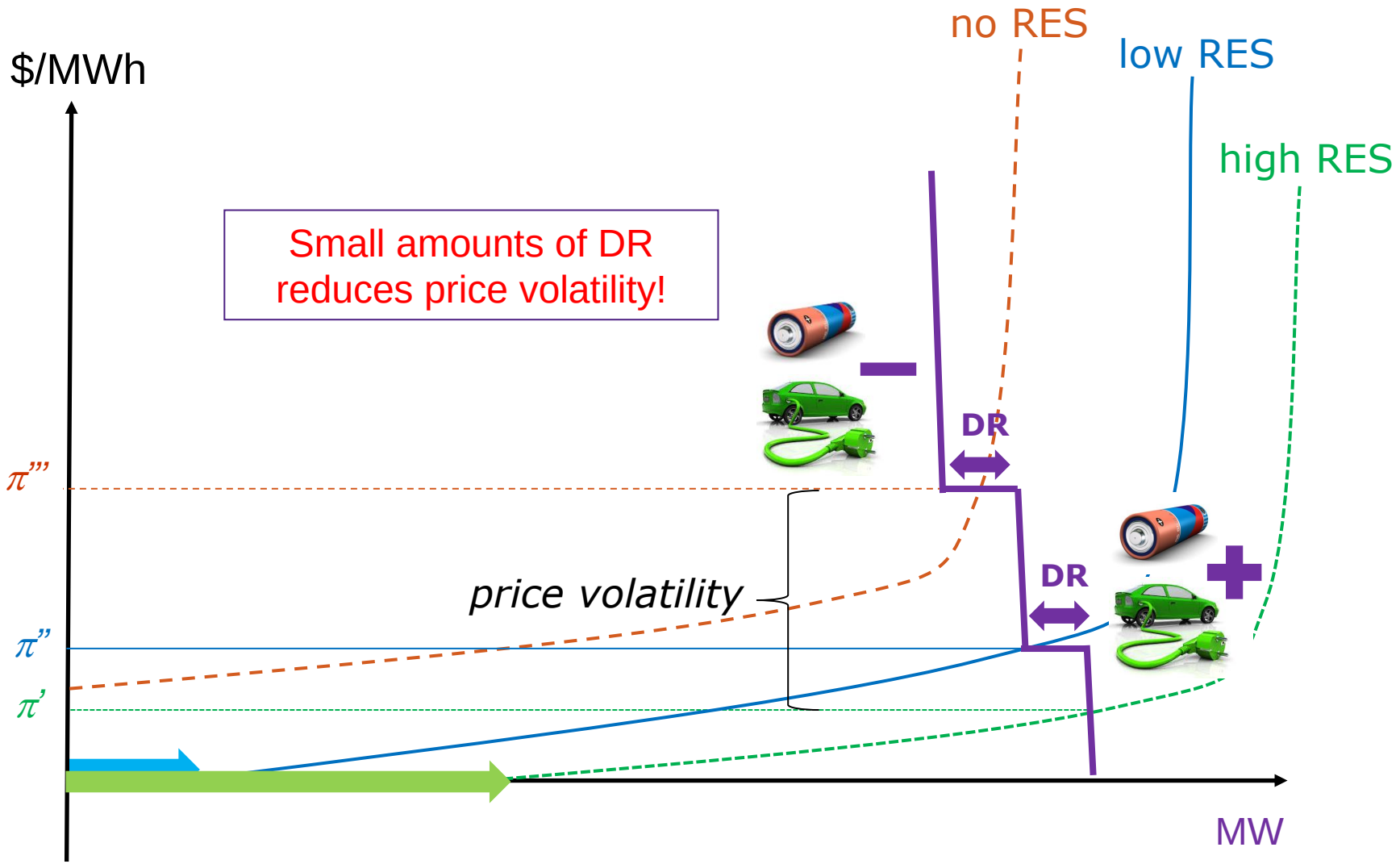


A small amount of DR brings huge price benefits to the system!

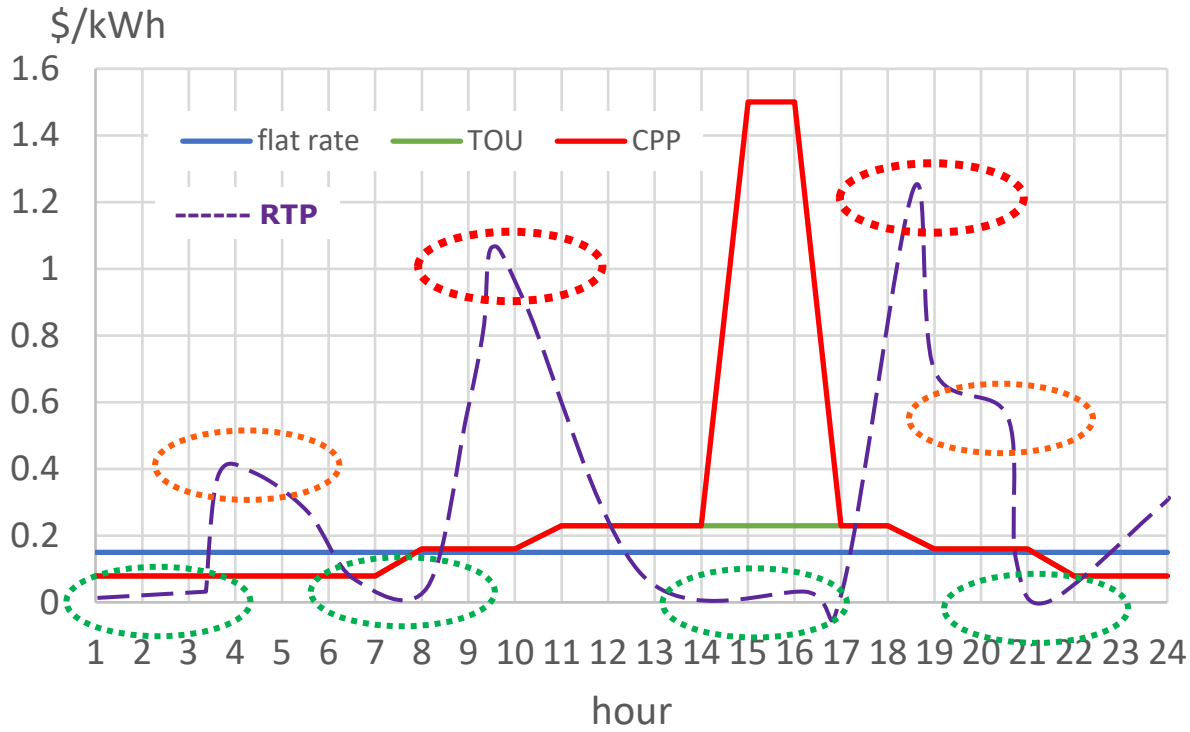
DR and price volatility



DR and price volatility



How do you harness DR: Price-based DR incentives

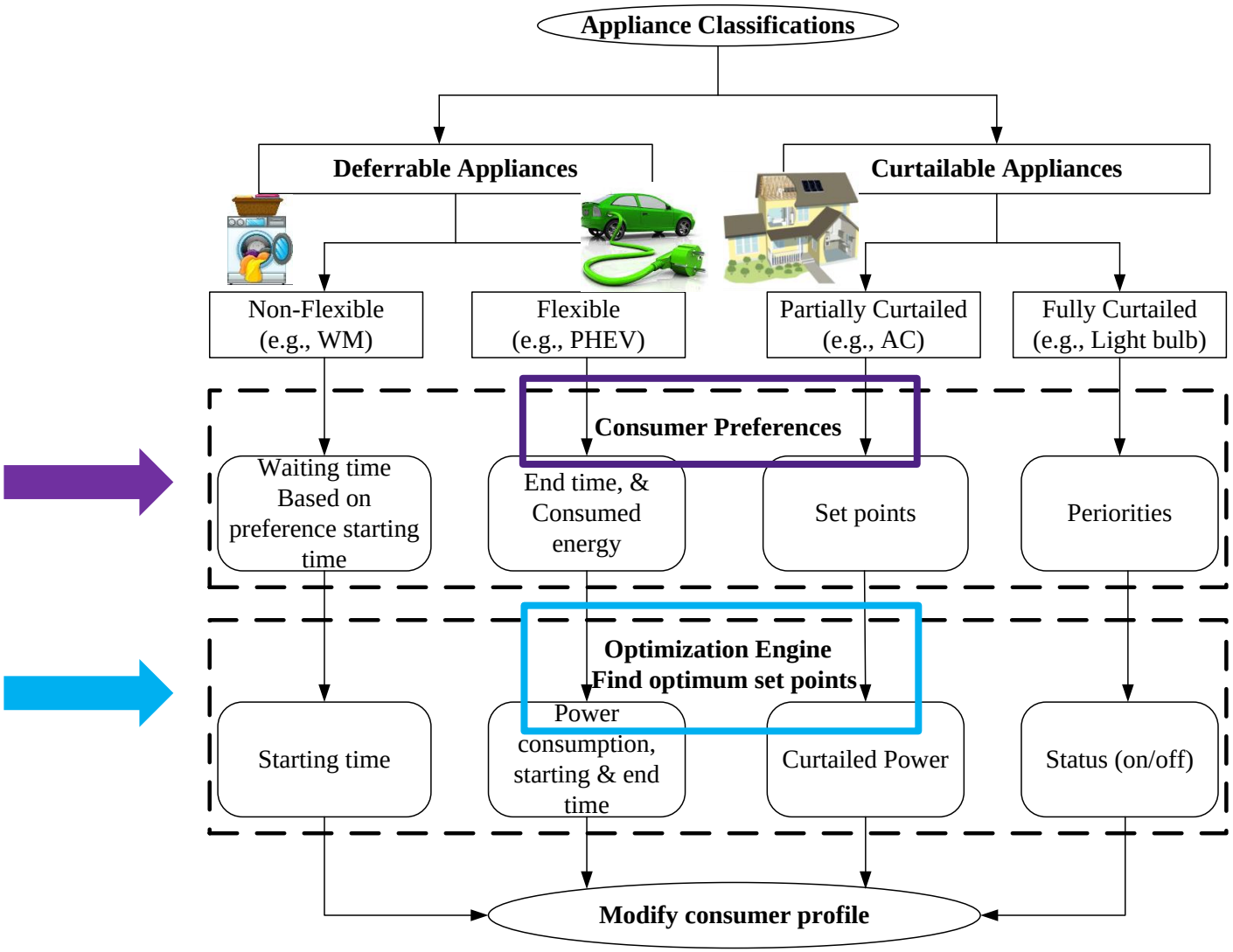


How about real-time pricing?

Would you bother playing with energy prices and DR?

Note: Dynamic pricing may, in case, be facilitated by an aggregator or the retailer, in order to partially "shield" (small) consumers from extreme volatility and excessively high prices

"Automated" Demand Response



Adapted from: S. Altaher, P. Mancarella, and J. Mutale, Automated Demand Response from Home Energy Management System under Dynamic Pricing and Power and Comfort Constraints, *IEEE Transactions on Smart Grid*, Volume 6, No. 4, July 2015, Pages 1874-1883

Buildings as virtual batteries

N. Good, *et al.*, "Optimization under uncertainty of thermal storage based flexible demand response with quantification of residential users' discomfort," *IEEE Trans. on Smart Grid*, vol. 6, no. 5, pp. 2333–2342, 2015

L. Zhang, *et al.*, "Building-to-grid flexibility: Modelling and assessment metrics for residential demand response from heat pump aggregations," *Applied Energy*, vol. 233–234, pp. 709–723, 2019

Storing flexibility in clothes and dishes

Storing the world cup final's last penalty?

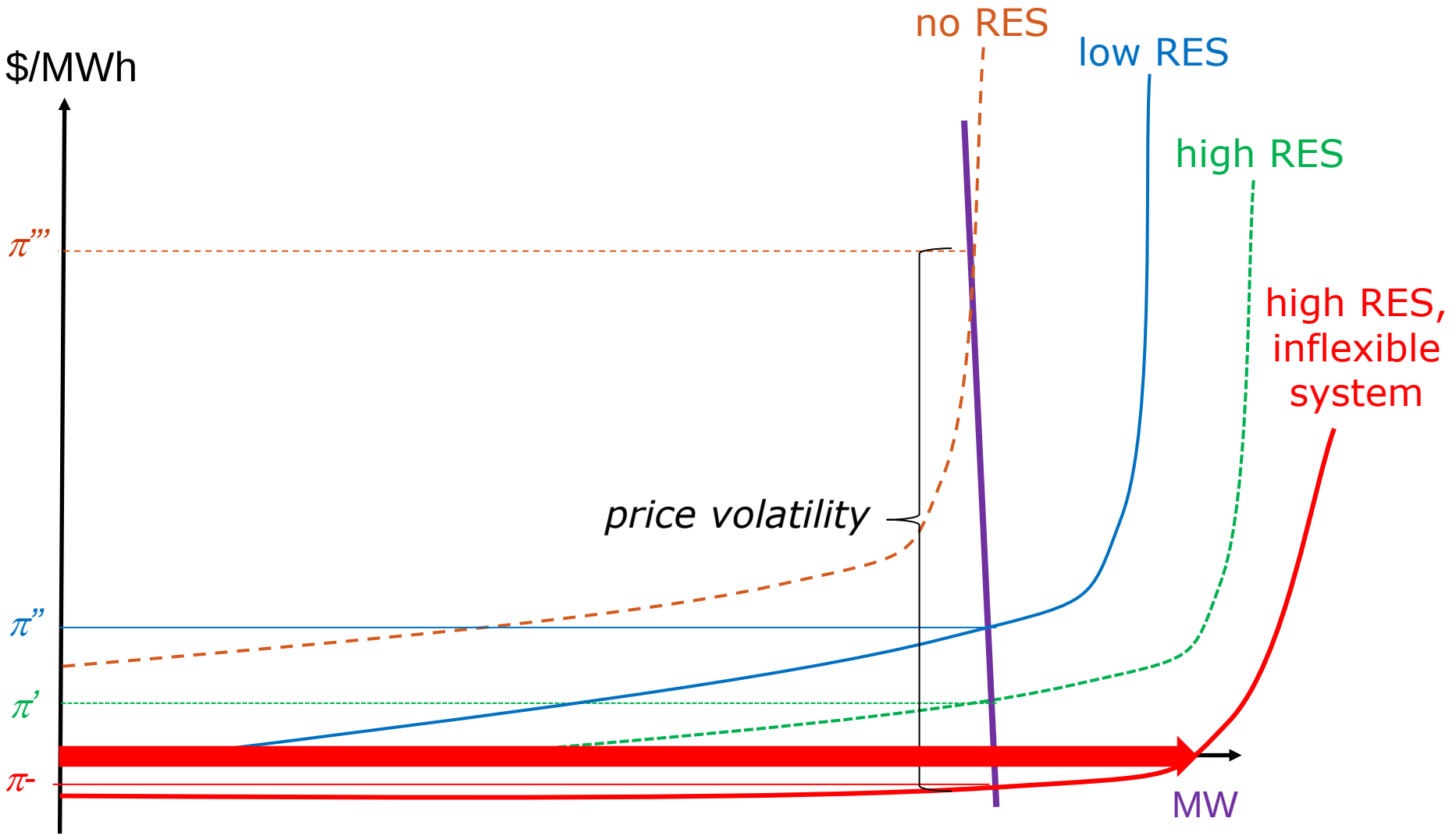
(Images sourced from the internet)

DR appliances and (consumer) flexibility

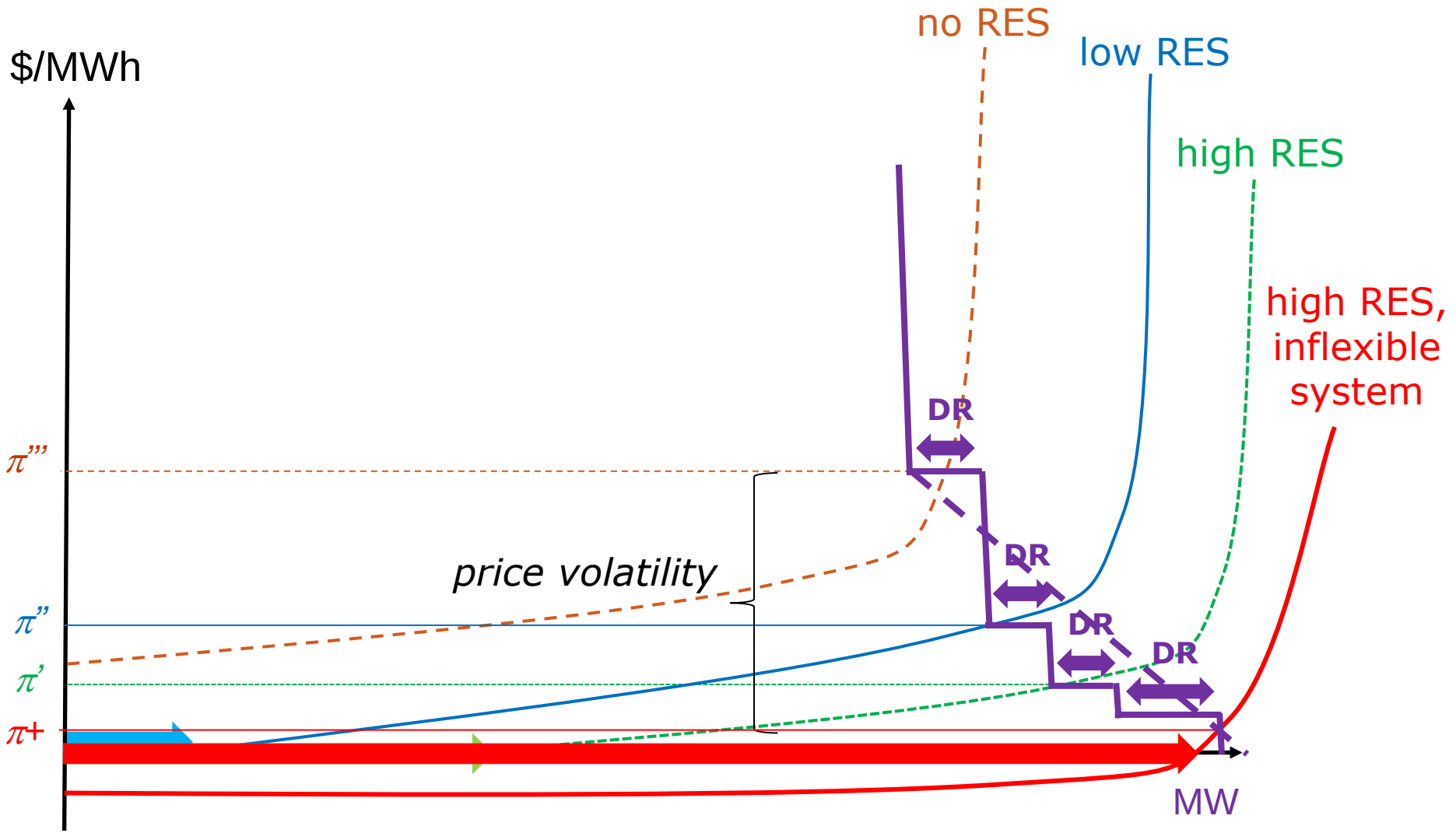
	Deferrable		Curtailable	
	Nonflexible	Flexible	Partially	Fully
TV				
Playstation				
Microwave oven				
Kettle				
Hob				
Oven				
Laptop				
Water heater				
Dishwasher				
Storage heater				
…				

Let’s pause for a few mins for questions

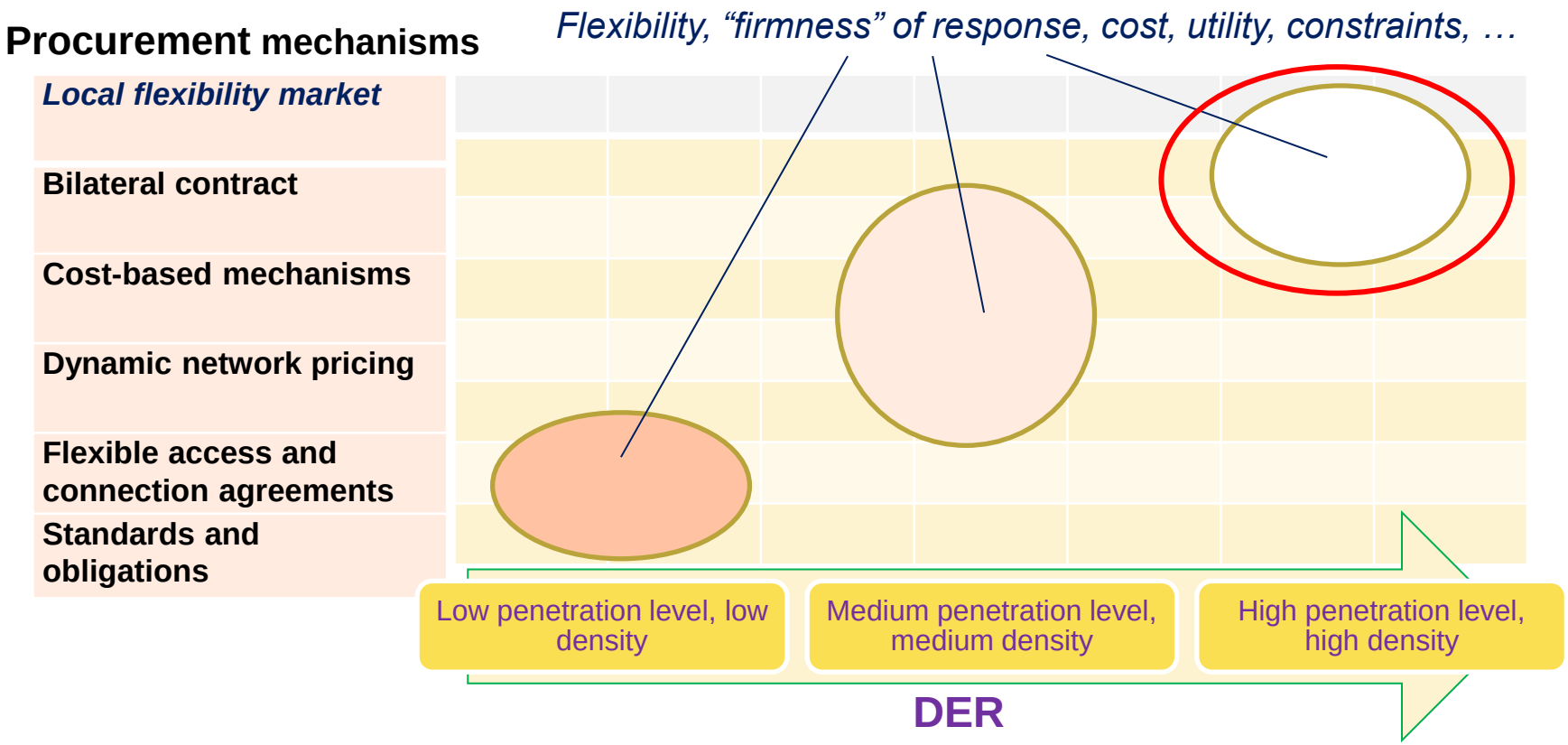
Remember the negative prices?



More and more (automated) DR brings the needed flexibility to the system



More and more DER: From standards to markets



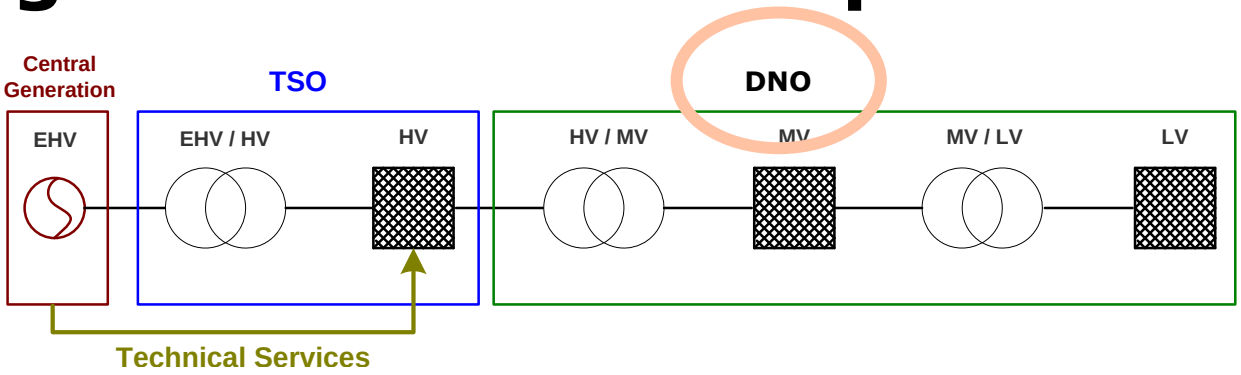
Digitalization of energy: new architectures and stakeholders

- Aggregators and Energy Service Companies (ESCOs)
- Virtual Power Plants (VPPs)
  - Commercial VPP: CVPP
  - Technical VPP: TVPP
  - Conceptual model
- Community energy systems
- Microgrids

- Distribution System Operator (DSO)

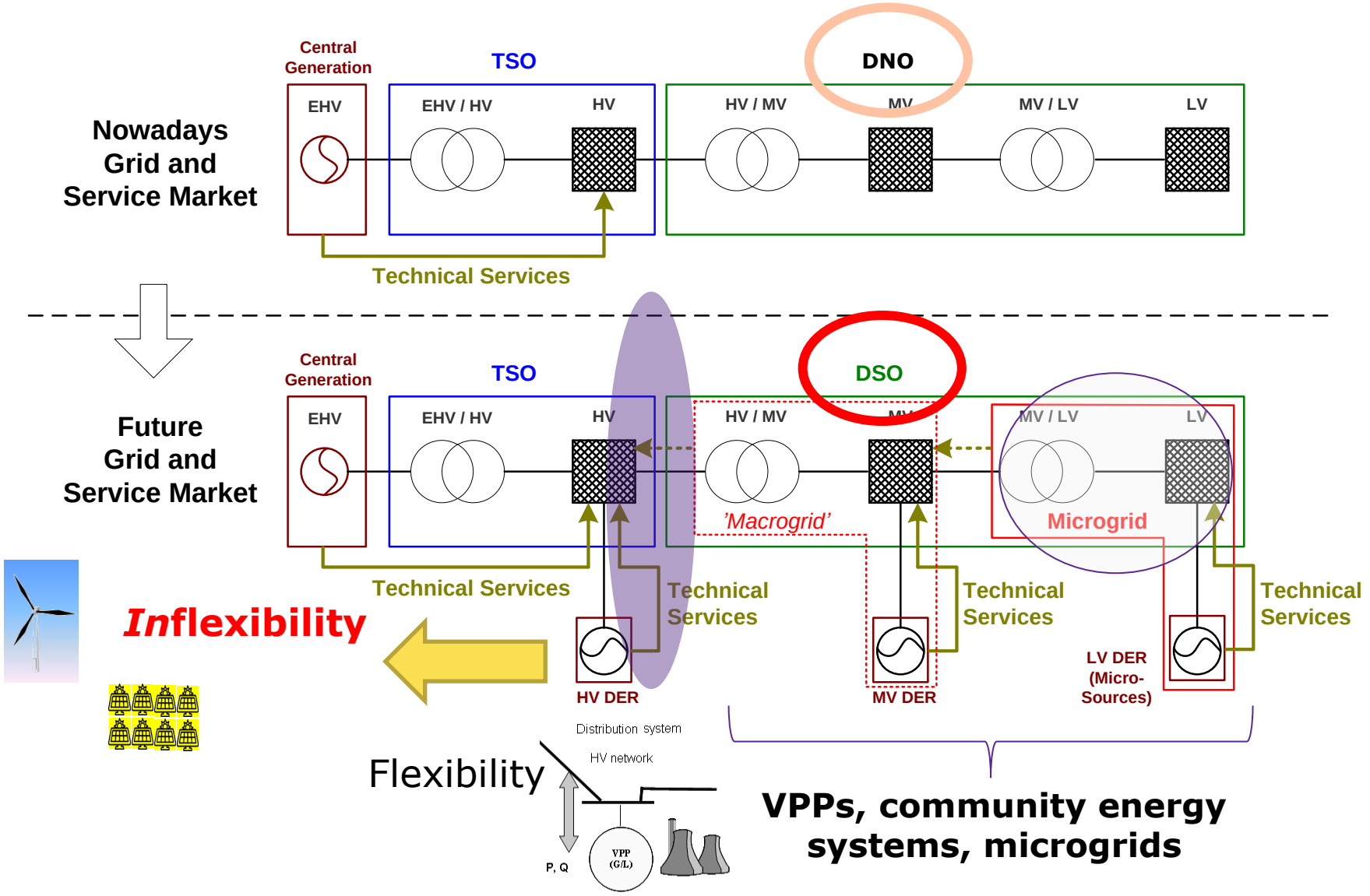
Flexibility and grid services in the past…

Nowadays Grid and Service Market



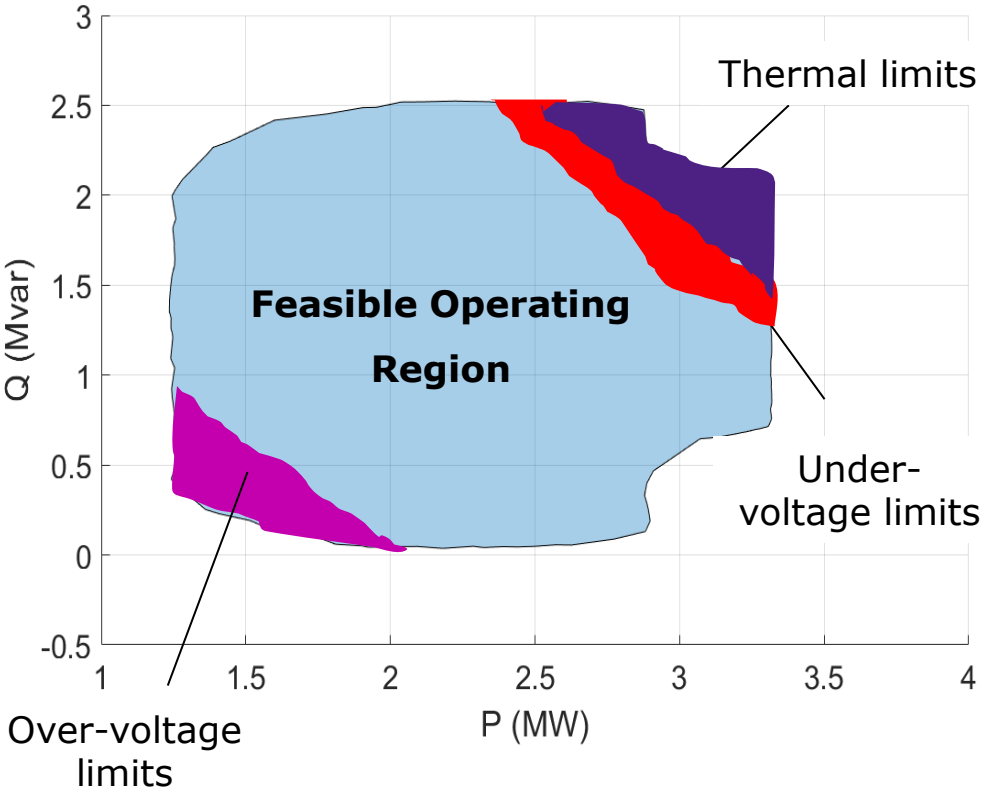
Source: "More Microgrids" project, 2009

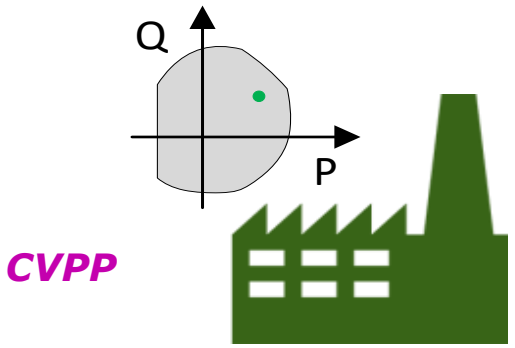
… and in the future…

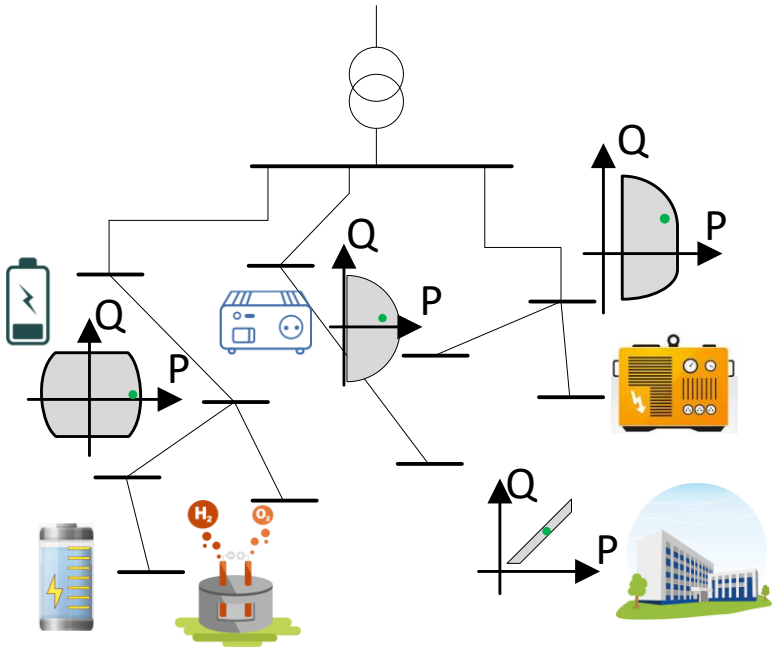


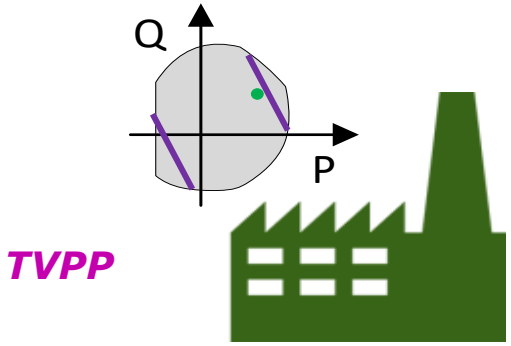
Source: "More Microgrids" project, 2009

VPPs and DSO

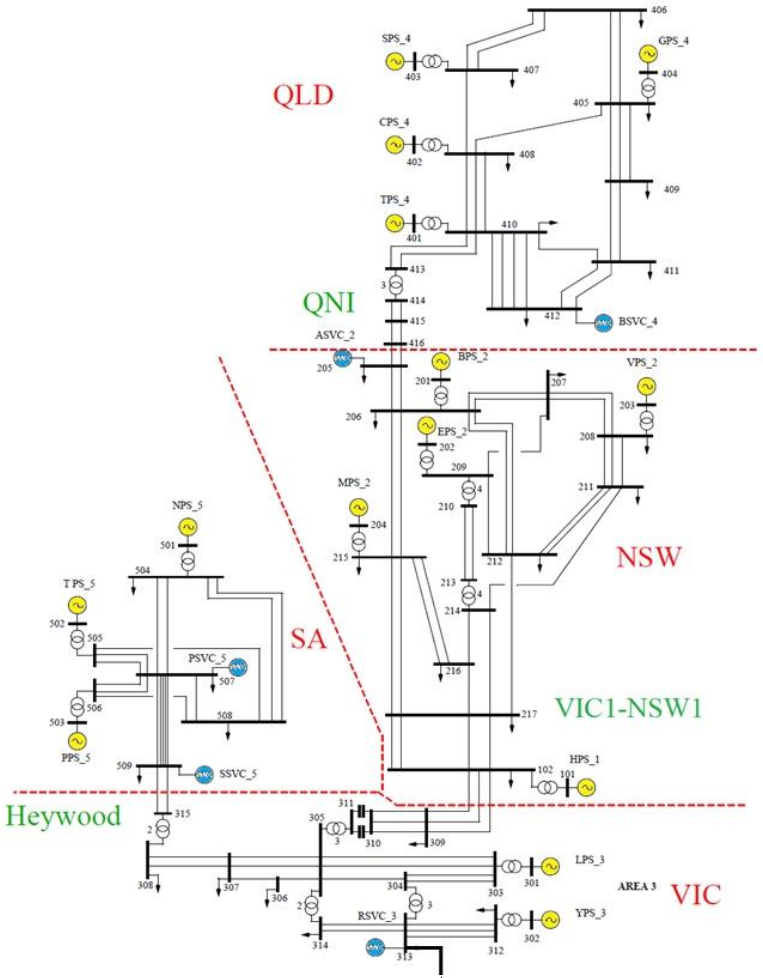

Thermal limits
Feasible Operating Region
Under-voltage limits
Over-voltage limits
Q (Mvar)
P (MW)
3
2.5
2
1.5
1
0.5
0
-0.5
1
1.5
2
2.5
3
3.5
4

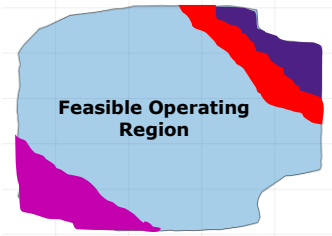

Q
P
CVPP


Q
P
Q
P
Q
P
Q
P


Q
P
TVPP

VPPs, DSO and markets

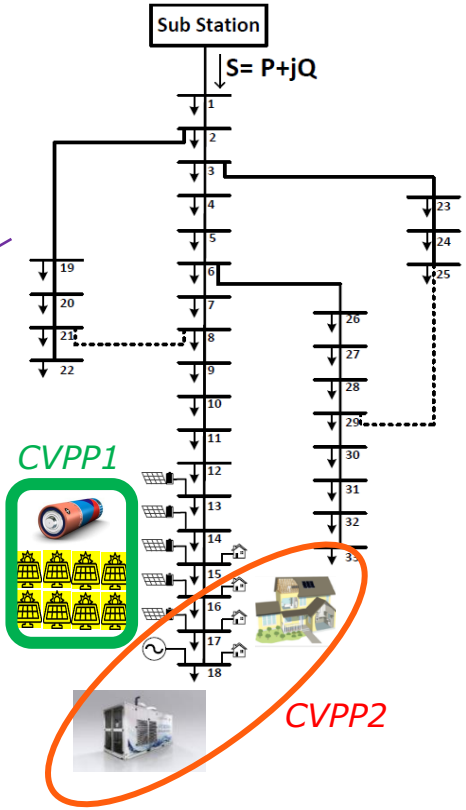


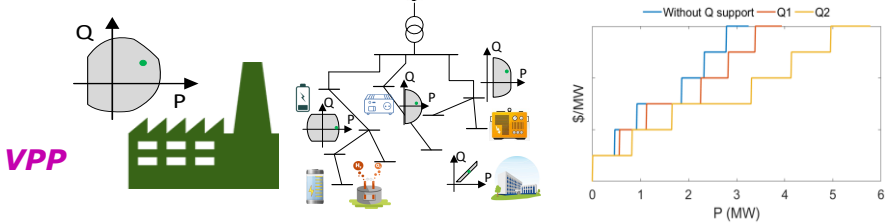


DSO

TVPP

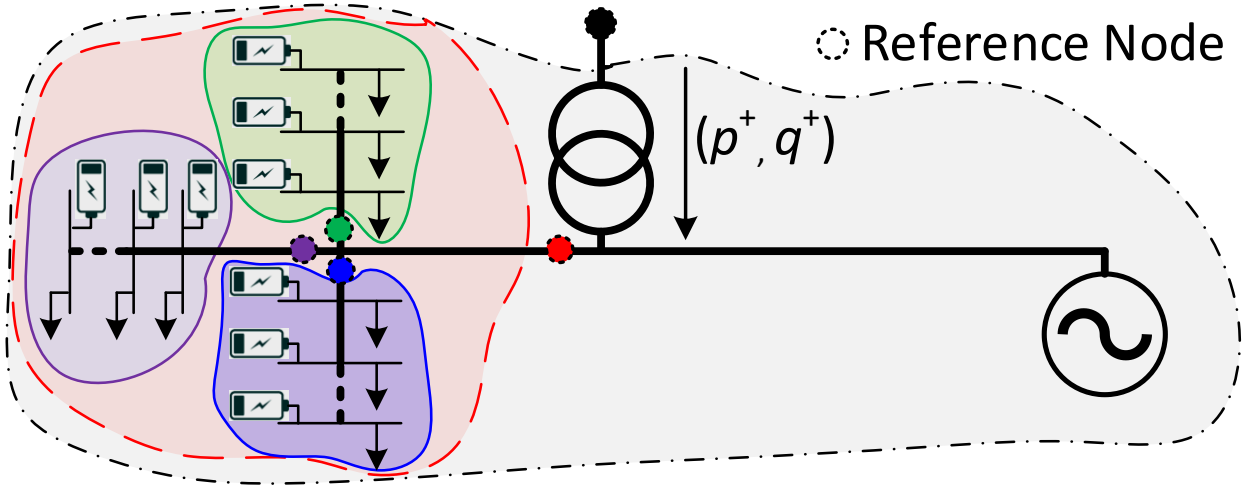
Market operator

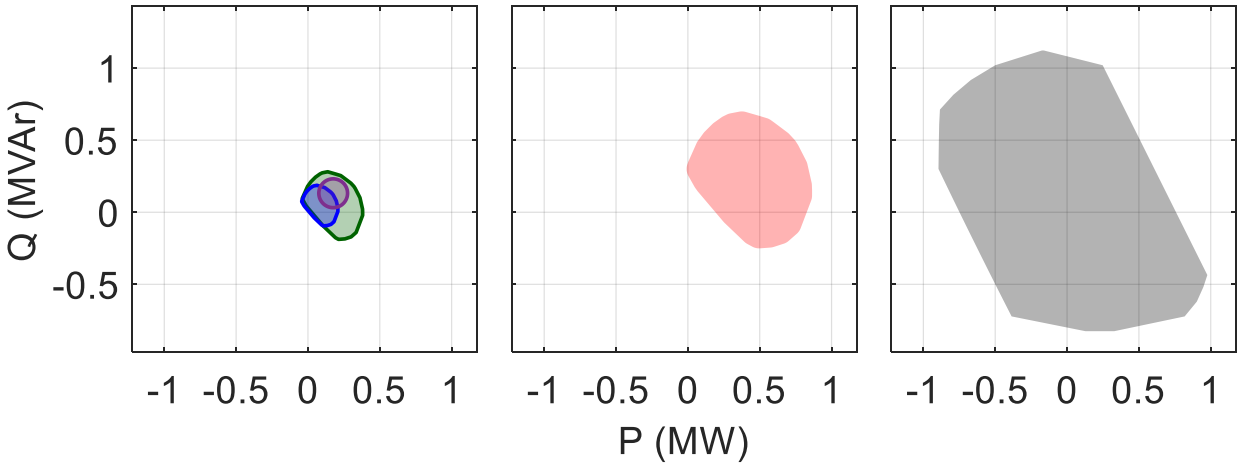


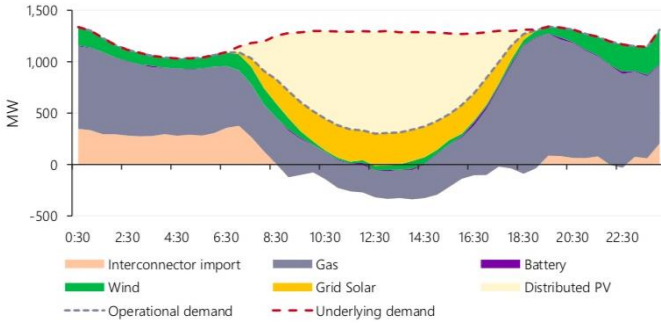


Having a DSO is essential to enhance visibility and enable both efficient deployment of DER and competition with wholesale market resources

Providing *visibility* and *scalability*



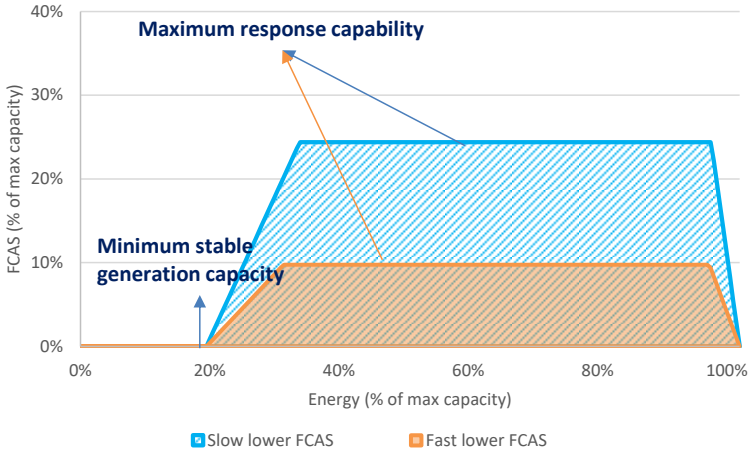




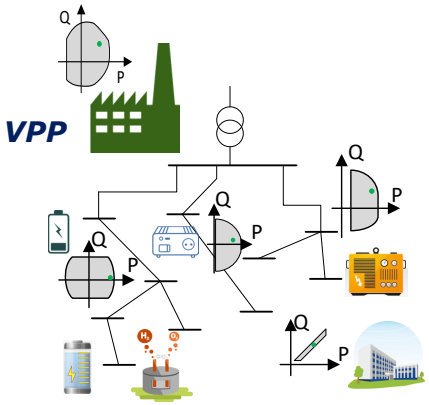
Source: AEMO

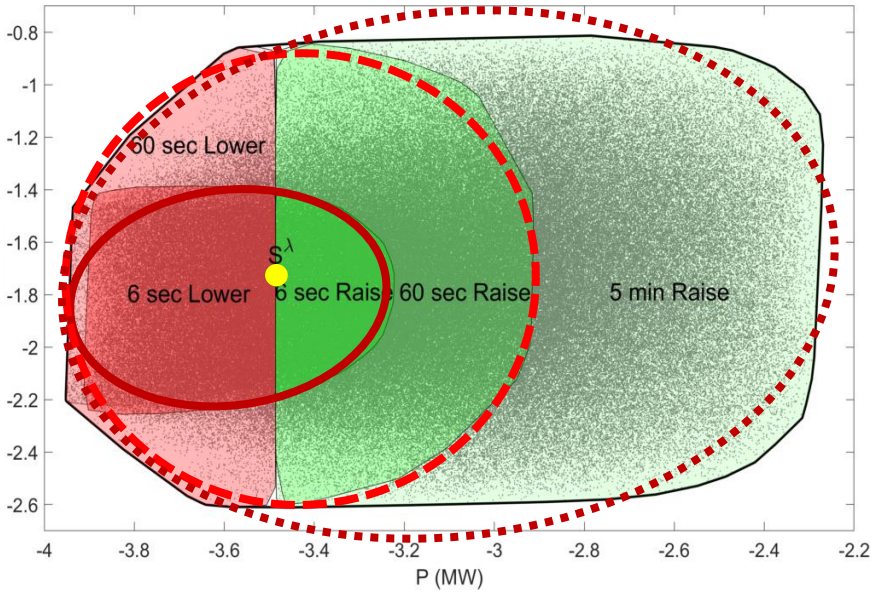
Source: S. Riaz *et al*, "Modelling and characterisation of flexibility from distributed energy resources", *IEEE Transactions on Power Systems*, July 2021

More than just energy



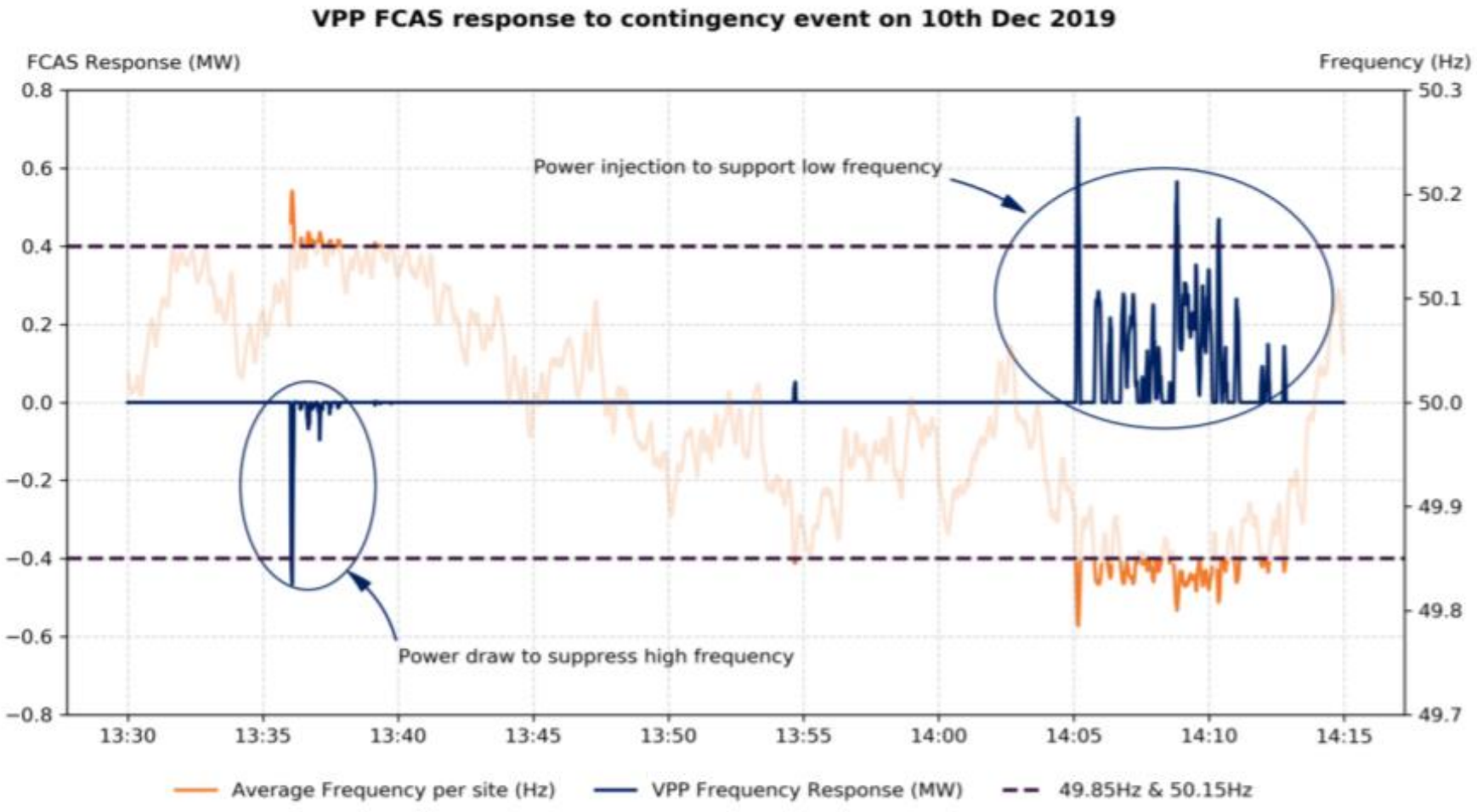
CCGT





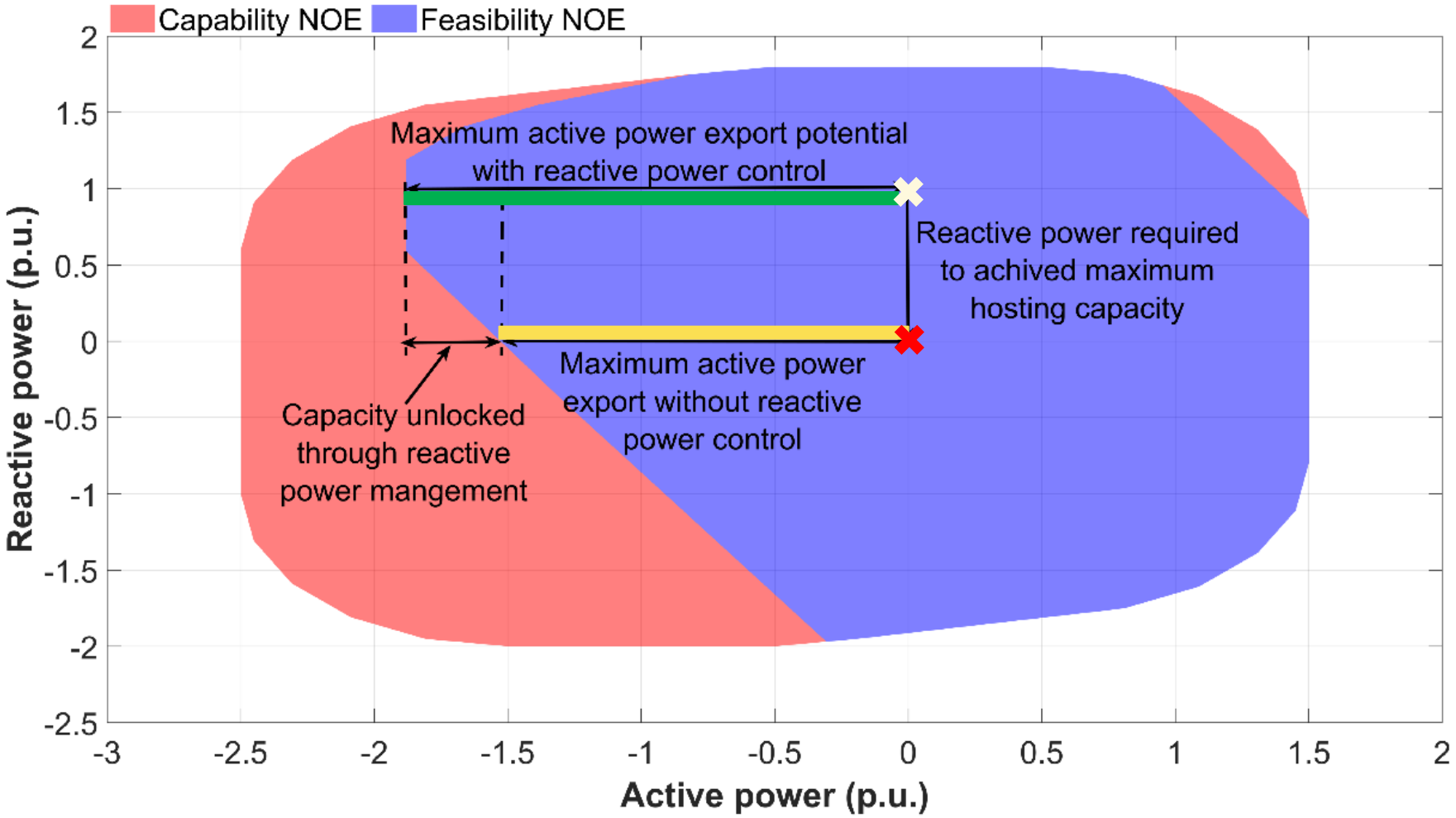
See: H. Wang, *et al*, "Integrated Techno-economic Modeling, Flexibility Analysis, and Business Case Assessment of an Urban Virtual Power Plant with Multi-market Co-optimization", *Applied Energy*, Volume 259, 1 February 2020, 114142.

VPP response to high- and low-frequency events



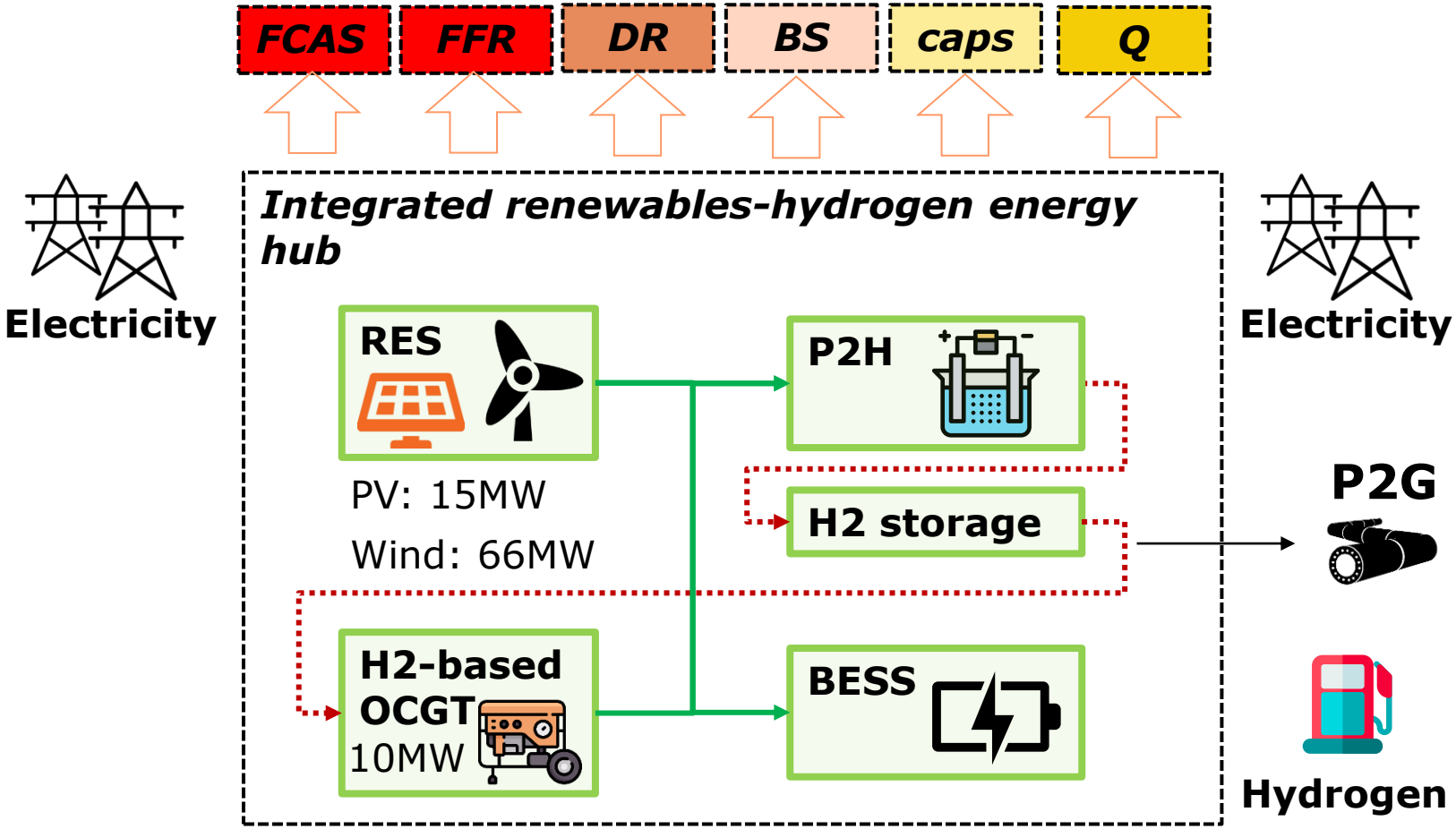
Source: AEMO

Integrated provision of system and local services



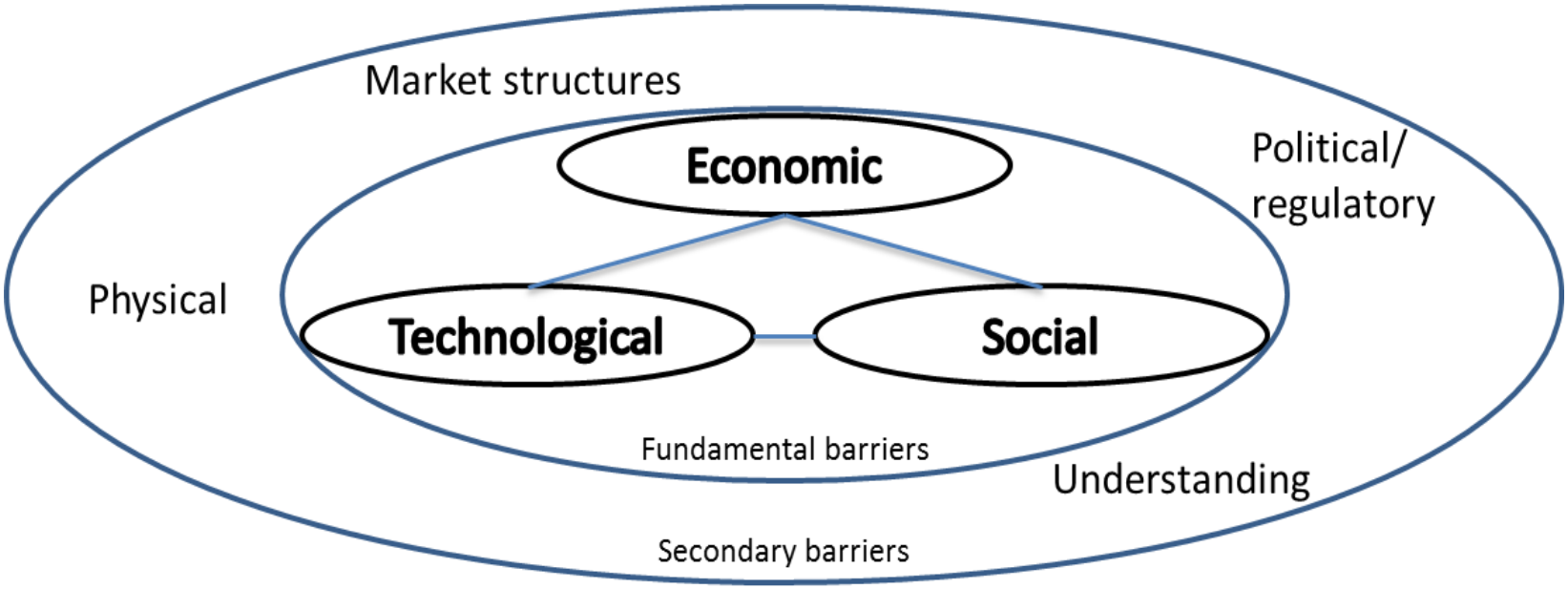
Source: M. Liu *et al.*, "Grid and market services from the edge", *IEEE Power and Energy Magazine*, July/August 2021, *Invited Paper*

Integrated renewables-hydrogen VPPs



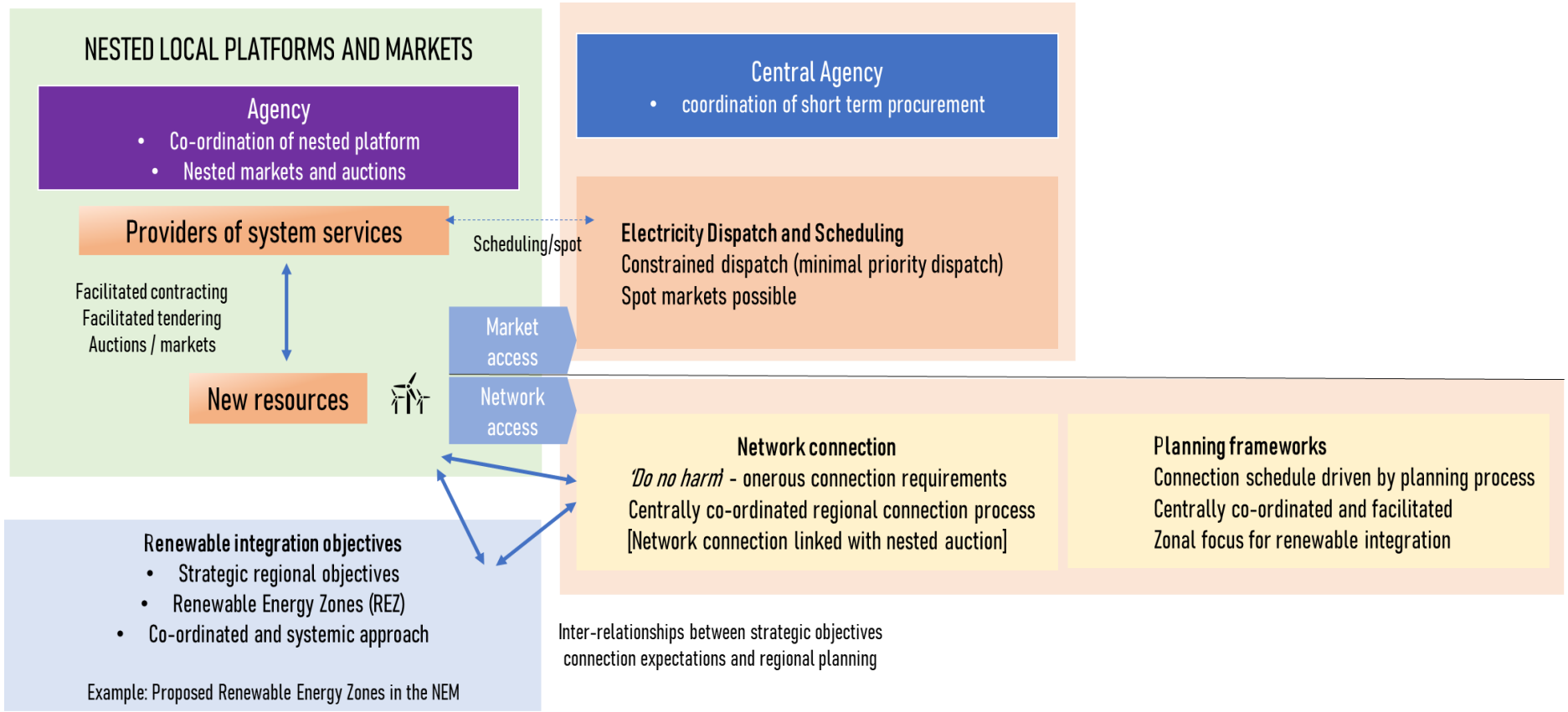
J. Naughton *et al.*, "Optimization of Multi-Energy Virtual Power Plants for Providing Multiple Market and Local Network Services", *Electric Power System Research*, 2020

Harnessing DER flexibility:
Overcoming multi-dimensional barriers



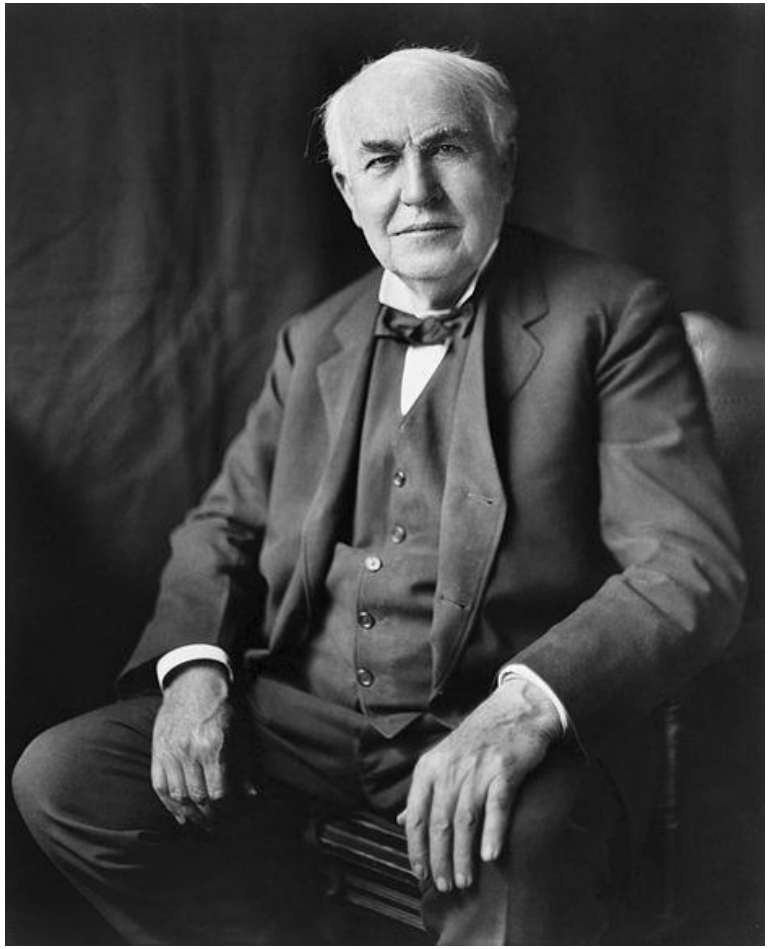
N. Good, et al., "Review and classification of barriers and enablers of demand response in the smart grid", *Renewable and Sustainable Energy Reviews*, vol. 72, pp. 57-72, May 2017

Harnessing DER flexibility:
New markets and regulation



F. Billimoria, et al., "Market design for power system security in low-carbon grids: from physics to economics", *Oxford Open Energy*, *under review*, Nov 21

Back to the future



"We will make electricity so cheap that only the rich will burn candles"

Thomas Edison, 1878

Acknowledgements

- Ausnet, Mondo and AEMO for Project "*EDGE*"
- *veski* and the Victorian Government for my 2017 *veski* Innovation Fellowship
- The "*Future Fuels*" Cooperative Research Centre
- The UK EPSRC for the "*MY-STORE*" and "*TERSE*" projects
- The European Commission for the "*ADDRESS*", "*COOPERATE*", "*DIMMER*", "*H2ME2*", "*ATTEST*", "*EUniversal*" projects

Recent key references on DR, DER flexibility, and VPPs

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Thank you!
Any question?

Melbourne Energy Institute

MEI*network*21 Energy Systems Seminar Series

Seminar 6
Demand Response and Virtual Power Plants

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The University of Melbourne

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The "new physics" and security challenges

Risk	Emerging issues	Possible Mitigations
Frequency control and inertia	- Sustained frequency excursions (regulation) - High ROCOF following contingency - Insufficient regional inertia - Insufficient PFR - Risk of low-inertia and insufficient PFR after separation	- Minimum inertia levels - Compulsory droop response - Additional amount of PFR - Co-optimization of energy, frequency response, and (regional and system-level) inertia - Regional allocation of reserves - New sources of fast frequency response (e.g., batteries, electrolysers) - Management of largest contingency and interconnector flows (system at risk of regional separation)
Variability and uncertainty	- Large variation in net demand - Insufficient short- and medium-term and ramping reserves	- Better forecasting - Artificial intelligence to assess reserves (e.g., dynamic Bayesian belief network tools) - Use of more flexible resources including energy storage (e.g., pumped hydro)
System strength	- Fault current shortage - Voltage instability - Sustained voltage oscillations after fault - Fault-ride through issues	- Minimum level of inertia and fault current (generators constrained on) - Synchronous condensers - STATCOM and SVC to improve voltage stability - Improvements of control loops (especially in solar farms) - Grid forming inverters

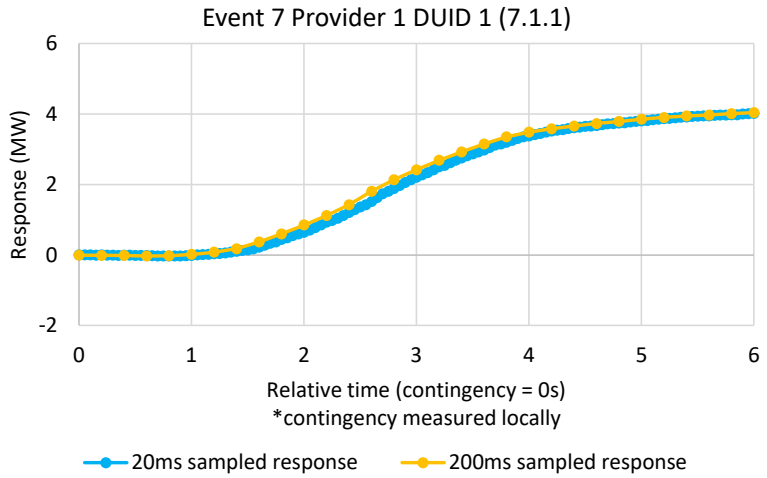
P. Mancarella and F. Billimoria, 'The Fragile Grid – The physics and economics of security services in low-carbon power systems", *IEEE Power and Energy Magazine*, 2021

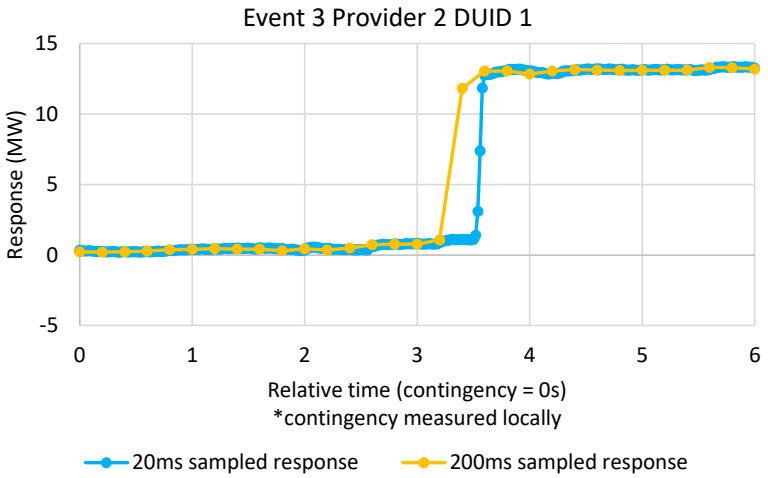
A possible classification of DR appliances

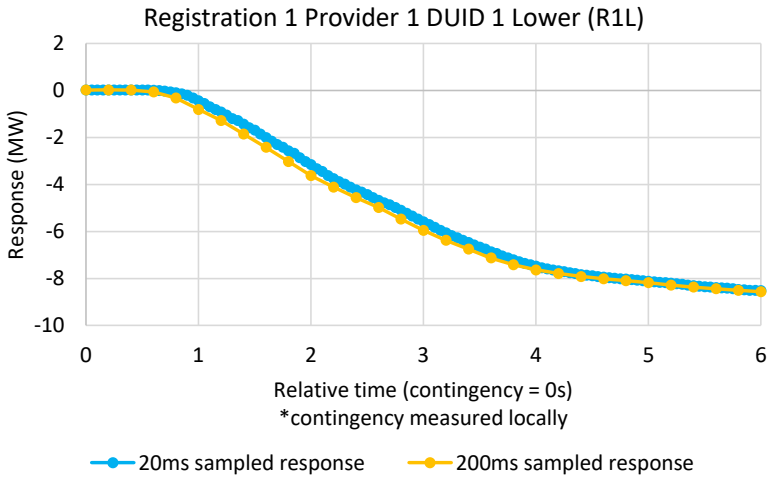
- **Deferrable** load may be classified into:
  - → *Non-flexible* load such as Washing Machine (WM), which has a predefined profile that cannot be altered during operation time
  - → *Flexible* load such as Electrical Vehicle (EV)
- **Curtailable** load may be classified into:
  - → *Partially curtailable* load such as Air Conditioning (AC), whose power consumption can be controlled according to its temperature set point
    - → Power needs to be re-established back for comfort level
  - → *Fully curtailable*, according to the consumer priorities, meaning that these appliances can be switched off without the need for turning them back on later (for example, light bulbs)

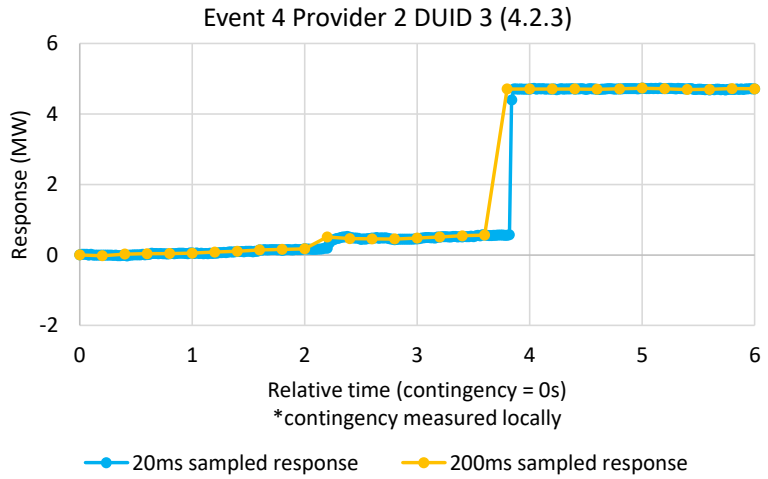
Adapted from: S. Altaher, P. Mancarella, and J. Mutale, Automated Demand Response from Home Energy Management System under Dynamic Pricing and Power and Comfort Constraints, *IEEE Transactions on Smart Grid*, Volume 6, No. 4, July 2015, Pages 1874-1883

Validating VPP performance



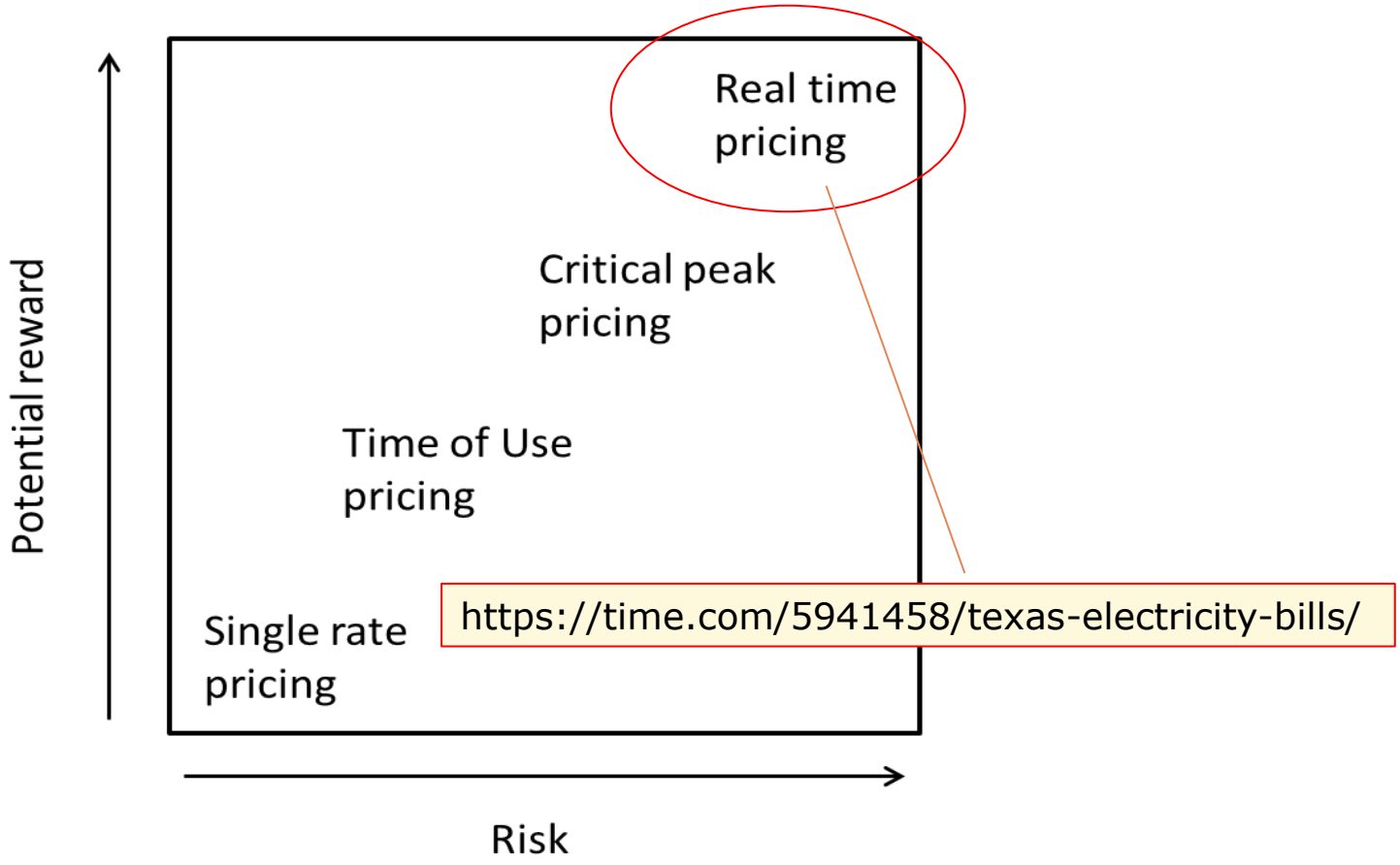






Source: AEMO and University of Melbourne, https://aemo.com.au/en/consultations/current-and-closed-consultations/mass-consultation

Market exposure and DR flexibility: benefits and risks for the customer



The aggregator/retailer will, in practice, often bear most of the wholesale price risk and protect the customer from full market exposure

Source: FP7 Cooperate project, Deliverable D6.2