Transactive Energy; Paving the Path for Integration of Distributed Energy Resources

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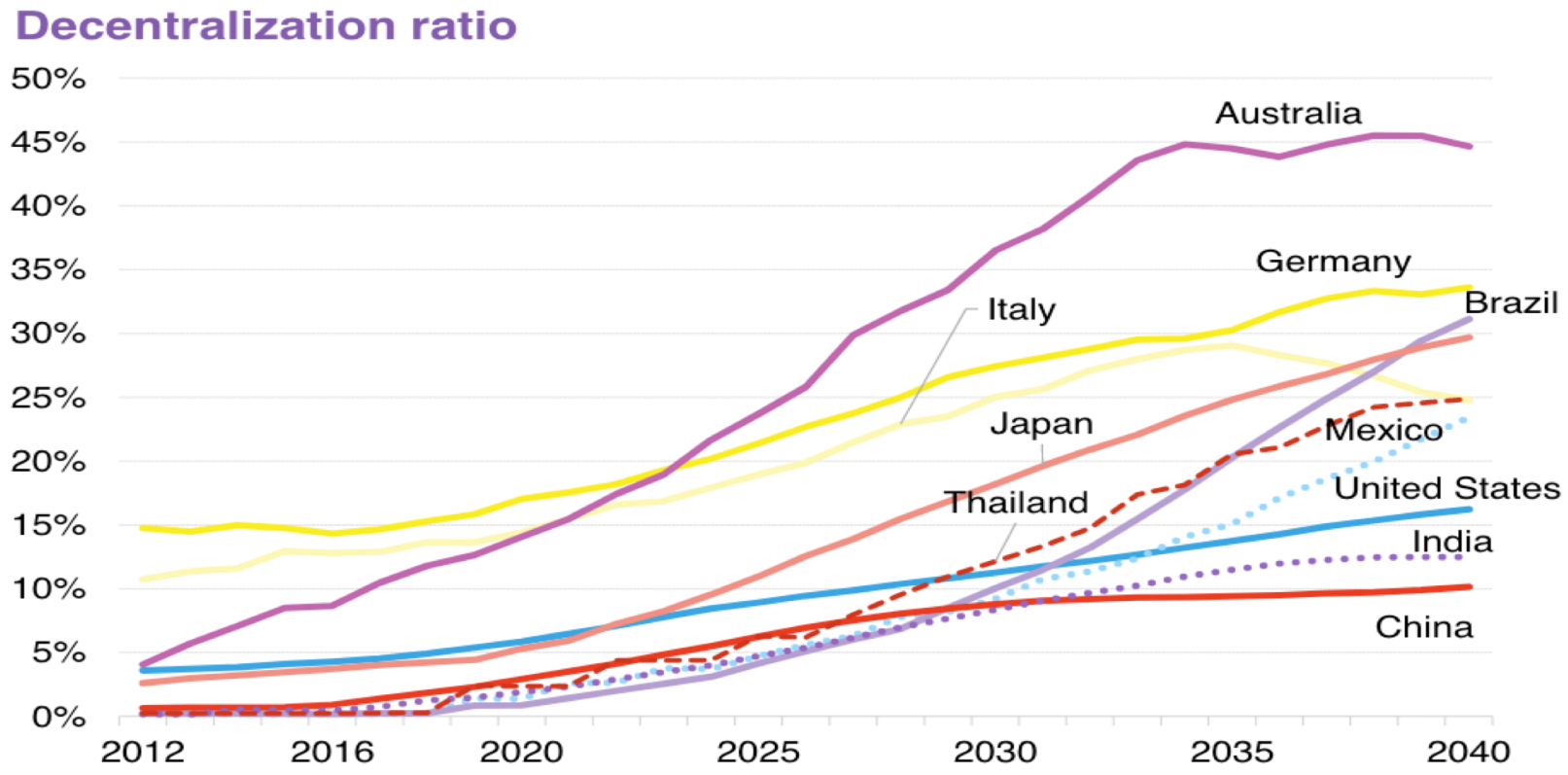
AGENDA

- Background and Motivation
- New markets for DER integration
  - Two-sided markets
  - Infrastructural requirements
- Trading arrangements
  - Demand response
  - Virtual power Plants
  - Peer-to-peer trading
  - Transactive Energy
- Conclusions

Background and Motivation

INCREASE IN DISTRIBUTED ENERGY RESOURCES (DER) INTEGRATION

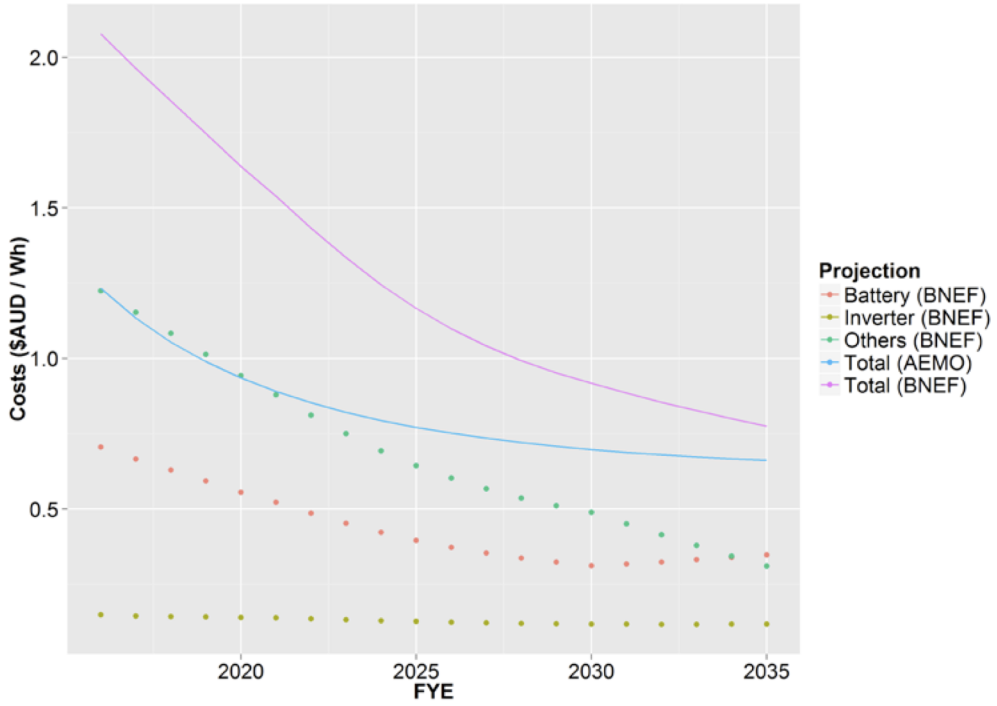
Global rate of electricity market decentralisation



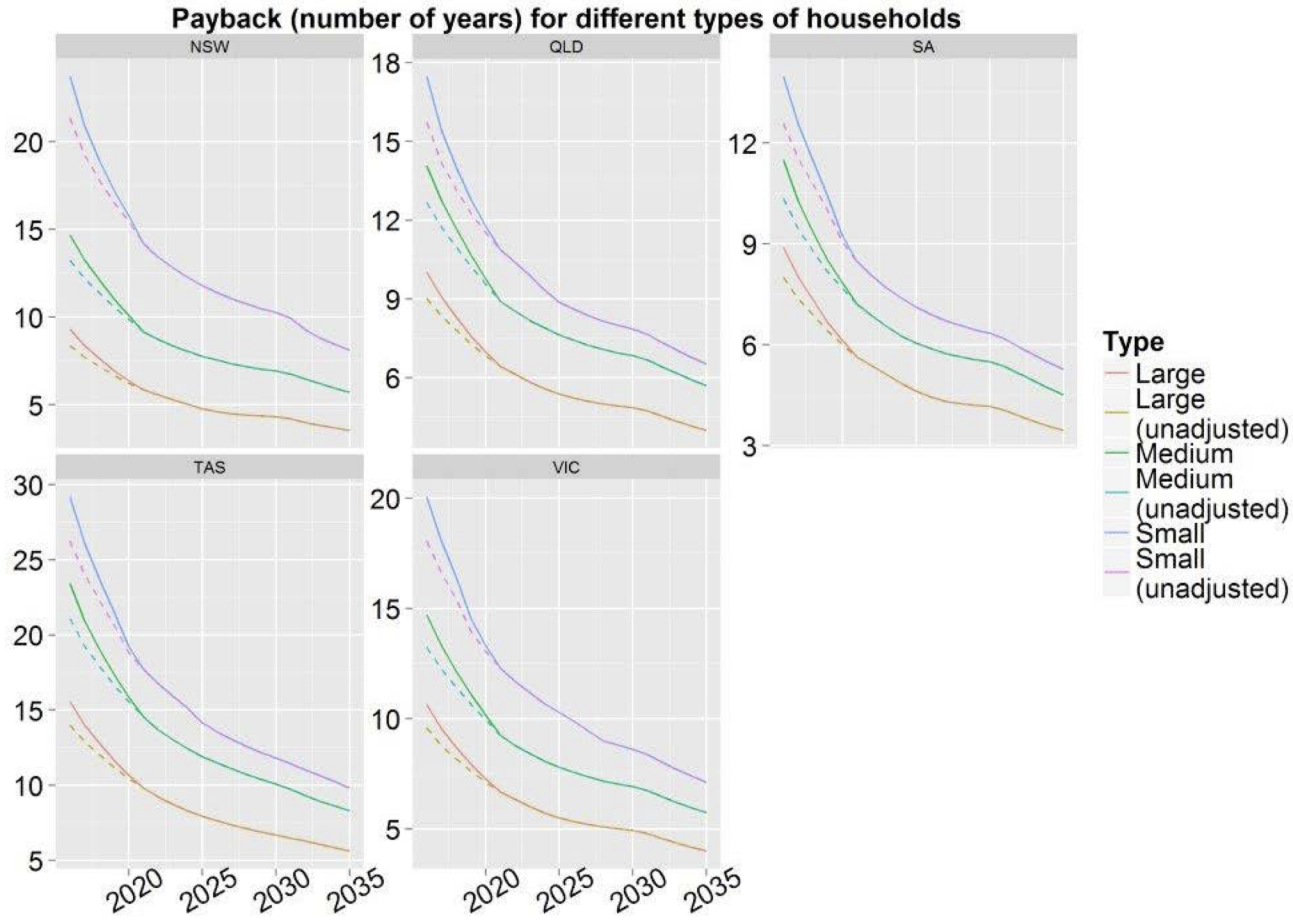
Source: Bloomberg New Energy Finance Note: decentralization ratio is the ratio of non-grid-scale capacity to total installed capacity.

REDUCE IN TECHNOLOGY COST

Battery system forecast technology costs by component



Payback period for PV-battery systems in different regions (AUS)

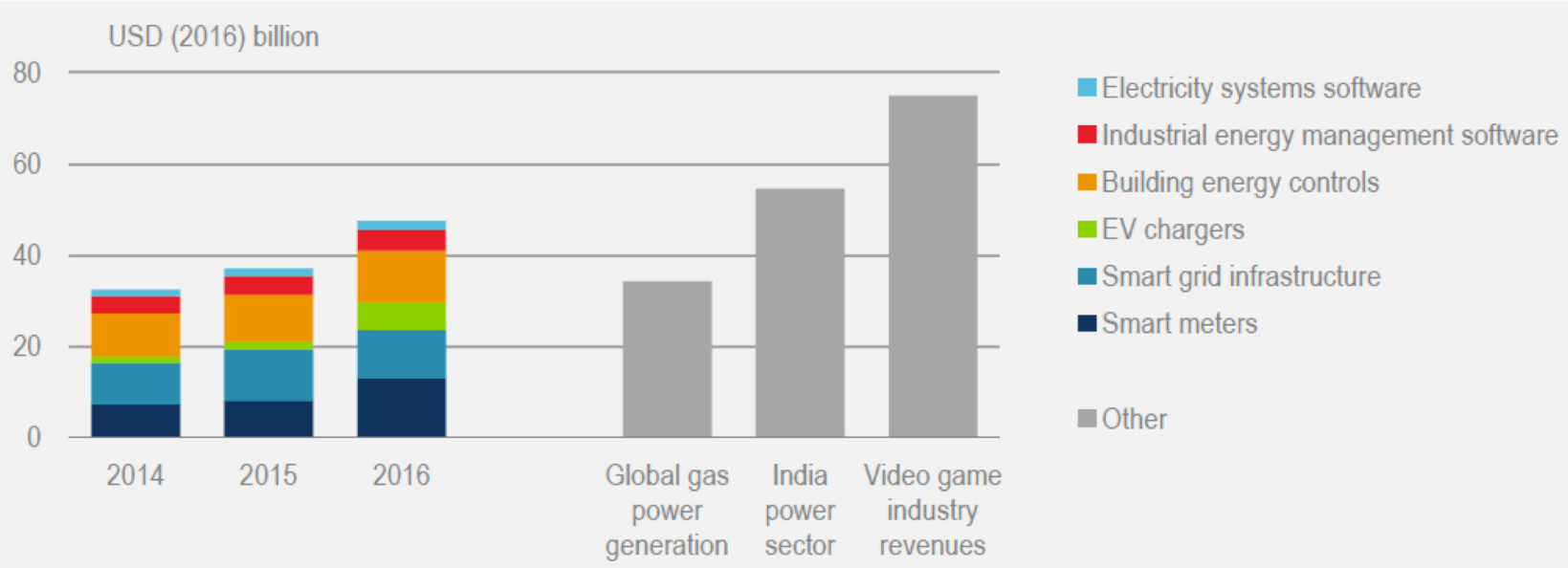


Source: Australian Energy Market Operator (AEMO), "Emerging Technologies Information Paper," 2015.

DIGITALIZATION OF THE ENERGY SECTOR

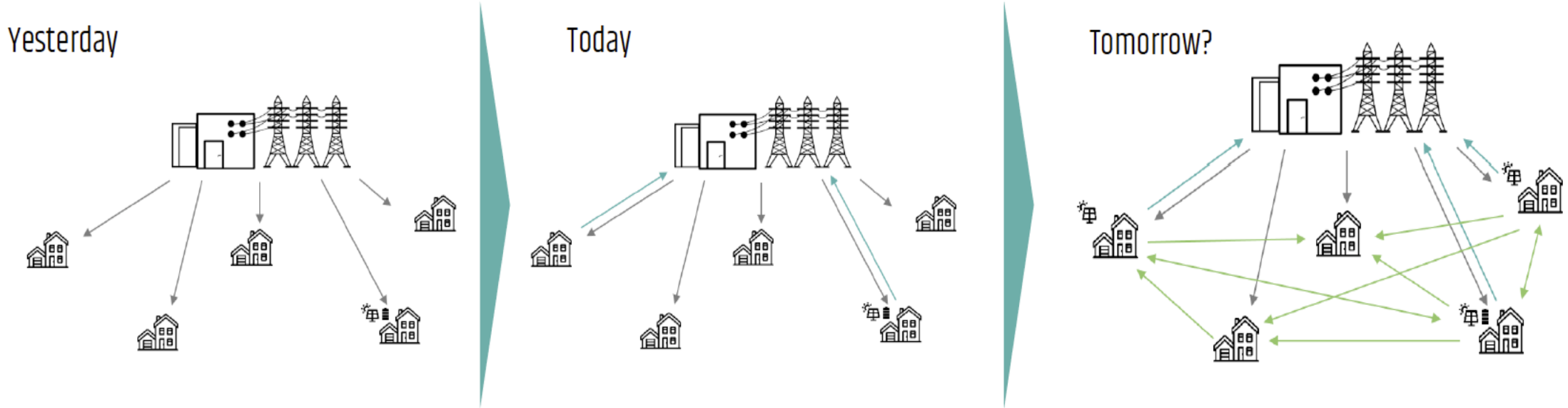
- Internet of Things
- Smart devices
- Blockchain
- Machine learning

Global investments in digital electricity infrastructure and software



International Energy Agency (IEA), "Digitalization & Energy", 2017.

FUNDAMENTAL TRANSFORMATION IN THE ENERGY MARKET



- Centralized generation
- One direction power flow

- Distributed energy resources (DER)
- Bi-directional power flow

- High penetration of DER
- Energy sharing

WHY NEW MARKETS?

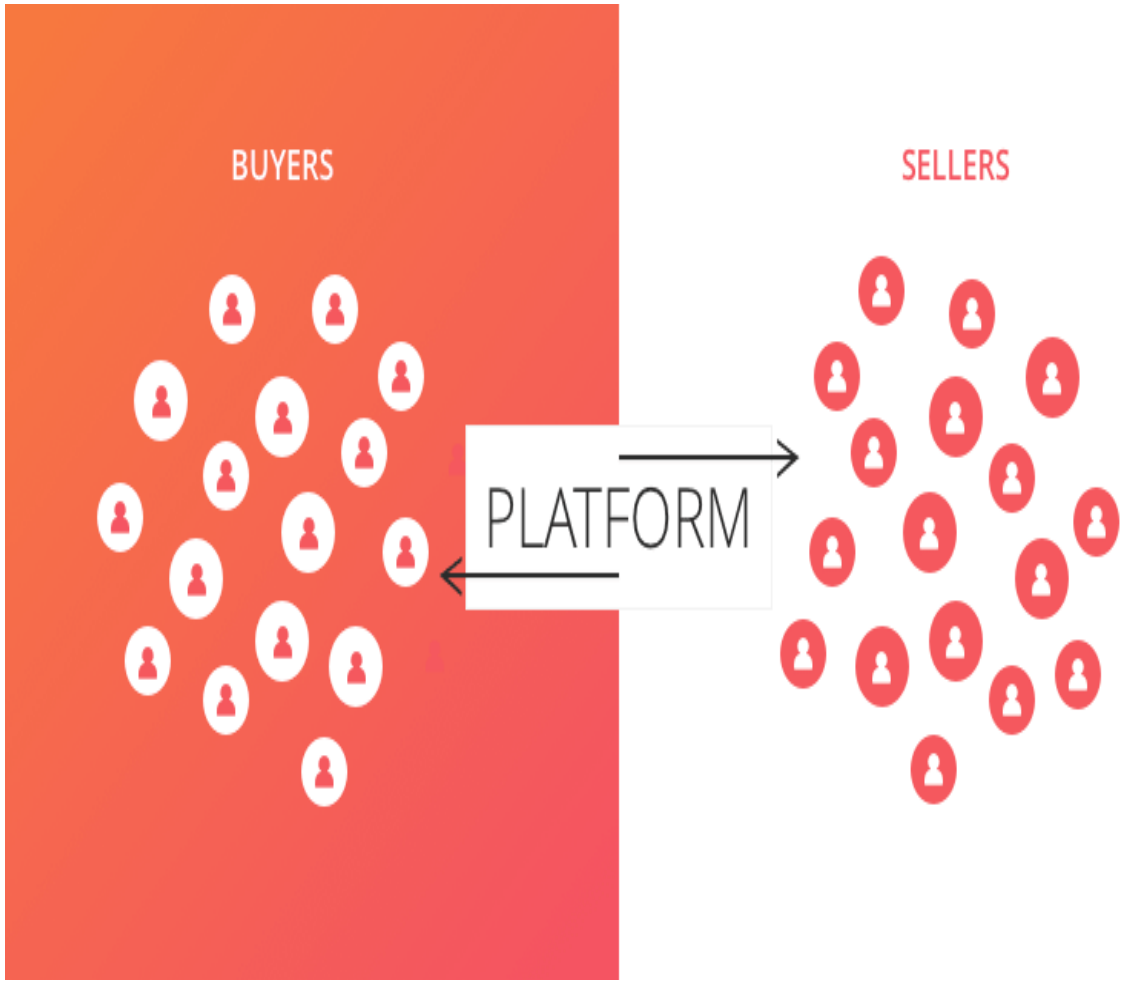
- Recent developments in Information and Communication Technologies (ICT) and smart systems has motivated consumers to become more active players instead of being submissive ratepayers.
- The new active consumers participate in the power generation and consumption process as **Prosumers** (producer+consumer) by using their local resources, managing their demand, and communicating with other players.
- Increase in the number of prosumers raises operational and market challenges such that existing incentives and tariffs support cannot be sustained.
- Some of these challenges include but not limited to lack of visibility of Distributed Energy Resources (DER), congestion and voltage issues.
- A two-sided market can facilitate the integration of these new players.

New Markets for DER Integration

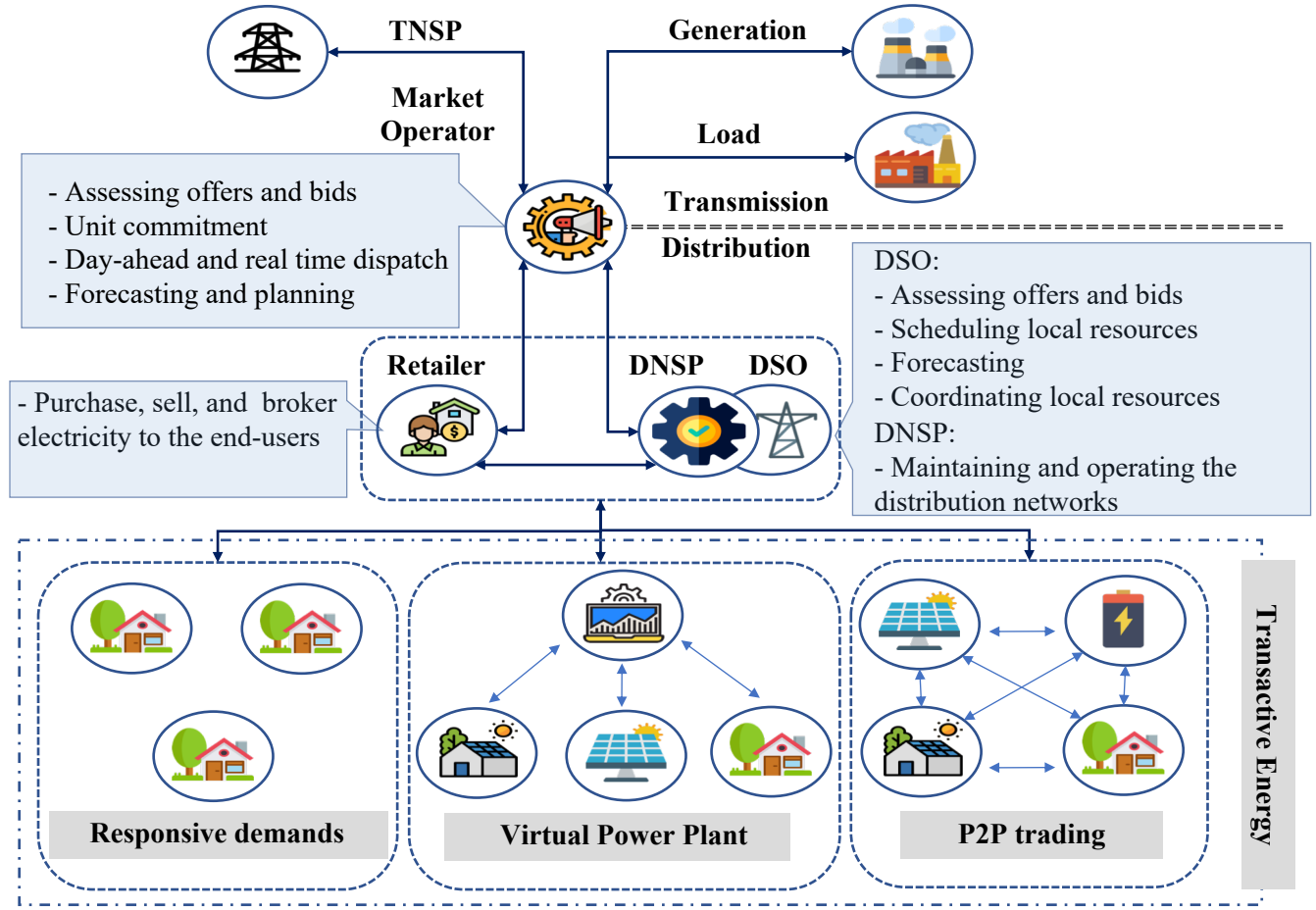
TWO-SIDED MARKET

- A two-sided market is a market model that promotes direct interaction between suppliers and customers

- In a two-sided market, two user groups or agents interact through an intermediary or platform to the benefit of both parties, and the decisions of each set of agents affect the outcomes of the other set of agents



TWO-SIDED MARKET STRUCTURE



TNSP: Transmission network System Provider **DSO:** Distribution System Operator **DNSP:** Distribution Network System Provider

BENEFITS

For end-users:

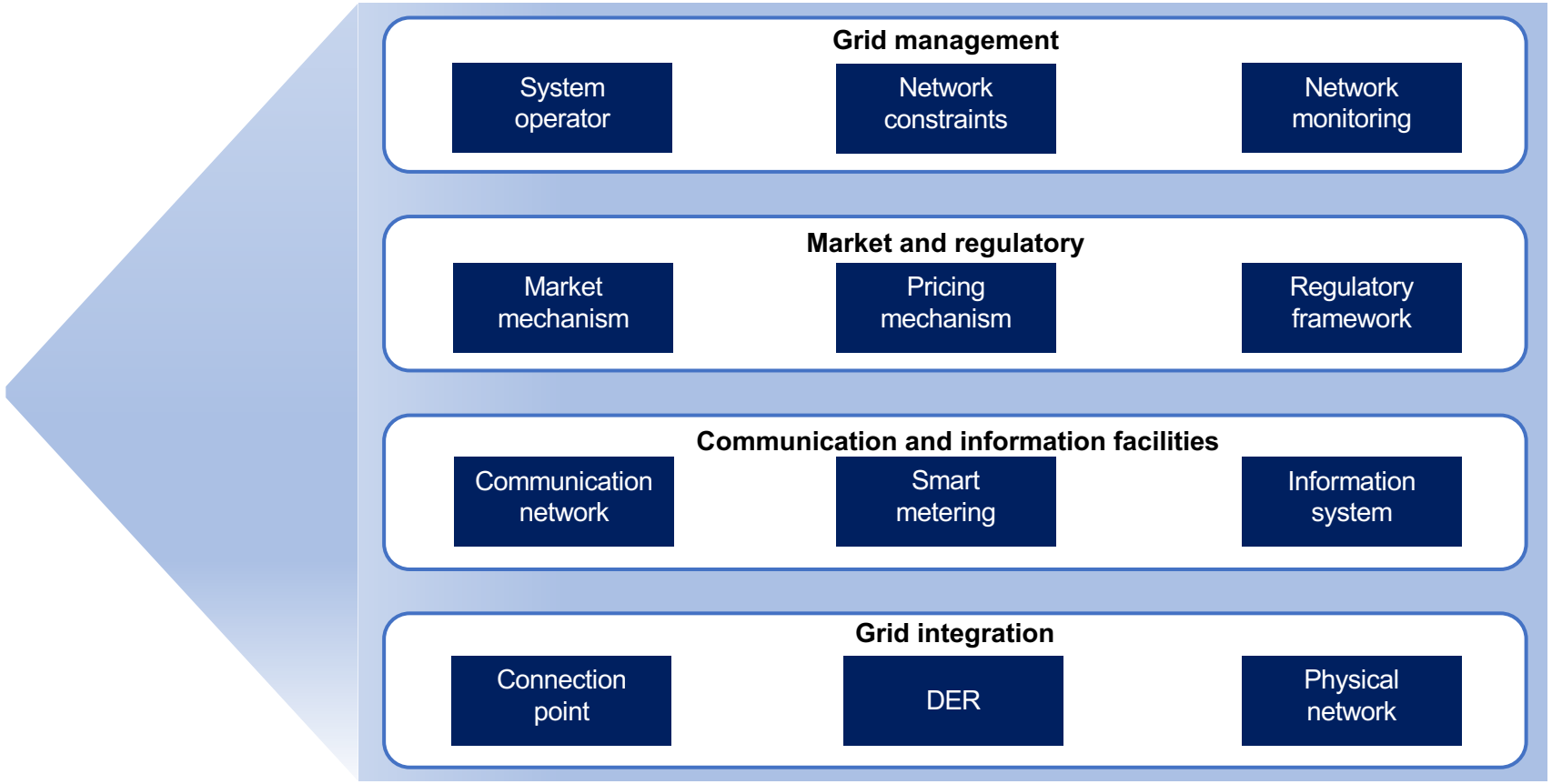
- Providing access to localized clean energy
- More efficient utilization of DER
- Reduced energy costs for all end-users

For the network and market operators:

- More accurate demand forecasts of end-users behaviour
- Managing demand and supply by providing incentives to end-users
- Maintaining the safe, secure and reliable operation of the power system with less operational interventions

CORE ELEMENTS

TWO-SIDED MARKET FRAMEWORK



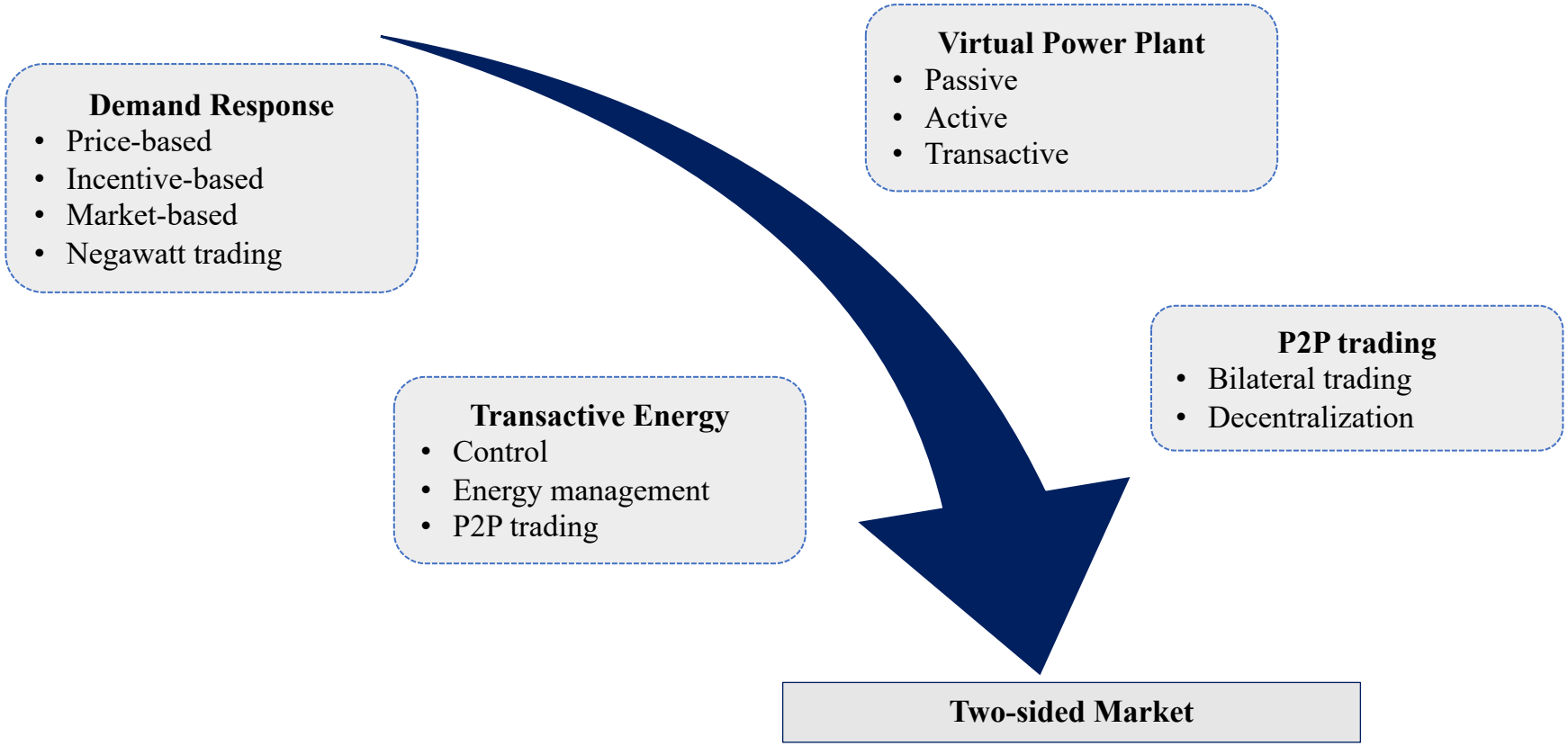
ENABLING TECHNOLOGIES

- Internet of Things (IoT):
  - Smart meters and smart appliances e.g., smart washing machines
  - Collect information about the energy consumption/generation patterns of the end-users
  - Can be controlled by the end-user or energy companies to balance the load in the grid
- Blockchain:
  - An immutable database, shared across all participants, that stores the history of communications
  - Provides decentralization, security, anonymity, and auditability

- Machine learning:
  - Enhances the energy demand/generation prediction accuracy
  - Can be implemented in a decentral way through federated learning

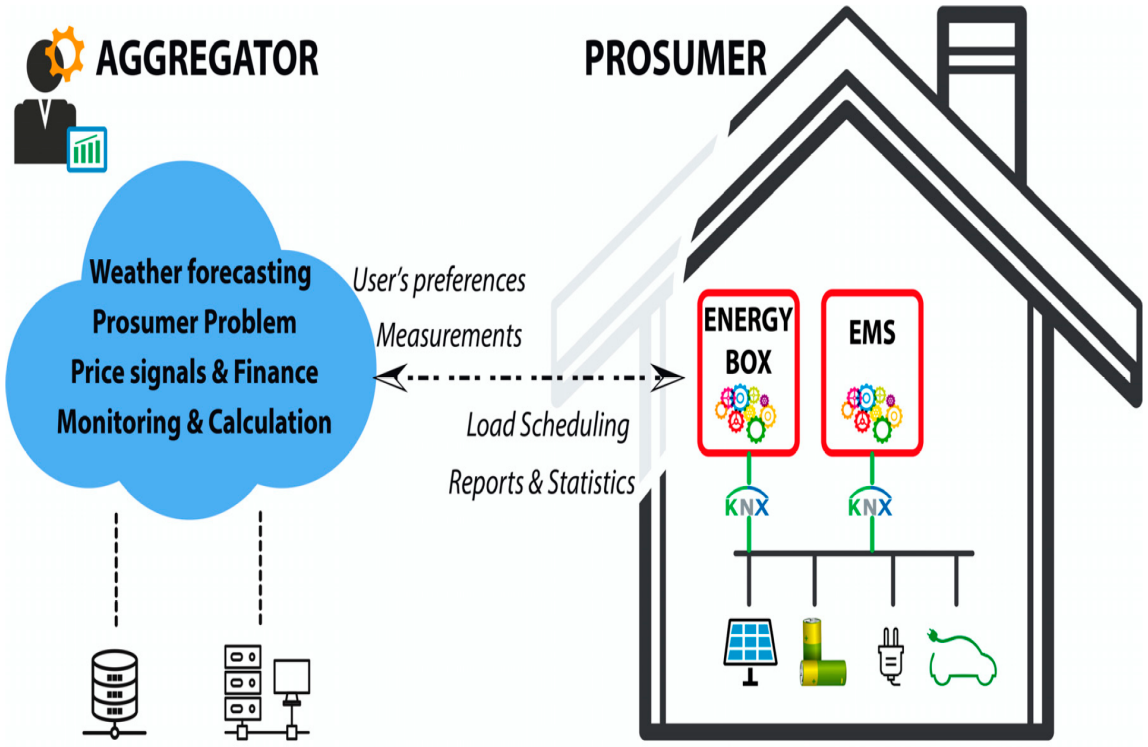
Trading Arrangements

TRADING IN TWO-SIDED MARKETS

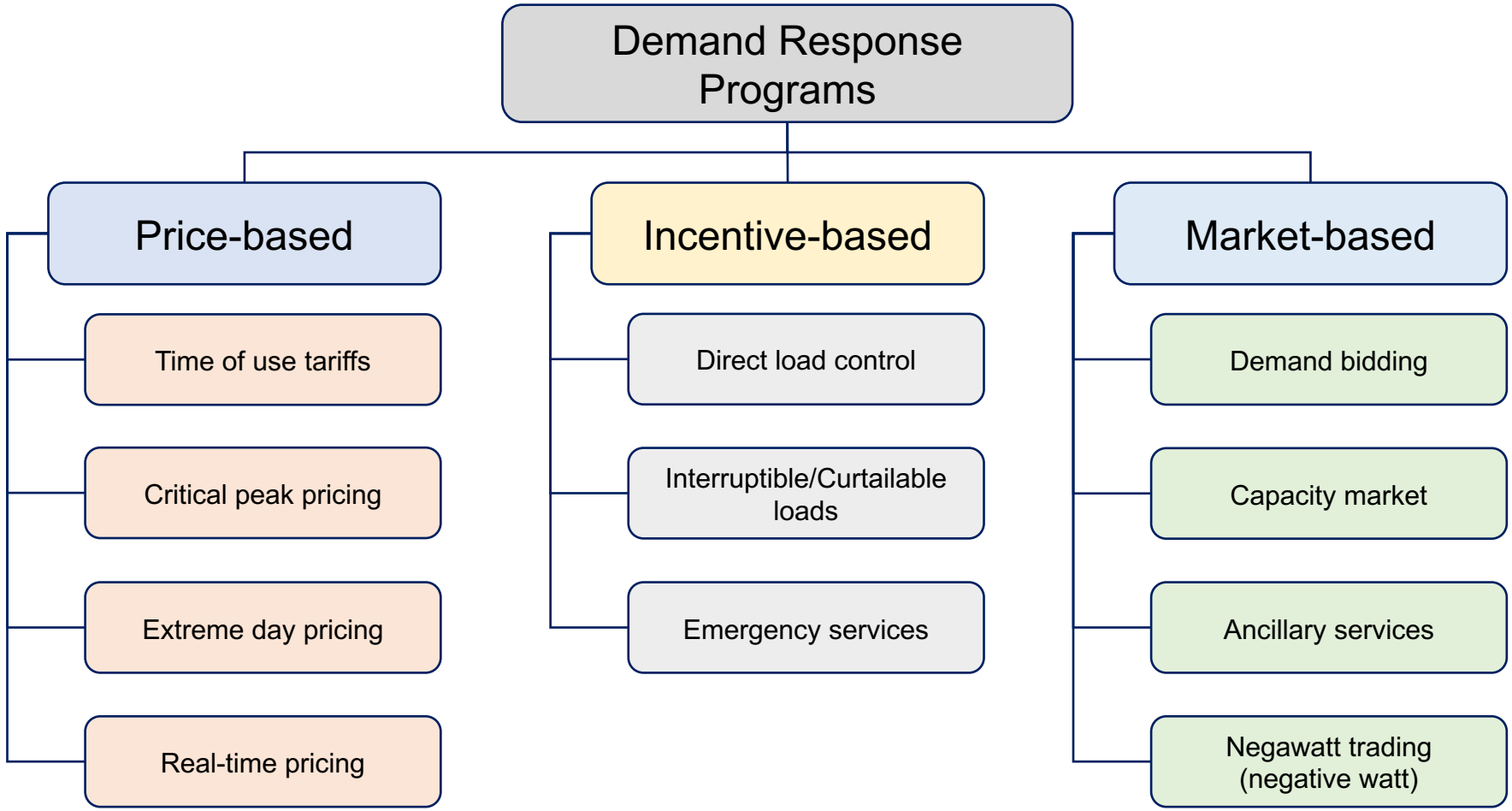


DEMAND RESPONSE (DR)

- Motivates changes in electric consumption by end-user in response to changes in the price of electricity.
- Allows to achieve the supply-demand balance by the lowest combination of resources, and to prevent the congestion problem.
- DR can be provided by:
  - Giving permission to direct load control of end-users appliances to a third party.
  - Cutting electricity use at high price times by signing a contract with a retailer or an aggregator.
  - Reducing or shifting the load of controllable devices of end-users.

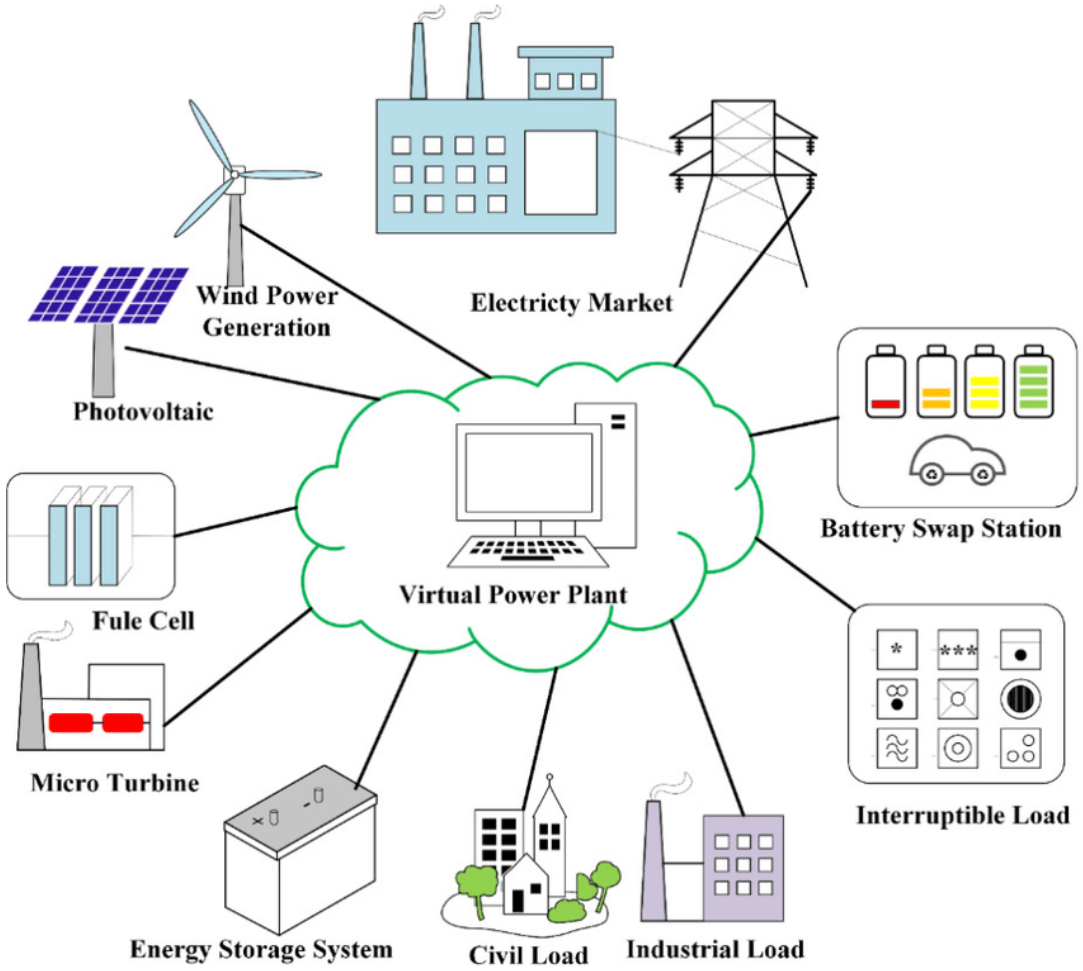


DIFFERENT DR PROGRAMS



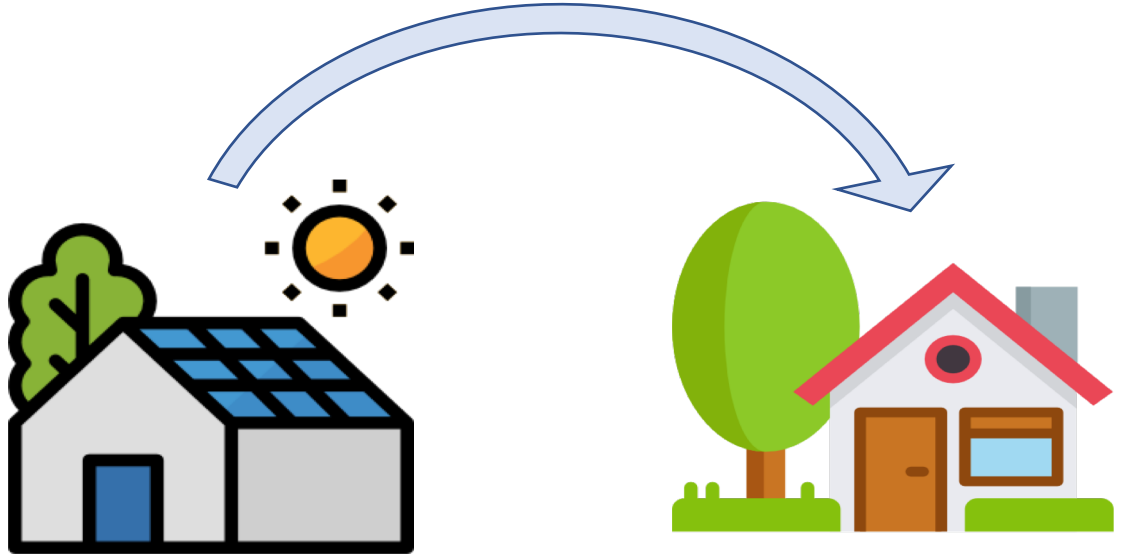
VIRTUAL POWER PLANT (VPP)

- Aggregates and coordinates DER across the network to exploit their flexibility.
- A VPP can be considered as an alternative version of DR programs, which includes DR aggregation by focusing on flexible loads.
- VPP enables demand-side participation in the market, either by direct control of their flexibility, or influencing their energy consumption pattern by sending indirect control signals, such as price signals.

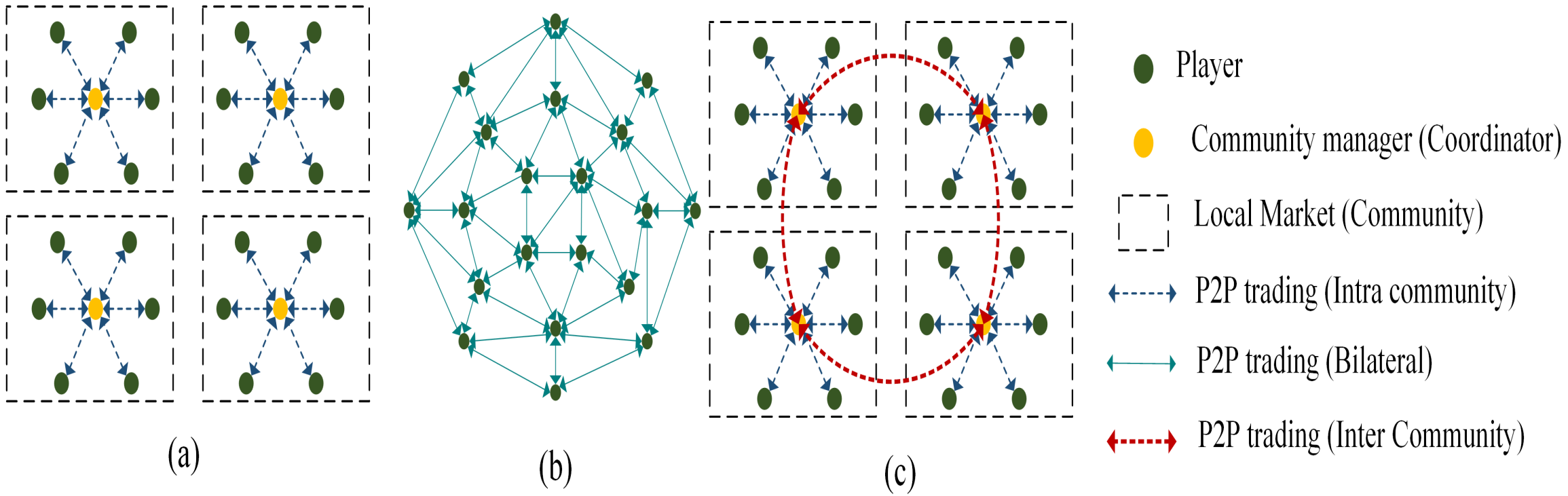


PEER-TO-PEER (P2P) TRADING

- Allows electricity consumers with small scale embedded generation systems, such as rooftop solar PV systems, to directly sell the excess electricity they produce to other local consumers.
- Provides a decentralized environment, in which small-scale prosumers and consumers can exchange electricity and other services among themselves, instead of interacting with third parties like utilities, and aggregator.
- Facilitates the arrangement of transactions between numerous individual agents.



MARKET STRUCTURE



Community-based (Pool)

Full P2P

Hybrid

OBJECTIVE FUNCTION

- The objective is to minimize cost or maximize social welfare

$$minimise\ F(\mathbf{x}), \qquad x \in \mathbb{X}$$

Subject to:

- Technical constraints of DER
- Technical constraints of the network

$F(\mathbf{x})$ Can incorporate:

- Utility of agents
- Cost of generation
- Willingness to pay
- Grid service charge
- …

OBJECTIVE FUNCTION-EXAMPLE

Seller objective

$$SO_i: \max_{s_i^{\min} \le s_i \le s_i^{\max}} s_i \times (\wp - \varpi) - C_i(s_i)$$

Market price

Price signal for network constraints

Buyer objective

$$BO_j: \max_{d_j^{\min} \le d_j \le d_j^{\max}} U_j(d_j) - d_j \times (\wp + \varpi)$$

Market price

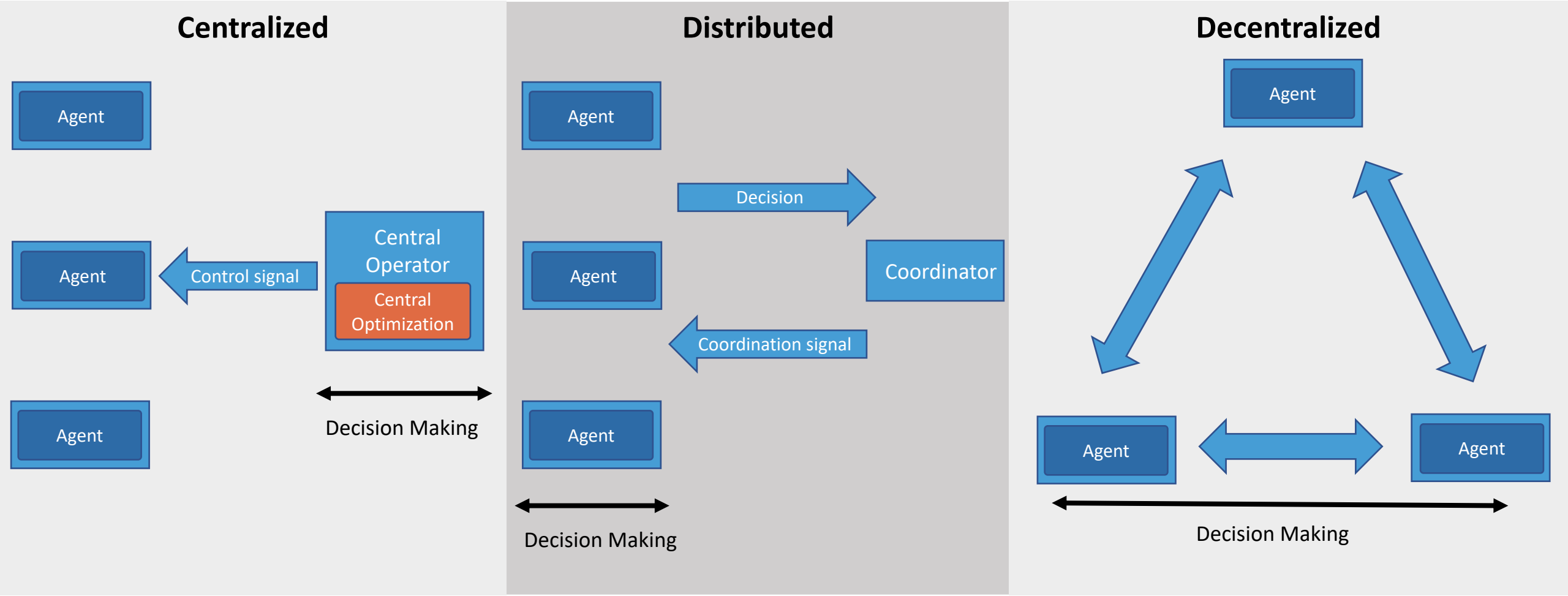
Price signal for network constraints

Total objective

$$TO: \max_{\mathbf{S},\mathbf{D}} \left(\sum_{j=1}^{N_B} U_j(d_j) - \sum_{i=1}^{N_S} C_i(s_i) \right)$$

$$\sum_{i=1}^{N_S} s_i = \sum_{j=1}^{N_B} d_j$$

MARKET CLEARING



Trading Arrangement

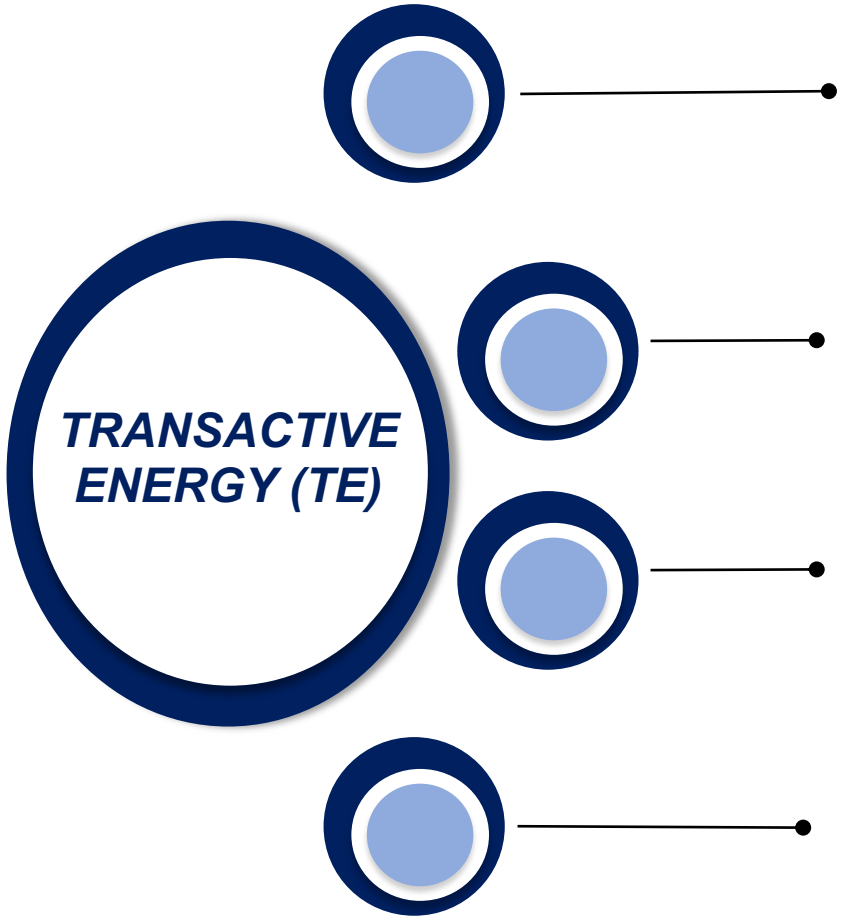
TRANSACTIVE ENERGY (TE)

A system of **economic** and **control** mechanisms that allows the dynamic balance of supply and demand across the entire electrical infrastructure using **value** as a key operational parameter.

GridWise Architecture Council

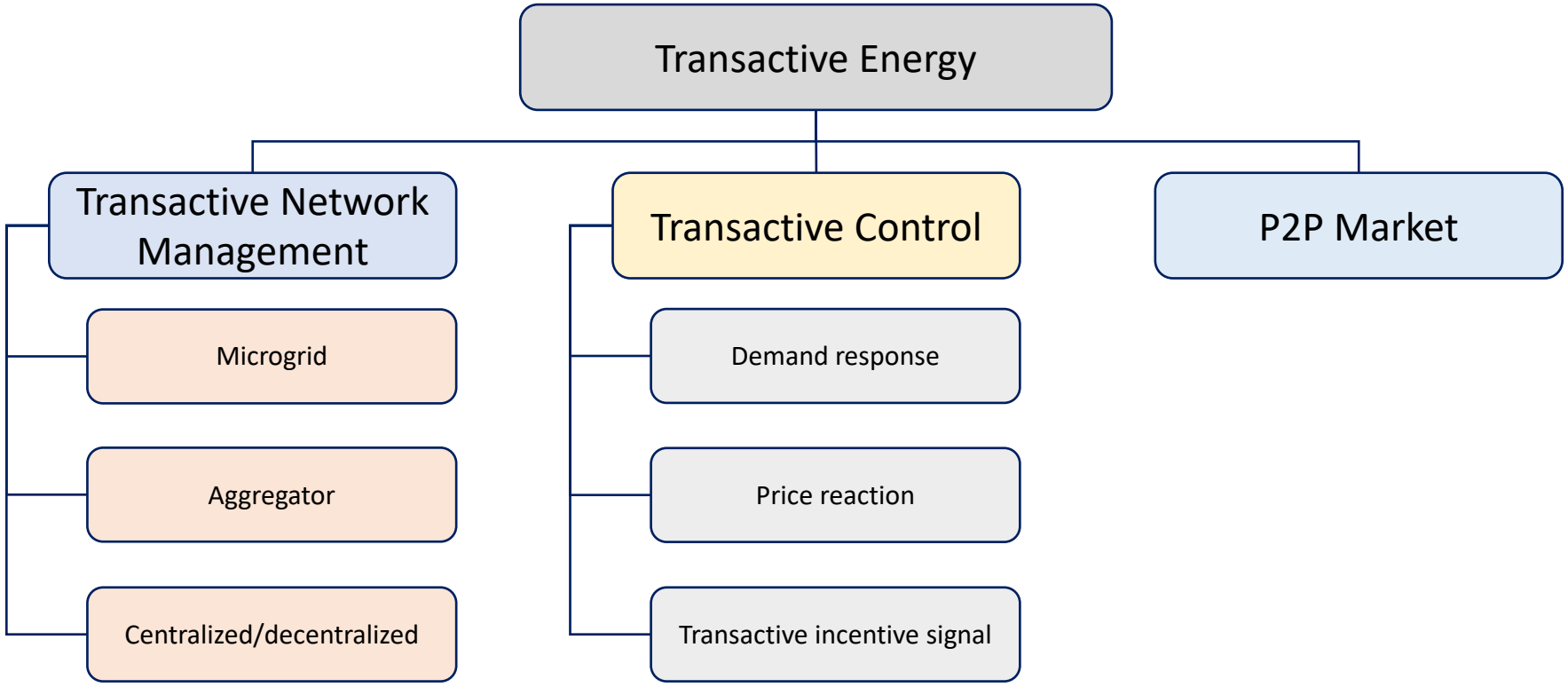
- A market-based approach for energy management, which uses price signals to coordinate demand and supply across the network and among all users and entities.
- Facilitates the integration of DER in the grid, while maintaining the system reliability.
- Provides a transformative solution to technological and socioeconomic challenges of the power grid modernization.
- Can be considered as a smart paradigm that sets market rules to manage the system with high reliability, while enabling active participation of end-users in the energy management process.

TRANSACTIVE ENERGY (TE)

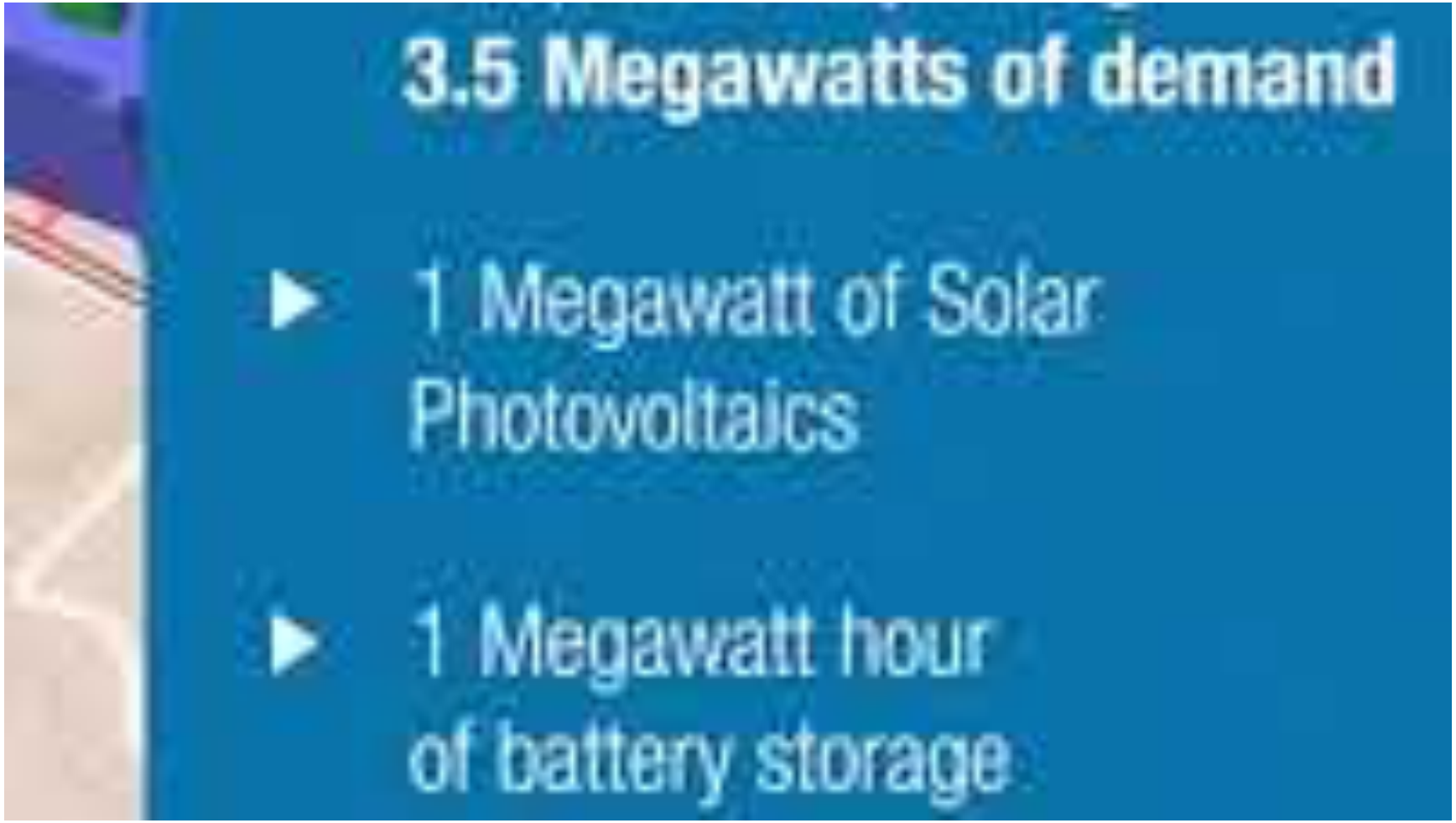


- It enables end-users to specify their preferences through active participation in energy management process.
- It provides a decentralized system, in which end-users are decision makers.
- Coordination signals are used to coordinate end-users to achieve system-level objectives while respecting power system constraints.
- TE exploits the flexibility of both demand and supply sides in energy management and coordinates them through market interactions.

CLASSIFICATION OF TE APPROACHES

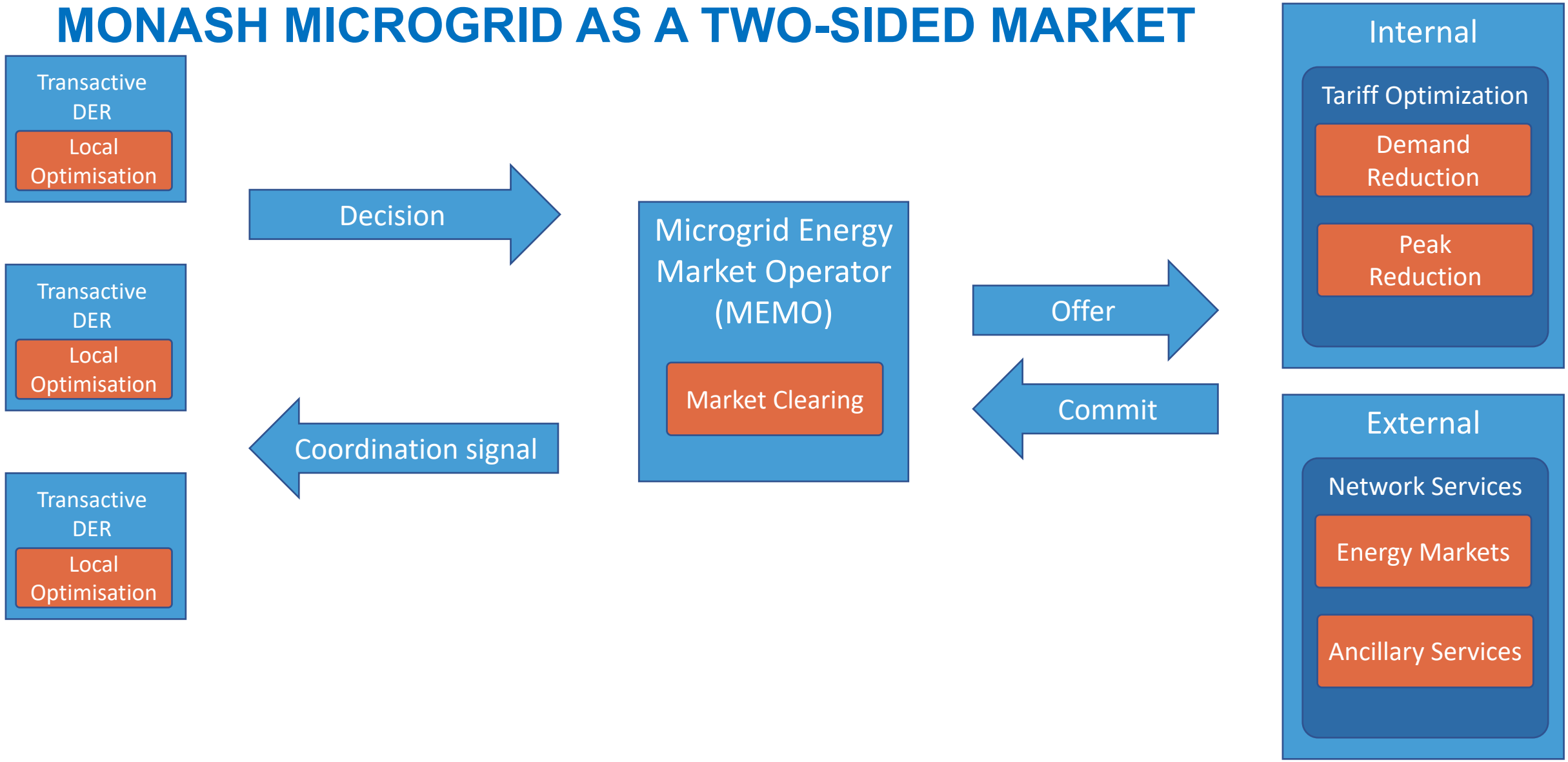


MONASH MICROGRID AS A TE SYSTEM



Source: https://www.youtube.com/watch?v=DgOfenYwb30&t=1s

MONASH MICROGRID AS A TWO-SIDED MARKET



Trading Arrangement

COMPARISION OF DIFFERENT APPROACHES

	Participation in market	Focused side	Exchanged signals	Main challenges
DR	Uncoordinated	Demand	Price/Control	• Incorporating comfort level of end users • Privacy concerns in direct control methods • Network issues due to uncoordinated operation
VPP	Coordinated	Demand	Price/Control	• Incorporating preferences of end-users • Autonomy and privacy of end-users • Scalability due to top-down structure
P2P	Uncoordinated/ Coordinated	Demand	Price	• Secure operation of power network • Decentralized balancing of demand and supply • Coordination of trading at different levels
TE	Coordinated	Demand/supply	Price/Control	• Implementation costs • Data privacy and cybersecurity threat • Assessment and valuation of TE systems

Conclusions

KEY POINTS

- DR, VPP, P2P, and TE have unique features and challenges, and hence, their implementation in a two-sided market leads to different outcomes.

- TE maximizes the participation of both demand and supply sides in the bidding and scheduling process, and hence, employing TE approaches for different programs supports the move to a two-sided market.

- Emerging technologies for two-sided markets can play a key role transitioning to two-sided markets.

FUTURE RESEARCH DIRECTIONS

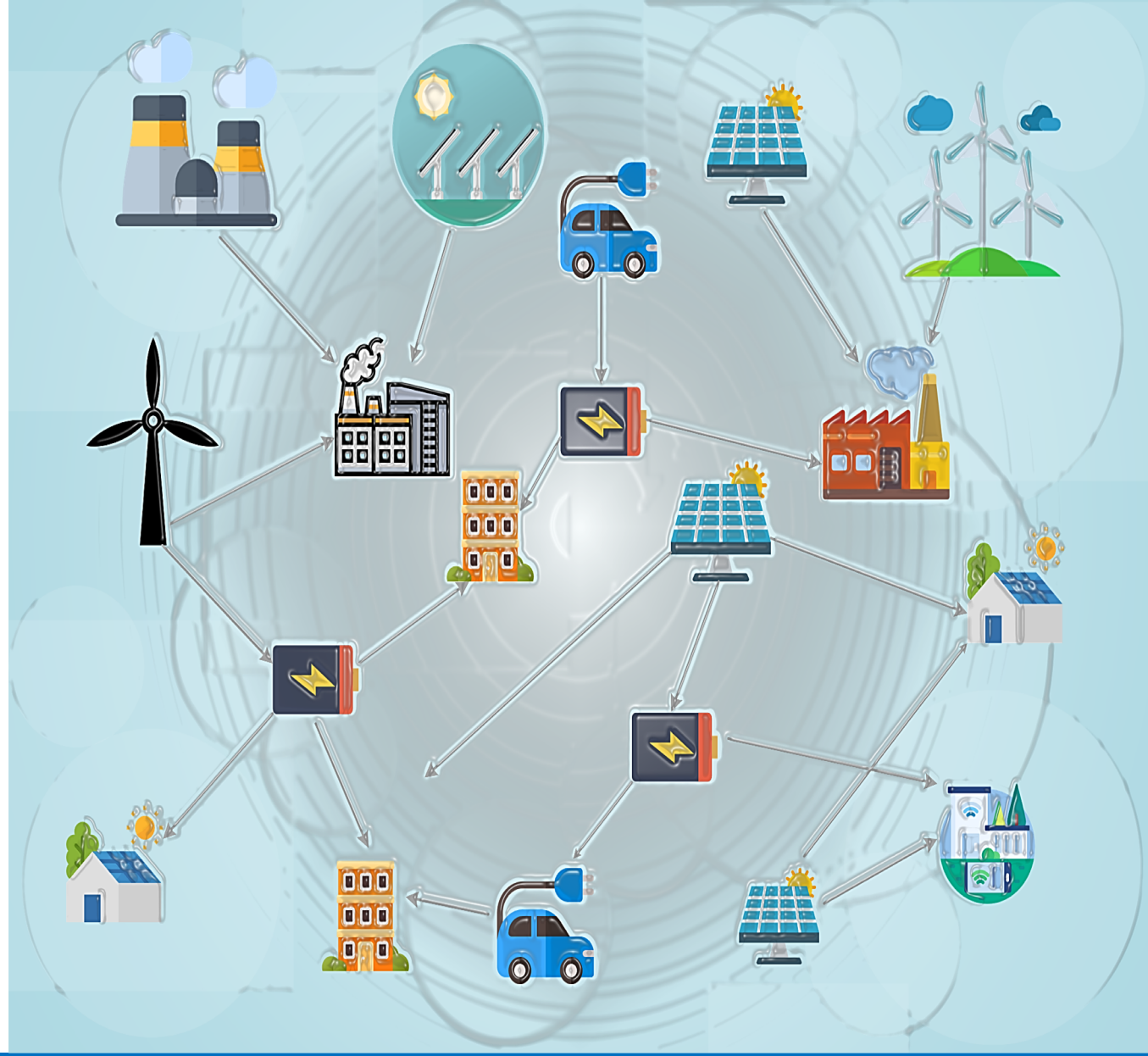
- Interaction of different markets with the two-sided markets
- Network charging
- Scalability
- Data security and privacy

For More reading:

[1] **Khorasany et al.** *Paving the Path for Two-sided Energy Markets: An Overview of Different Approaches*, IEEE Access, 2020, doi: 10.1109/ACCESS.2020.3040391.

[1] **Khorasany et al.** *Transactive Energy Market for Energy Management in Microgrids: The Monash Microgrid Case Study*, Energies, 2020, doi: 10.3390/en13082010.

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QUESTIONS?

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Innovative Solutions for Integration of Distributed Energy Resources

Special Issue Editor

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This Special Issue, for the international journal Sustainability, mainly covers original research and studies related to the topics including, but not limited to:

- Integration of DER into power systems
- Management of distributed and renewable energy resources
- Demand response integration for DER management
- Use of energy storage systems
- Integrated community-based energy systems
- Local energy systems
- .....

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