TradeRES
New Markets Design & Models for 100% Renewable Power Systems

Flexibility Market to Support a Cost-Effective Electricity System Decarbonisation

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Background and Motivation

Key objective: achieving cost effective transition to secure, low/zero carbon energy future

- Low-carbon transition and environmental protection have promoted the **increasing penetration of renewable energies**, e.g., PV and Wind >> **high variability, no inertia**.
- Increased **electrification of transportation and heating sectors**, e.g., EV, HVAC systems, present crucial techno-economic challenges for power systems >> **high demand peaks**.

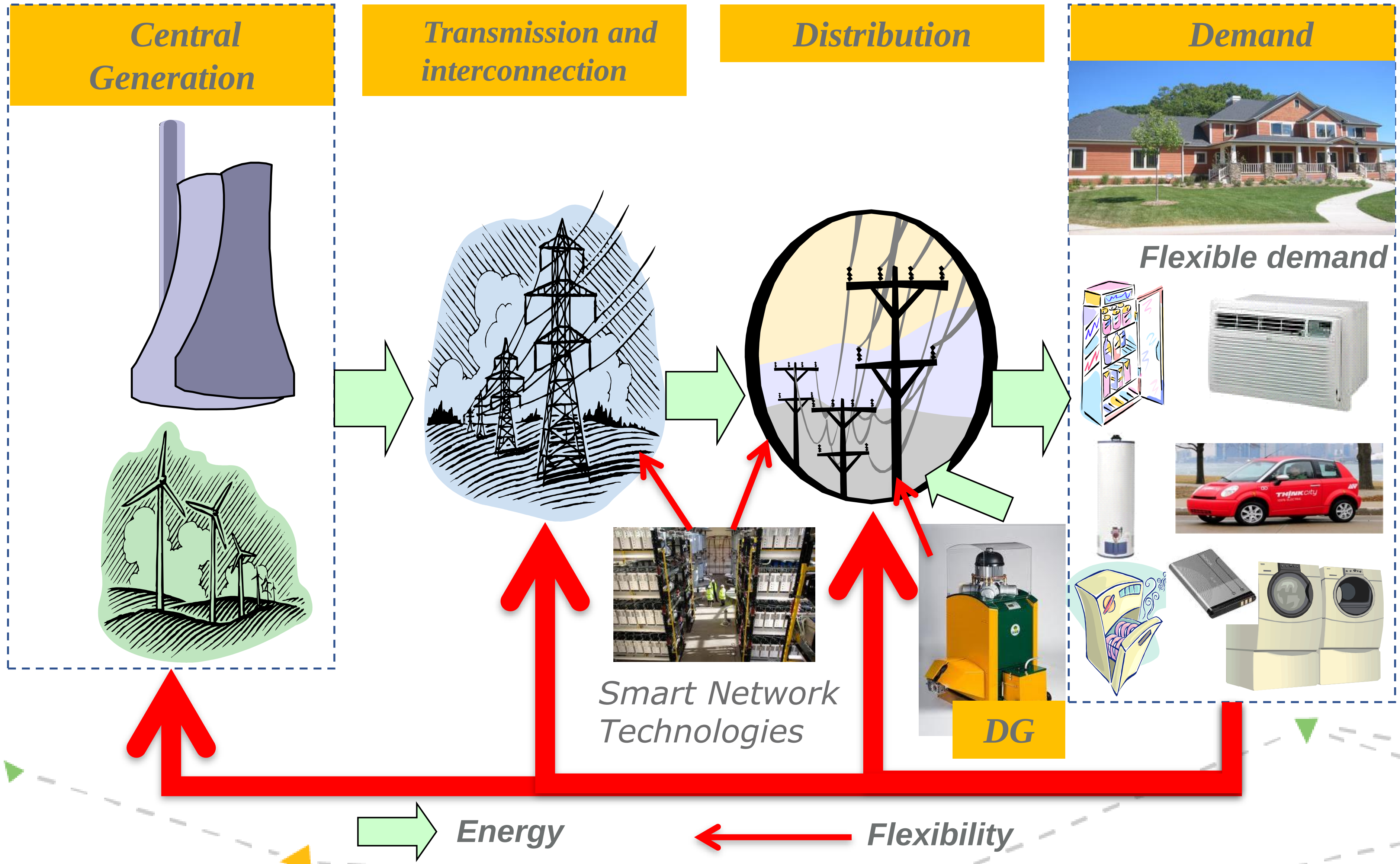
Integrating and coordinating demand-side flexibility

- Distributed generators (DG), energy storage systems (ES) and flexible demand technologies (FD /EV, Heating, Ventilation, Air Conditioning, Smart appliances).
- Balancing demand-supply locally >> reduce energy costs and demand peaks.
- Multi-energy microgrids >> provide effective energy management solutions for decarbonisation from the perspective of customer side.

Solution: transition to digitalised energy paradigm - appropriate **market design and control scheme** are required for efficiently coordinating this large number of small-scale demand-side flexibilities at the distribution level for **cost-effective energy trading and low-carbon transition**.

Energy: From the System to Consumers

Flexibility: DSR, DG, Storage, smart network technologies

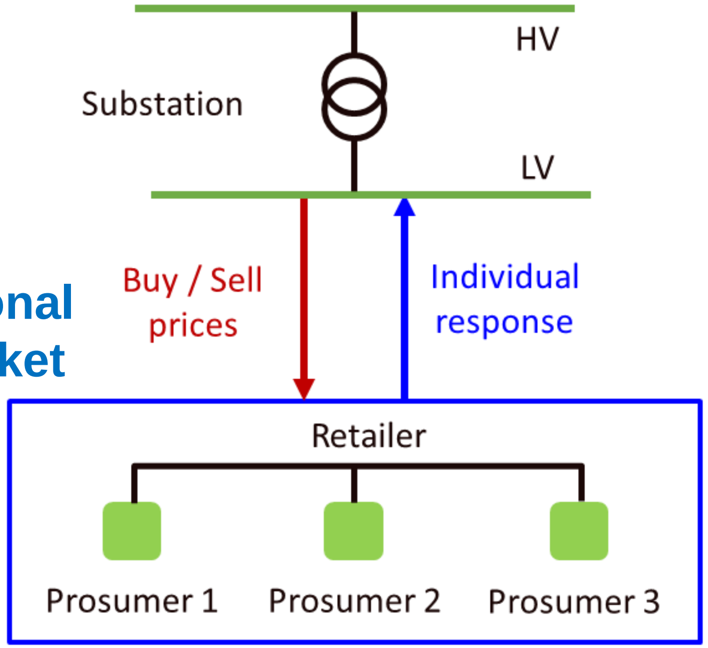


Peer-to-Peer Energy Trading in Local Energy Market

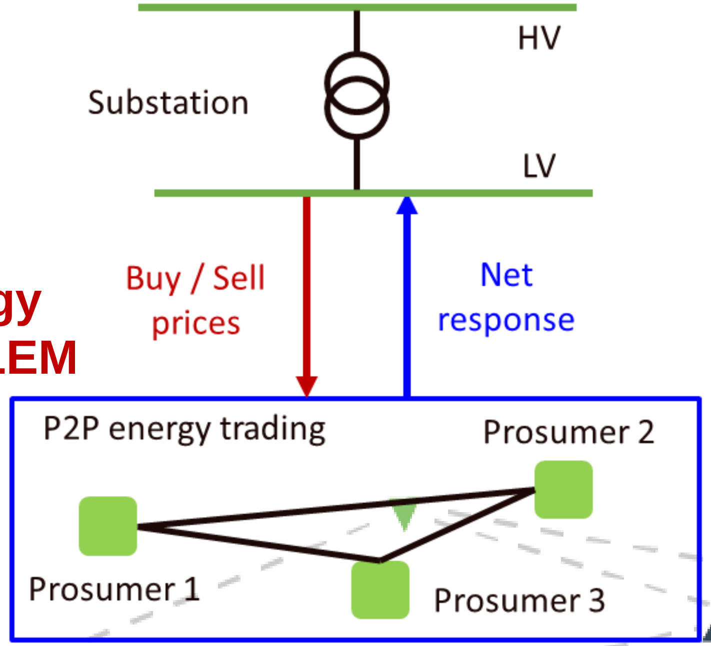
Peer-to-Peer (P2P) energy trading has emerged as a new market paradigm that ***enables direct and autonomous energy trading among prosumers*** within a local energy market (LEM):

- Enhance coordination and exploitation of prosumers' PV production and storage flexibility.
- Demand and generation are balanced at the local level.
- Reduce energy dependency on upstream electricity suppliers.
- Reduce national demand peaks, towards a cost-effective and low-carbon transition.
- Maximise economic benefits through local trading at more attractive local prices in comparison to the high retail price and low feed-in-tariff (FiT).
- Price is between FiT and retail price
- Deferral or even avoidance of energy infrastructure reinforcement.

Conventional retail market



P2P energy trading in LEM



P2P Community Market for Households

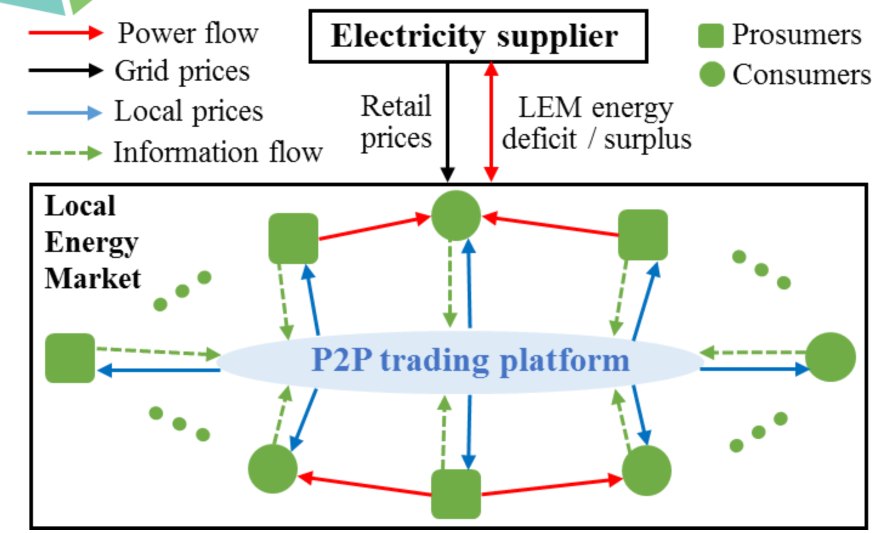


Fig 1: P2P energy trading platform.

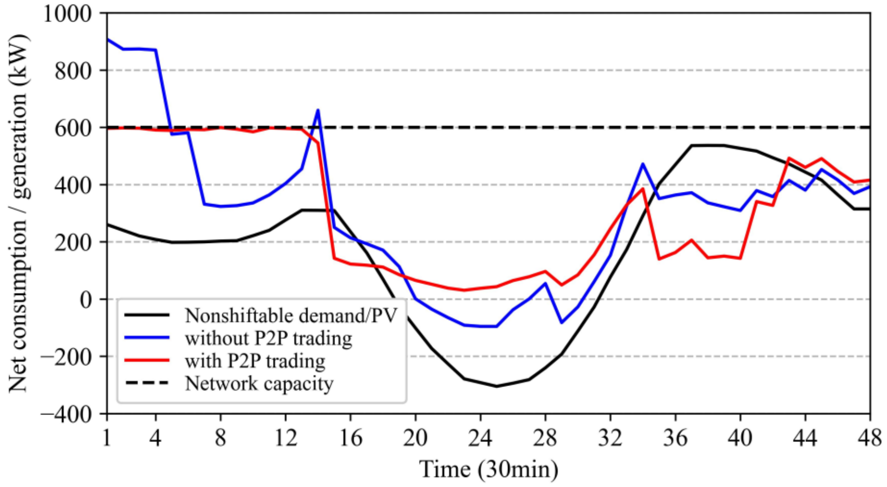


Fig 2: Community net load profiles.

Table1: Peak demand and daily energy cost of local community without (w/o) and with P2P market – 300 households.

Market	Peak demand (kW)	Cost (€)
w/o P2P	910	1,882
with P2P	600	1,478

Aggregated demand/generation profiles in the community

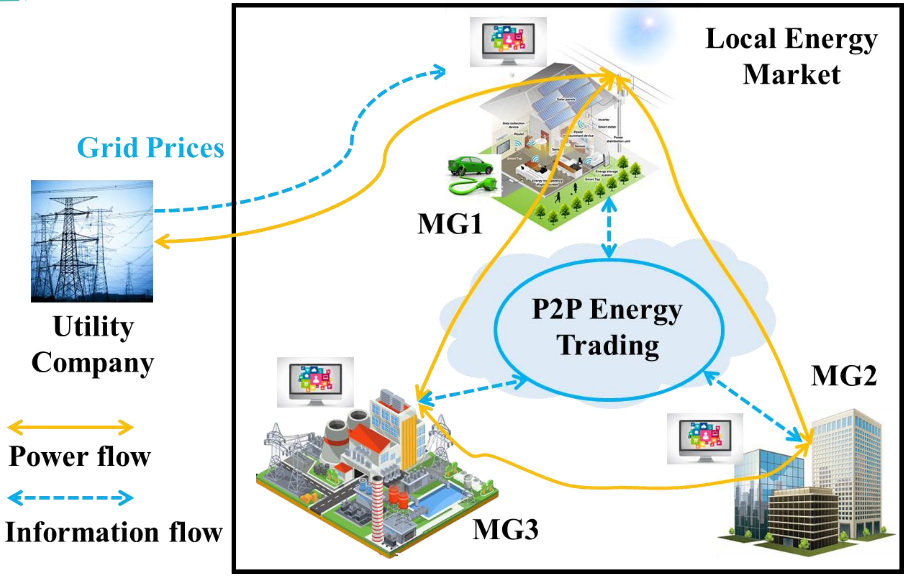
- Energy is shifted from peak demand of high-price periods to off-peak demand of low-price periods.
- PV generation is absorbed to supply peak demand.

Impact of P2P energy trading

- ***Peak demand reduction:*** demand peaks are reduced given the local market mechanism restricting the households' contribution to peak concentrations.
- ***Absorption of PV generation:*** more PV generation is absorbed during mid-peak hours, since P2P energy trading allows households to **fully exploit flexibility to absorb neighbours' PV generation**.

P2P Energy Trading for Microgrids

MG: micro-grid
P2G: power-to-grid
P2P: peer-to-peer
ToU: Time-of-Use
FiT: Feed-in-Tariff



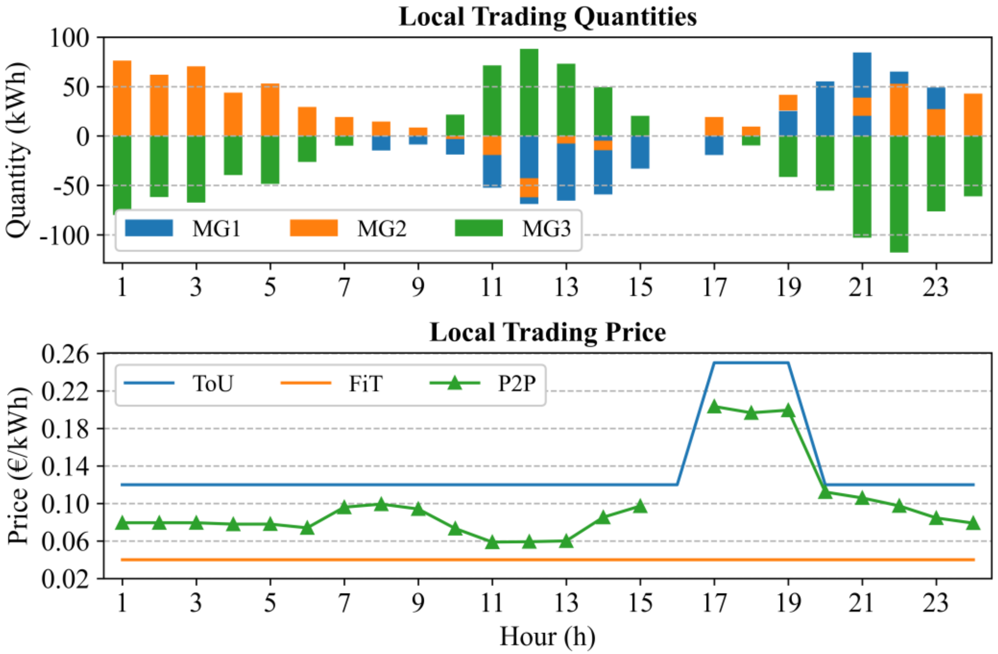


Fig1: Local trading quantities (above) and prices (below) among three MGs.

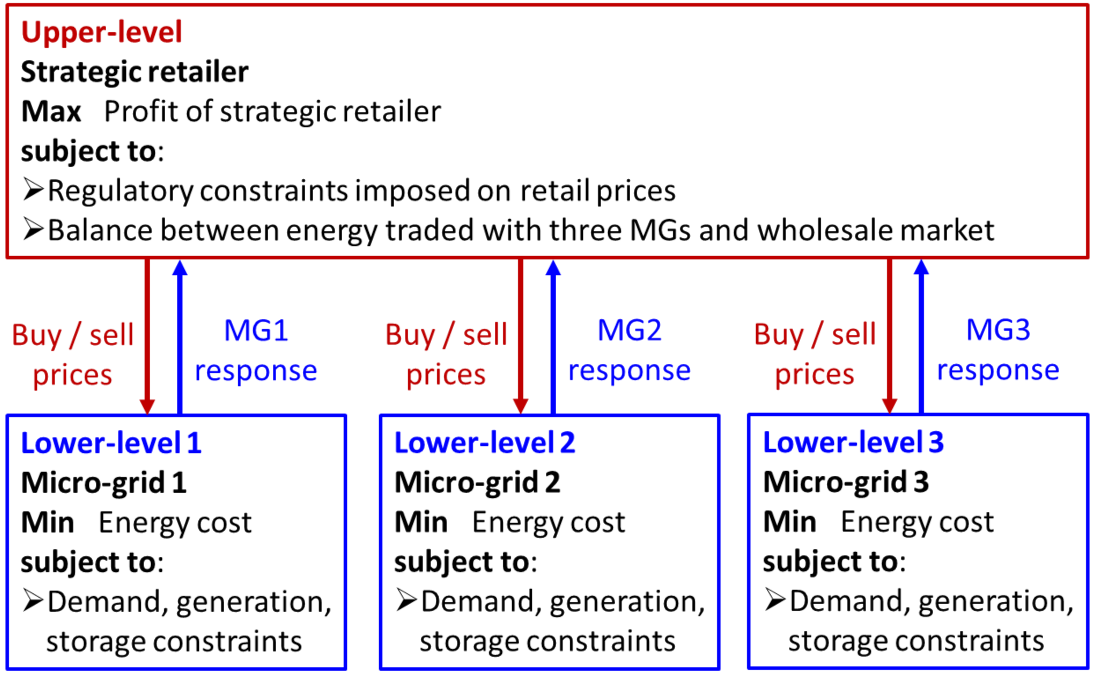
Table1: Daily internal and external trading quantities and daily energy costs of three MGs for P2G and P2P markets.

Markets	Internal trading (kWh)	External trading (kWh)	Cost (€)
P2G	-	7,382	1,151
P2P	7,263	1,933	703

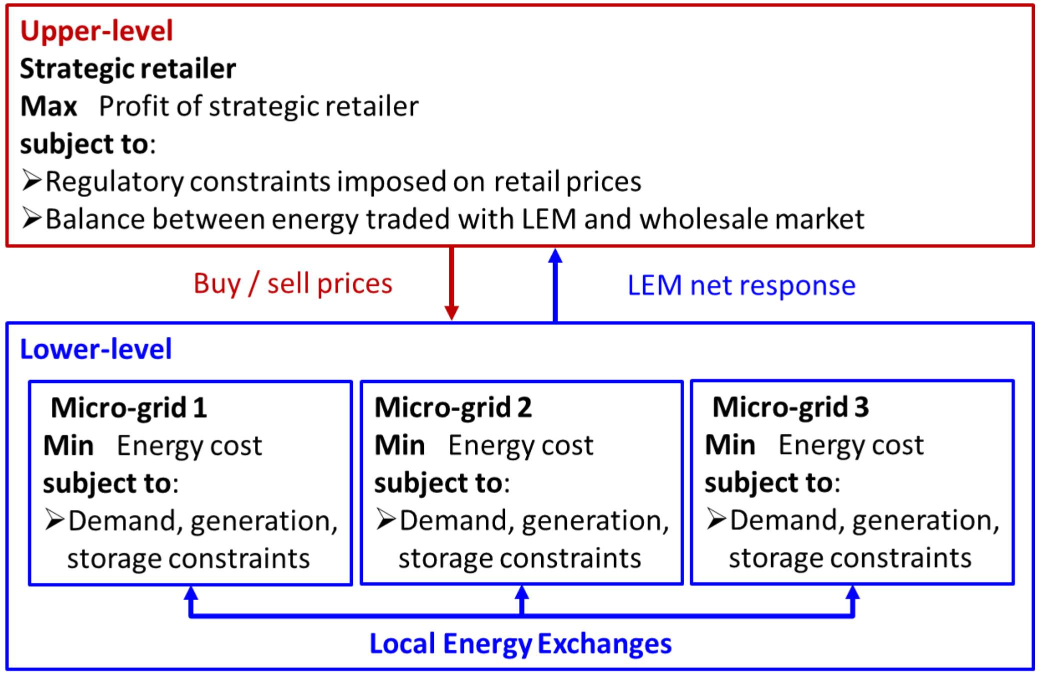
- Three MGs trade frequently (24 hours) and exchange significant amount of energy among themselves during the day.
- Three MGs economically benefit from the attractive local prices within the range of low FiT and high ToU.
- Compared to the conventional P2G market, three MGs in P2P market can **reduce energy costs for 40% (save 448€) by conducting 7,263 kWh of internal trading**.

Bilevel Model between Retailer and LEM

Peer to Grid (P2G)



Local Energy Market (LEM)



Added value of LEM with respect to P2G:

- Investigate the strategic retail pricing for LEM – net response .
- Evaluation of economic benefits of flexible demand, local generation, and energy storage participating into LEM rather than independently trading with the retailer.

Impact of LEM on Customers and Retailer

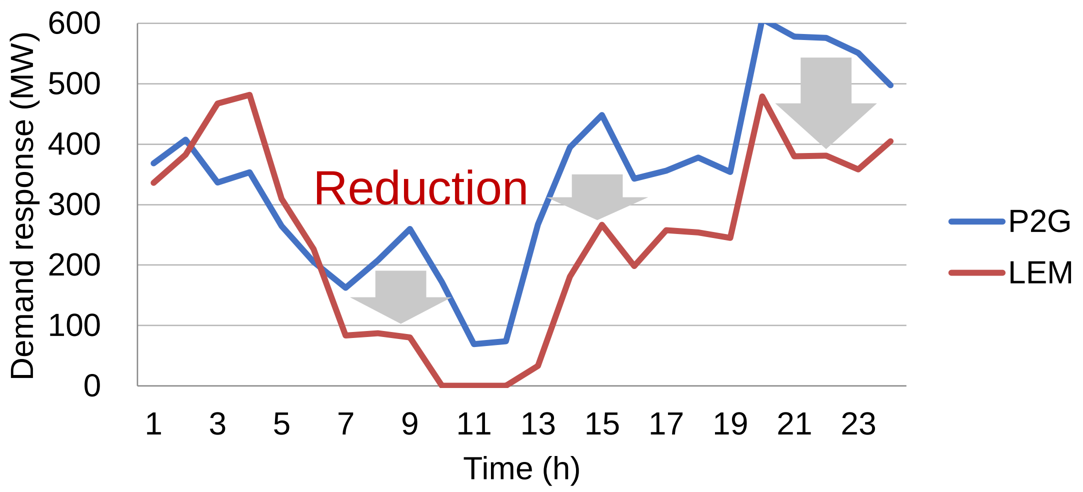


Fig1: Demand response for P2G and LEM.

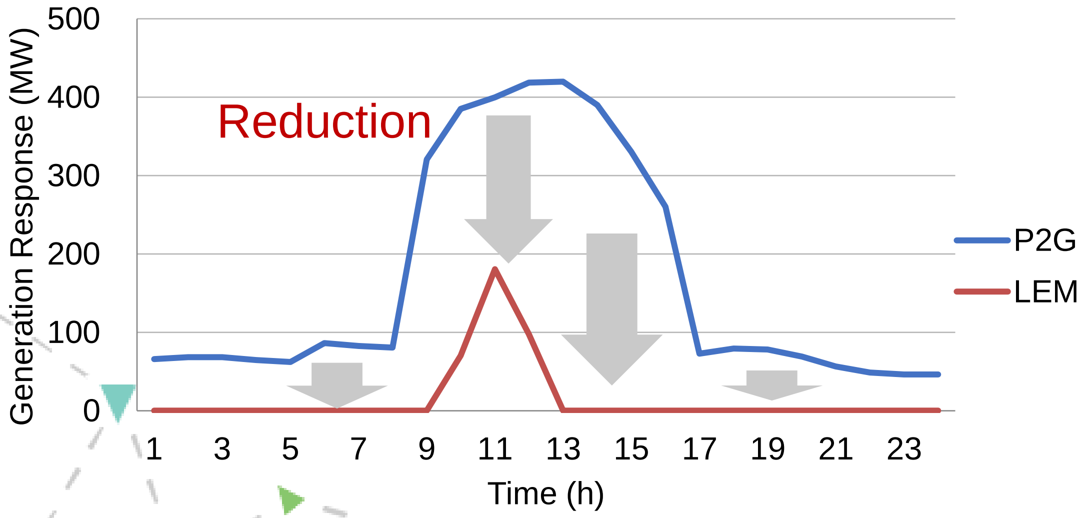


Fig2: Generation response for P2G and LEM.

Table1: Daily customer utility and retail profit for P2G and LEM.

Markets	Customer Utility (thous.€)	Retail Profit (thous.€)
P2G (peer-to-grid)	105.77	220.85
LEM (local energy market)	280.61	94.64

- Customer utility = demand benefit – generation cost
- Retail profit = retail revenue – wholesale cost

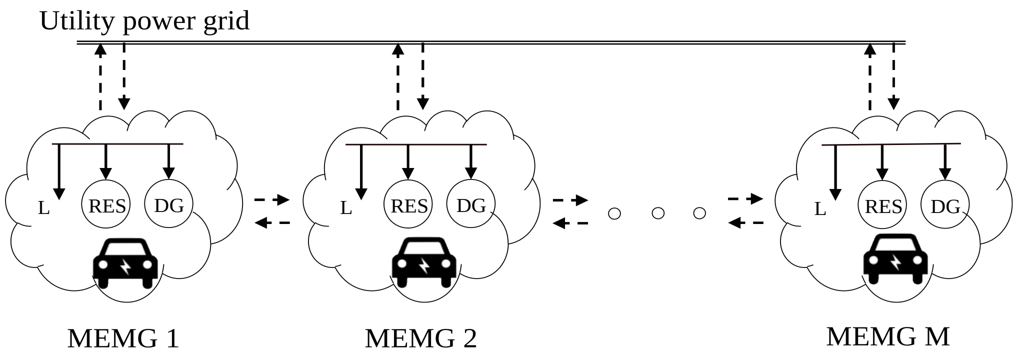
The dependency of local customers on retailer is limited; both the demand and generation served by the retailer are significantly reduced (Red lines in Fig 1. and Fig. 2).

Key insights:

1. ***Customers benefits from LEM in achieving higher utility.***
2. ***Retailer losses business cases in LEM by serving less customers.***

Decarbonised Multi-Energy Microgrids (MEMGs)

MEMGs: electricity, heat, cooling, fuels, transport, and so on optimally interact with each other at MG levels

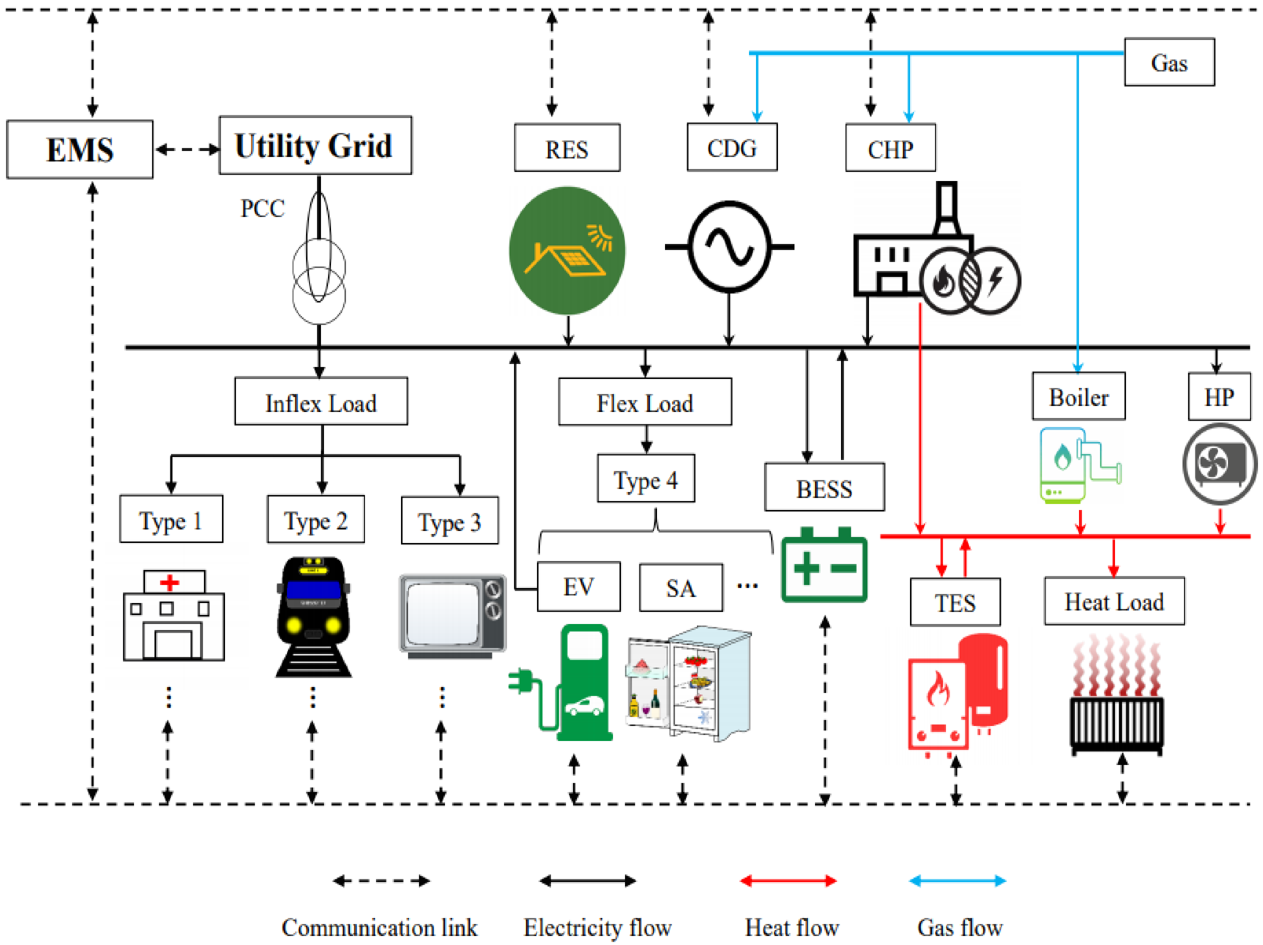


Local resources

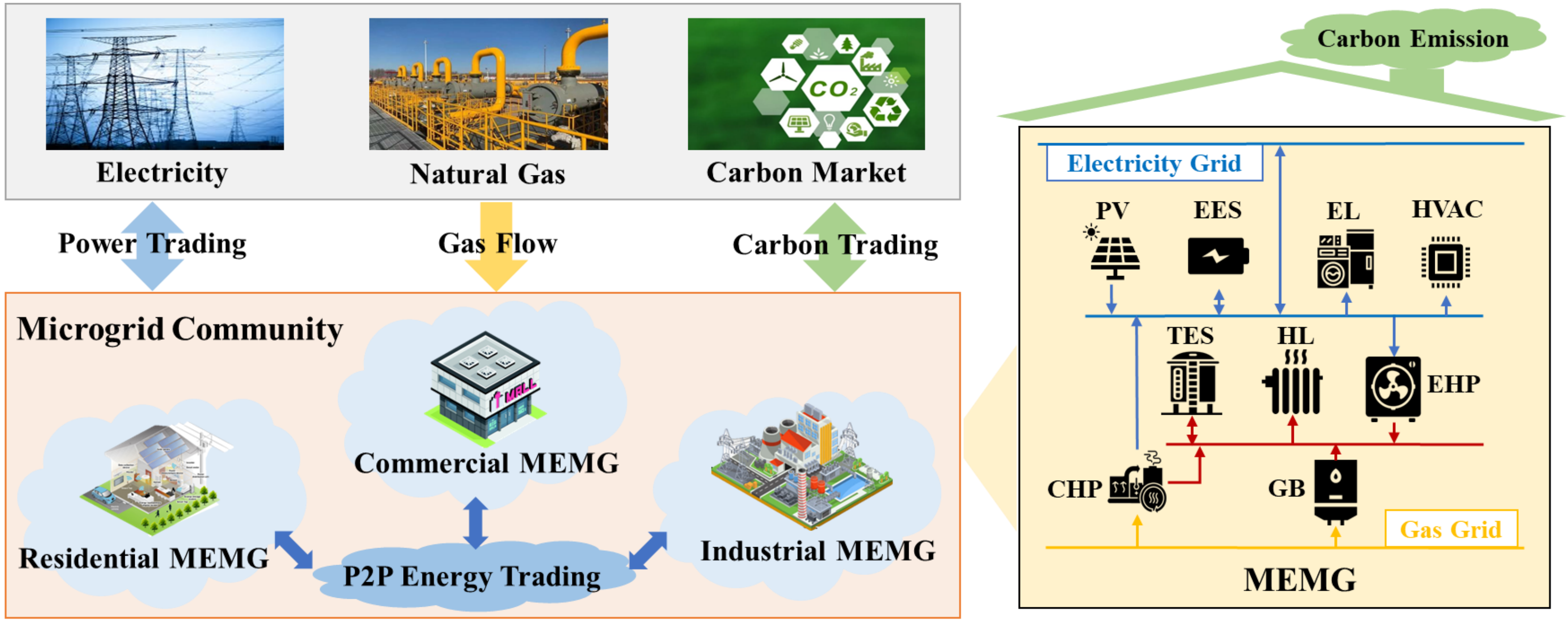
- Local micro-generators
- CHP, EHP, gas boiler
- Energy storage (electric, heat, building)
- Electric vehicles / V2G
- Demand side response
- Smart appliance
- Mobile power sources

Different types of demand

- Continuously essential
- Decreasingly essential
- Non-essential
- Flexible



Joint P2P Energy and Carbon Trading



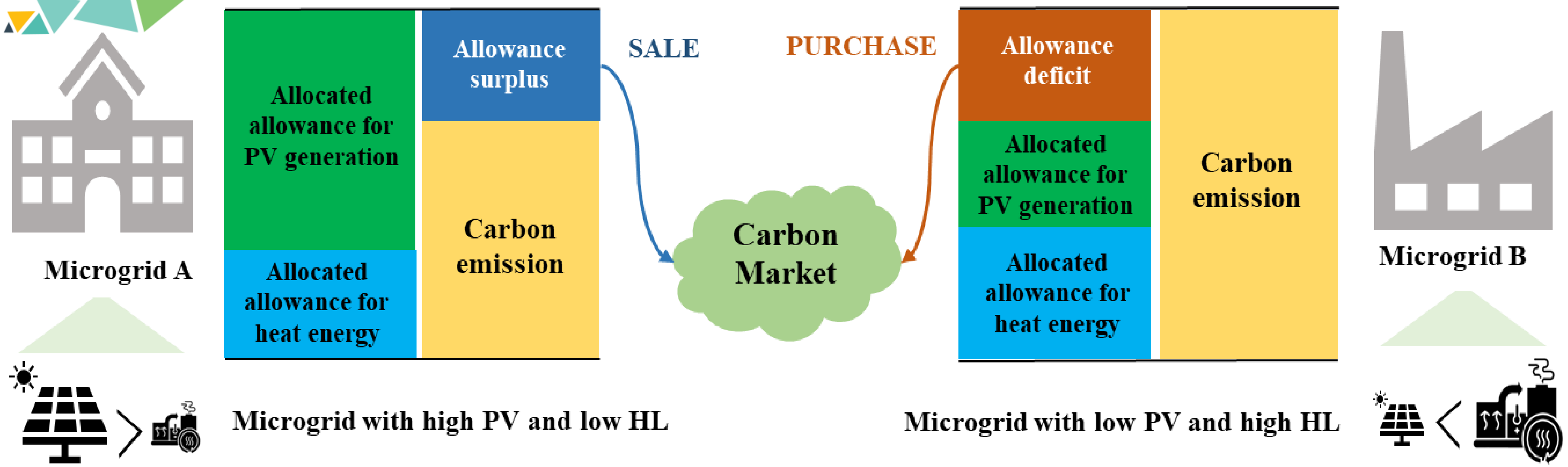
- Photovoltaics (PV)
- Electric heat pump (EHP)
- *Combined heat and power unit (CHP)*
- *Gas boiler (GB)*
- Heating, ventilation, and air conditioning (HVAC)
- Electric energy storage (EES)
- Thermal energy storage (TES)
- Electric load (EL)
- Heat load (HL)

Figure: Paradigm of joint P2P energy and carbon allowance trading framework for a MEMG community

The joint energy and carbon trading mechanism can be designed as two stages:

- **P2P Energy Trading:** Smart MEMGs can trade electricity on the main grid and purchase natural gas as fuel from the gas grid, but they can also exchange electricity locally through P2P trading platform.
- **Emission Trading Scheme (ETS):** Smart MEMGs are allowed to trade their carbon allowances locally but also purchase/sell carbon deficit/surplus in the carbon market.

Cap and Trade (CAT) approach



Energy and Carbon trading activities are coupled within the local market.

Figure: Operations of the cap-and-trade (CAT) approach for different MEMGs.

Within emission trading scheme (ETS), a ***free carbon allowance allocation*** method and a carbon trading mechanism are designed in the multi-energy microgrid (MEMG) community:

- **Allocation of free carbon allowance:**
  1. **Heat energy components:** MEMGs with heat energy components can receive a certain level of carbon allowances for free based on heat benchmark.
  2. **PV power generation:** MEMGs with PV sources can also receive a certain level of free carbon allowance based on grid carbon intensity.
- **Carbon trading:** After deducting the free carbon allowance allocation, the remaining carbon allowance with a surplus (deficit) can be sold (bought) in the carbon market.

Energy Flows

Heat electrification via electric heat pump - EHP (6,119 kWh)

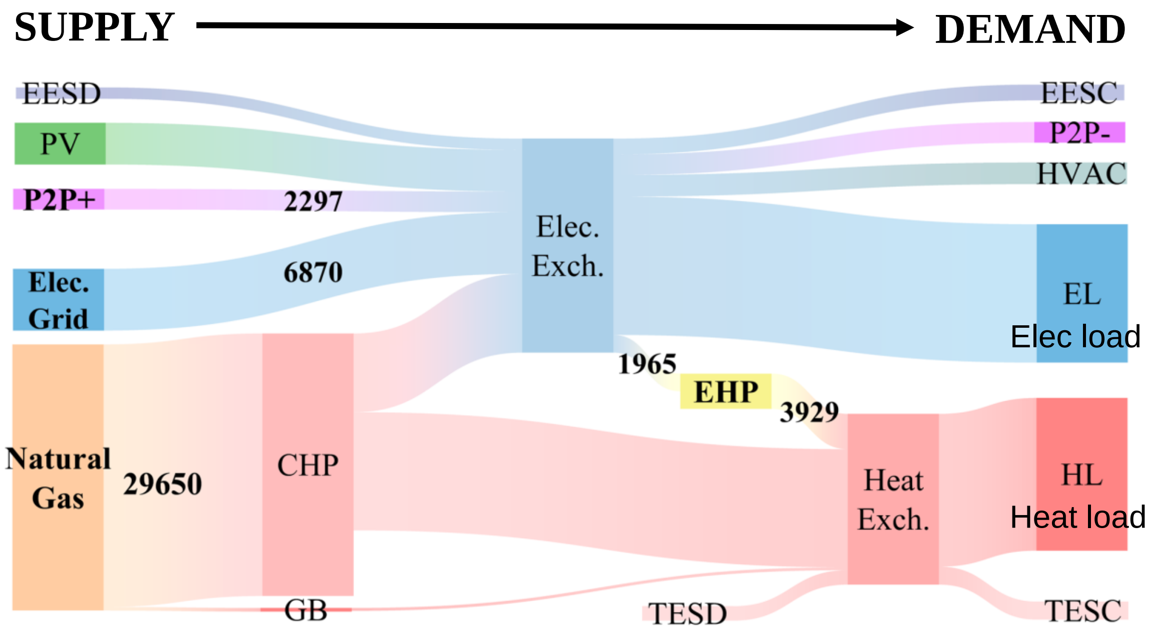


Fig1: Energy flow in community under P2P.

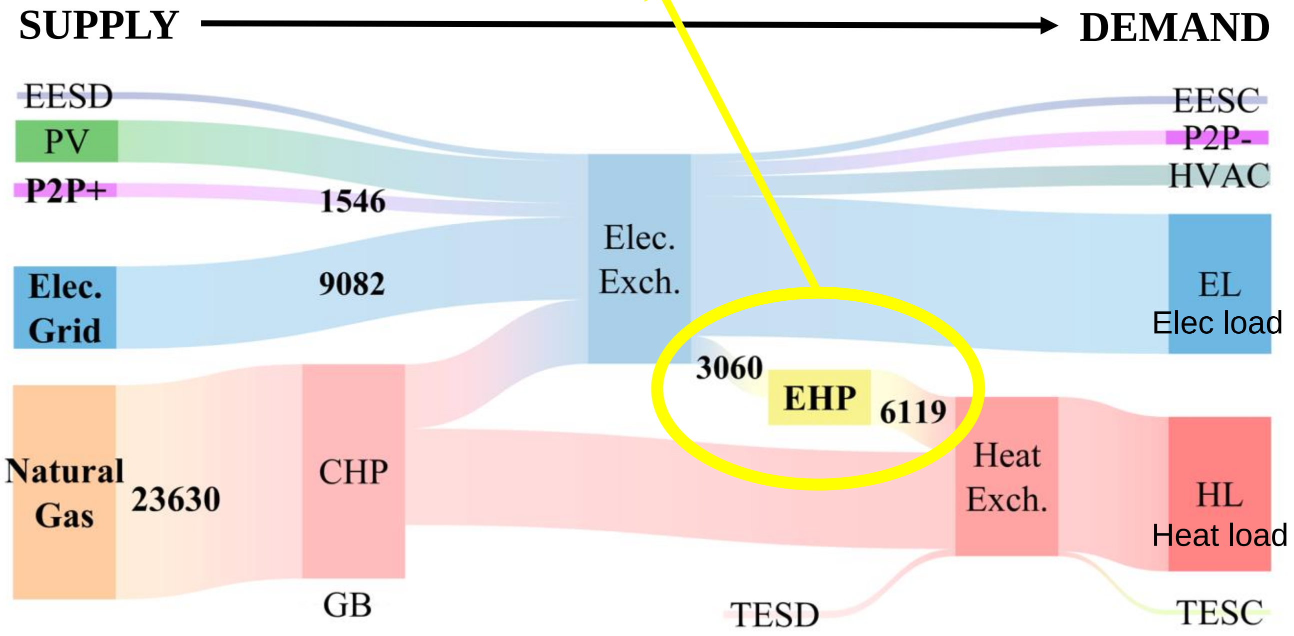


Fig2: Energy flow in community under JPC.

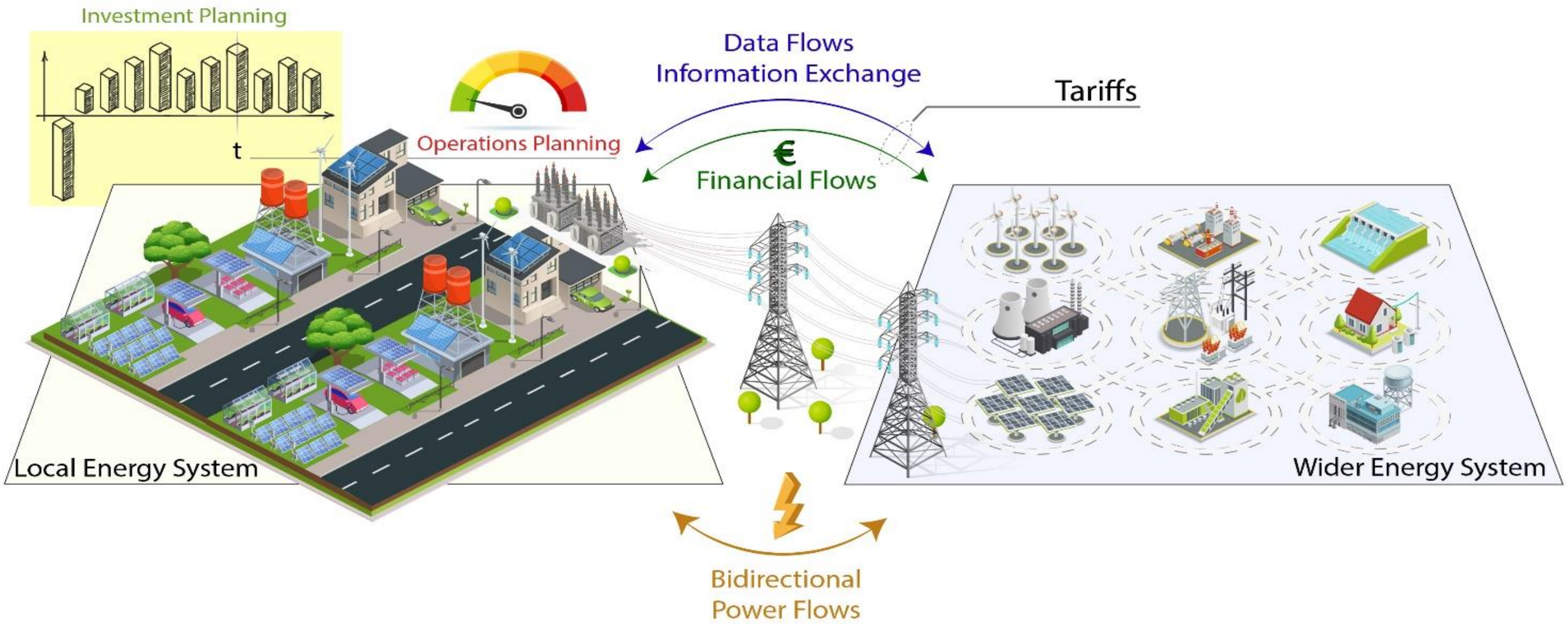
When **P2P** energy trading is allowed while carbon trading is not allowed (P2P):

1. More P2P energy trading quantity (2,297 kWh)
2. More natural gas import (29,650 kWh) and less electricity grid import (6,870 kWh).

When **J**oint **P**2P energy trading and **C**arbon trading are allowed (**JPC**):

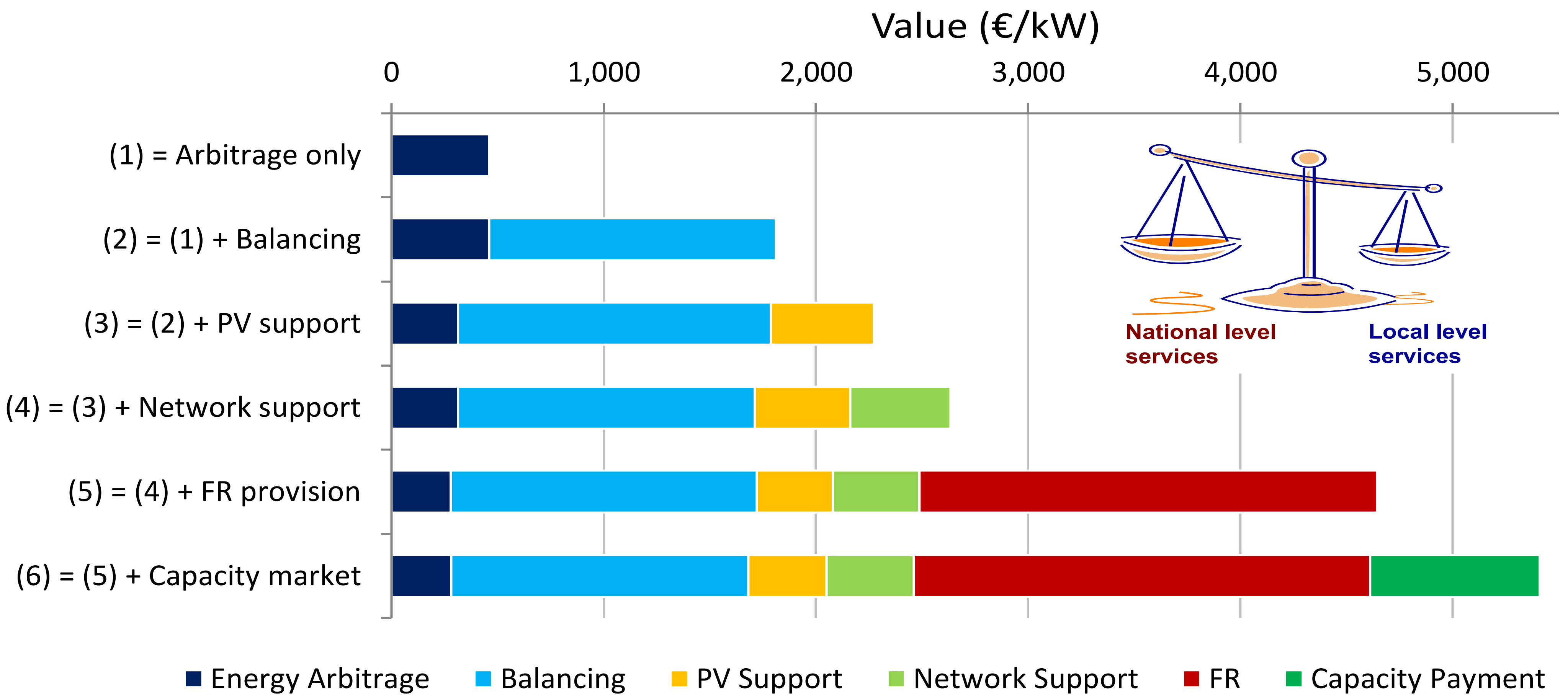
1. Less P2P energy trading quantity (1,546 kWh)
2. ***Less natural gas import*** (23,630 kWh) and more electricity grid import (9,082 kWh).

Linking local, national and international markets



Flexibility resources at the local level should support operation of the national/international markets – EU Wide approach is critical

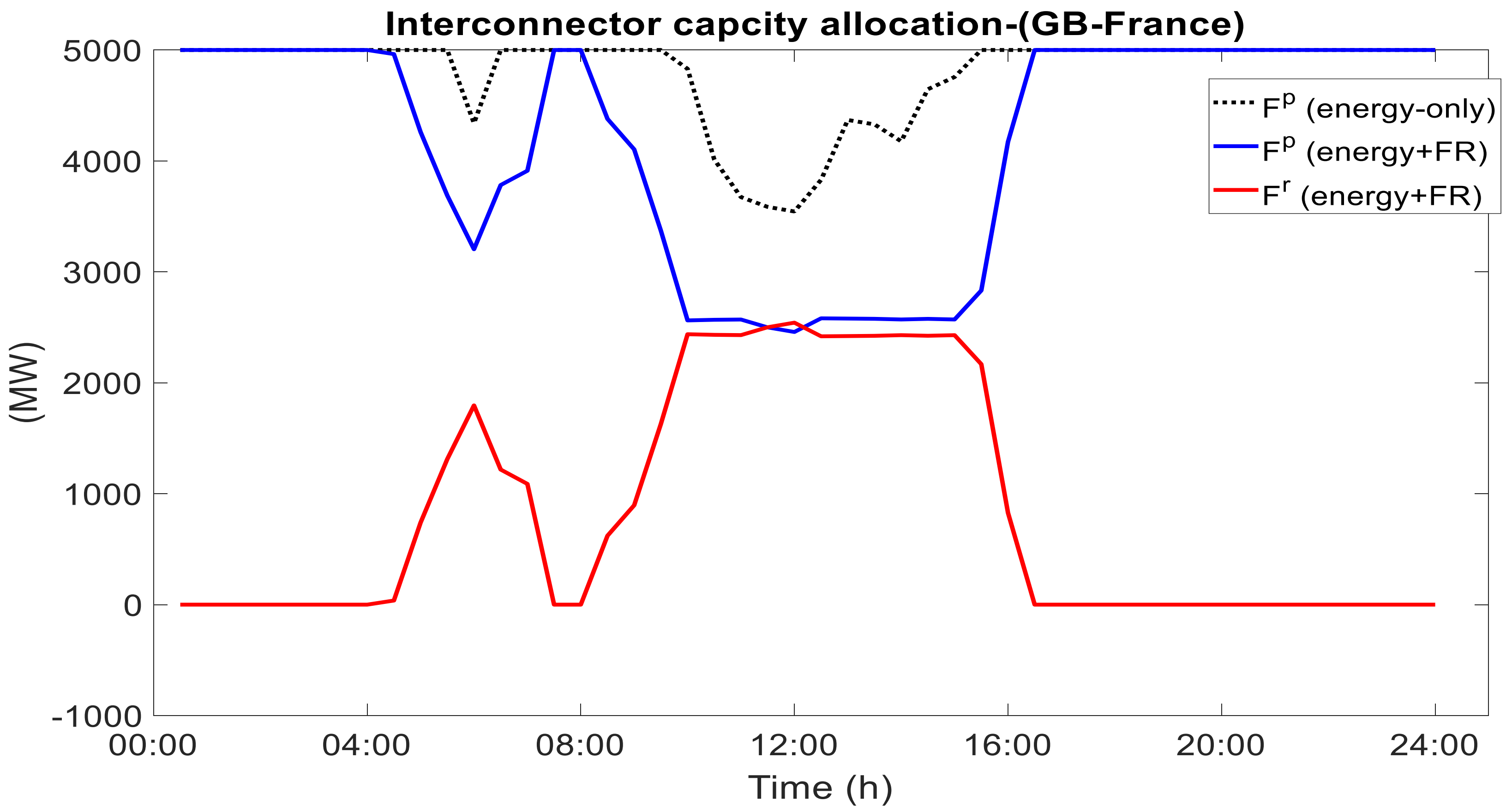
Provision of both local and national level flexibility services by DER



Multi-service provision by Distributed Energy Resources

- **Arbitrage**
  - ✓ Participate in day-ahead energy market
- **Balancing services**
  - ✓ Participate in real-time balancing market
- **Frequency regulation services**
  - ✓ Providing primary/secondary / tertiary frequency regulation services
- **Contribution to meeting peak demand**
  - ✓ Reducing need for peaking plant
- **Network Support**
  - ✓ Reducing need for network reinforcement
- **Low carbon generation mix**
  - ✓ Flexibility supports meeting carbon targets while reducing LC generation
- **Option value**
  - ✓ Providing flexibility to deal with uncertainty

Co-optimization of energy and reserve cross-border will become critical for achieving efficient market operation



	Energy+FR	Energy-only
Operational cost (M£)	118.81	132.29

Conclusions and Key Findings

Flexibility is the key for provision of cost-effective transition to low/zero carbon future

P2P energy trading in LEM

- P2P energy trading is allowed to trade/balance demand and generation locally >> reduce energy cost, reduce energy dependence on upstream main grid, avoid network reinforcement, etc.
- The impact of local energy market on national level should be considered.

Key findings towards cost-effective P2P energy trading

- More PV absorptions and higher demand peak reductions in P2P energy trading.
- Local trading pricing scheme guarantees the economic benefits of market participants in P2P energy trading.
- Social welfare is increased and shifted from strategic retailer to local customers in P2P energy trading.

Key findings towards future low-carbon transition

- Multi-energy microgrids (MEMGs): localized small energy systems with high flexibility.
- New local market mechanism design: joint energy and carbon trading.
- Decarbonization can be effectively enhanced through smart, multi-energy microgrid operation.
- Energy and carbon are coupled in local market towards the future cost-effective and low-carbon transition.
- Carbon emissions will be reduced by electrifying heat sector using electric heat pumps.

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