Implicit and explicit flexibility procurement mechanisms: unlocking the grid-safe use of LV flexibility

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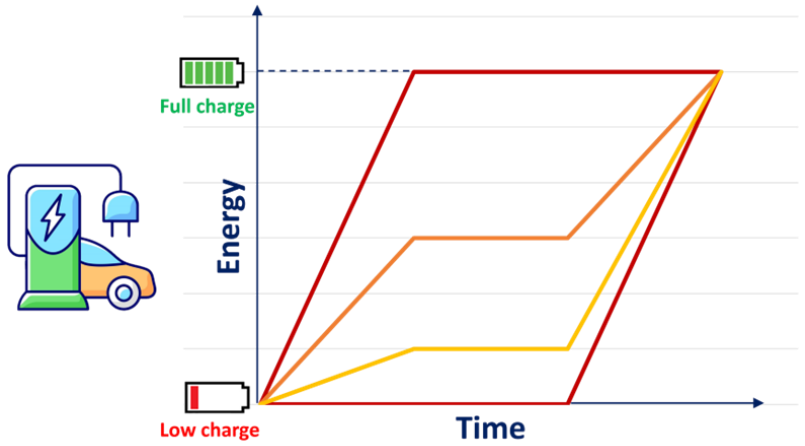
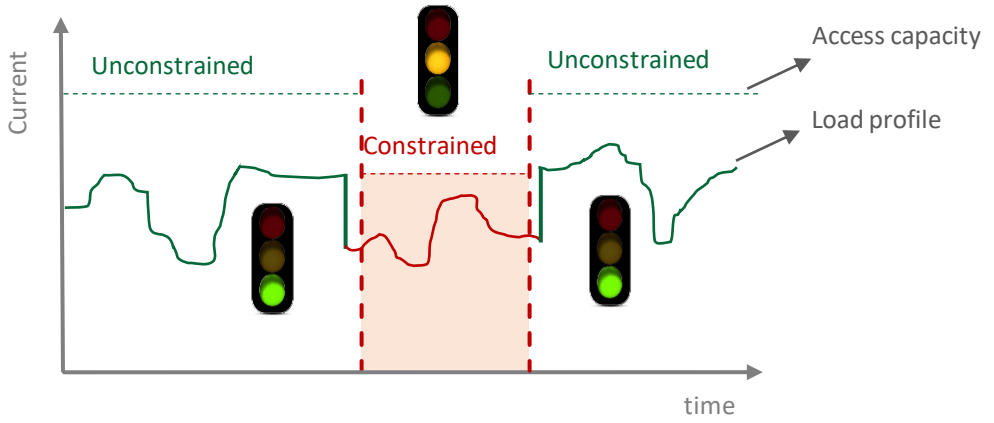
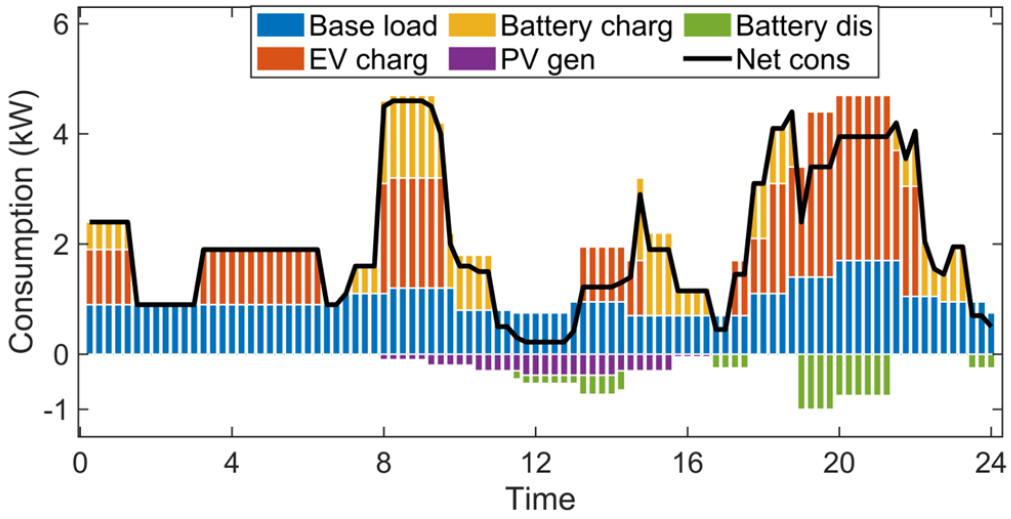
What is flexibility?

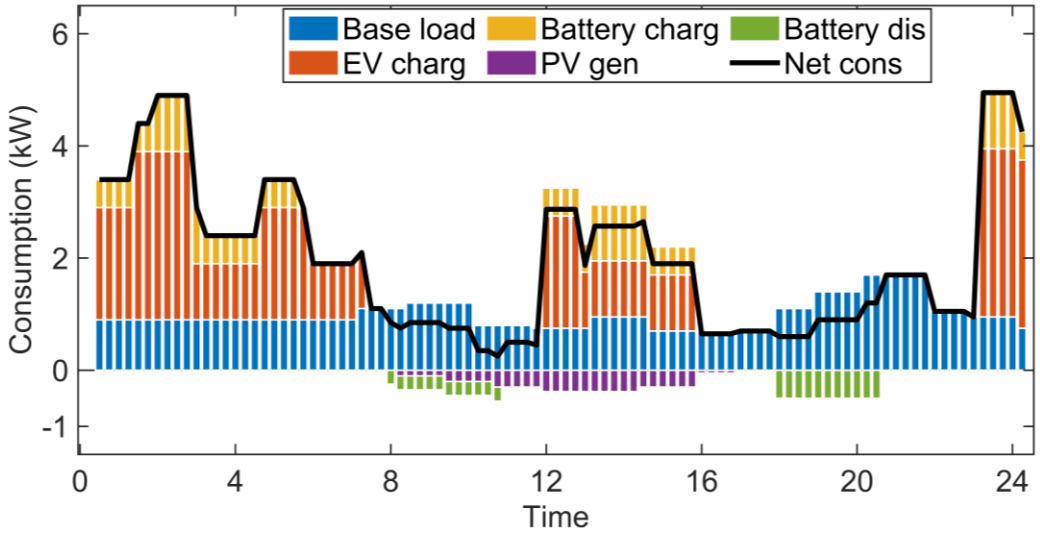






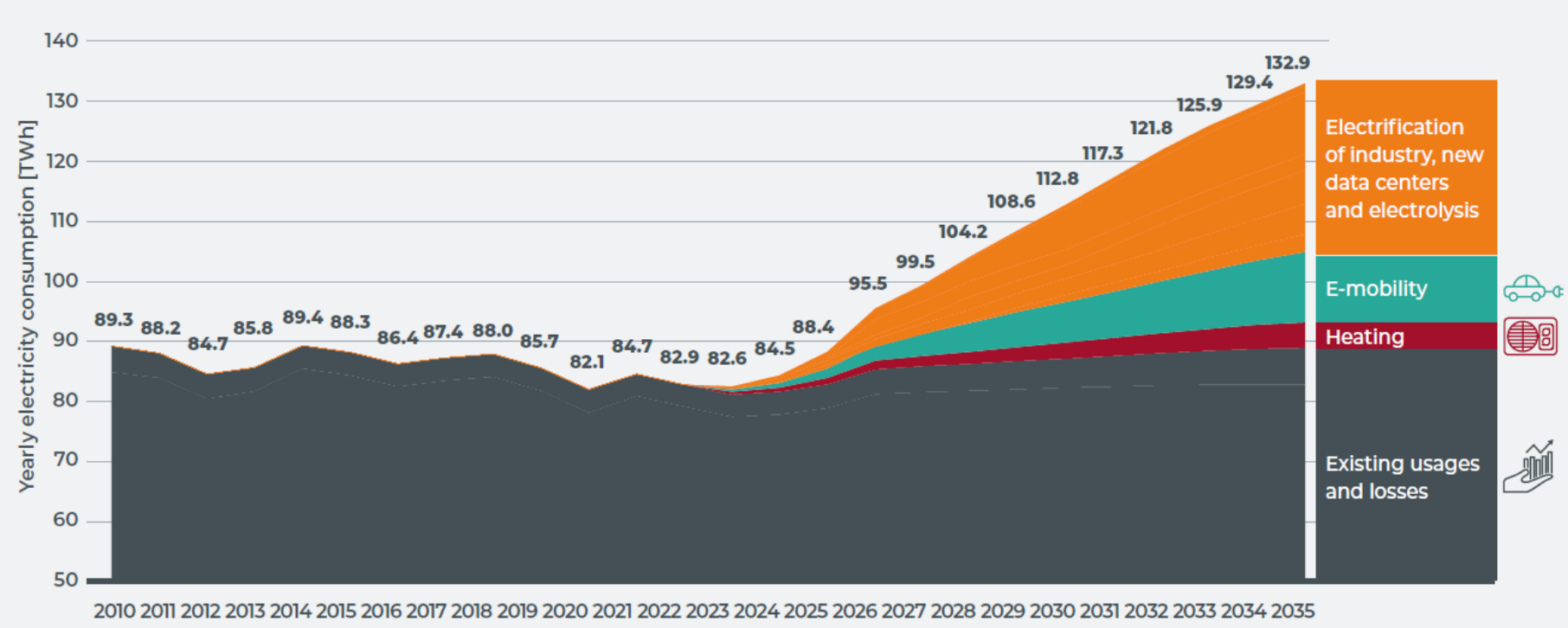
Change in

Consumption schedule



Why the need for flexibility?

Adequacy/Security of Supply

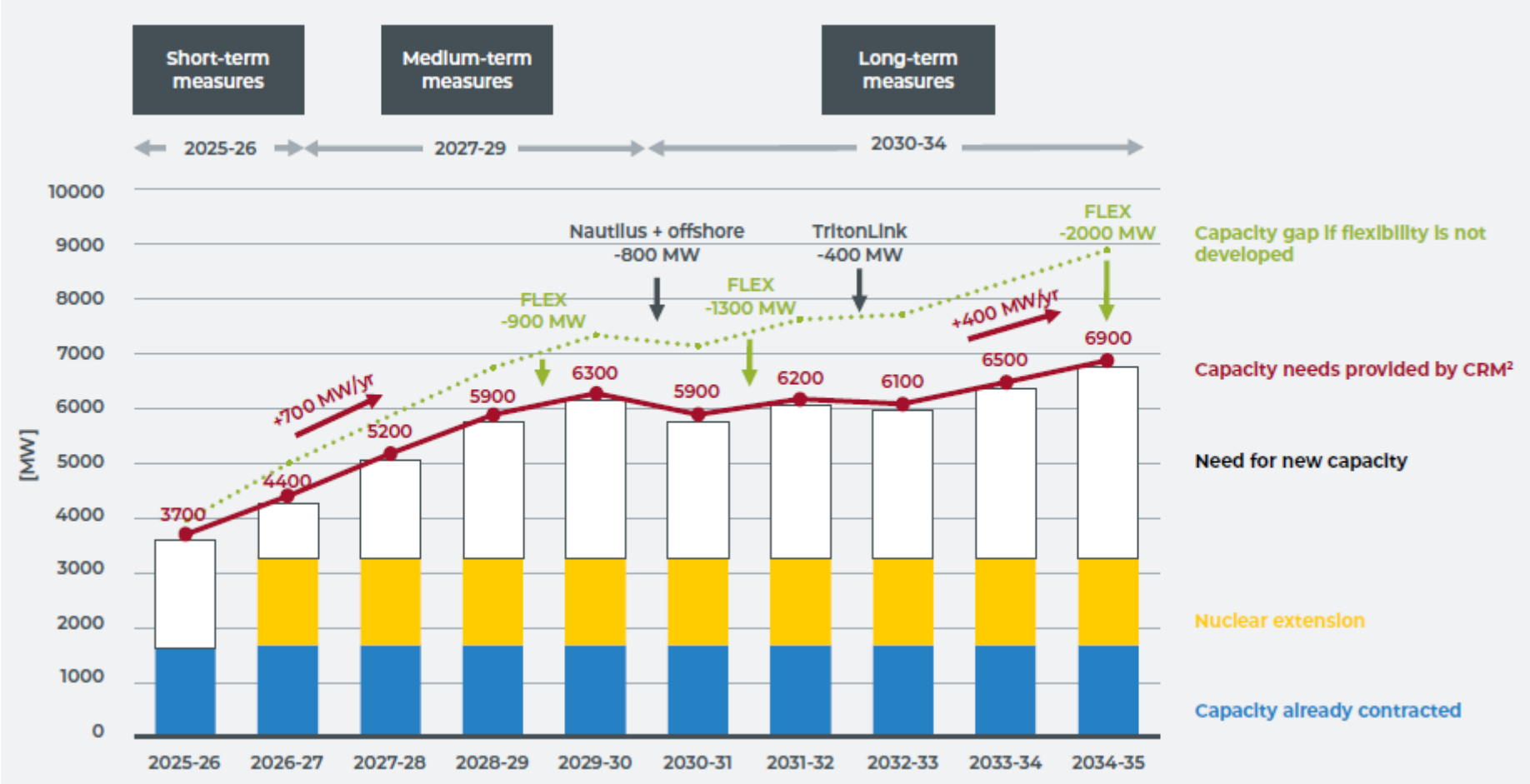


Changes in Belgium's electricity consumption (2010 – 2035)

Source: Adequacy and Flexibility Study for Belgium (2024 – 2034) – *Elia, 2023*

Why the need for flexibility?

Adequacy/Security of Supply

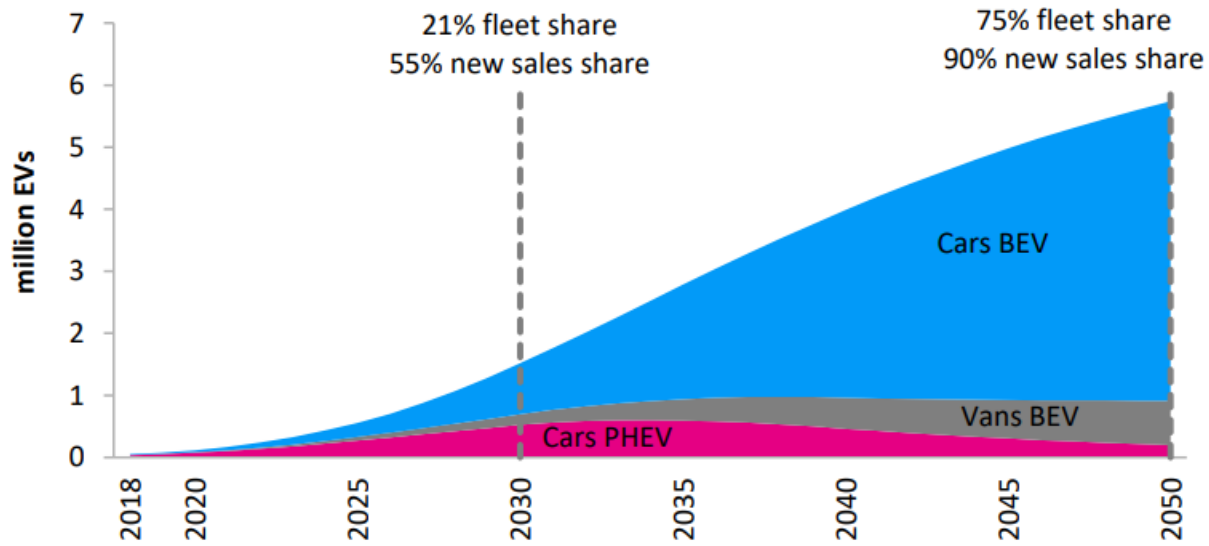


Impact of unlocking flexibility & timely built-out of HVDC interconnectors

Source: Adequacy and Flexibility Study for Belgium (2024 – 2034) – *Elia, 2023*

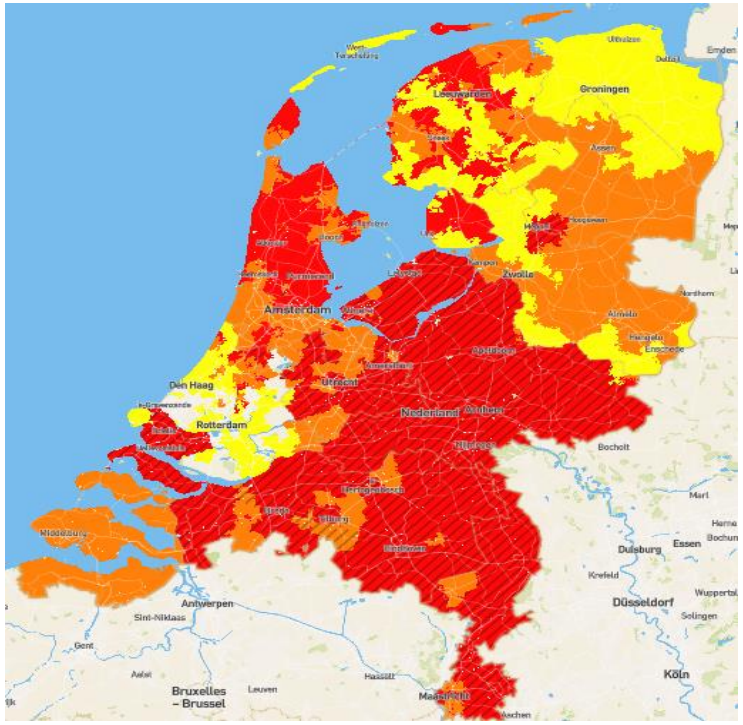
Why the need for flexibility?

Active system management



Without additional measures to coordinate charging behavior, by 2030 (2040), the evening peak load can overload up to 11% (21%) of distribution feeders

Source: Future impact of EVs on the Belgian electricity network – Baringa/*Synergrid*, 2019. *EV uptake based on IEA Global EV Outlook 2018.*

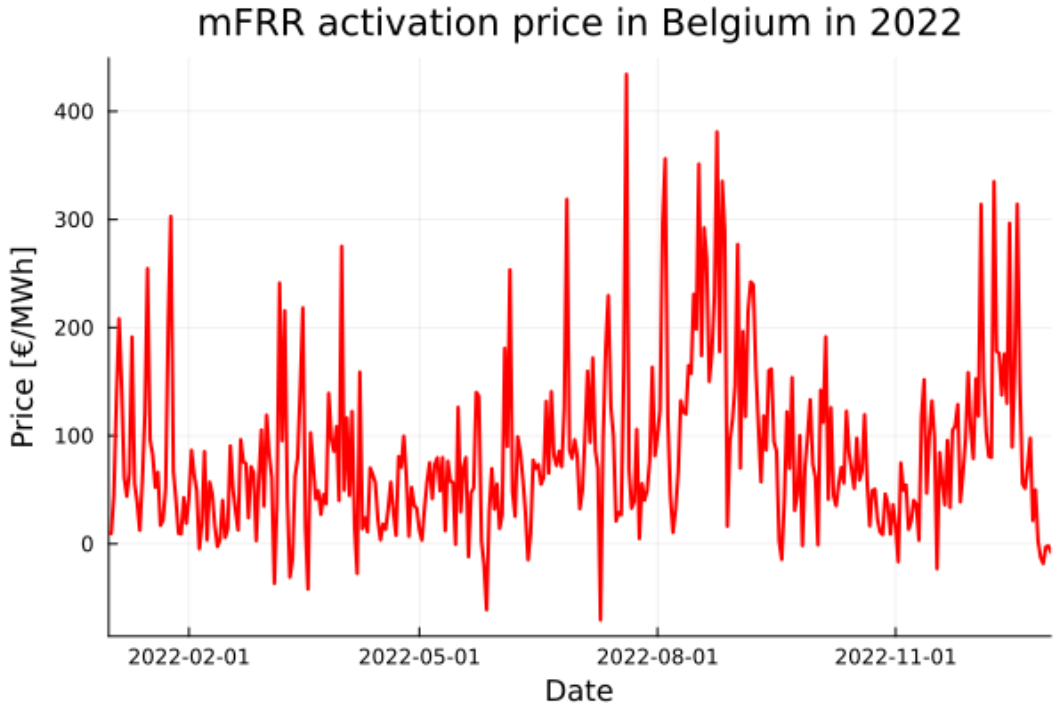


Consumption congestion map in the Netherlands

Source: Capaciteitskaart elektriciteitsnet (netbeheernederland.nl)

Why the need for flexibility?

Balancing



mFRR activation prices in Belgium in 2022

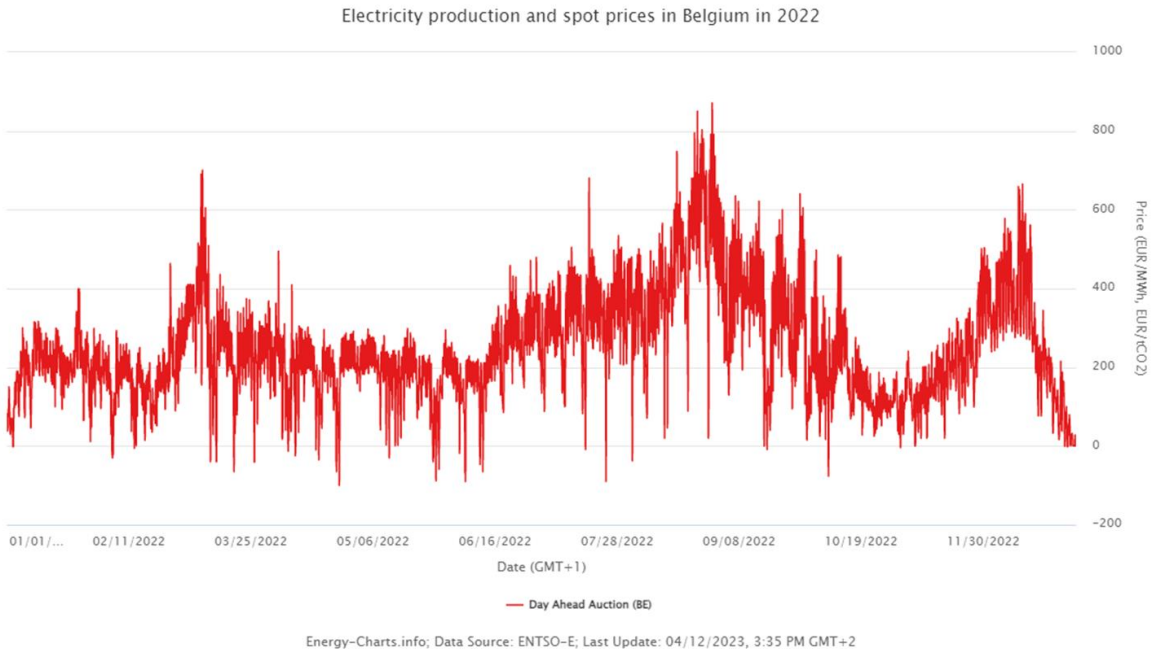
Data source: Elia open data.

Opportunities:

- ✓ Matching generation variability, reduce curtailment, contribution to system balancing
- ✓ Avoid elevated prices
- ✓ Benefit from reduced prices

Why the need for flexibility?

Price Volatility



DA electricity prices in Belgium (*energy-charts.info)*

Opportunities:

- ✓ Matching generation variability, reduce curtailment, contribution to system balancing
- ✓ Avoid elevated prices
- ✓ Benefit from reduced prices

How to access flexibility?

Technology enablers of prosumers' flexibility:

Behavioral enablers of prosumers' flexibility:

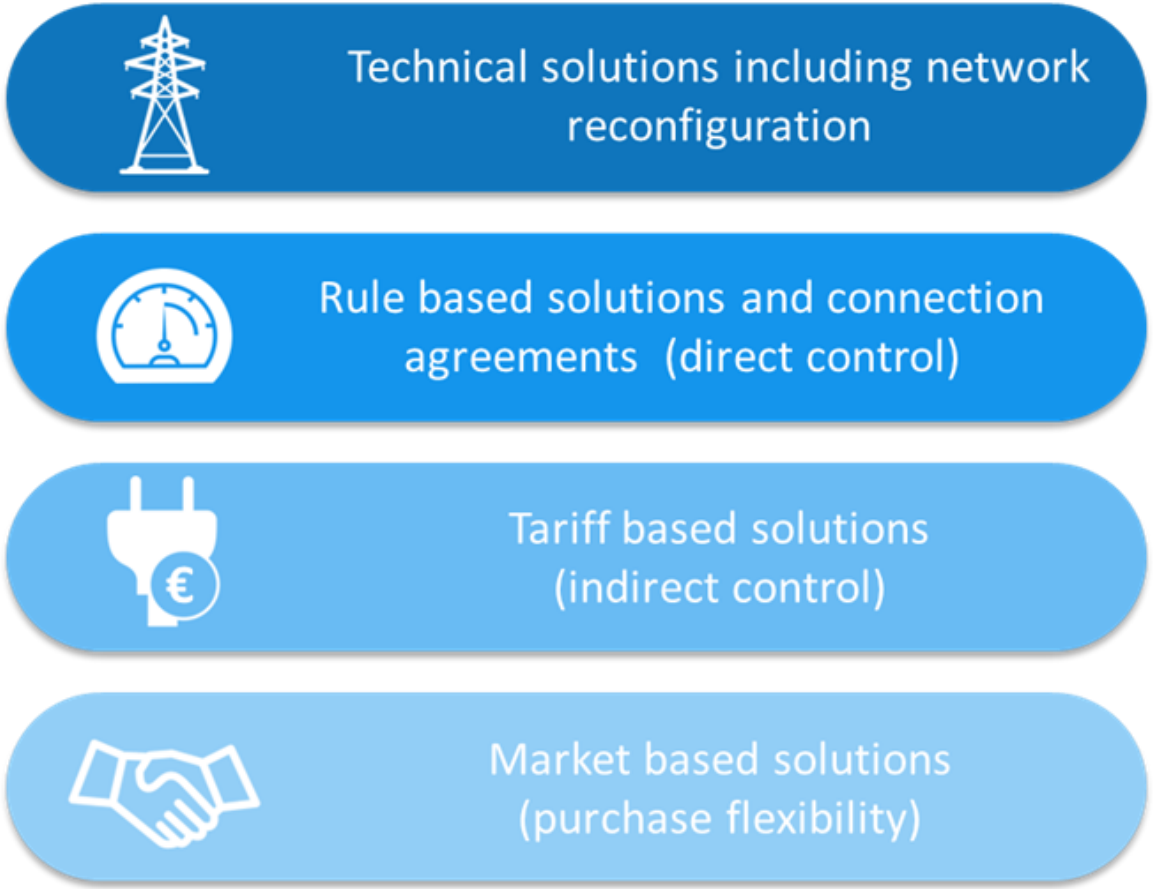
Industrial flexibility

Residential (LV flexibility)

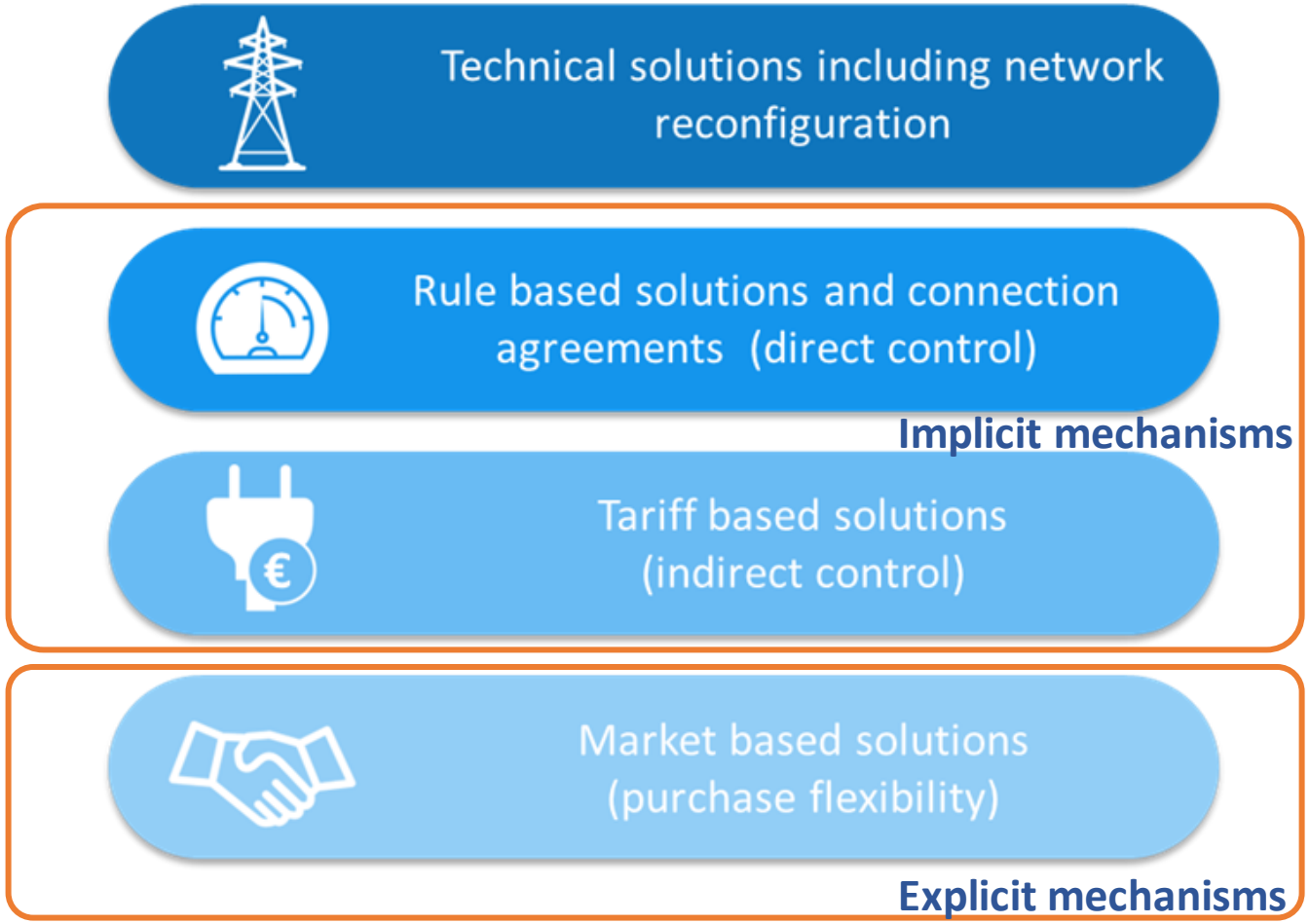
In *Elia's adequacy & flexibility study for Belgium for 2024-2034*: By **2030**, scenario estimation:

- Two-thirds of EVs are assumed to have a form of **intelligent charging capabilities**
- One-third of HPs are assumed to respond to **local or market signals**;
- Over half of home batteries are assumed to **actively participate in the energy market**.

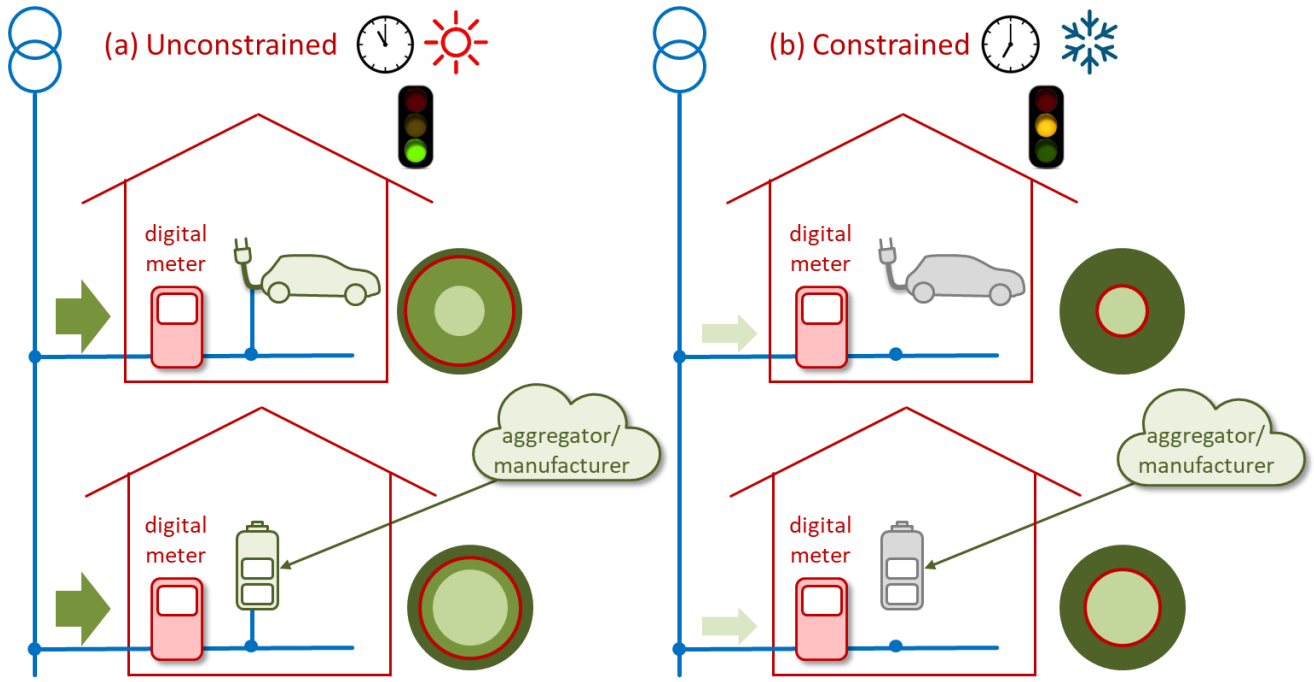
Flexibility Mechanisms (Implicit and Explicit)



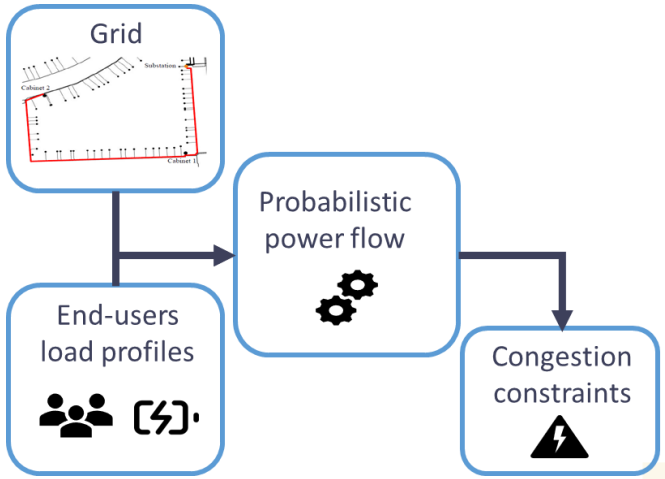
Flexibility Mechanisms (Implicit and Explicit)



Dynamic connection agreements and prequalification

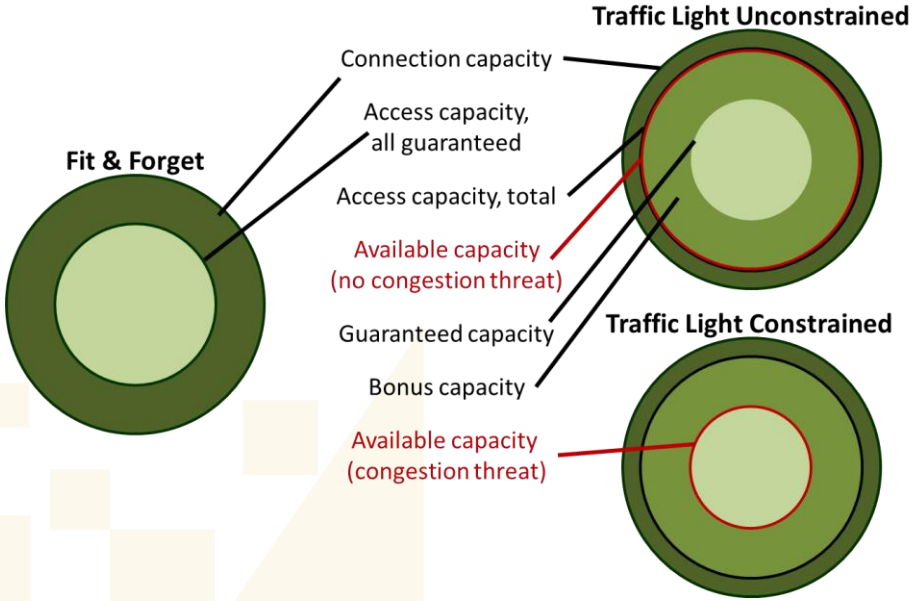


Dynamic connection agreements and network prequalification methods

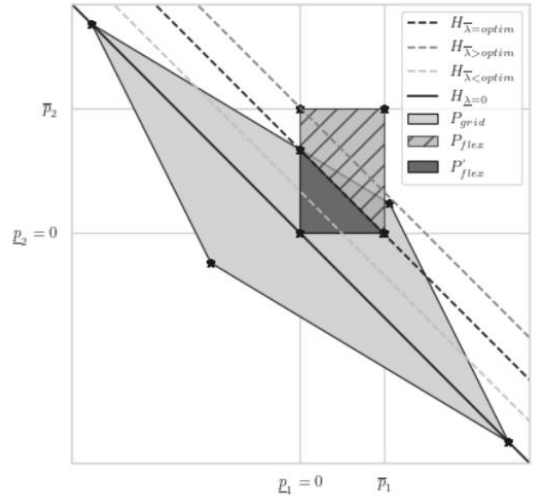


Probabilistic power flow calculation

Source: Alexander D3.1



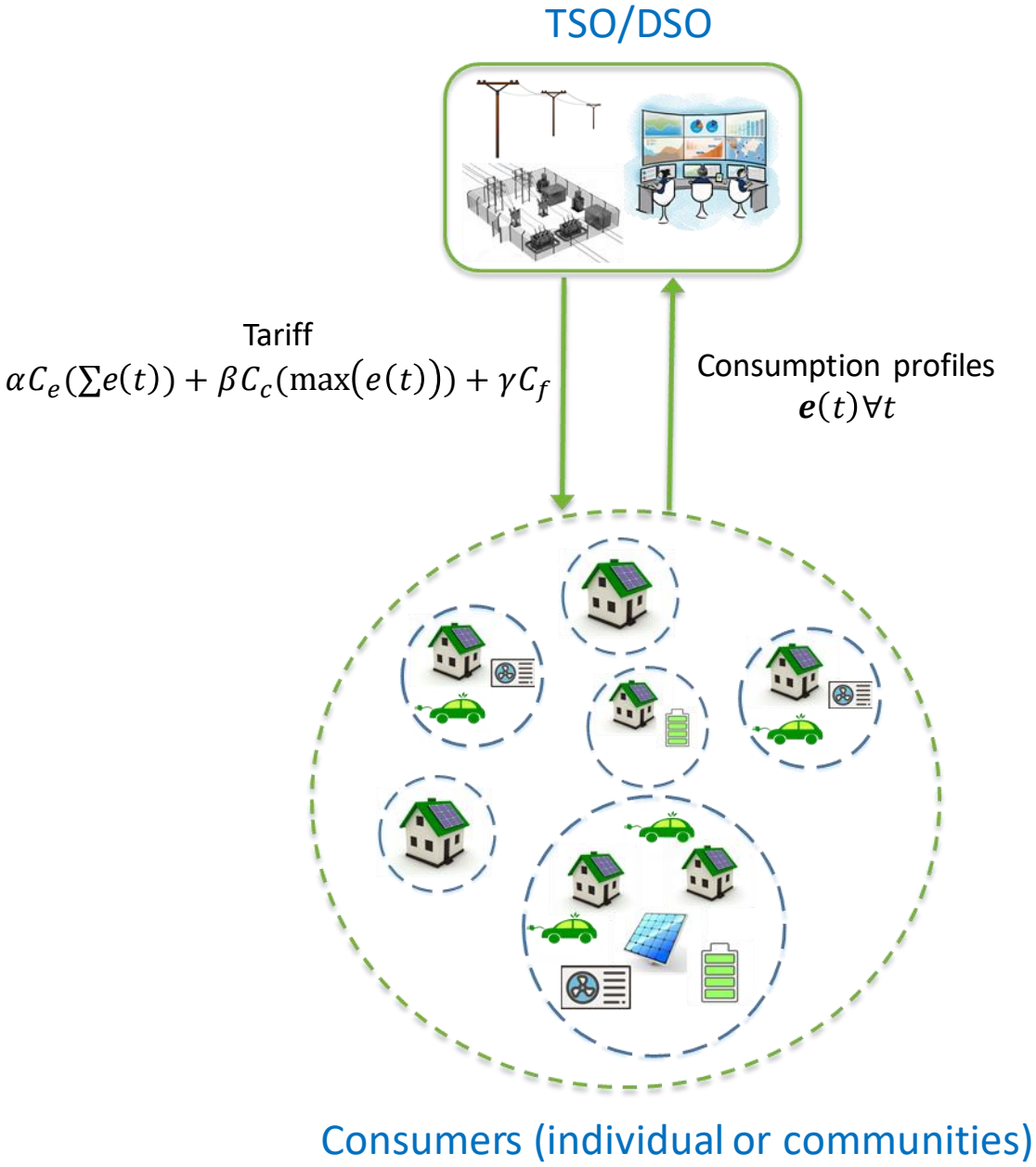
Non-firm connection agreement



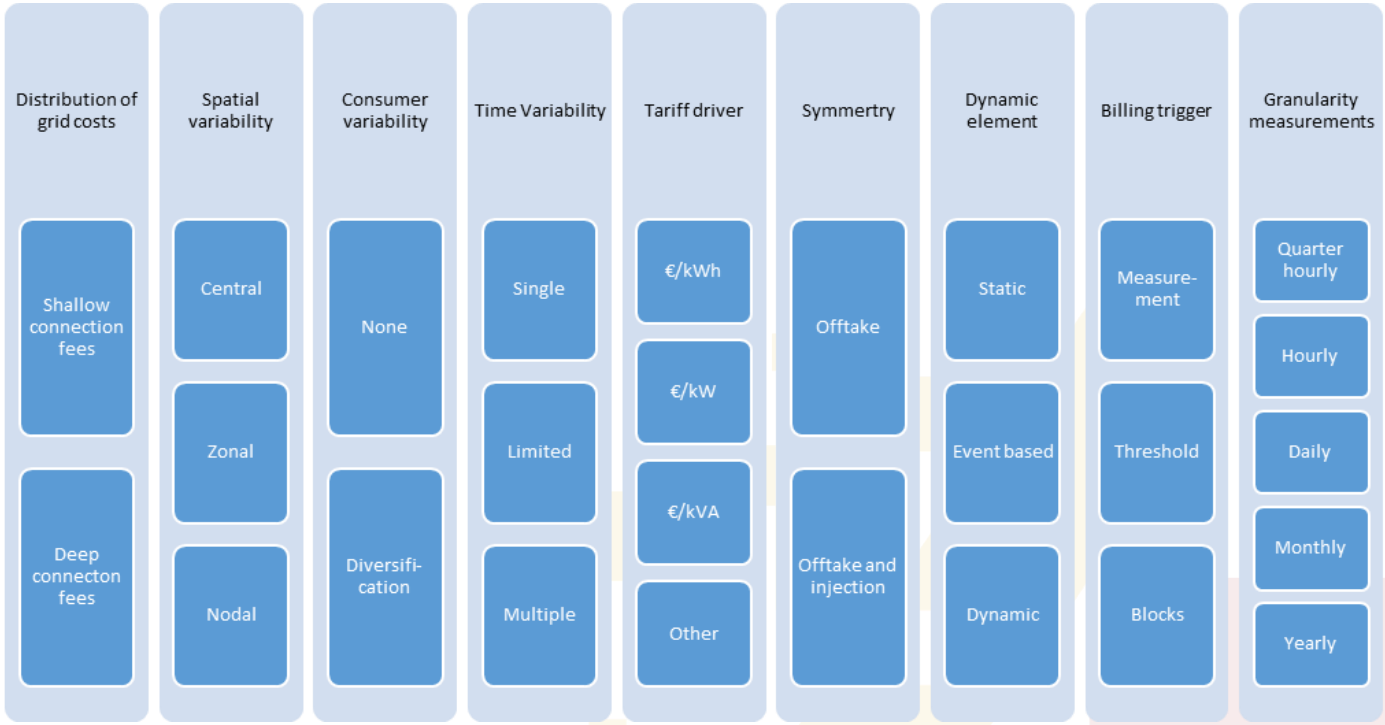
Headroom calculations

Source: ALEXANDER D3.1

Dynamic price signals and tariffs



Dynamic Price Signals and Tariffs (implicit flexibility mechanisms)



Network tariff dimensions

Source: EUniversal Project D5.2 [1]

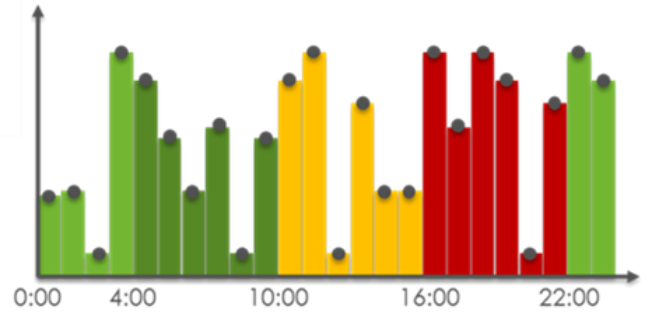


Illustration of static Time of use tariffs

Source: EUniversal Project D5.2 [1]

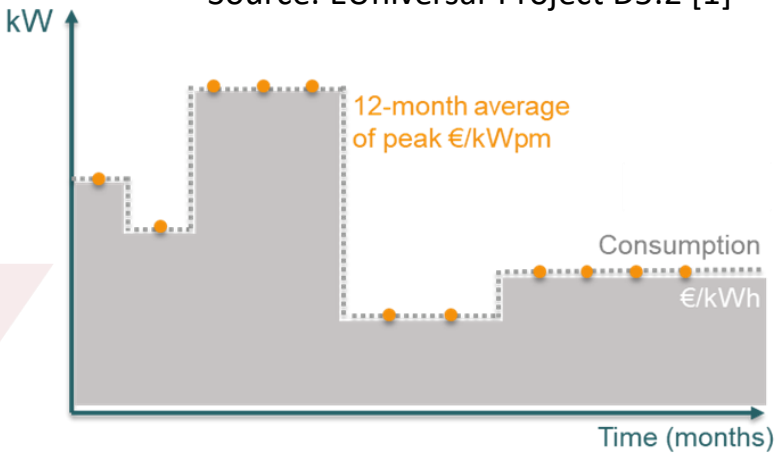
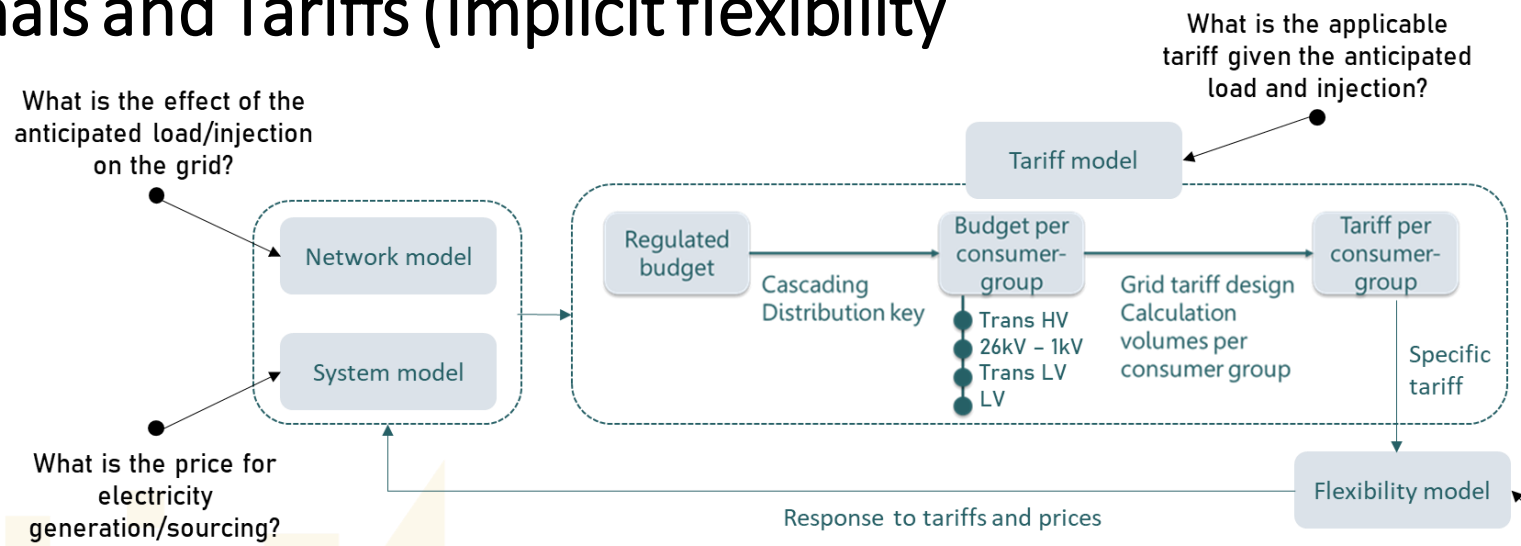


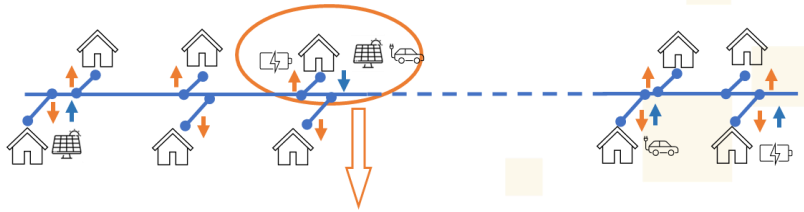
Illustration of capacity-based grid tariff (Flanders)

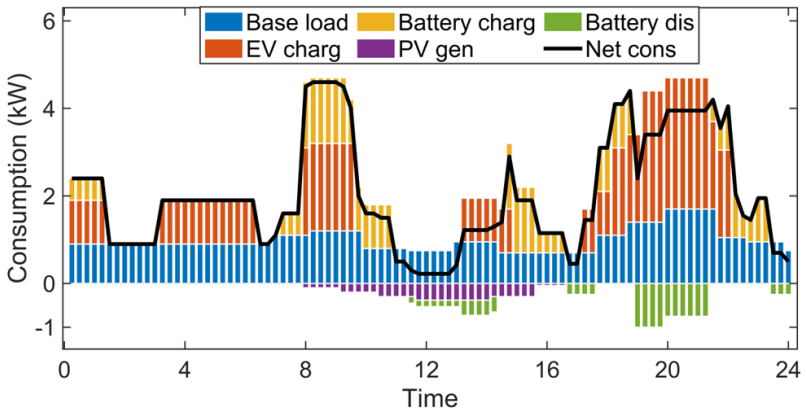
Source: EUniversal Project D5.2 [1]

Dynamic Price Signals and Tariffs (implicit flexibility mechanisms)

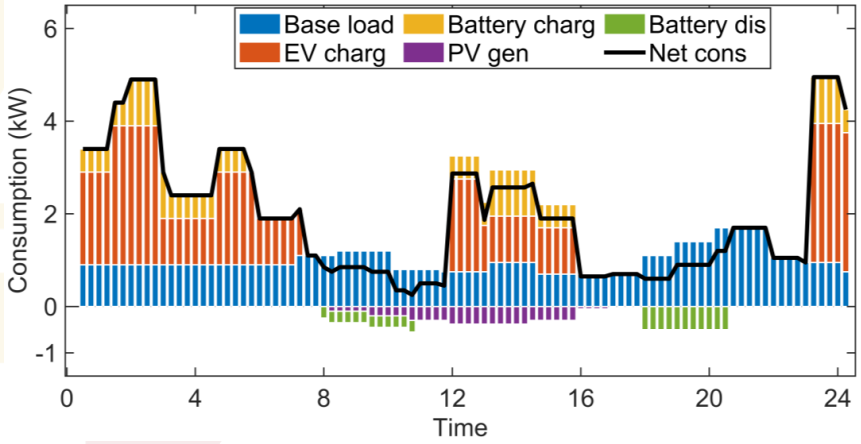


Source: EUniversal Project D5.2

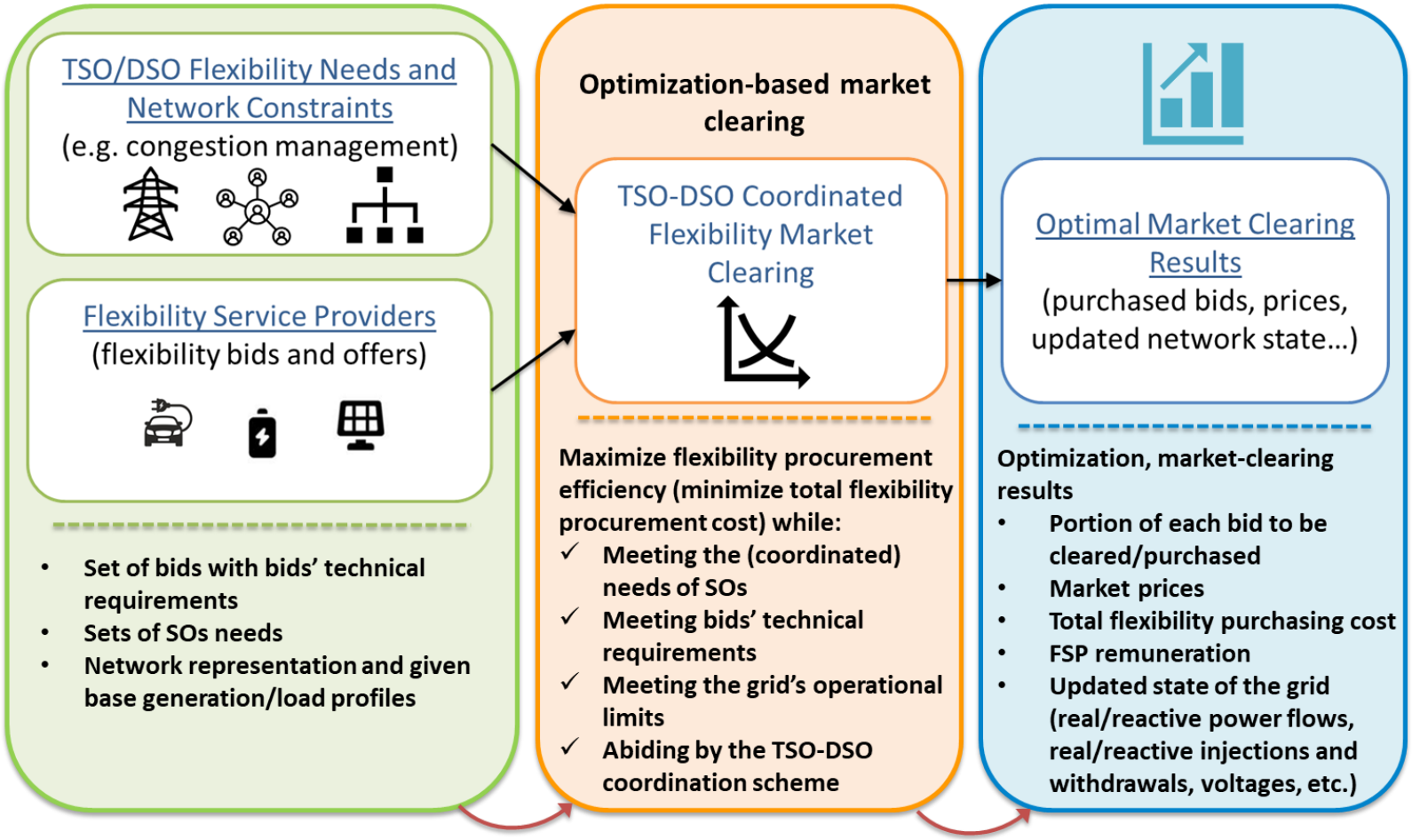




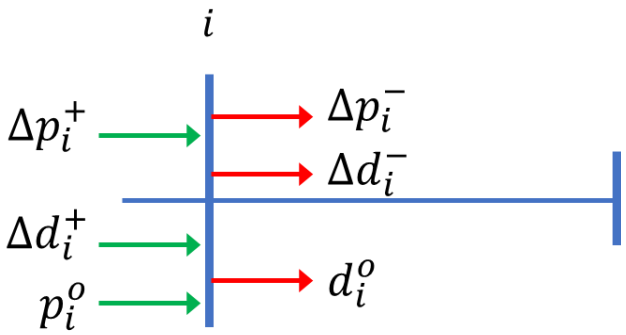
Implicit flexibility



Flexibility Markets



Flexibility Markets – Network and Market Representation



$\boldsymbol{c_p^+, \Delta p^+, c_p^-, \Delta p^-}$

$\boldsymbol{c_d^+, \Delta d^+, c_d^-, \Delta d^-}$

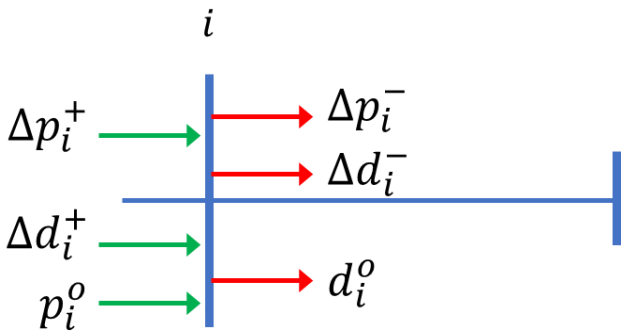
Flexibility Market

- Bids' acceptance levels
- Prices
- Updated flows (real, reactive, magnitude)
- Updated voltage magnitudes
- Updated generation and load at each node (baseline + activation)

Market representation

Source: CoordiNet D6.2 [3]

Flexibility Markets – Network and Market Representation



$\boldsymbol{c}_p^+, \Delta\boldsymbol{p}^+, \boldsymbol{c}_p^-, \Delta\boldsymbol{p}^-$

$\boldsymbol{c}_d^+, \Delta\boldsymbol{d}^+, \boldsymbol{c}_d^-, \Delta\boldsymbol{d}^-$

Flexibility Market

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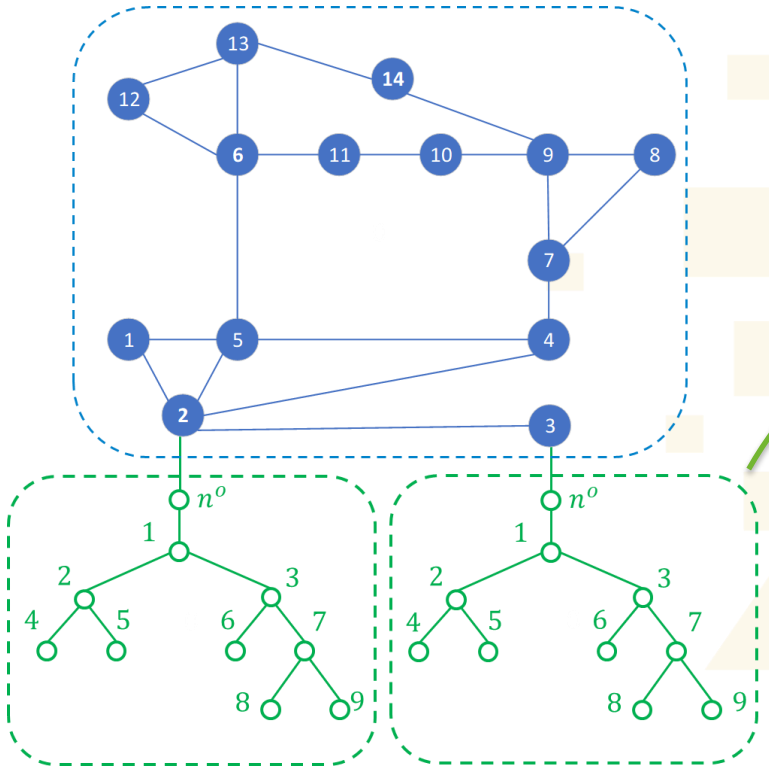
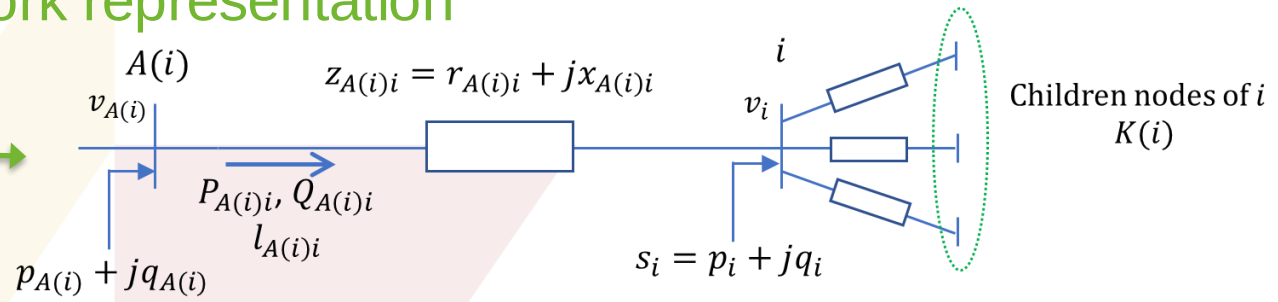


Market representation

Network representation



- Network representation (topology and constraints):
  - Network model & power flow calculations (variations thereof)
  - Abstracted constraint representation (feasibility space)

Source: CoordiNet D6.2 [3]

TSO-DSO Coordinated Flexibility Markets – Common Markets

Disjoint Transmission

$$\min_{\Delta P, \Delta D} C(\Delta P, \Delta D)$$

s.t

$$F(\Delta P, \Delta D, P^o, D^o, T^P, U) = 0$$
$$G(\Delta P, \Delta D, P^o, D^o, T^P, U) \leq 0$$
$$0 \leq \Delta P, \Delta D \leq \Delta P^{max}, \Delta D^{max}$$
$$T_i^P = constant \ \forall i$$

Disjoint Distribution

$$\min_{\Delta p_i, \Delta d_i} c(\Delta p_i, \Delta d_i)$$

s.t

$$f_i(\Delta p_i, \Delta d_i, p_i^o, d_i^o, T_i^p, u_i) = 0$$
$$g_i(\Delta p_i, \Delta d_i, p_i^o, d_i^o, T_i^p, u_i) \leq 0$$
$$0 \leq \Delta p_i, \Delta d_i \leq \Delta p_i^{max}, \Delta d_i^{max}$$
$$T_i^P = constant$$

Common Market

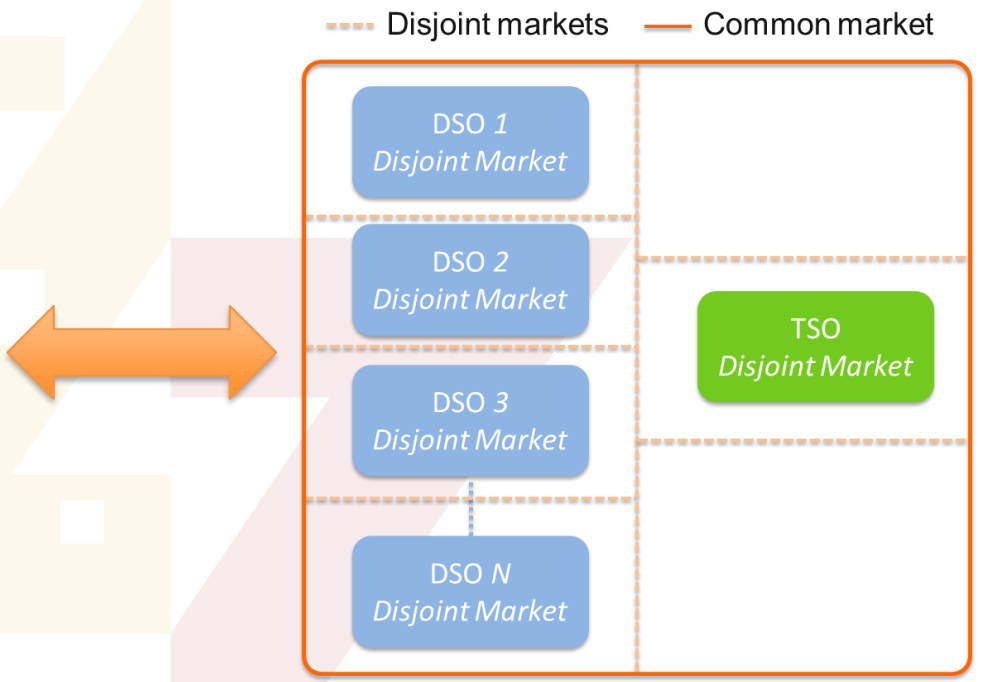
$$\min_{\Delta P, \Delta D, \Delta p, \Delta d} C(\Delta P, \Delta D) + \sum c(\Delta p_i, \Delta d_i)$$

s.t

$$F(\Delta P, \Delta D, P^o, D^o, T^P, U) = 0$$
$$G(\Delta P, \Delta D, P^o, D^o, T^P, U) \leq 0$$
$$0 \leq \Delta P, \Delta D \leq \Delta P^{max}, \Delta D^{max}$$

$$f_i(\Delta p_i, \Delta d_i, p_i^o, d_i^o, T_i^P, u_i) = 0$$
$$G(\Delta p_i, \Delta d_i, p_i^o, d_i^o, T_i^P, u_i) \leq 0$$
$$0 \leq \Delta p_i, \Delta d_i \leq \Delta p_i^{max}, \Delta d_i^{max} \quad \forall i$$

$$T_i^P = h(\Delta p_i, \Delta d_i, p_i^o, d_i^o) \quad \forall i$$
$$T_i^{P,min} \leq T_i^P \leq T_i^{P,max}$$



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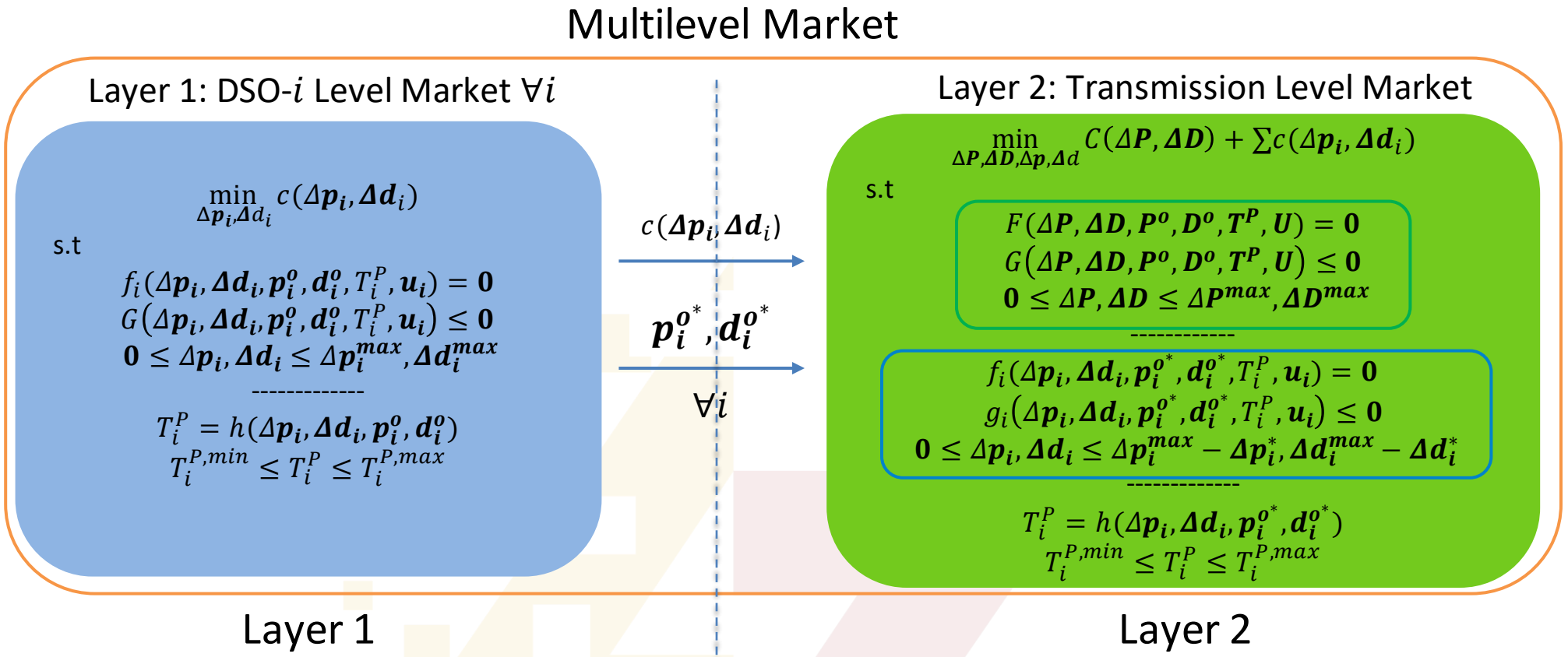
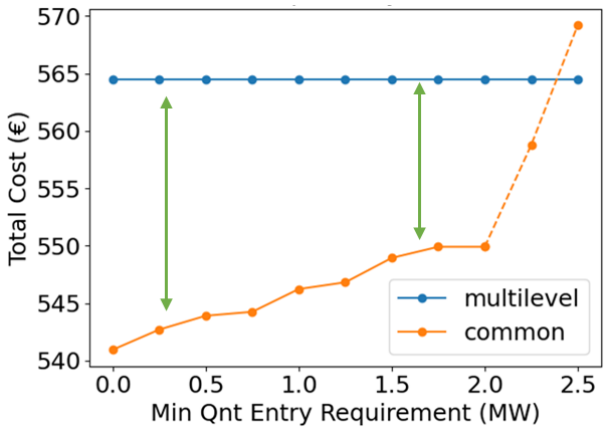
TSO-DSO Coordinated Flexibility Markets – Multi-Level Markets

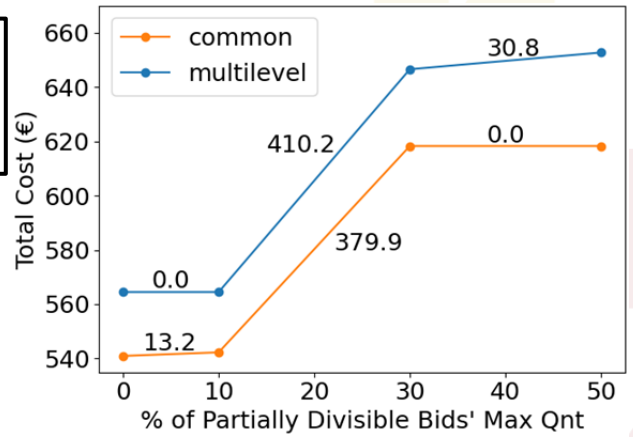


TSO-DSO Coordinated Flexibility Markets – Completed Analyses and Developed Tools

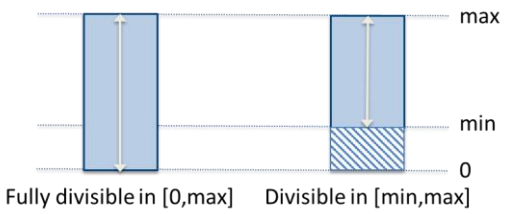


Impact of minimum bid quantity entry requirements (impact entry barriers) [6]

- Joint markets can improve efficiency (pooling effect and value stacking potential) [2,3,5]
- Other key elements can also have a direct impact [2-8]



Impact of partially divisible bids' minimum clearing requirement [6]



- ✓ TSO-DSO Coordinated market models [2-6]
- ✓ Efficiency and sensitivity to key factors (entry barriers, FSP bidding processes, cross-system flexibility pricing, bid formats, etc.) [2-6]
- ✓ TSO-DSO cooperation and flexibility cost allocation [4]
- ✓ TSO-DSO coordination and grid safety under limited network information sharing [5]
- ✓ FSP strategic bidding (gaming potential) and impacts on market efficiency [2], [3], [8]
- ✓ Network modeling in local flexibility markets [7]
- ✓ Flexibility market implementation for congestion management demonstration in Sweden [9]
- ✓ Market clearing algorithm for a flexibility market demonstration in Finland, Estonia, Latvia, Lithuania [10]

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Grid-Safe Use of Distributed Flexibility

Distributed flexibility

DSO-level market clearing

- Local FSPs
- Grid constraints of distribution systems

TSO-level market clearing

- FSPs from TSO and DSOs
- Grid constraints of transmission systems
- ~~Grid constraints of distribution systems~~

TSO/EU-Level Markets
(System and Grid Services)

$$\min_{\Delta P, \Delta D, \Delta p, \Delta d} C(\Delta \boldsymbol{P}, \Delta \boldsymbol{D}) + \sum c(\Delta \boldsymbol{p_i}, \Delta \boldsymbol{d}_i)$$

s.t

$$F(\Delta \boldsymbol{P}, \Delta \boldsymbol{D}, \boldsymbol{P^o}, \boldsymbol{D^o}, \boldsymbol{T^P}, \boldsymbol{U}) = \boldsymbol{0}$$
$$G(\Delta \boldsymbol{P}, \Delta \boldsymbol{D}, \boldsymbol{P^o}, \boldsymbol{D^o}, \boldsymbol{T^P}, \boldsymbol{U}) \leq \boldsymbol{0}$$
$$\boldsymbol{0} \leq \Delta \boldsymbol{P}, \Delta \boldsymbol{D} \leq \Delta \boldsymbol{P^{max}}, \Delta \boldsymbol{D^{max}}$$

$$f_i(\Delta \boldsymbol{p_i}, \Delta \boldsymbol{d_i}, \boldsymbol{p_i^o}, \boldsymbol{d_i^o}, T_i^P, \boldsymbol{u_i}) = \boldsymbol{0}$$
$$G(\Delta \boldsymbol{p_i}, \Delta \boldsymbol{d_i}, \boldsymbol{p_i^o}, \boldsymbol{d_i^o}, T_i^P, \boldsymbol{u_i}) \leq \boldsymbol{0} \quad \forall i$$
$$\boldsymbol{0} \leq \Delta \boldsymbol{p_i}, \Delta \boldsymbol{d_i} \leq \Delta \boldsymbol{p_i^{max}}, \Delta \boldsymbol{d_i^{max}}$$

$$T_i^P = h(\Delta \boldsymbol{p_i}, \Delta \boldsymbol{d_i}, \boldsymbol{p_i^o}, \boldsymbol{d_i^o}) \quad \forall i$$
$$T_i^{P,min} \leq T_i^P \leq T_i^{P,max}$$

Distribution grid-safety validation options:

- Pre-market (dynamic prequalification)
- During market clearing (constraint inclusion – distributed solutions)
- Post-market clearing (correction/re-dispatch mechanisms)

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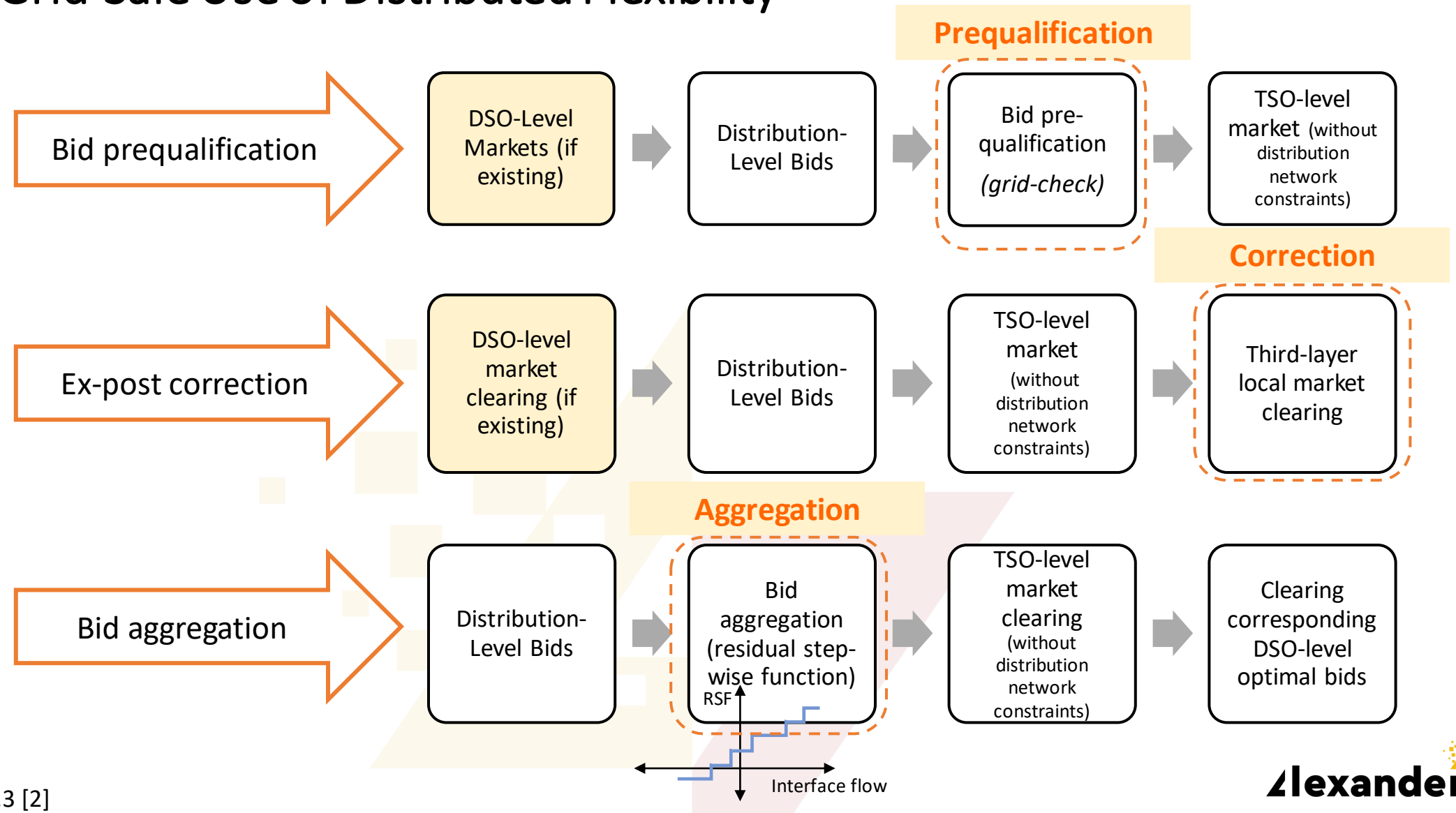
Grid-Safe Use of Distributed Flexibility*



*OneNet D3.3 [2]

Grid-Safe Use of Distributed Flexibility*

Assessment dimensions:
Grid Safety | Optimality | Computational Burden | Regulatory Coherence

Bid prequalification

- Grid safety guaranteed depending on *grid-check*
- Possible sub-optimality tradeoff depending on grid-check
- Computational complexity relatively-low
- General coherence with regulatory dimensions

Ex-post market correction

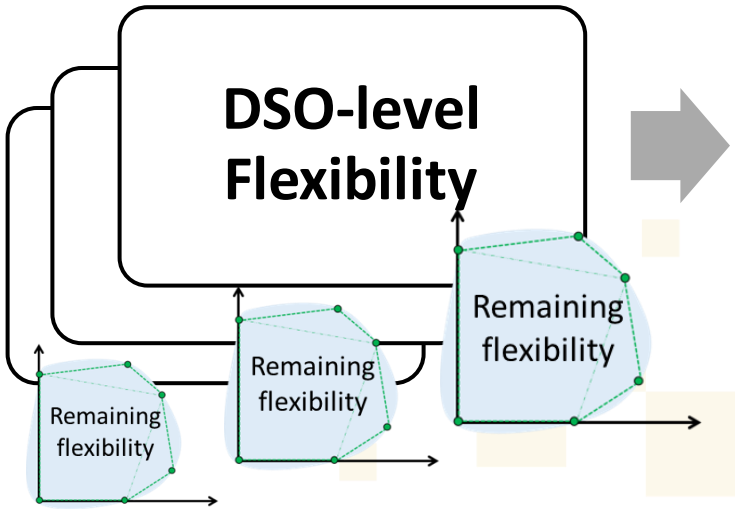
- Grid-safety depends on liquidity of the flexibility market (feasibility of third layer)
- Possible sub-optimality issues
- Low computational complexity
- High consistence with regulatory dimensions

Bid aggregation

- Grid-safety guarantee (in the defined setting)
- Sub-optimality can be improved by RSF parameter
- High computational complexity
- Regulatory challenges (role of the DSO)
- High imposed role on DSOs

*OneNet D3.3 [2]

Grid-Safe Use of Distributed Flexibility – Next steps



TSO-level market clearing

- FSPs from TSO and DSOs
- Grid constraints of transmission systems
- *Representation of distribution grid constraint space without network information sharing (grid-safety with avoided complexity)*

- ✓ On a pre-qualification basis
- ✓ Adapted depending on network state (dynamic)
- ✓ Allows including complex network constraints (when needed)
- ✓ Grid-safety guarantees

References

[1] G. de Almeida Terça et al., “Methodology for dynamic distribution grid tariffs”, *H2020 Euniversal D5.3*, 2022 (euniversal.eu).

[2] A. Sanjab et al., “Recommendations for Consumer-Centric Products and Efficient Market Designs”, *H2020 OneNet D3.3*, 2023 (onenet-project.eu)

[3] A. Sanjab et al., Evaluation of combinations of coordination schemes and products for grid services based on market simulations, *H2020 CoordiNet D6.2*, 2022 (coordinet-project.eu)

[4] A. Sanjab, H. Le Cadre and Y. Mou, "TSO-DSOs Stable Cost Allocation for the Joint Procurement of Flexibility: A Cooperative Game Approach," in *IEEE Transactions on Smart Grid*, vol. 13, no. 6, pp. 4449-4464, Nov. 2022.

[5] L. Marques, A. Sanjab, Y. Mou, H. Le Cadre and K. Kessels, "Grid Impact Aware TSO-DSO Market Models for Flexibility Procurement: Coordination, Pricing Efficiency, and Information Sharing," in *IEEE Transactions on Power Systems*, vol. 38, no. 2, pp. 1920-1933, March 2023

[6] A. Sanjab, L. Marques, H. Gerard and K. Kessels, "Joint and sequential DSO-TSO flexibility markets: efficiency drivers and key challenges," *27th International Conference on Electricity Distribution (CIRED 2023)*, 2023.

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Thank you!

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