Impact of Building Electrification on the Electric System of the Future

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Session: Building Sector Decarbonization in Energy Systems Modeling

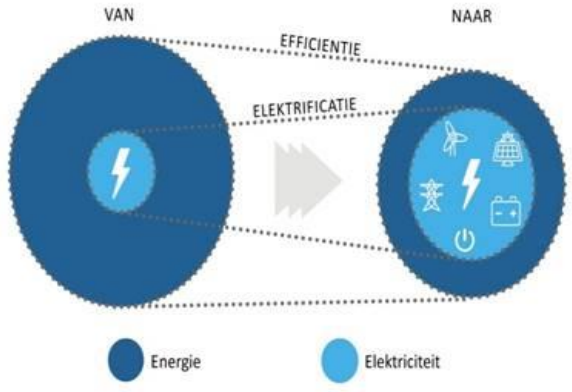
Overview

- Impact of Building Electrification on the Electric System of the Future
  - Building electrification
  - Distribution grid impact
  - System-level impact
  - Interactions and flexibility valorization
  - Modeling these interactions
  - Conclusions

Building electrification

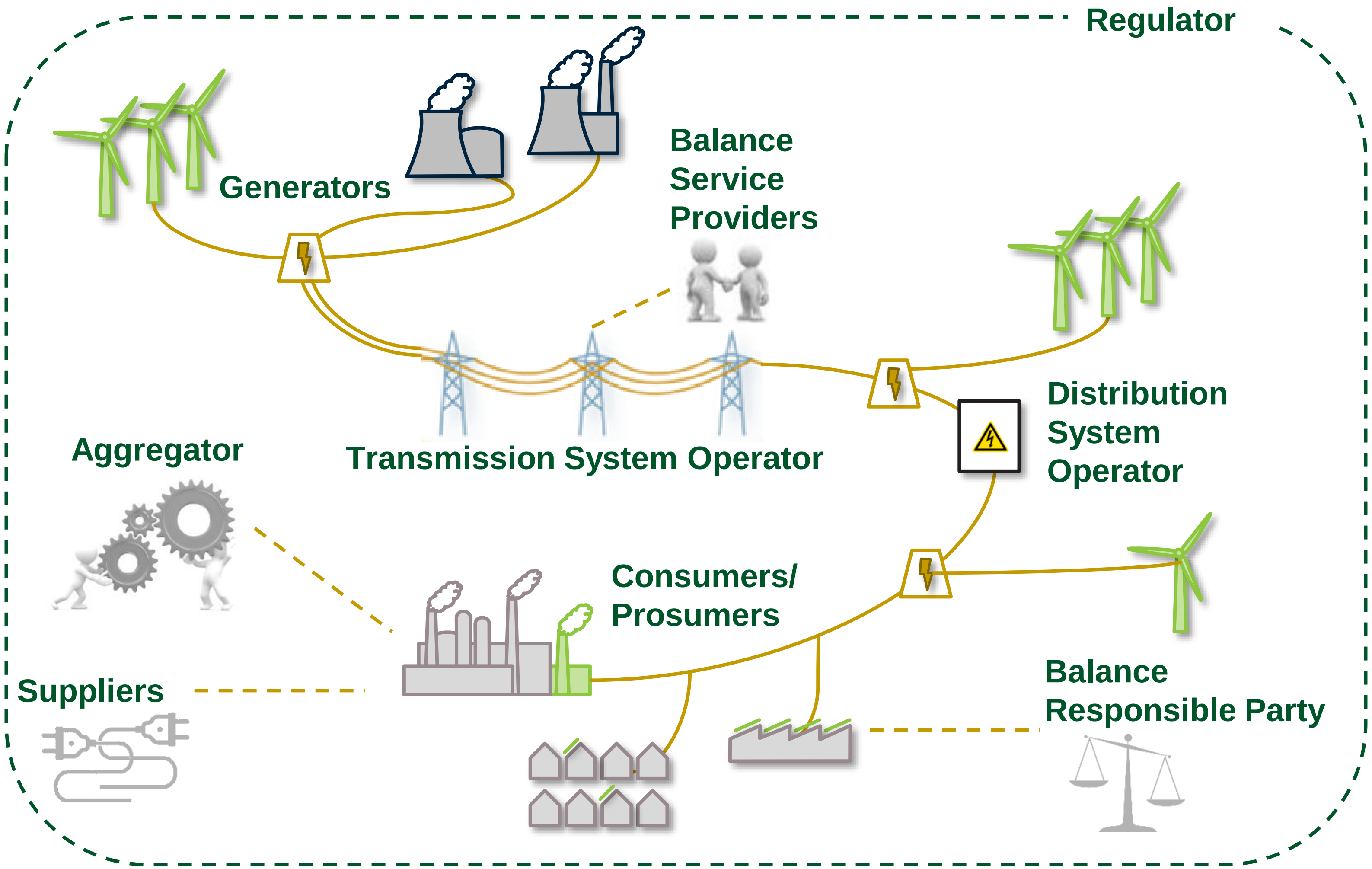
- Electrification to increase energy efficiency and decarbonize

- Consumers becoming prosumers or prosumagers
  - Becoming central actor in the transition
  - Possible assets
    - Local generation: solar PV
    - Local storage: home battery, electric vehicle (with V2G)
    - Local (flexible) demand: Heat pumps (with thermal inertia, water buffers), electric water heaters, electric vehicles, smart devices



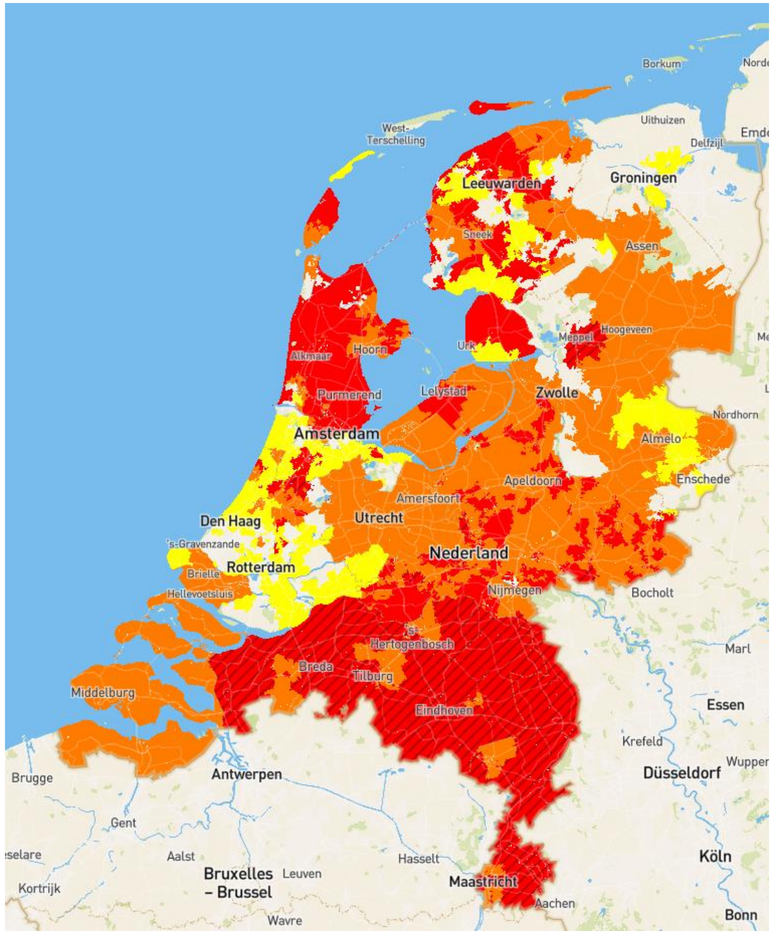
Source: VREG 2020

Building electrification

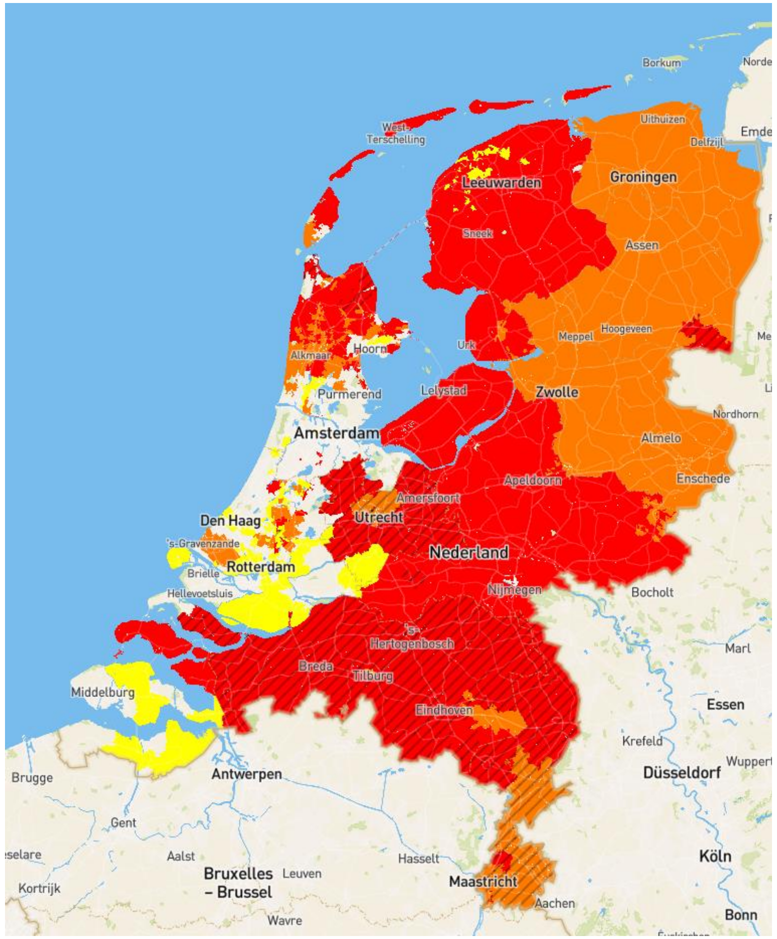


Distribution grid impact

Offtake



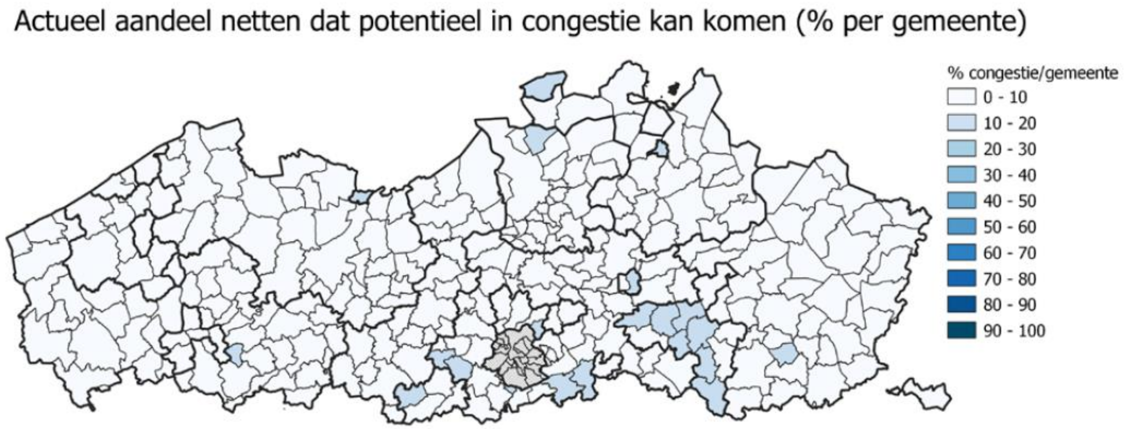
Injection

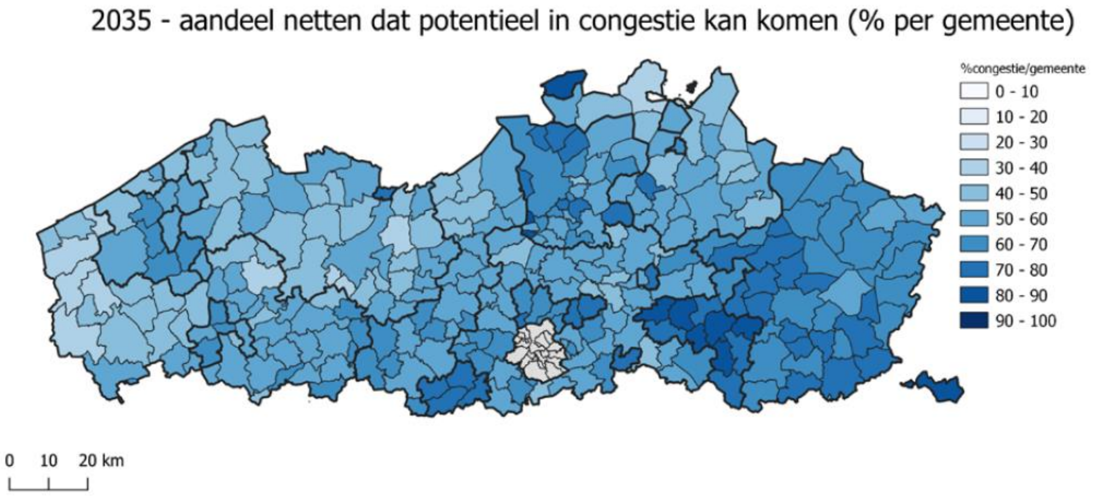


Netbeheer Nederland (2023), https://capaciteitskaart.netbeheernederland.nl/

Distribution grid impact

- Development of distribution network investment plans





Fluvius (2023). Investment plan 2023-2032, https://partner.fluvius.be/sites/fluvius/files/2022-06/investeringsplan-2023-2032.pdf

Distribution grid impact

- To support development of distribution network plans, Clean Energy Package introduced provisions across five planning dimensions:
  - Planning frequency
  - Coordination with the TSO
  - Digitalization
  - Transparency
  - **Flexibility as an alternative/complement to grid investments**
- Description of these provisions remains relatively high-level, leaving detailed implementation up to Member States

Beckstedde, E., Delarue, E. (sup), Meeus, L. (sup) (2023). Fostering Flexibility in Distribution Networks Through empirical studies, regulatory analyses, and mathematical programs. PhD Dissertation KU Leuven.

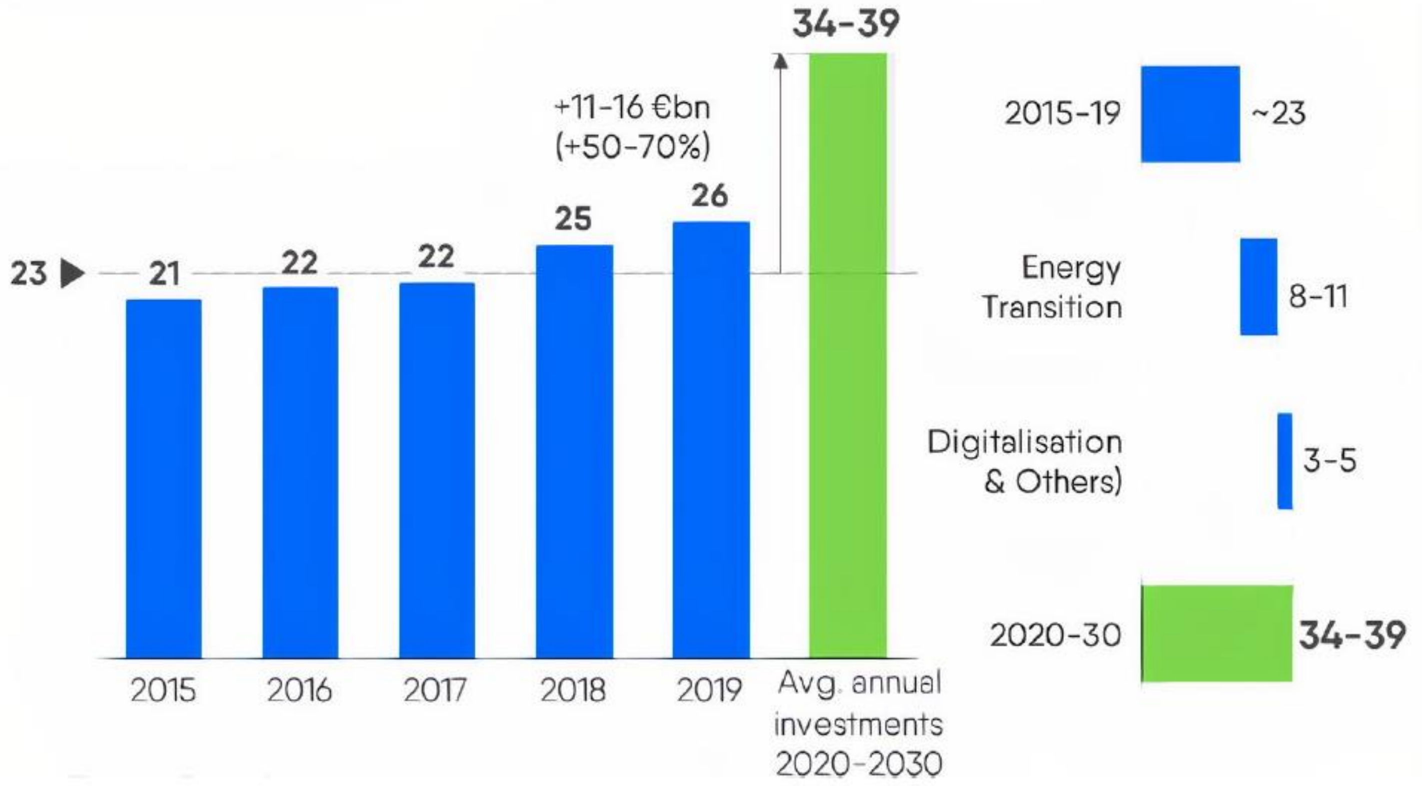
Distribution grid impact

- DSOs can use regulatory tools to source flexibility at the distribution level:
  - Dynamic network tariffs
  - Flexible connection agreements
  - Flexibility markets
  - Bilateral contracts
  - Cost-based mechanisms
  - Obligations
- Currently most mature in Europe: dynamic distribution network tariffs and flexible connection agreements

Beckstedde, E., Delarue, E. (sup), Meeus, L. (sup) (2023). Fostering Flexibility in Distribution Networks Through empirical studies, regulatory analyses, and mathematical programs. PhD Dissertation KU Leuven.

Distribution grid impact

- Annual distribution network investment cost in Europe



Eurelectric, E.DSO, and Monitor Deloitte. Connecting the dots: Distribution grid investment to power the energy transition, 2021. Available at https://www.eurelectric.org/connecting-the-dots/

System-level impact

- Impact of increased electrification
    - Affect residual demand (or injection) profiles as seen on transmission level
        - E.g., impact of massive EV penetration with certain charging behavior
    - Impact ‘optimal’ generation mix of system / profitability of transmission level assets
    - Offer flexibility services
        - On different time scales
            - Long-term – Adequacy
            - Short-term – Arbitrage
            - Real-time – Balancing

Interactions and flexibility valorization

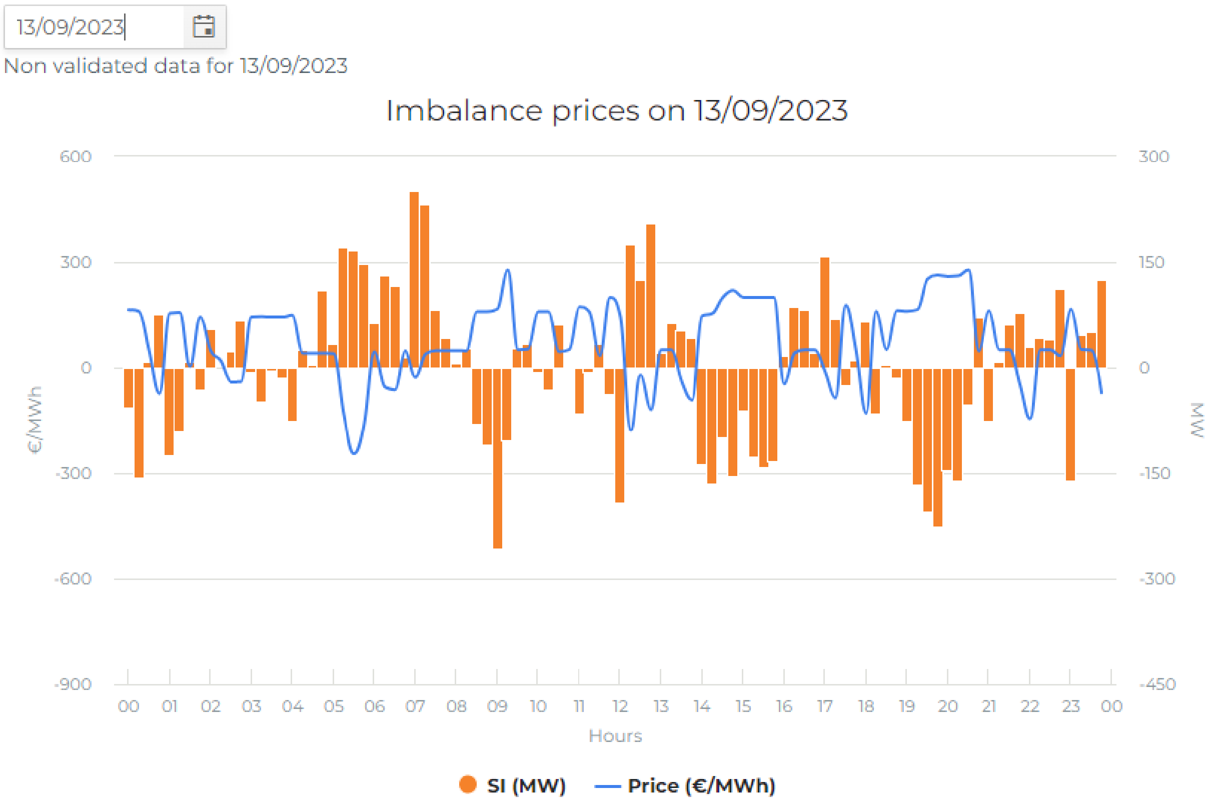
- As a consumer directly
  - Responding to
    - Dynamic electricity tariffs
    - Distribution tariff (design)
  - Being active in energy community / P2P trading

- Via intermediary / aggregator
  - Revenue stacking, offering services to/interacting with
    - DSO (e.g., flexibility market)
      - Manage congestion issues
    - TSO
      - Balancing capacity and energy (e.g., FCR/aFRR/mFRR)
      - Adequacy / CRM
    - BRP
      - Market arbitrage
      - Balancing position

Source: energypost.eu

Interactions and flexibility valorization

- Example of system imbalance and imbalance price in Belgium

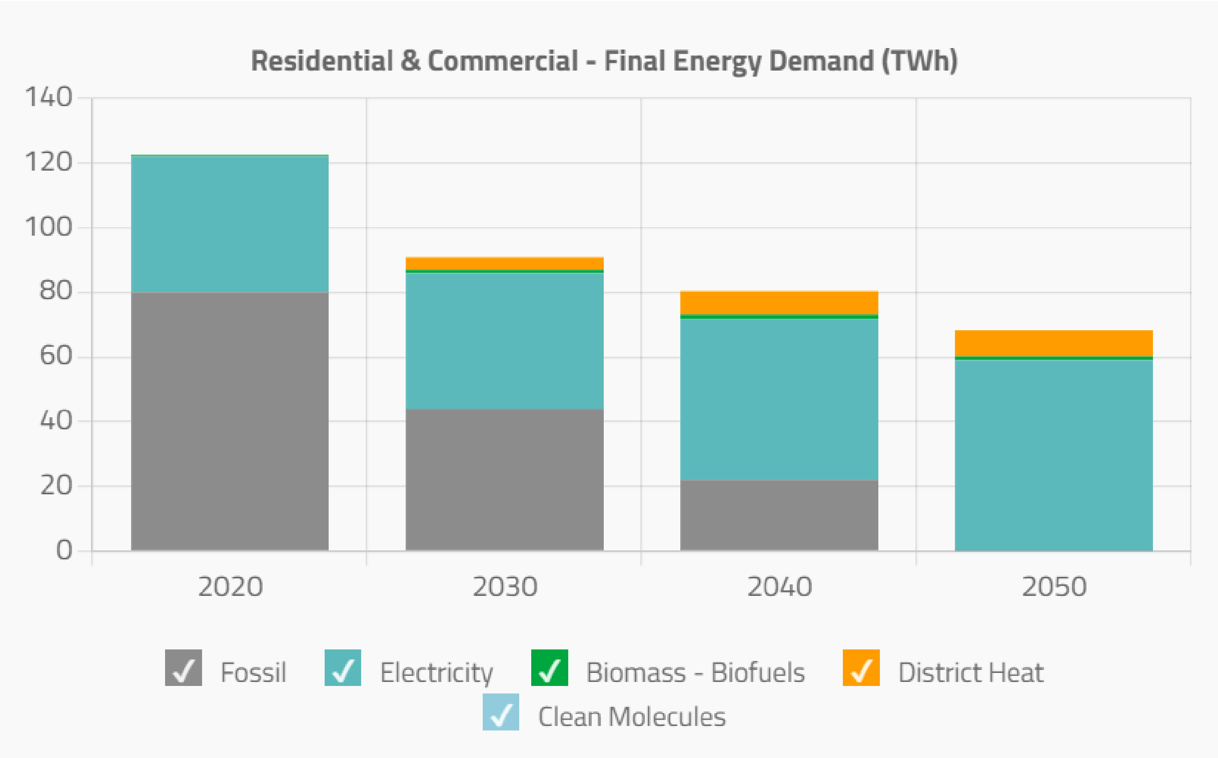


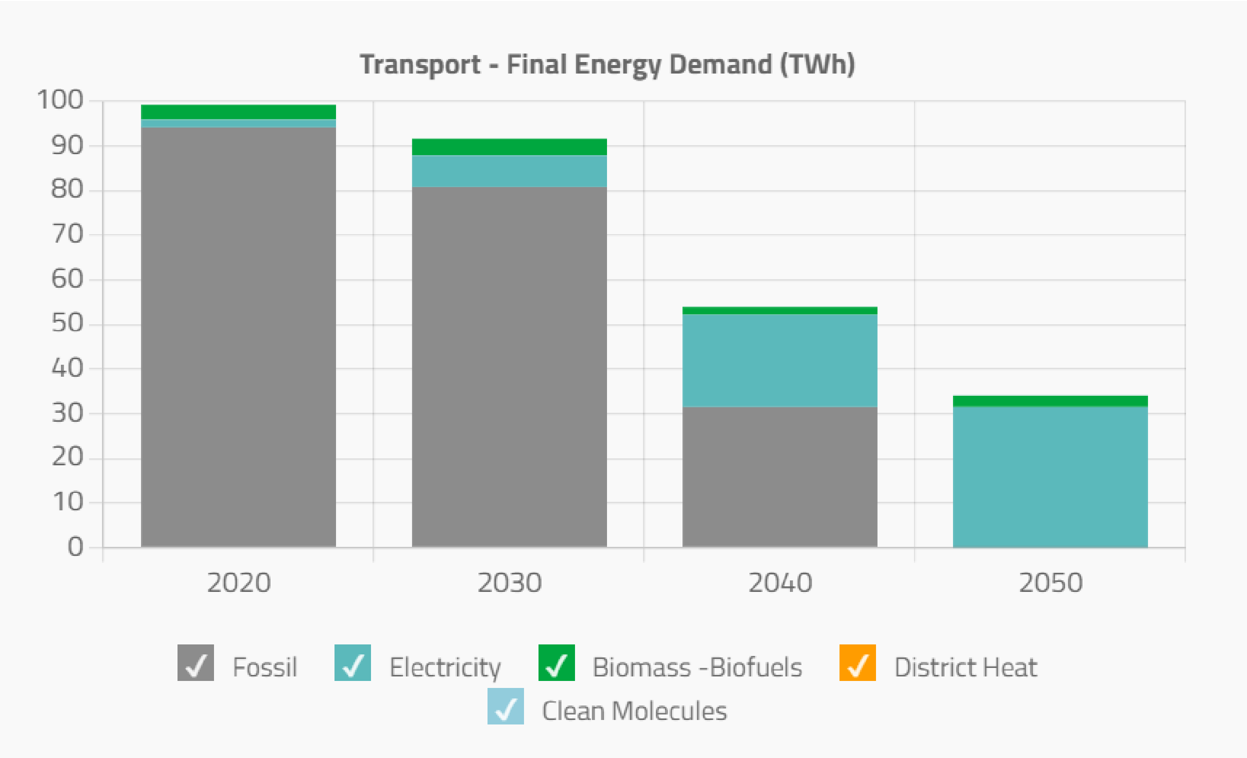
Elia (2023). https://www.elia.be/en/grid-data/balancing/imbalance-prices-15-min

Energy Systems Modeling

- Our modeling framework
  - System optimization models
    - Operational model
    - Expansion planning models
  - Equilibrium modeling
    - Including e.g., risk-averse or strategic behavior
  - Agent-based modeling
    - More flexibility to account for incentives, boundedly rational decision process, and social interactions
  - Statistical methods and data-driven approaches
  - Open toolboxes and models
    - SpineOpt

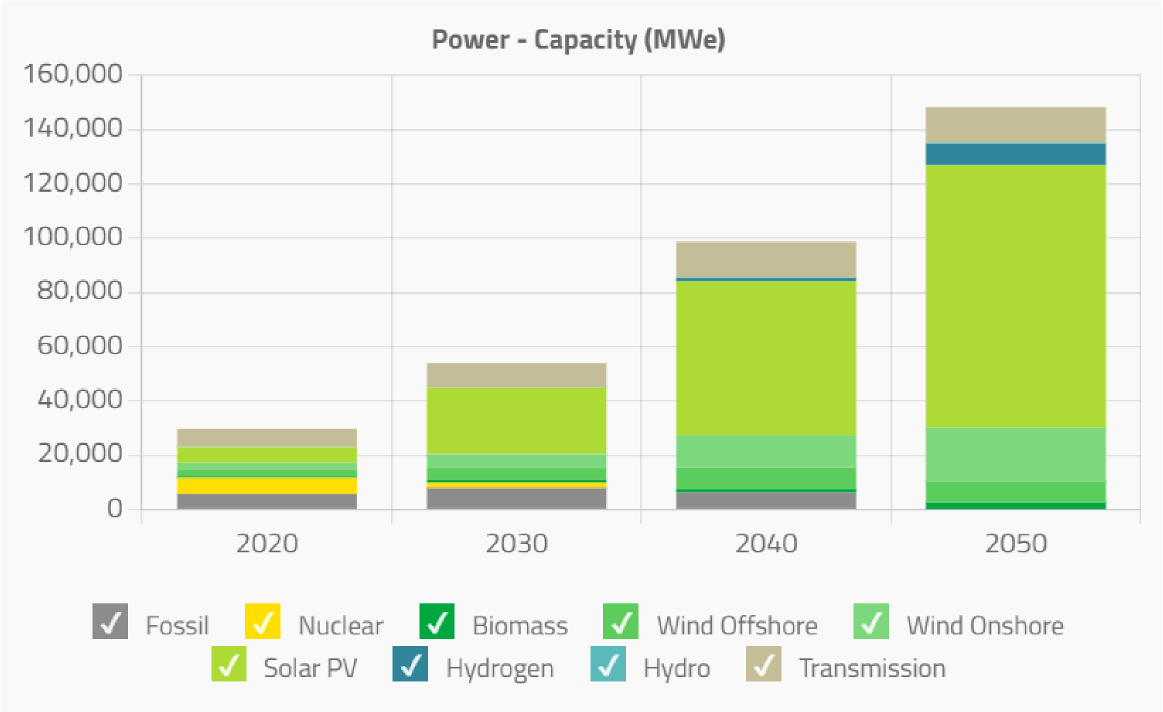
Modeling example 1: Long-term planning model for BE

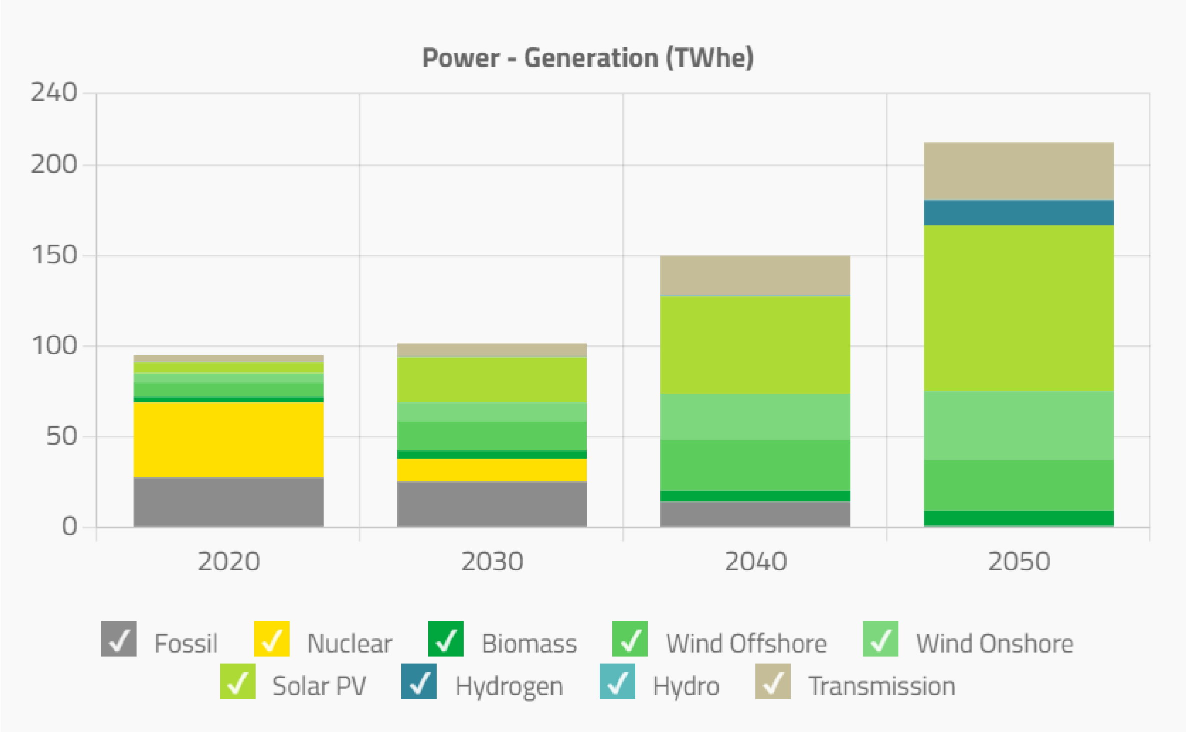




EnergyVille (2022). PATHS2050, The Power of Perspective, https://perspective2050.energyville.be/

Modeling example 1: Long-term planning model for BE

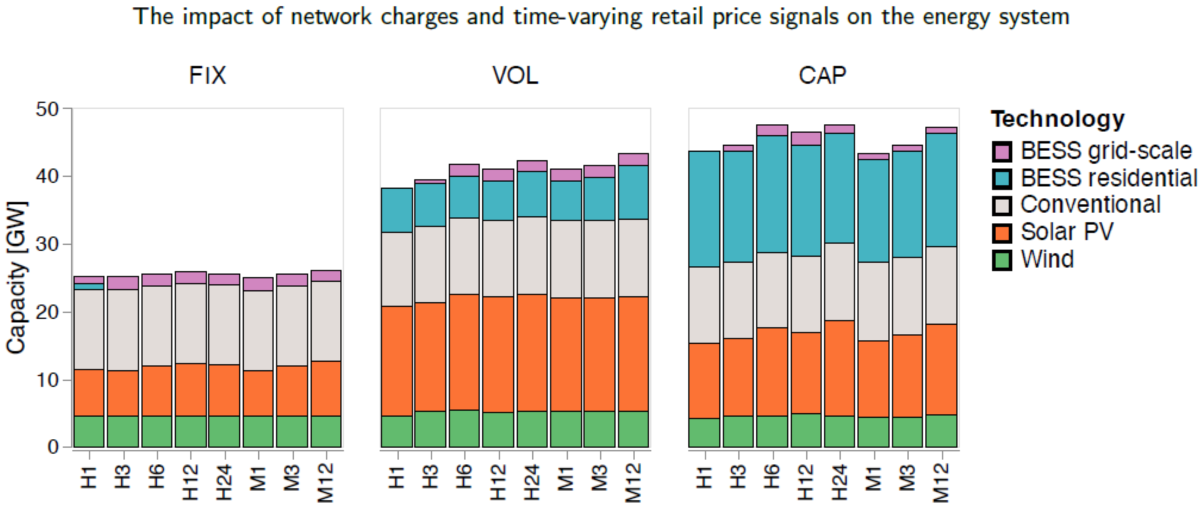


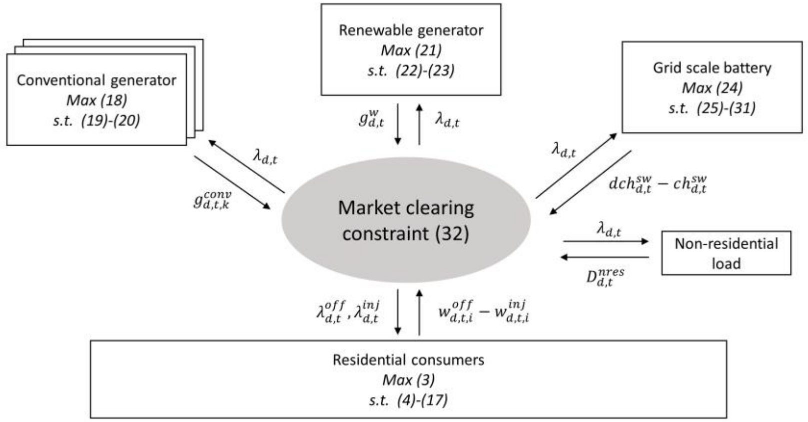


EnergyVille (2022). PATHS2050, The Power of Perspective, https://perspective2050.energyville.be/

Modeling example 2: Impact of network charges and dynamic retail price signals on the energy system

- Decreasing price granularity leads to energy systems with less cost-effective generation mix
  - Distribution tariffs have stronger impact on generation mix

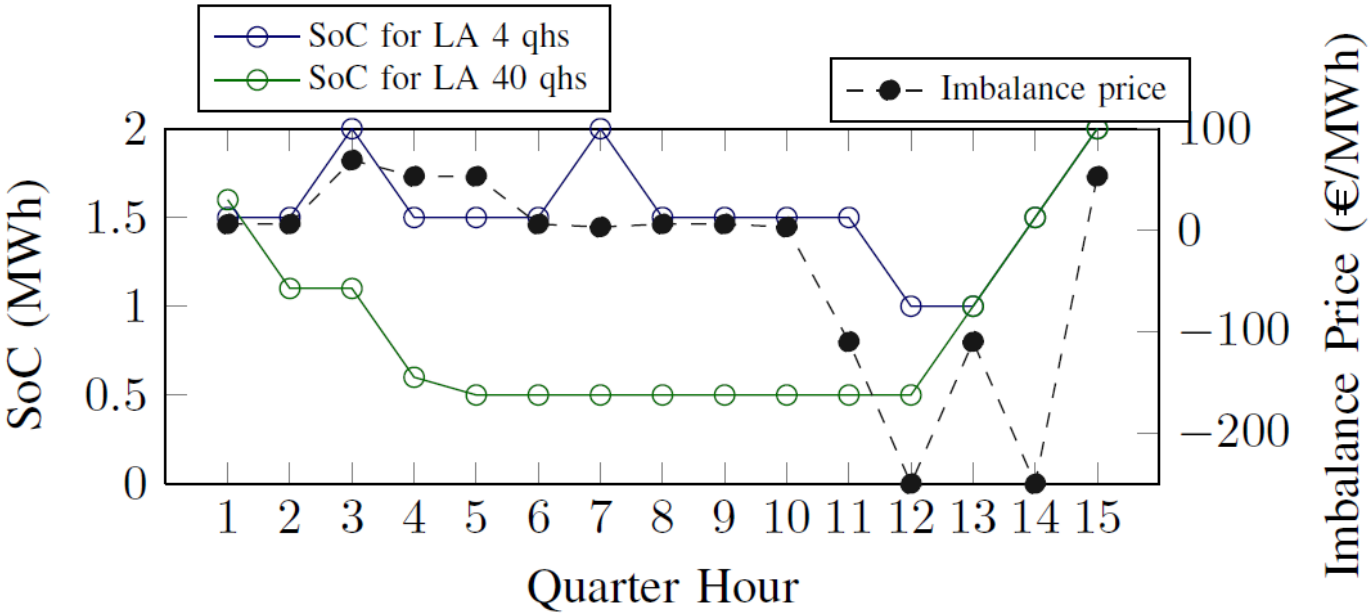




Lu, Y., Gorrasi, C., Meus, J., Bruninx, K., Delarue, E. (2023). System-wide benefits of aligning wholesale-retail electricity prices. *ESIM Working Paper*.

Modeling example 3: Implicit balancing with storage

- Implicit balancing by taking out-of-balance positions in near-real time for storage
- Higher profit compared to optimizing profits solely from day-ahead electricity market with perfect price foresight



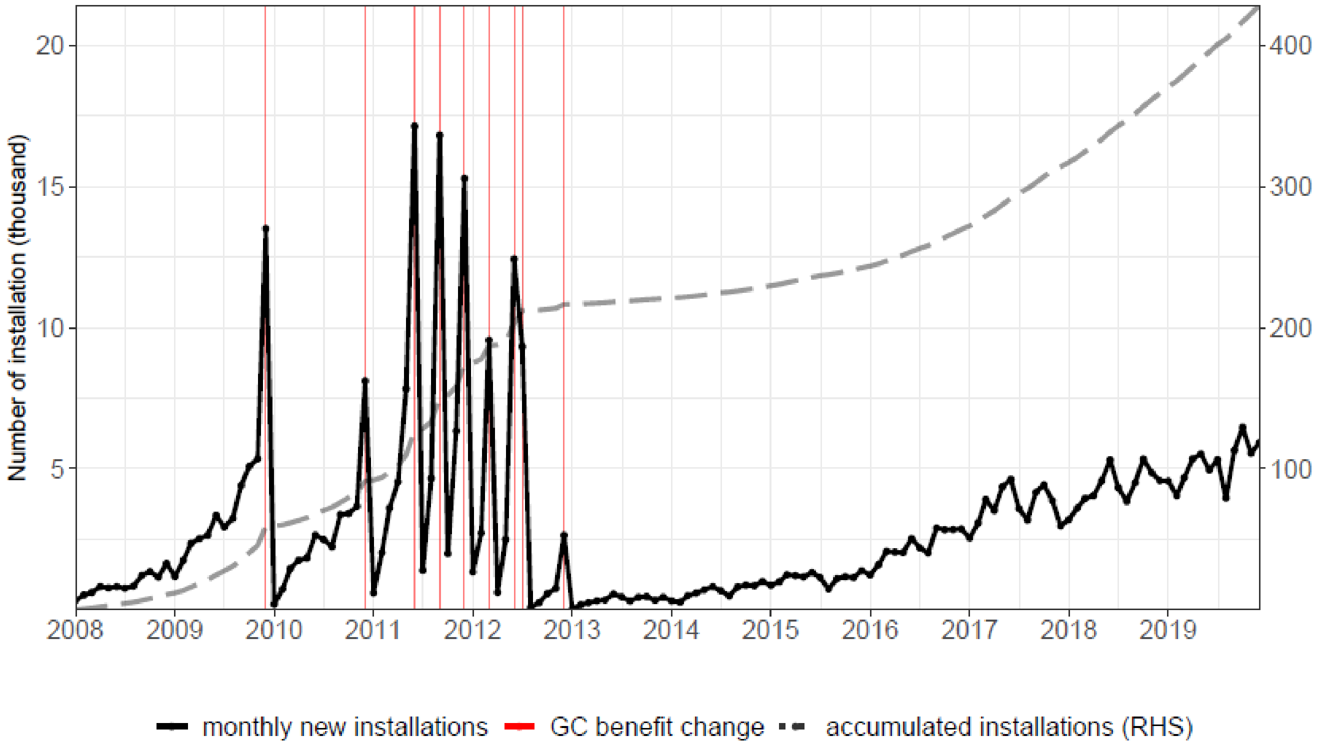
Smets, R., Bruninx, K., Bottieau, J., Toubeau, J-F., Delarue, E. (2023). Strategic Implicit Balancing with Energy Storage Systems via Stochastic Model Predictive Control. *IEEE Transactions on Energy Markets, Policy and Regulation*. doi: 10.1109/TEMPR.2023.3267552

Modeling example 4: Drivers of PV adoption

- Effect of different incentive schemes with future financial benefits on photovoltaic (PV) adoption patterns

- Direct compensation more effective than cost-saving

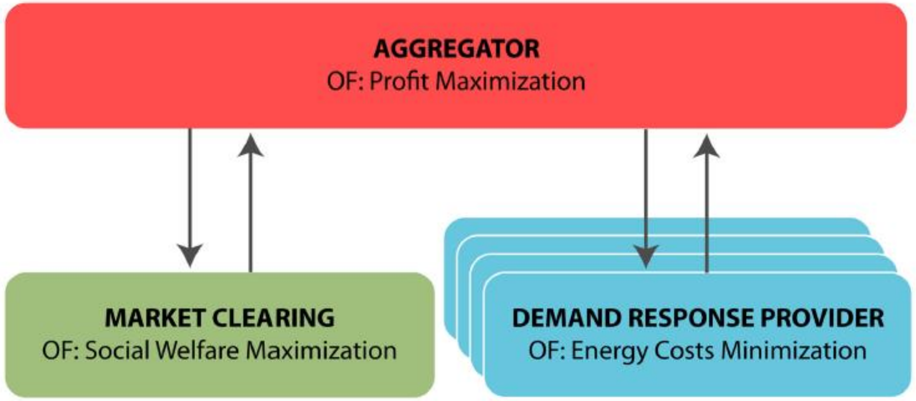
Monthly number of new and accumulated PV installations in Flanders

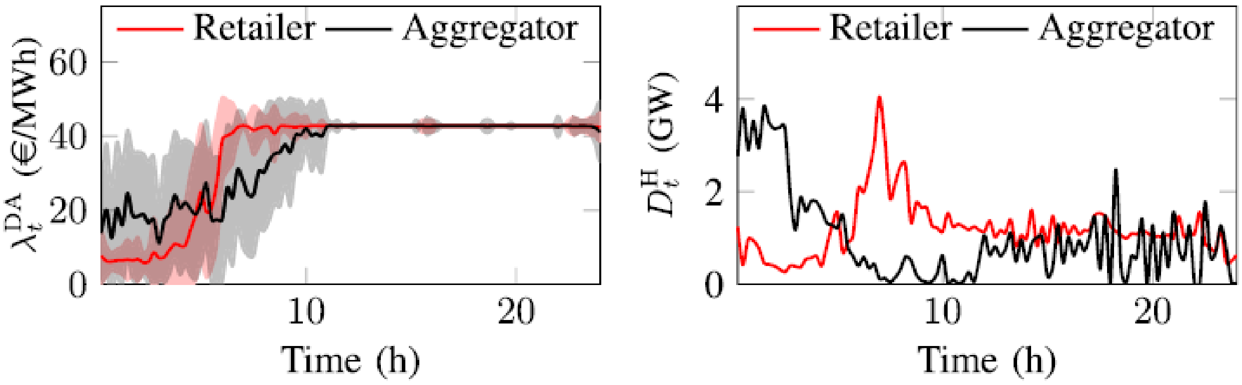


Böning, J., Bruninx, K., Ovaere, M., Pepermans, G., Delarue, E. (2023). The Effect of Future Financial Benefits on PV Adoption Patterns. *ESIM Working Paper*.

Modeling example 5: Aggregator and DR providers

- Strategic interactions between an aggregator, its consumers and the DAM
  - Using a bi-level optimization framework
  - Aggregator takes strategic positions in the DAM, considering uncertainty on market outcome





Bruninx, K., Pandzic, H., Le Cadre, H., Delarue, E. (2020). On the interaction between aggregators, electricity markets and residential demand response providers. *IEEE Transactions On Power Systems*, *35* (2), 840-853. doi: 10.1109/TPWRS.2019.2943670

Wrap-up

- Building electrification, impacting
  - Distribution grid
    - Development plans, including use of flexibility
  - System-level
    - Modified demand and injection patterns + flexibility
- Interactions directly (via tariffs) or via intermediary
- Modeling examples
  - System-wide optimization models, equilibrium models, data-driven approaches
  - Capturing & modeling consumer behavior & decision making

Research group

Energy System Integration & Modeling

https://www.mech.kuleuven.be/en/tme/research/energy-systems-integration-modeling