

Future Energy Systems Center

Space conditioning electrification impact on distribution networks

Interim Project Update

April 26, 2023



Project Team

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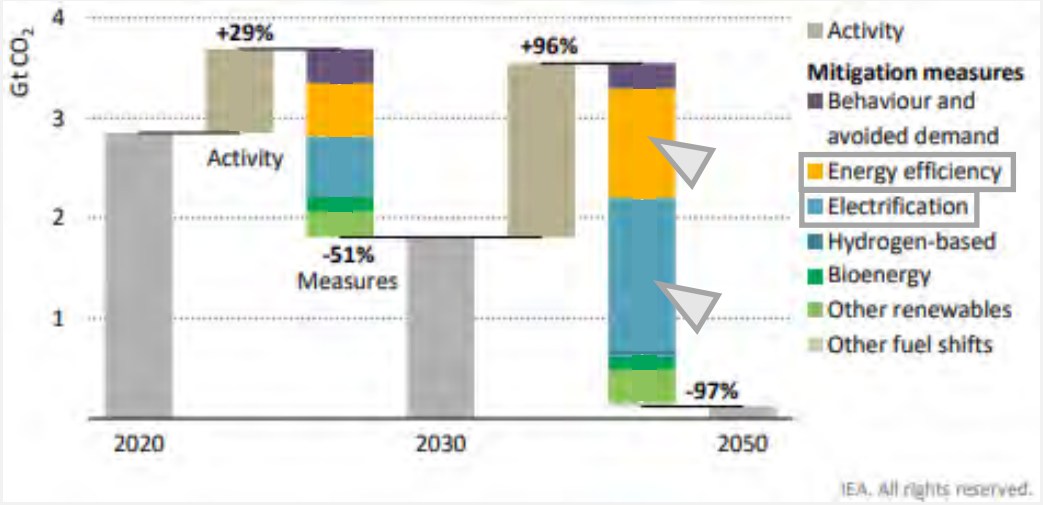
Project Alumni

Karen Tapia-Ahumada—Research scientist
Jameson McBride—TPP ‘22
Tony Lee—TPP ‘22
Jonte Dancker—Visiting student

Project motivation and objectives

Motivation

- Buildings can actively contribute to reducing carbon emissions through electrification as well as demand response, energy efficiency, or adoption of distributed energy resources.
- But distribution networks were designed for supplying millions of passive nodes in a centralized top-down approach.



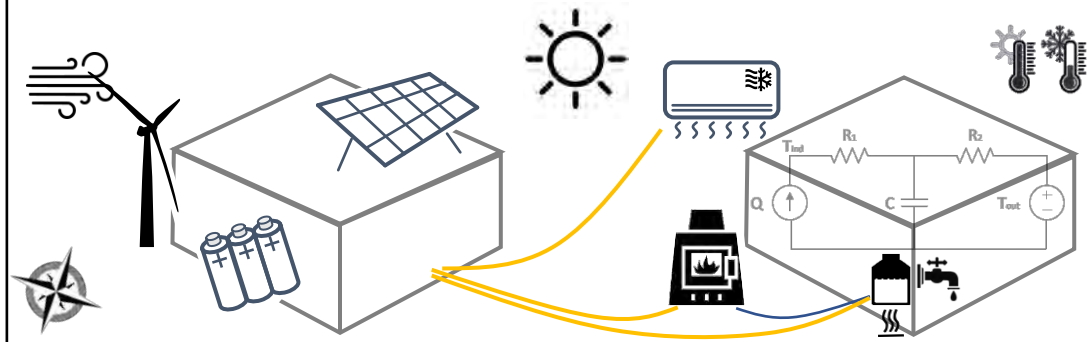
Objectives

1. Evaluate the impact on distribution networks of high electrification rates.
2. Value the opportunity for heat pumps to succeed in traditional fossil-fuel heating areas.
3. Design network tariffs and market mechanisms to enable consumers' flexibility under high electrification scenarios.

Research and analysis performed

Buildings model

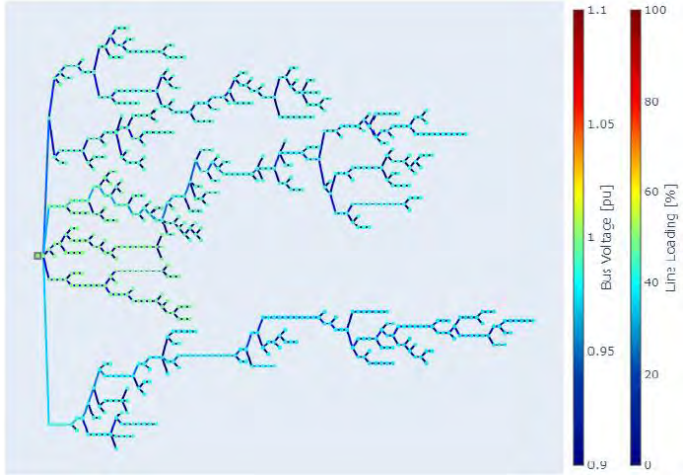
Optimize the energy bill—electricity and gas/fuel-oil purchase—of an individual building defining three intertwined energy models: electricity, temperature and domestic hot water.
Consider PV panels, wind turbines or batteries; heat pumps, CHPs or boilers/furnaces; and water heaters.



Alexander W. L. Yee; "The Impact of Distributed Energy Resources (DERs) in Integrated Gas-Electricity Energy Systems" MIT Technology and Policy Program, 2018. –v0.1

Network model

Optimize the electric distribution network that connects buildings to substations, minimizing the operation and planning costs while observing technical constraints: thermal and voltage limits; and topological constraints.

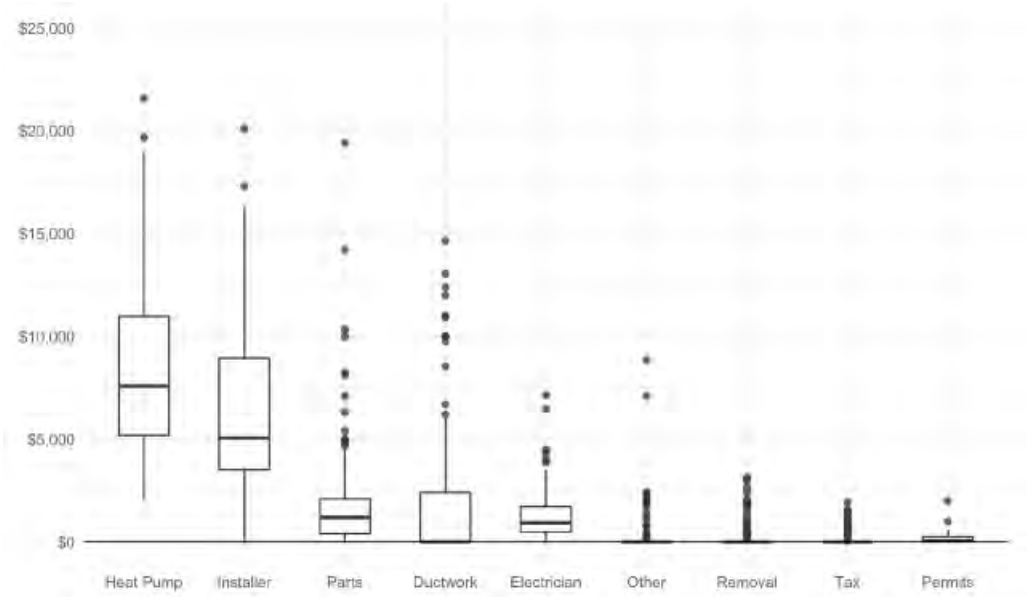


Tony L. Lee, "Implications of heating electrification on distribution networks and distributed energy resources." MIT Technology and Policy Program, 2022.

Interim results, take-aways and project contributions to decarbonization

Policymakers must not overlook real costs for consumers and focalize policies on existing barriers: overnight or operating cost?

- Incentives for heating electrification are ineffective if oriented to equipment acquisition when electricity is less economical than natural gas.
- Heat pump equipment costs account for less than 50% of installation costs and their utilization as proxy for electrification of heating underestimates actual total costs.



Cost components of whole-home heat pump electrification projects in Massachusetts

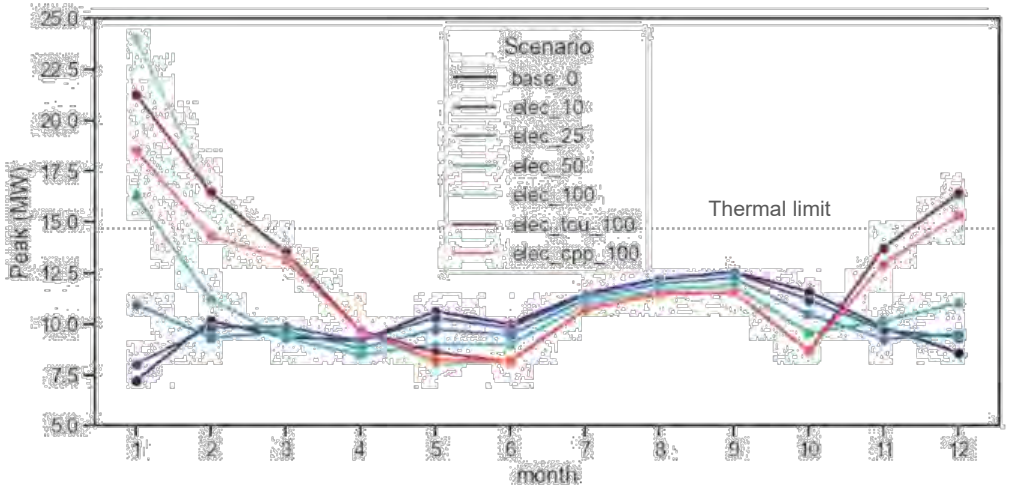
Jameson R. McBride, "Clean heat at what cost? Economic optimization of residential space heating in Massachusetts." MIT Technology and Policy Program, 2022.

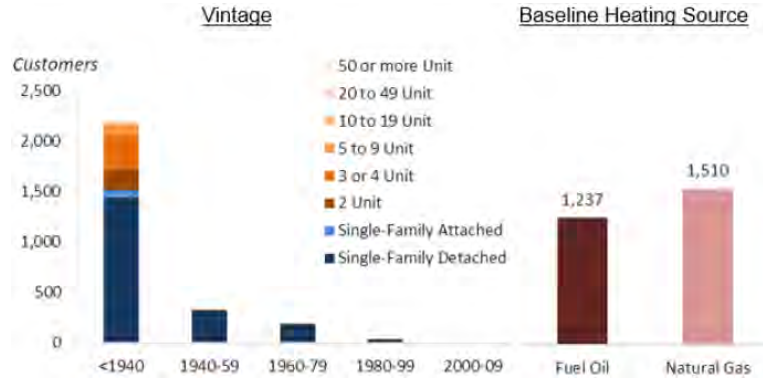
Interim results, take-aways and project contributions to decarbonization

Advanced rate designs can improve heat pump economics, coordinate "non-wires alternative" solutions to reduce peak impacts, and mitigate rate pressure on remaining "captive" natural gas customers

- Near-term adoption levels suggest potential for "beneficial" heating electrification: lower summer peak demand, higher retail sales.
- Demand flexibility depends on building envelopes and automated participation.

Tony L. Lee, "Implications of heating electrification on distribution networks and distributed energy resources." MIT Technology and Policy Program, 2022.





Building portfolio characteristics

Interim results, take-aways and project contributions to decarbonization

Hydrogen proves uneconomical to fully decarbonize residential heating where back-up boilers are required for extremely cold days

- Most distribution feeders are expected to cope with an increasing number of HPs and rooftop PV systems. Reasonable scenarios of HP adoption, 40 %, using all available roof area for PV, 26 %, show a limited impact on voltage limit violations and congestion.
- Hydrogen blending (up to 20 vol%) would moreover involve meaningful and expensive interventions in existing gas distribution networks and barely diminish CO_2 emissions (7%).

Jonte Dancker, Pablo Duenas, and Martin Wolter, "Impact of heat pumps, rooftop PV, and hydrogen blending on gas-electricity distribution networks in Northeast US." IEEE Access, vol. 11, 12963–12972, Feb. 2023.

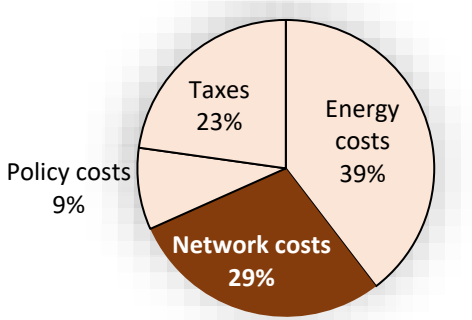
Our latest contribution…

Network tariff design under heat pump deployment: Ex-post pricing and customer response coordination

What is the optimal tariff to recover network costs?

- **Design principles** for network tariffs:
  - Economic efficiency
  - Equity
  - Transparency
- **Decentralization** is empowering and putting customers at the center of the electricity system
- **Digitalization** through smart meters provide new opportunities to send more accurate economic signals

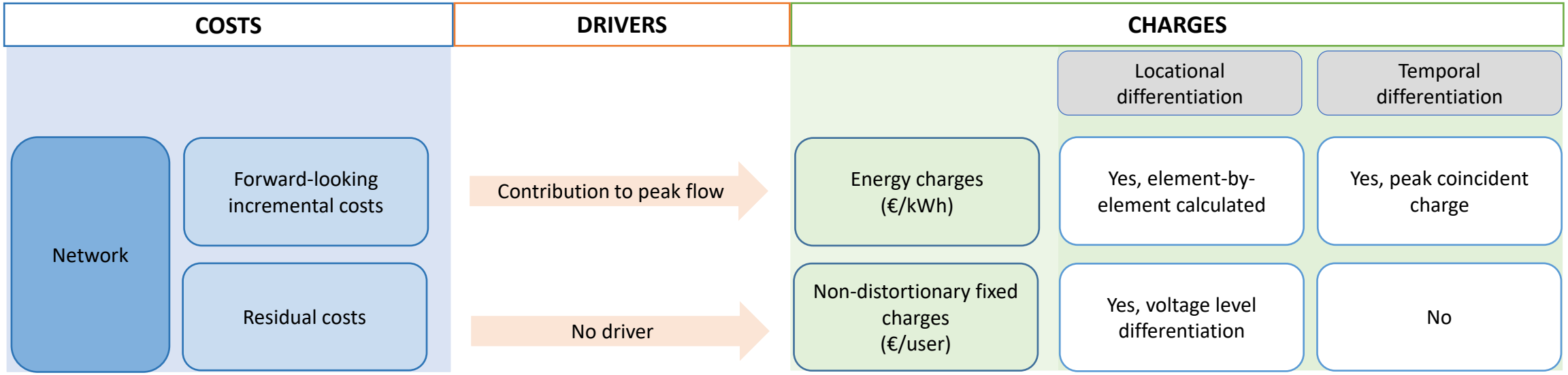
European electricity weighted average breakdown 2021, ACER MMR



Regulated costs and incomes, Spain 2022

Regulated Costs		Incomes	
Total:	**16.525 M€**	Total:	**16.525 M€**
Network costs (T&D)	**6.757 M€ (41%)**	**Network charges**	**6.668 M€ (40%)**
Renewable generation incentives	**6.636 M€ (40%)**	Policy charges	**4.488 M€ (27%)**
Annuity of past system debt	**2.396 M€ (14%)**	Incomes from CO2 auctions	**4.500 M€ (27%)**
Others	**736 M€ (4%)**	Others	**869 M€ (5%)**

Our proposal for network tariff design



Advancing current network tariff practices:

- TOTEX methods lead to overreaction of customer responses.
- Net-metering approaches, leading to death-spiral.
- No symmetry in network charges between injections and withdrawals.

Ill-designed tariffs often create undesired effects

Peak shifting. Customers synchronize their reaction to static tariffs and displace their (increased) peak consumption to an off-peak hour.

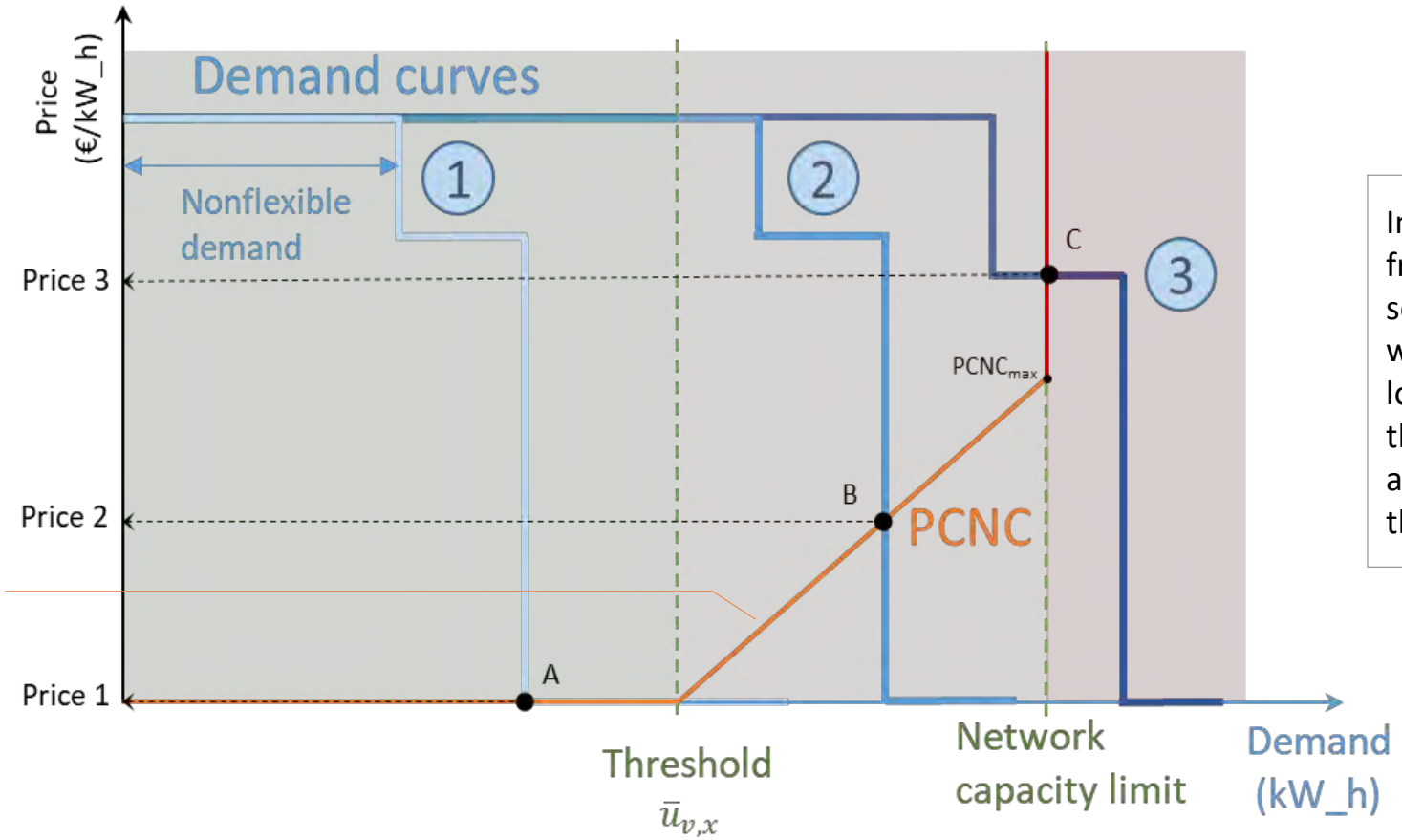
- Consequence of increasing automation and ability to react to price signals.
- Happening even if the price-setting periodicity is “day ahead”.
- Overlook cost-causality principle as synchronized customers pay off-peak network charges.
- Eventually call for network reinforcements.

Ex-post pricing. Charges are calculated after delivery time.

- Potential solution to link network charges to actual network costs.
- Reduced predictability of network charges for customers, since charges depend on other customers’ network usage.

Our solution: customer response coordination

- Auction-based local network capacity market where customers book hourly capacity during critical days



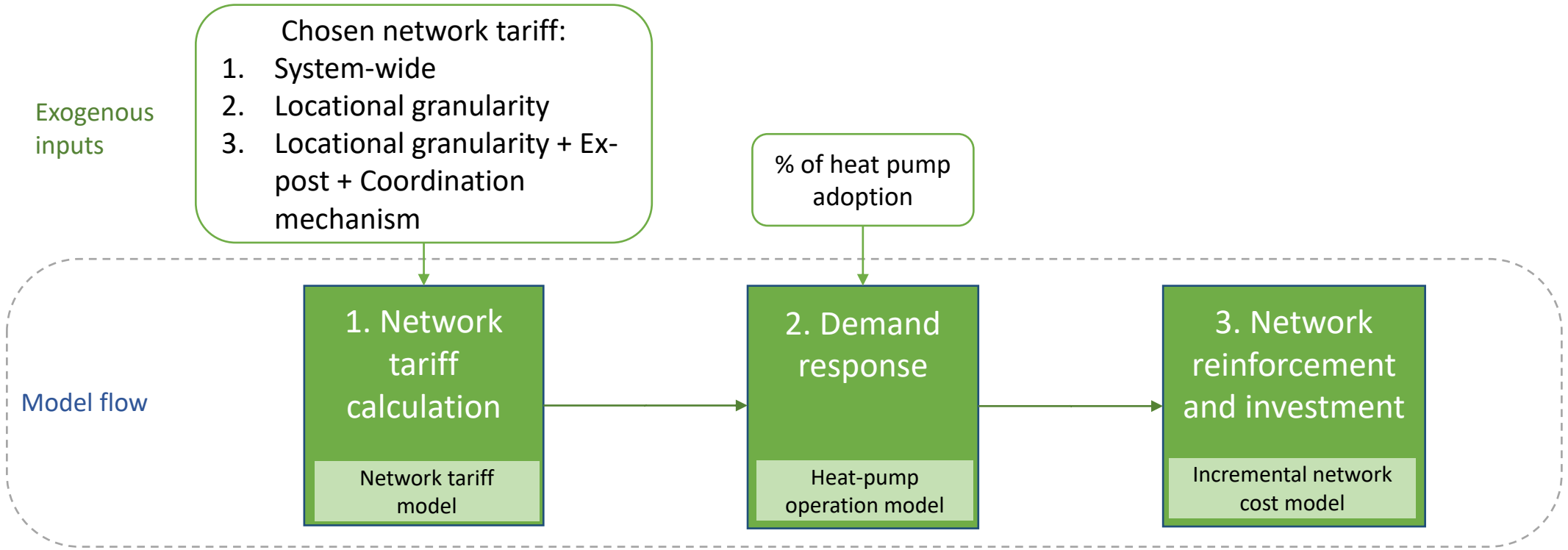
The available network capacity is offered by the DSO at a price that reflects the forward-looking incremental costs in each area

Individual energy deviations from booked capacity are settled at the same PCNC price, which depends on the forward-looking incremental costs, and the difference between the aggregated network usage and the threshold

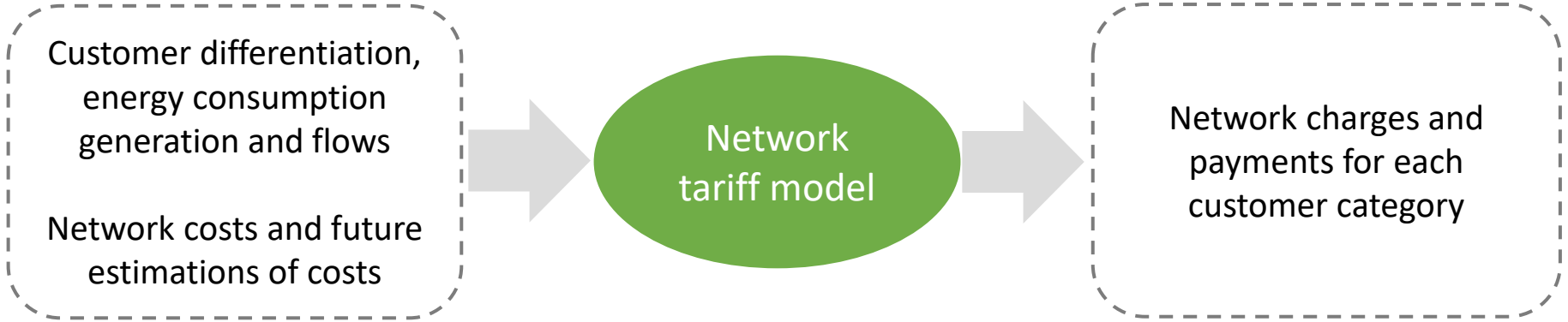
The threshold depends on the top 1200 hours of the Load Duration Curve of the area, and the expected demand growth.

For more details, see working paper Morell Dameto et al. (2023) or contact authors.

Case study. Model flow



Case study. Network tariff model



Analysed network area: 10,000 customers

Two heat-pump deployment scenarios:

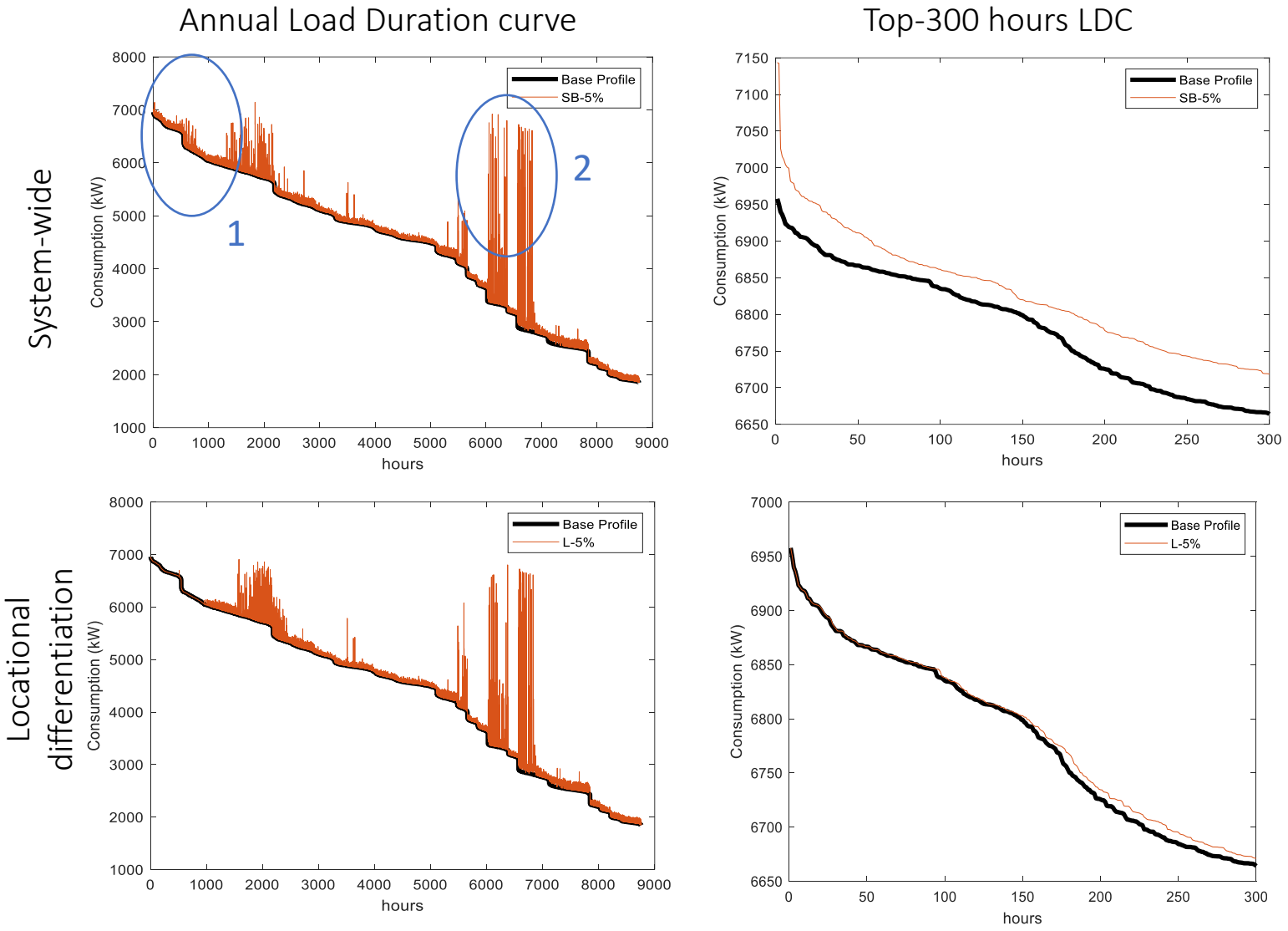
1. 5% of customers adopt heat pumps
2. 20% of customers adopt heat pumps

Three tariffs are calculated:

1. System-wide. Forward-looking peak coincident tariff
2. Locational granularity. Ex-ante
3. Locational granularity. Ex-post. Customer response coordination mechanism

Results. Locational granularity

- Load Duration curves are shown before and after Heat Pumps responses to each network tariff
- Two effects are observed:
  1. System network peaks are not time-coincident with local network peaks
  2. Synchronization of customer responses lead to newly created peaks on hours considered as off-peak
- Locational granularity solves the first effect, aligning network charges with local network peak periods. However, response synchronization is not avoided
- 5% of heat pump adoption does not mean an increase of future network costs in any of the tariff designs



Results. Customer response coordination

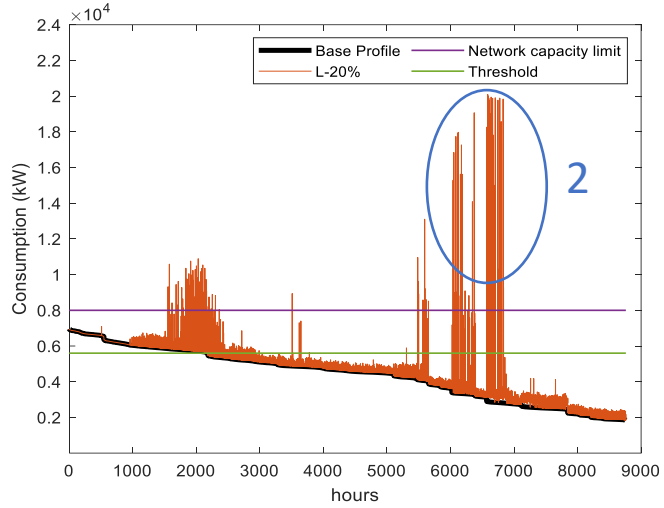
When the heat pump adoption rate grows to 20% of customers:

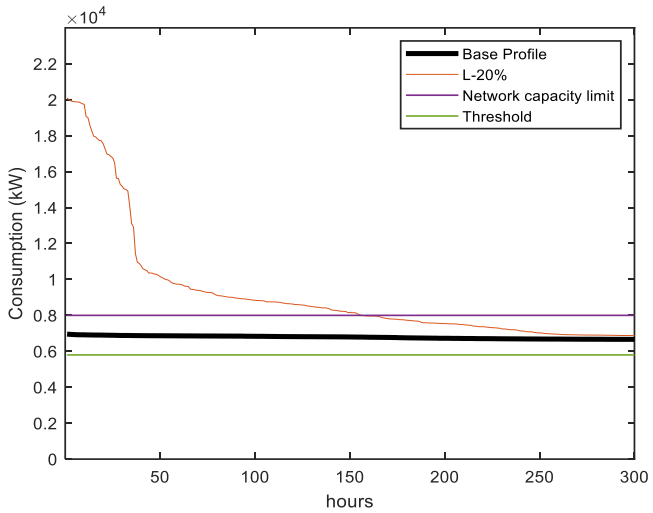
- Customer response synchronization becomes the dominating effect under locational tariffs.
- Newly created peaks surpass the threshold and the network capacity limit, leading to earlier network reinforcements
- Under the customer response coordination mechanism and ex-post pricing, network charges increase when network usage reaches the threshold
- Customers are incentivized to collectively use the network below the threshold

Annual Load Duration curve

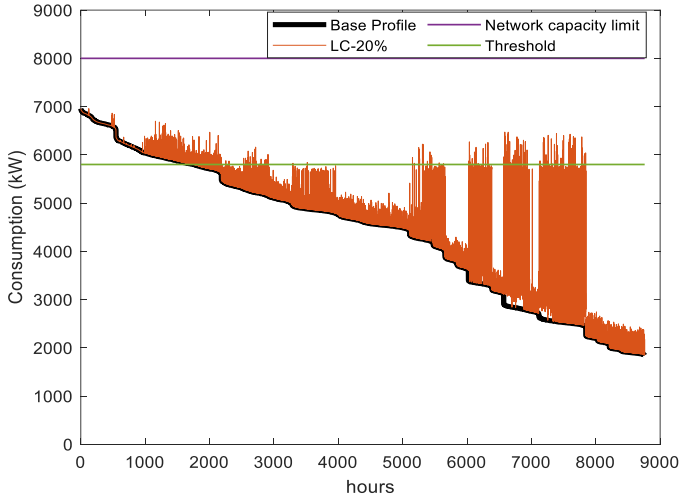
Top-300 hours LDC

Locational differentiation

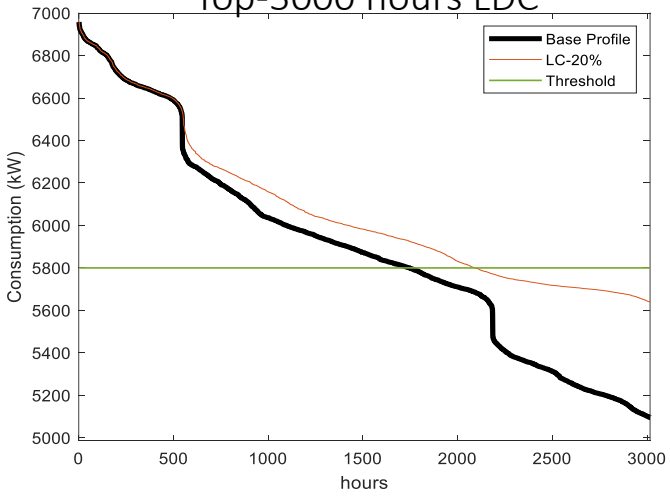




Locational differentiation + Ex-post + Coordination



Top-3000 hours LDC



Interim results, take-aways and project contributions to decarbonization

Customer response coordination mechanism serves as a platform where customers compete in critical days for network capacity and avoids new network peaks due to a synchronized response

- A higher locational granularity allows a better alignment between network charges and long-term network costs of the specific networks that customers use.
- Ex-post pricing guarantees an accurate identification of network peak hours, which can only be known after the delivery time.

Nicolas Morell-Dameto, Jose P Chaves-Avila, Tomas Gomez San Roman, Pablo Duenas-Martínez, and Tim Schittekatte. "Advancing in the implementation of forward-looking incremental network charges: locational granularity, ex-post pricing, and customer response coordination." Energy Policy, under review.

Remaining project activities

Within the next six months…

Analysis oriented

- Add electric vehicles as an additional load and resource for flexibility; and explore combined impacts with heating electrification.
- Expand our distribution impact analysis of electric tariffs and heat pump adoption to diversified feeders, climate areas, and building types.

Outreach oriented

- Dissemination of Jameson's and Tony's master theses through working/journal papers.
- Make publicly available our modeling tools, collected data and analysis results.

And beyond…

- Analyze a real area (buildings + network) including PV and batteries uptake, HP and EV deployment, potential V2G functionality, and provision of local services by end consumers.

Q&A and Project Discussions