Impacts of Residential Energy Efficiency and Electrification of Heating on Energy Market Prices

Christian F. Calvillo*, Karen Turner, Keith Bell, Peter McGregor

15th IAEE European Conference 2017, 3rd to 6th September 2017

*christian.calvillo@strath.ac.uk, Research Associate and CXC Fellow,
Centre for Energy Policy, University of Strathclyde

Introduction

UNIVERSITY of STRATHCLYDE
INTERNATIONAL PUBLIC POLICY INSTITUTE
CENTRE FOR ENERGY POLICY

- The decarbonisation of the energy system is attracting the attention of policy makers worldwide, with many measures targeting the residential sector.
- This is likely to bring changes on the energy system, such as energy conservation measures and the electrification of heating (if the electric system is highly decarbonised).
- However, the changes on electricity prices due to the electrification of heating have been scarcely addressed in the literature.

Objective of the paper

- Provide an assessment of the impact on electricity prices produced by the decarbonisation of heating and energy efficiency in the residential sector.

Source: http://www.telegraph.co.uk/bills-and-utilities/

Model description

- An aggregator managing a large number of residential clients (implementing HP systems).
  - Connection to the electricity market, making it possible to sell and buy energy in the day-ahead market session.
- A mixed-integer linear programming problem.
  - used to find the optimal operation of electric heating and residential loads.
- Price-maker approach.
  - the impacts on electricity prices in the wholesale day-ahead market are estimated considering different residential electric heating profiles and energy conservation scenarios.

UNIVERSITY of STRATHCLYDE
INTERNATIONAL PUBLIC POLICY INSTITUTE
CENTRE FOR ENERGY POLICY

Considerations

- Spanish case study.
- 8 million households aggregated (1/3 of total residential demand).
- Residual demand curves taken from historic values of the Spanish electricity market.
- The considered residential houses have enough HP capacity to full supply their heating needs.
- HP systems have an average COP of 2.5.
- Costs of HP and energy efficiency measures are not considered in this study.

Objective function

$$min\{vCostEE + vCostPowE + vCostET + vCostPowT\}$$

- Where:

$$vCostEE = \sum_{y}\left(pCostE_y * \sum_{m}\left(daysMonth_m * \sum_{h}(vElectricCost_{m,h} + vGridCostEE_{m,h})\right)\right)$$

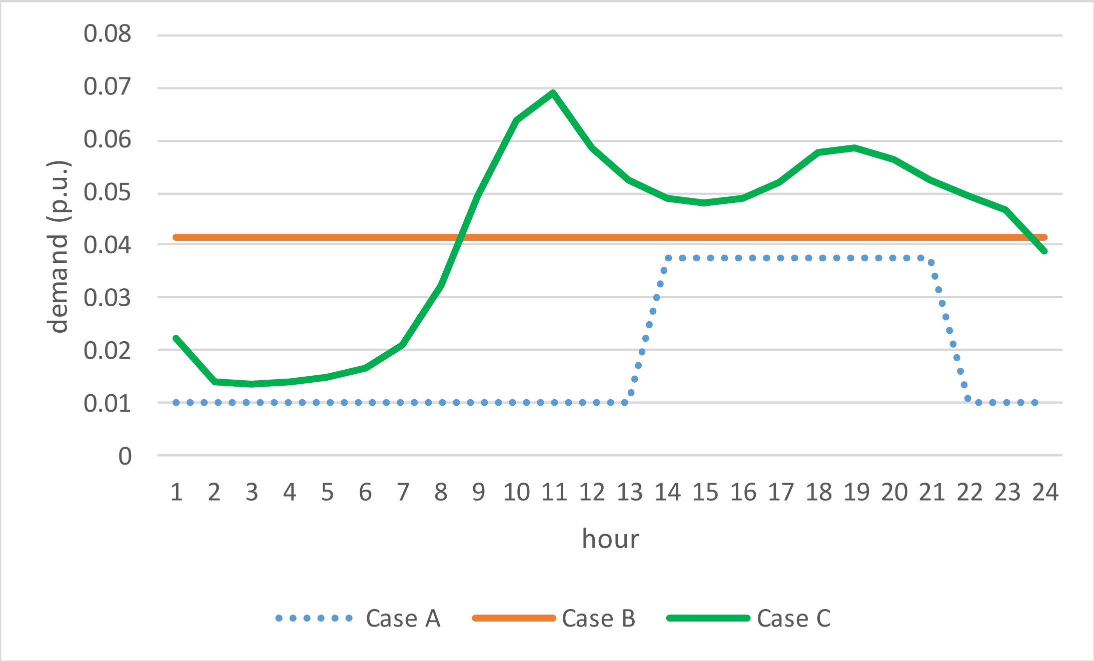
$$vCostPowE = \sum_{y}\left(pCostE_y * pFixEpow * \sum_{c}(vPowElect_c)\right)$$

$$vCostET = \sum_{y}\left(pCostT_y * \sum_{c}\sum_{m}(pDaysMonth_m * vBoughtEnergyT_{c,m})\right)$$

$$vCostPowT = pLifespan * pFixTpow * \sum_{c} pHouseMultiplier_c$$

Case studies
Heating demand profiles

- Case study A: optimised heating demand profile (defined by the model, according to electricity price curves), with a minimum requirement.
- Case study B: uniform (i.e. flat) heating demand profile.
- Case study C: typical heating demand profile.



Scenarios
Energy conservation

- Scenario 1: no energy conservation measures.
- Scenario 2: energy conservation measures implemented for a 20% heating demand reduction.
  - selected as the average energy savings potential of retrofitting measures, such as double glazing and external wall insulation, in a typical household [1].

[1] I. El-Darwish and M. Gomaa, ‘Retrofitting strategy for building envelopes to achieve energy efficiency’, *Alex. Eng. J.*

Results
Cost changes

UNIVERSITY of STRATHCLYDE
INTERNATIONAL PUBLIC POLICY INSTITUTE
CENTRE FOR ENERGY POLICY

		Sc1: No Energy Eff.			Sc2: 20% Energy Eff.		
Costs (M€)	**Base case**	**Case A**	**Case B**	**Case C**	**Case A**	**Case B**	**Case C**
Elec energy	106920	174210	215130	244810	159210	187790	203460
Change %	0%	63%	101%	129%	49%	76%	90%
Elec. power	8115	9420	11015	11562	8115	10435	10873
Change %	0%	16.1%	35.7%	42.5%	0.0%	28.6%	34.0%
Gas energy	77275	0	0	0	0	0	0
Change %	0%	-100%	-100%	-100%	-100%	-100%	-100%
Gas access tariff	849	0	0	0	0	0	0
Change %	0%	-100%	-100%	-100%	-100%	-100%	-100%
Total	*193159*	*183631*	*226145*	*256372*	*167326*	*198225*	*214333*
Change %	*0%*	*-4.9%*	*17.1%*	*32.7%*	*-13.4%*	*2.6%*	*11.0%*

Important increase in elec. costs

Case study A, performs best, and case study C performs worst.

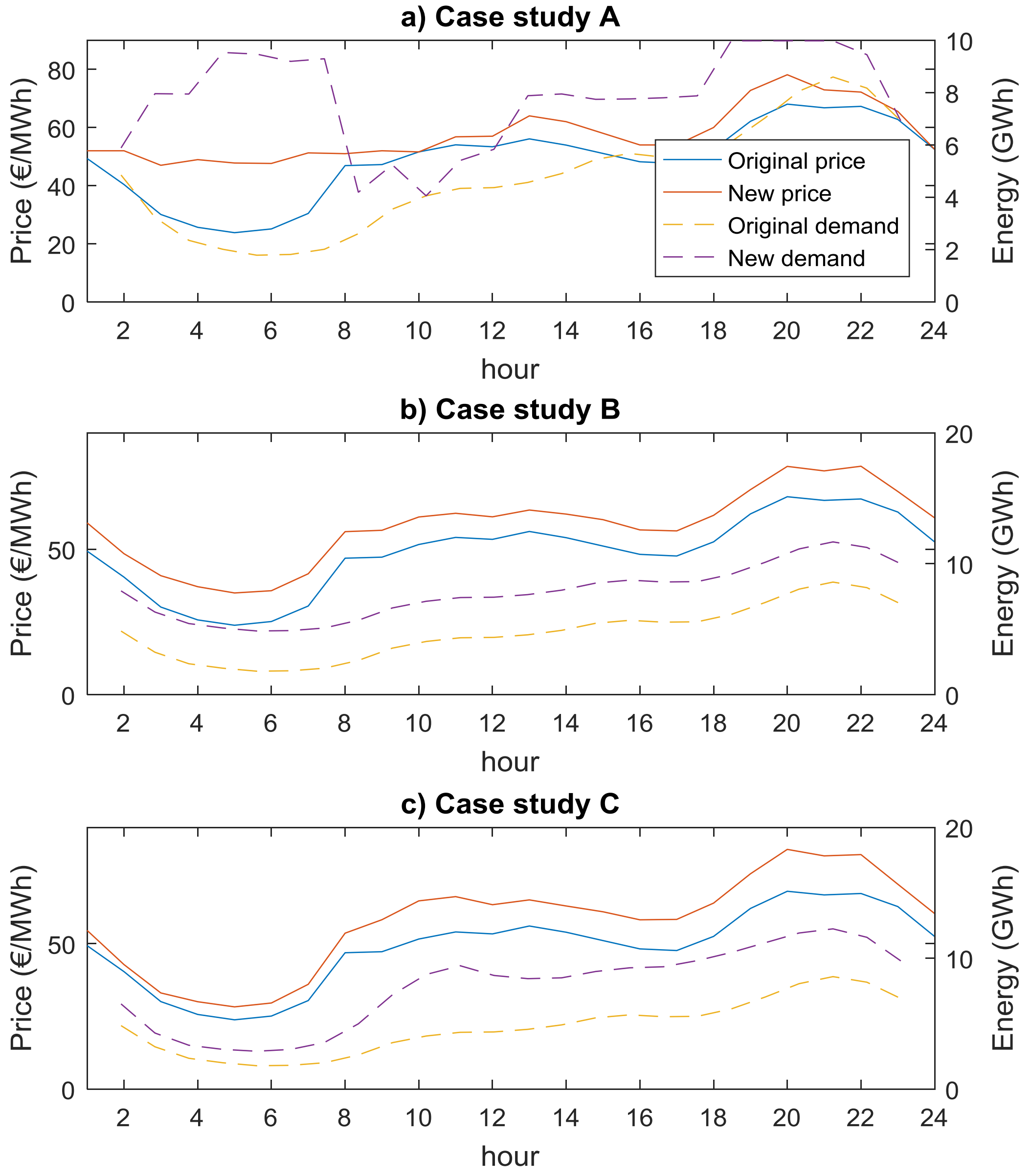
Sc2 presents lower costs, especially for Case study C

Results
Market price changes

	Average price change			Max. price change		
	case A	case B	case C	case A	case B	case C
Sc1: No						
Energy Eff.	14%	15.2%	14.1%	67.2%	39.5%	50%
Sc2: 20%						
Energy Eff.	11.2%	12.3%	11.4%	59.9%	31.5%	40.9%

Similar average change for all case studies

But the price curves and maximum changes differs considerably



Concluding remarks

UNIVERSITY of STRATHCLYDE
INTERNATIONAL PUBLIC POLICY INSTITUTE
CENTRE FOR ENERGY POLICY

- Results show that the electrification of heating increases electricity prices, directly affecting the affordability for consumers.
  - In this study, a cost increment of up to 32.7% was found.
- The conventional heating profiles partly coincides with the typical electricity market price curves.
  - Therefore, the extra load, especially in peak hours, tends to increase the peak price (approximately 35% in this analysis) and the difference between off-peak and peak prices.
- Conversely, an ‘optimal’ heating demand profile, able to choose the best time to produce heat according to the market price, tends to flatten the energy price curve.
  - Showing the importance of a smarter heating management, which could be done with the assistance of energy conservation measures and thermal storage.

Concluding remarks (ii)

- Even though the price-maker model used is a simplified representation of the market (other agents' reactions to new prices are not considered), it provides potentially useful insights on the expected energy cost changes due to the electrification of heating.
- This could be relevant for policy makers and stakeholders, to understand better the potential impacts of decarbonisation of services and energy efficiency measures in the residential sector.
  - also providing awareness on potential conflicting targets, such as decarbonisation of heat vs energy affordability.

Limitations and future work

- The analysis developed in this paper intends to be a first step on analysing the implications of a wider electrification of heating on market prices and energy affordability.
- The next steps for this analysis include (but not limited to) the following:
    - Updated and more heterogeneous heating demand profiles.
    - Better seasonal representation of the COP for HP systems.
    - More accurate representation of energy efficiency scenarios, analysing the effect of buildings' thermal inertia and thermal storage in HP operation.
    - Add investment costs for HP systems, thermal storage, and energy conservation measures, for a detailed profitability analysis of such systems.
    - Adapt all data to analyse the Scottish and UK contexts.

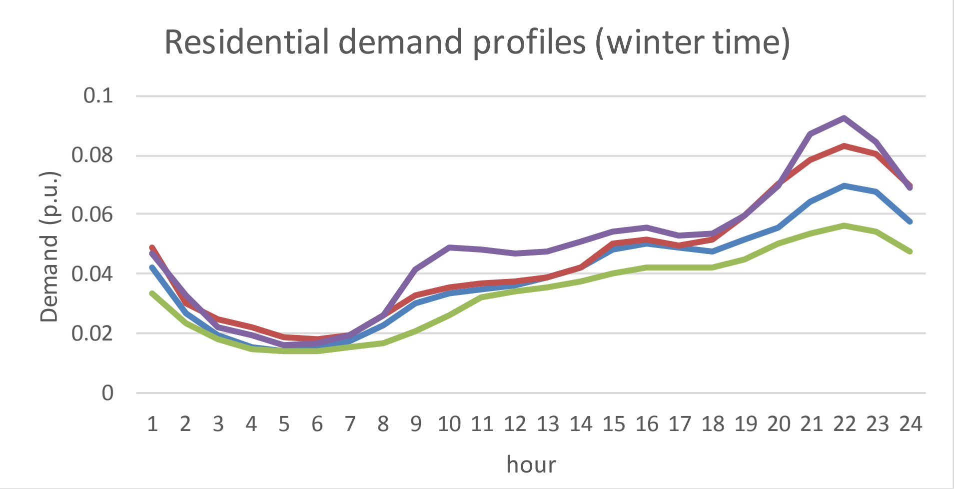
Thank you!

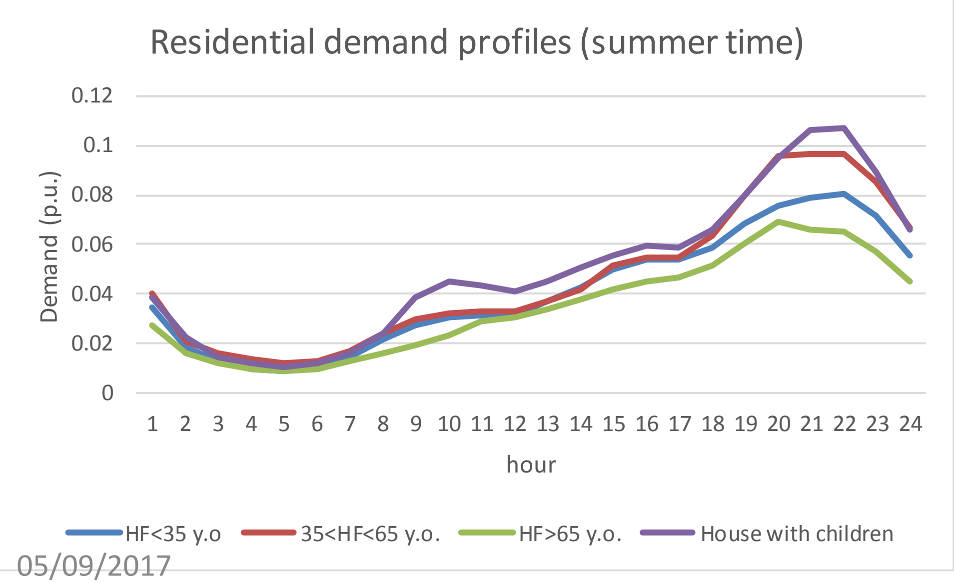
Christian Calvillo

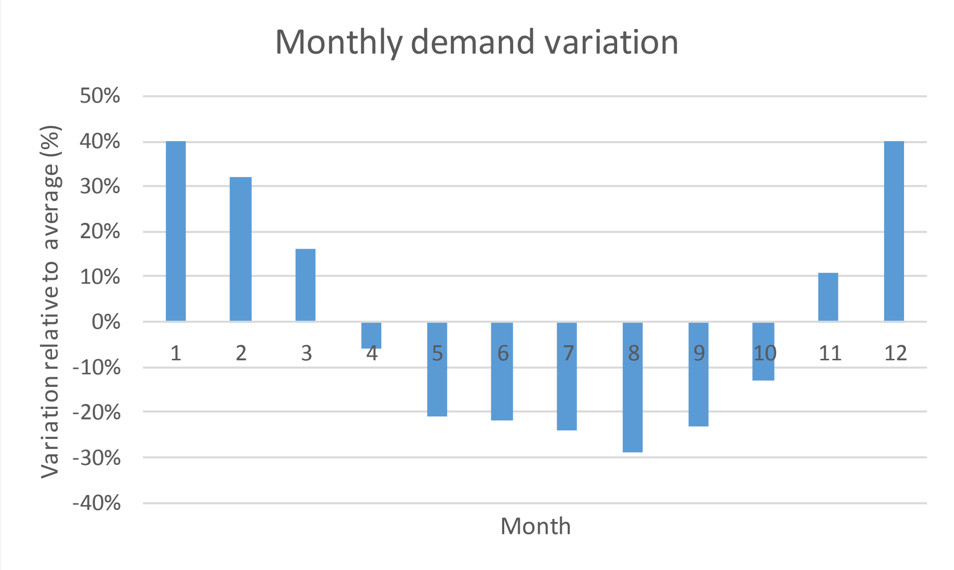
christian.calvillo@strath.ac.uk

https://www.strath.ac.uk/research/internationalpublicpolicyinstitute/centreforenergypolicy/

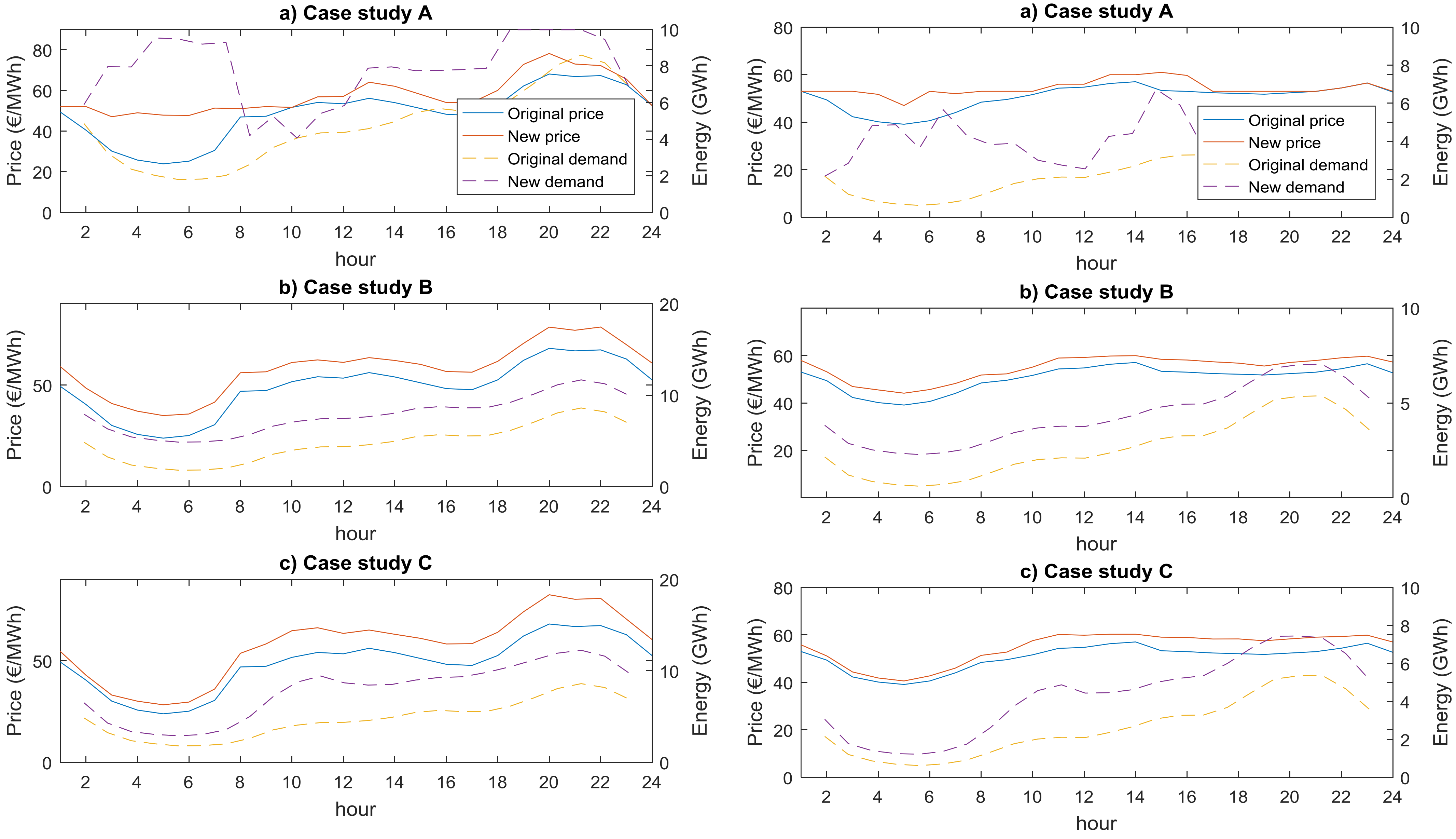
Residential demand







Type of client	Comparison with whole population average value	Annual Thermal (kWh)	Annual Electric (kWh)
HF<35 y.o.	-5%	6054.9747	3507.0613
35≤HF<65 y.o.	8%	6871.7046	3980.1140
HF≥65 y.o.	-19%	5174.3962	2997.0274
House with children	16%	7422.3987	4299.0778


a) Case study A
b) Case study B
c) Case study C
a) Case study A
b) Case study B
c) Case study C
Price (€/MWh)
Energy (GWh)
hour
Original price
New price
Original demand
New demand

Price-taker vs price-maker comparison

- Conventional tariffs (price-taker)

	Peak	Mid-peak	Off-peak
Flat tariff (€/MWh)		117.99	
Time schedule		0-24h	
TOU tariff (€/MWh)	163.2	84.3	56.4
Time schedule	13-22h	7-12, 23-24h	1-6h

- Comparison of electricity costs with the price-maker results

	Energy cost change relative to price-maker model(%)		
	A	B	C
Flat tariff	26.7%	24.7%	22.7%
TOU tariff	24.0%	26.5%	29.7%
Price-taker market prices	-14.5%	-13.2%	-13.8%

Residual demand curves