LCPDelta

# *Assessment of consumer risks and benefits of heat pumps with and without dynamic price contracts*

BEUC, The European Consumer Organisation

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## About this Project

### Context

In June 2019, following the directive (EU) 2019/944 on common rules for the internal market for electricity and an amendment to Directive 2012/27/EU, new provisions were introduced that entitle all final customers who have a smart meter installed to conclude a dynamic electricity price contract with at least one supplier in their market and with every supplier that has more than 200,000 final customers.

BEUC member organisations are asking how they should advise consumers on the topic – whether they would benefit from dynamic electric prices or not.

### Scope of this work

In this study we have:

- Compared the annual energy bills of an archetype apartment and archetype semi-detached home in Italy, Spain, Belgium and Hungary
- For each archetype, calculated energy bills with a condensing gas boiler and heat pump, and with a static tariff or dynamic tariff

### Scope of this work (cont.)

- For the cases with a dynamic tariff, additionally compared the energy bill with different user behaviours for when devices are run, in our low and high demand flexibility scenarios
- Categorized 19 home appliances by how flexible they are and modelled cost-optimised flexible usage of heating and air conditioning and all other flexible devices
- Built up the total energy bill from real price data spanning the period July 2021 to June 2023, including energy costs, network charges, supplier mark-up and taxes

4 countries: Belgium, Italy, Spain and Hungary

4 archetypes (2 household types and 2 heating types)

Static tariff

Typical use of all devices

Dynamic tariff

3 use cases: high flexibility, low flexibility (normal usage), and low flexibility (high-cost usage)

Flexible demand: Space heating and A/C

Flexible timing: Hot water, EV, dishwasher, washing machine

15 inflexible devices

# *Executive Summary (2/3)*

## Key Findings: Impacts on energy bills

**The variation in these ranges is due to the differences between modelled housing types, use cases and whether the household has an EV.**

**The impact of switching from a Condensing Gas Boiler to a Heat Pump, with a static tariff**

All countries saw savings except Hungary.

- Belgium: savings of €170 - €240/year
- Italy: savings of €460 - €720/year
- Spain: savings of €280 - €400/year
- Hungary: increased costs of €450 - €640/year

**The impact of switching from a static to dynamic tariff, with a heat pump**

All countries saw savings except Hungary.

- Belgium: savings of €540 - €1,240/year
- Italy: savings of €160 - €530/year
- Spain: savings of €620 - €1,350/year
- Hungary: increased costs of €1,460 and €1,900/year

**The impact of owning an EV**

For all countries EV owners have greater savings (relative and absolute) from switching to a dynamic tariff than those without an EV. The difference in relative savings is dependent on the country and can be as little as 2% in Belgium to 30% in Hungary.

**The impact of operating devices more flexibly**

All countries saw modest savings between 1-5% of annual bills between our high and low flexibility use cases.

- Belgium: 4-5% savings
- Italy: 1-2% savings
- Spain: 1-3% savings
- Hungary:4-5% savings

**The impact of operating inflexible devices at expensive times of day**

All countries saw additional costs <€40/year when inflexible devices were operated at times of day that were typically most expensive, rather than our default usage times.

**The impact on apartment residents versus semi-detached house residents**

For all countries, semi-detached house residents saw greater absolute impact of switching to a dynamic tariff or heat pump, but smaller relative impact on bills.

# *Executive Summary (3/3)*

## Conclusions

**The benefit of dynamic tariffs is not limited to consumers with smart controls, residential batteries and/or home generation.** Considering Belgium, Italy and Spain we find that using a dynamic tariff can result in absolute savings without daily optimisation of demand. Timing larger flexible loads (EVs, a dish washer and a washing machine) at times of day that are *usually* cheapest is sufficient to unlock the majority of the benefit of switching to a dynamic tariff.

**The risk of increased costs due to expensive timing of loads within the day with a dynamic tariff is very modest** for these same countries. In Belgium, Italy and Spain we have calculated dynamic tariff savings even when all inflexible loads (such as cooking, lighting and electronics) were used at peak times and without flexible usage of heating and air conditioning.

**The greater risk of dynamic tariffs comes not from intra-day price variations, but seasonal price variations.** While dynamic tariffs see the impacts of price hikes much more quickly than static tariffs, they also fall in price more quickly. The benefit or cost to the consumer is sensitive to the timing of this volatility in the year, particularly in countries with the greatest differences between space heating and air conditioning demands.

**Winter spikes in wholesale prices are the greatest risk to the favourability of dynamic tariffs.** The timing of wholesale energy price volatility seen in the two years of data assessed in this project has been favourable to dynamic tariffs. Highest wholesale and dynamic tariff prices have been in the summer when the demand has been lower, while static tariffs have recovered costs later in winter, when demand is higher. Different timings risk reducing the favourability of dynamic tariffs. However, we would expect energy suppliers with static tariff consumers to recover their costs no matter when high wholesale prices occur, mitigating much of this seasonality risk.

**Countries with subsidised energy price caps for fixed price contracts don't see the benefits of dynamic tariffs.** For example, Hungary sees very different results. A consequence of the energy price cap is that dynamic tariffs linked to wholesale prices are no longer of benefit to the consumer. This hinders development of dynamic tariffs and the expected savings these may have for the total energy system.

# *Results (1/4) – Belgium*

## Best tariff / use case combination

**Energy consumption**

- Household with gas boiler
- Household with heat pump
- EV

**Tariff/use cases**

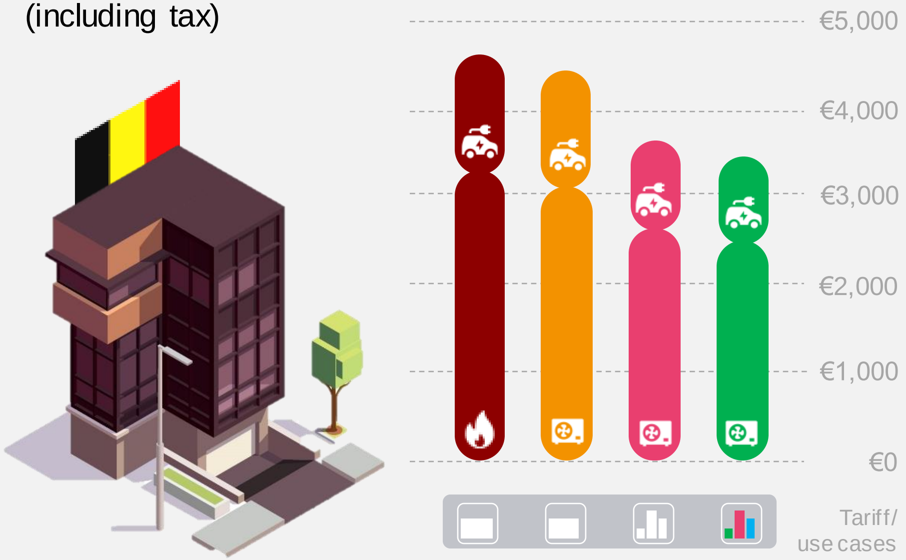
- Static variable tariff
- Dynamic tariff – low flex/high cost
- Dynamic tariff – high flex

### Apartment

Best value option with HP-Dynamic tariff-High flexibility

**€3,480** ✔

Est. annual energy bill (including tax)

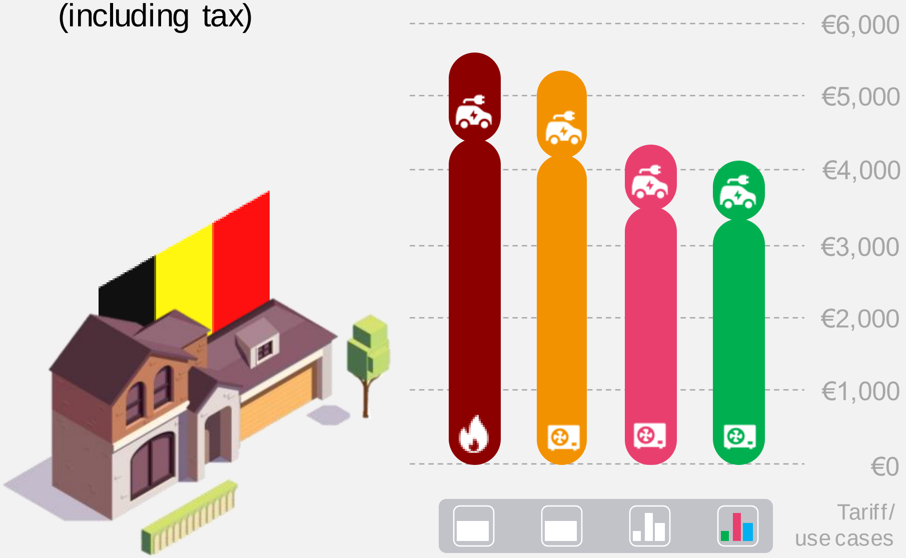



### Semi-detached house

Best value option with HP-Dynamic tariff-High flexibility

**€4,121** ✔

Est. annual energy bill (including tax)

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# *Results (2/4) - Italy*

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## Best tariff / use case combination

**Energy consumption**

- Household with gas boiler
- Household with heat pump
- EV

**Tariff/use cases**

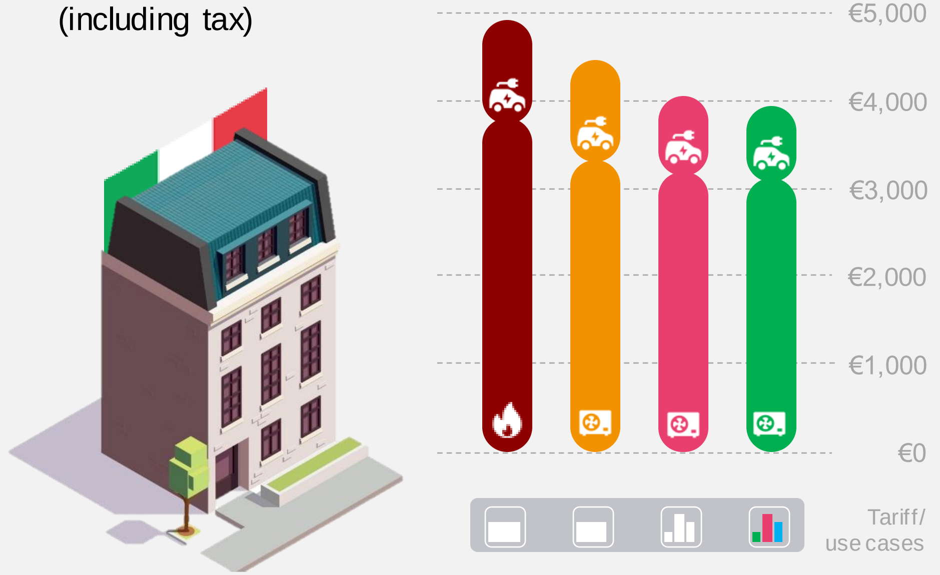
- Static variable tariff
- Dynamic tariff – low flex/high cost
- Dynamic tariff – high flex

### Apartment

Best value option with HP-Dynamic tariff-High flexibility

**€3,924** ✓

Est. annual energy bill (including tax)

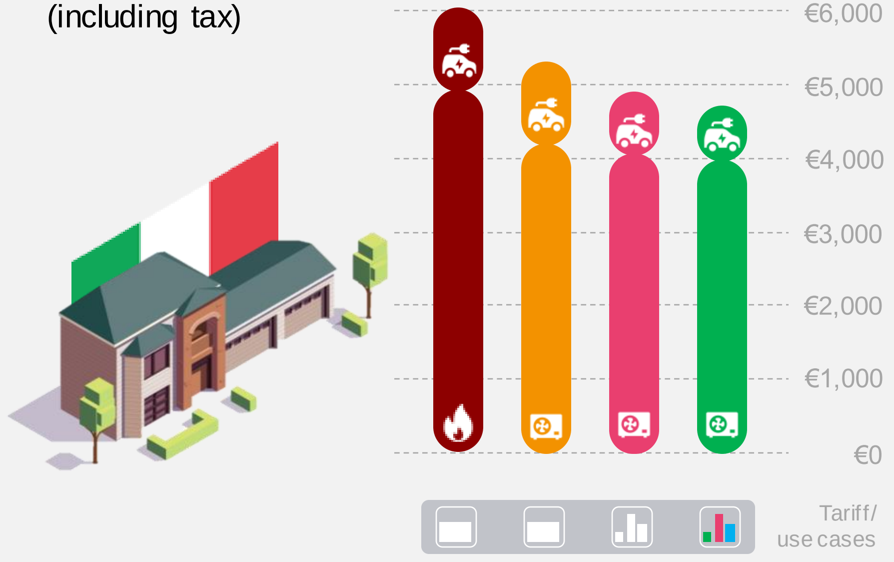



### Semi-detached house

Best value option with HP-Dynamic tariff-High flexibility

**€4,793** ✓

Est. annual energy bill (including tax)

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# *Results (3/4) - Spain*

## Best tariff / use case combination

**Energy consumption**

Household with gas boiler

Household with heat pump

EV

**Tariff/use cases**

Static variable tariff

Dynamic tariff – low flex/high cost

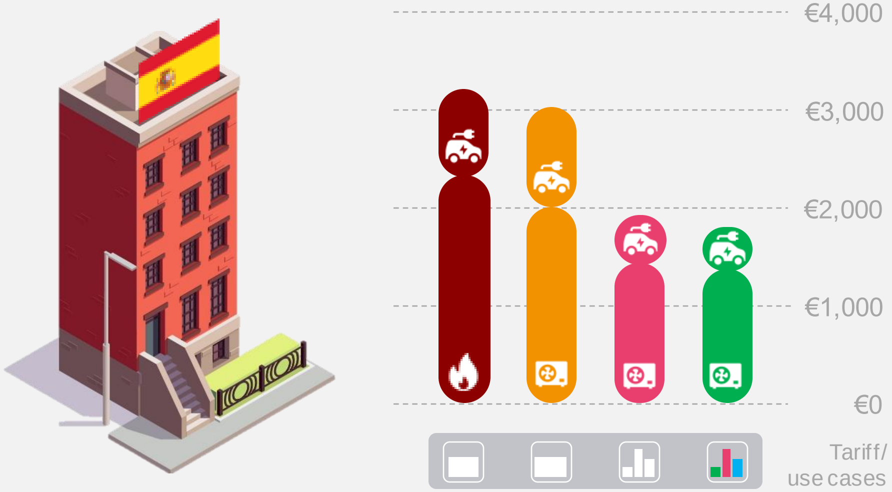
Dynamic tariff – high flex

### Apartment

Best value option with HP-Dynamic tariff-High flexibility

**€1,815**

Est. annual energy bill (including tax)

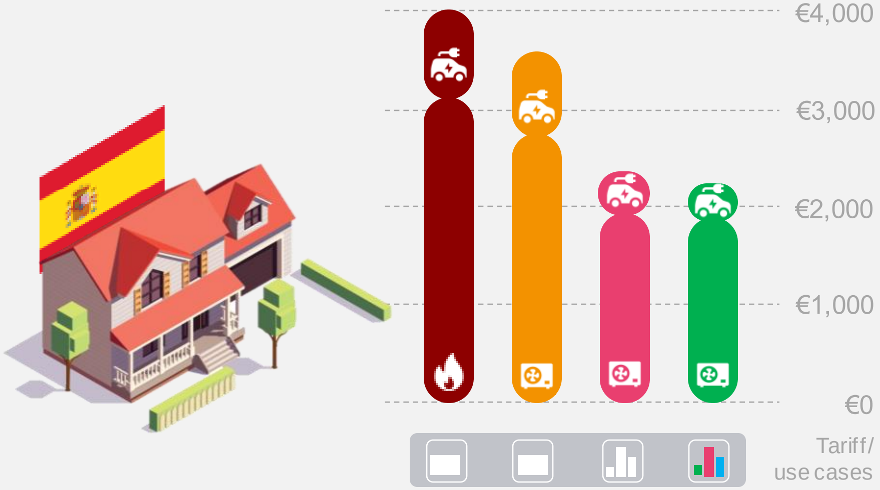



### Semi-detached house

Best value option with HP-Dynamic tariff-High flexibility

**€2,252**

Est. annual energy bill (including tax)

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# *Results (4/4) - Hungary*

## Best tariff / use case combination

**Energy consumption**

- Household with gas boiler
- Household with heat pump
- EV

**Tariff/use cases**

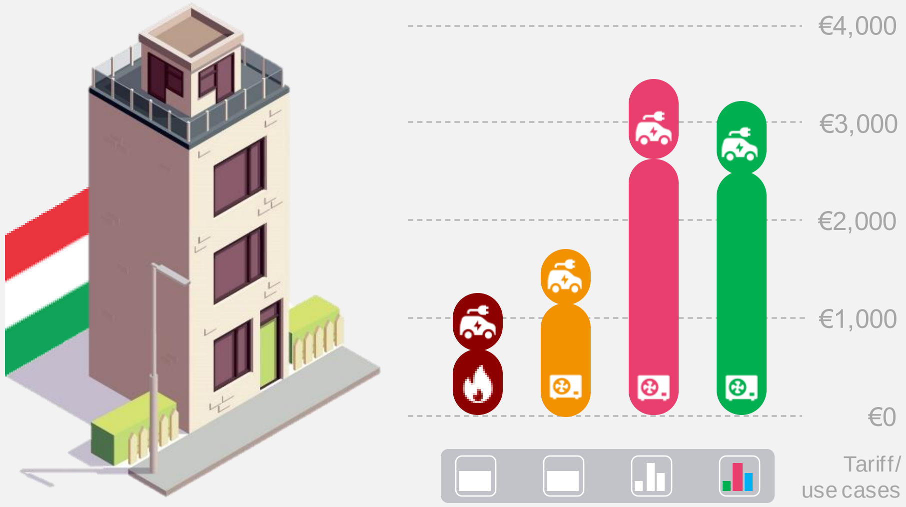
- Static variable tariff
- Dynamic tariff – low flex/high cost
- Dynamic tariff – high flex

### Apartment

Best value option with Gas boiler-Static variable tariff

**€1,256**

Est. annual energy bill (including tax)

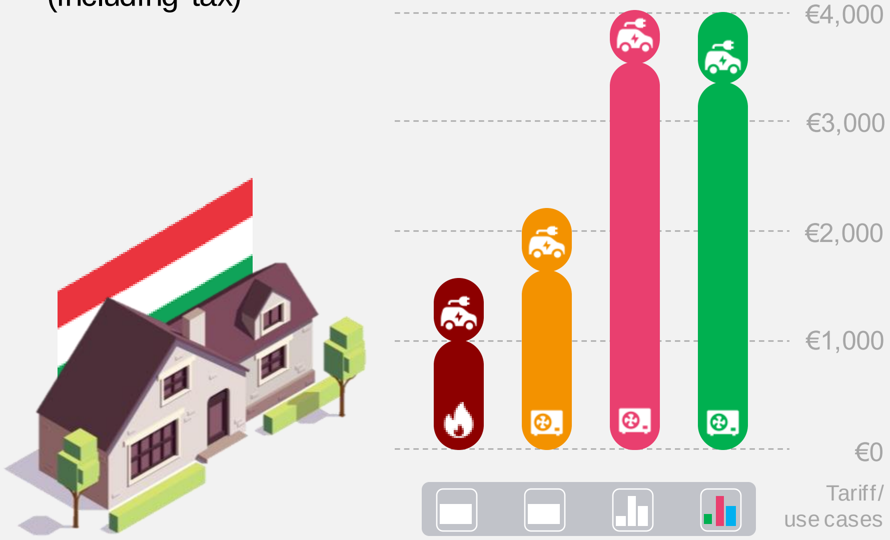



### Semi-detached house

Best value option with Gas boiler-Static variable tariff

**€1,559**

Est. annual energy bill (including tax)

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# *Methodology*

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# Our approach

## Summary

**We have assessed the average annual energy bill for the period July 2021 to June 2023 for the housing archetypes, countries and use case scenarios shown to the right.**

For each case:

- We consider a house with national average insulation, with and without an EV.
- The homeowners are modelled to have 18 energy efficient devices – each categorized by how easily their demand can be shifted to the cheapest times of day.
- Home heating and air conditioning demand is modelled to vary daily using real temperature data for this period.
- All other devices are modelled to have a constant average daily demand.
- Apartment owners are assumed to have a second electricity meter in their garage if they have an EV.

Further details provided in the appendix.

**4 Housing archetypes**

- A 70 $m^2$ apartment with condensing gas boiler
- A 70 $m^2$ apartment with an electric heat pump
- A 100 $m^2$ semi-detached house with a condensing gas boiler
- A 100 $m^2$ semi-detached house with an electric heat pump

**4 Countries**

Italy, Spain, Belgium and Hungary.

**4 Use Case Scenarios – explained further in the next slide**

- Static tariff
- Dynamic tariff, high flexibility
- Dynamic tariff, low flexibility – normal usage
- Dynamic tariff, low flexibility – high-cost risk

# *Our approach*

## Dynamic tariff use case scenarios

**Our dynamic use case scenarios showcase both the benefits and risks of dynamic tariffs by changing the time of day of electricity demands, without changing the total demand**

1. High flexibility: representing a user that actively optimises flexible devices daily and has smart heating and cooling controls.
2. Low flexibility – normal use: representing a user that runs their flexible devices at the time of day that is usually cheapest, reviewed annually, and does not have smart heating or cooling controls.
3. Low flexibility – high-cost risk: representing a user who runs their flexible devices in the same way, but also runs their inflexible devices at the time of day that is usually most expensive.

| Demand/Asset | High flexibility | Low flexibility – normal use | Low flexibility – high-cost risk |
|---|---|---|---|
| **EV** | Scheduling optimised daily | Scheduled at the time that is usually cheapest overnight | Scheduled at the time that is usually cheapest overnight |
| **Space heating and Air conditioning** | Demand profile optimised daily | Not flexed | Not flexed |
| **Dishwasher, Washing Machine, Hot Water Heating** | Scheduling optimised daily | Scheduled at the time that is usually cheapest | Scheduled at the time that is usually cheapest |
| **13 other devices** | Normal usage times (no flexibility) | Normal usage times (no flexibility) | **At time of day that is usually most expensive** |

# *Our approach*

## Constructing tariff costs

**Energy bills have been built up component by component, adding in network charges, supplier mark-up and taxes to wholesale electricity and gas prices**

**Constant taxes and network charges have been assumed in the studied period.**

| Country | Static tariff gas price | Static tariff electricity price | Dynamic tariff electricity price |
|---|---|---|---|
| Belgium* | Engie Easy Gas Fixed (Dec 2021 – Mar 2022) and Easy Gas Variable (Apr 2022 – Jun 2023) | Engie Easy Fixed until Mar 2022,<br>Engie Easy Variable from April 2022 to March 2023,<br>Engie Easy Fixed from April 23** | Engie Dynamic |
| Hungary | Average retail price as per HEPI index | Regulated retail tariff | Hourly day ahead prices with 5c EUR/kWh supplier mark-up, 1836.42 HUF/year and 23.4 HUF/kWh network charges |
| Italy | Average retail price as per HEPI index | Cheapest fixed price contract offered by Eni Plenitude on the 12th of each month:<br>• Eni Plenitude Flexi Luce until Feb 22<br>• Eni Plenitude Scontopiù Luce on Mar 22<br>• Eni Plenitude PLACET fissa luce domestico from Apr 22 to April 23<br>• Eni Plenitude Fixa Luce from from May 23<br>• Gaps in Feb, Mar and Jun 23 were interpolated from surrounding months | Hourly day ahead prices in Northern Italy bidding zone + 5c EUR/kWh and 144 EUR/year as markup |
| Spain | Average retail price as per HEPI index | Average retail price as per HEPI index | PVPC tariff |

* Network charges and taxes for Antwerp used

** Fixed price contract chosen for Engie where data available, otherwise a variable contract indexed to a 3-month benchmark – chosen to provide the longest price protection to consumers.

# *Results*

# *Overview*

## Results highlights

**Consumers in Belgium, Italy and Spain see savings from switching to a dynamic tariff and heat pump adoption, while these dramatically increase costs in Hungary.**

**Belgium**

Belgium has seen significantly lower dynamic tariff rates in the winter of 2022-2023 relative to static tariff rates, resulting in savings for those on dynamic tariffs, especially for heat pump and EV owners. Switching to a heat pump from a gas boiler and optimising the timing of demand can both save money, but these savings are less than the saving from adopting the dynamic tariff.

**Italy**

Higher electricity costs for static tariff customers in the winter of 2023 relative to dynamic tariff customers is responsible for absolute savings in switching to a dynamic tariff, even with low flexibility in demand. The savings are more modest though, partly due to air conditioning demand in the summer when the dynamic tariff has been more expensive. Although all countries have seen greater relative benefit for EV owners, this is particularly true in Italy where the relative savings are approximately double those of houses without an EV. Italy also sees the greatest relative savings from heat pump adoption of the countries assessed.

**Spain**

In Spain our assessment showed savings for both heat pump adoption and switching to a dynamic tariff. The greatest savings from switching to a dynamic tariff are seen here. Unlike Belgium and Italy these savings are less due to seasonal differences in tariff prices: our modelled static tariff is consistently more costly than the dynamic tariff average.

**Hungary**

In Hungary static price electricity tariffs have been heavily subsidised by the government, while dynamic tariffs remain pinned to wholesale prices. Consequently, the energy bill for a consumer on a dynamic tariff is more than double for the period in some cases. Persistently low gas prices have also meant that a heat pump is more costly to run than a gas boiler. Flexing demand does not come close to compensating for these extra costs.

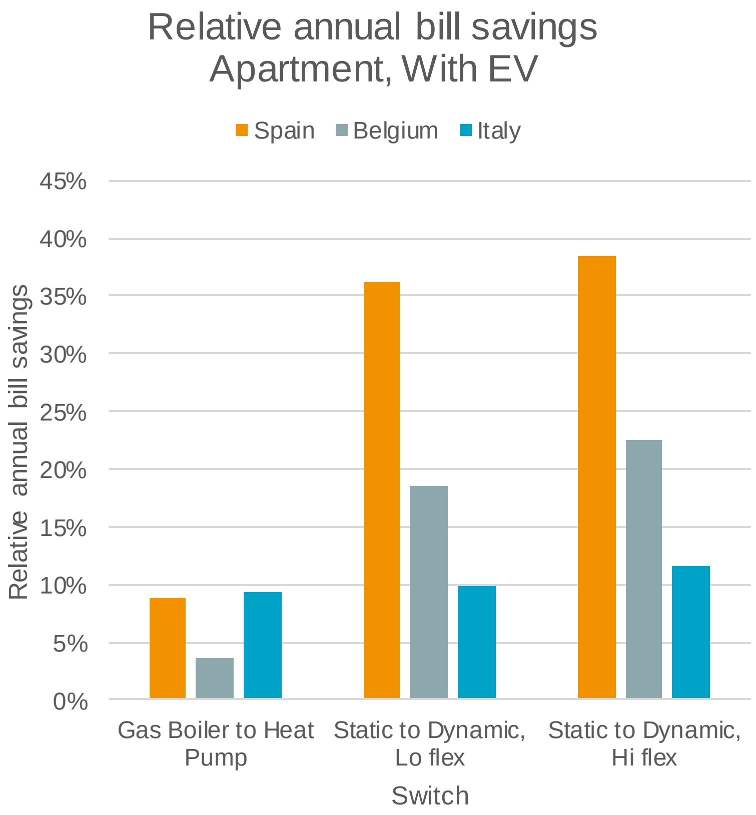
# *Overview*

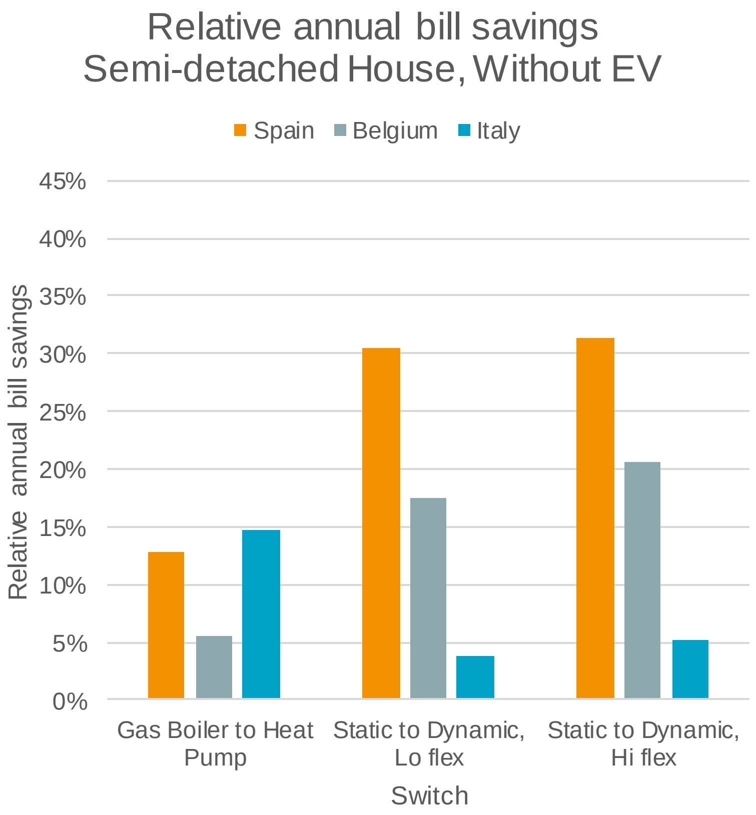
## Relative savings: Spain, Belgium and Italy

**Spain, Belgium and Italy all see savings, but vary considerably by country**

**An apartment with an EV sees the greatest relative benefit from switching to a dynamic tariff.**

**A semi-detached house without an EV sees the least relative benefit from switching to a dynamic tariff.**



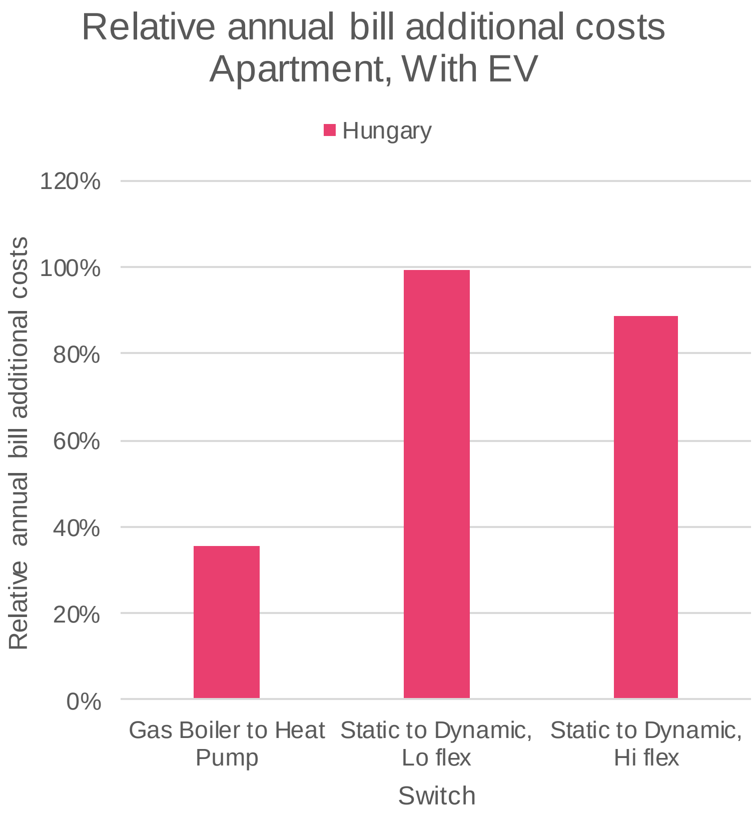
# *Overview*

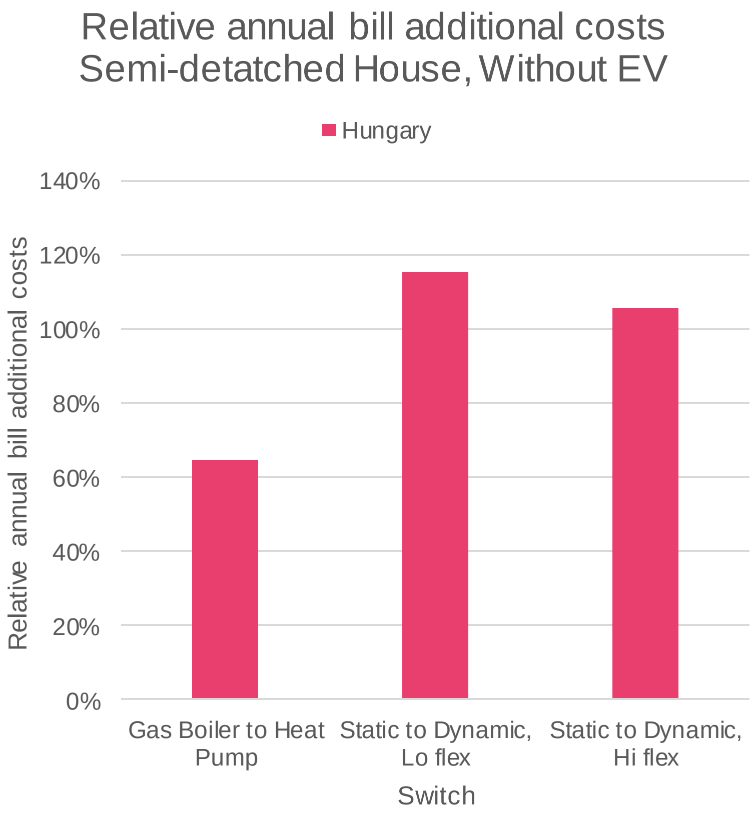
## Relative additional costs: Hungary

**In Hungary, a subsidised energy price cap makes dynamic tariffs linked to wholesale prices uncompetitive**

**An apartment with an EV sees the greatest relative benefit from switching to a dynamic tariff.**

**A semi-detached house without an EV sees the least relative benefit from switching to a dynamic tariff.**



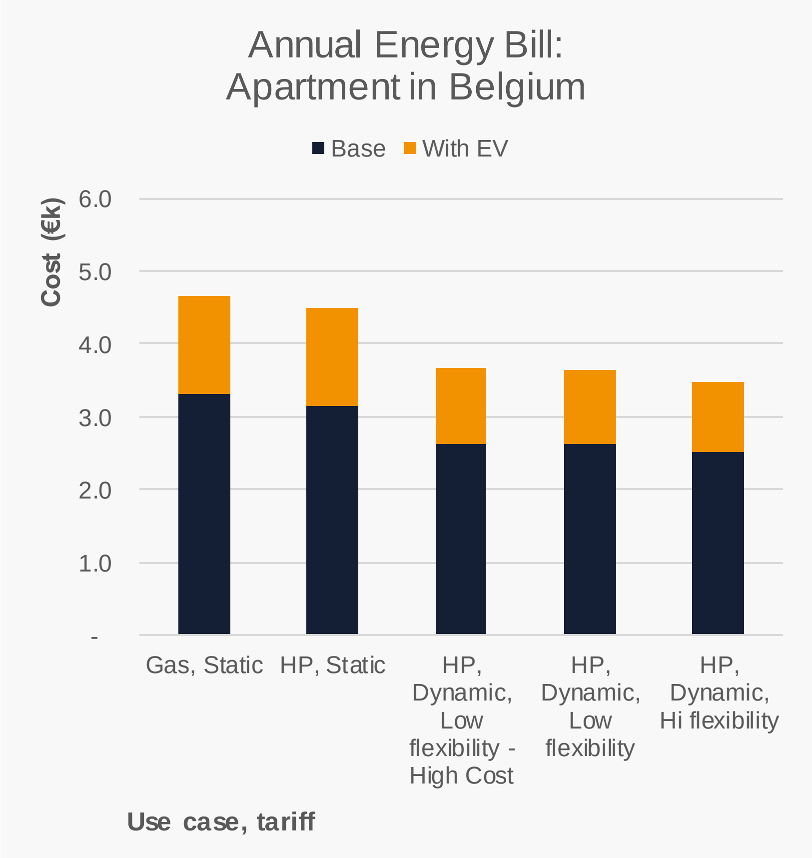



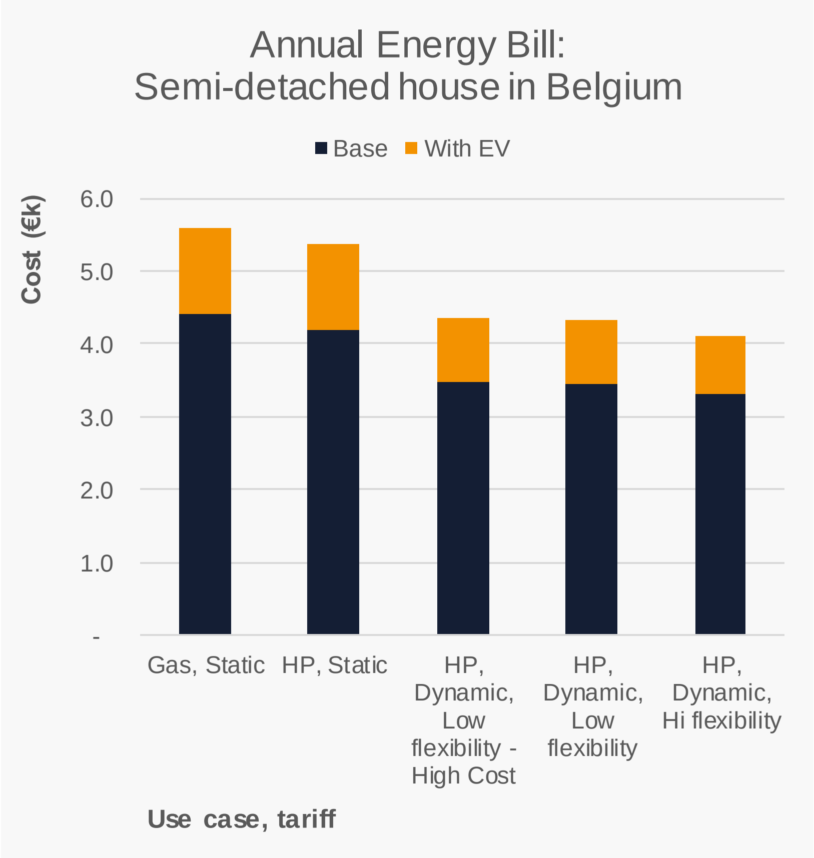
# Belgium

# *Results: Belgium*

## Average Annual Bill

**Savings of €540 - €1,240/year for switching to a dynamic tariff, and savings of €170 - €240/year for switching from a condensing gas boiler to heat pump**

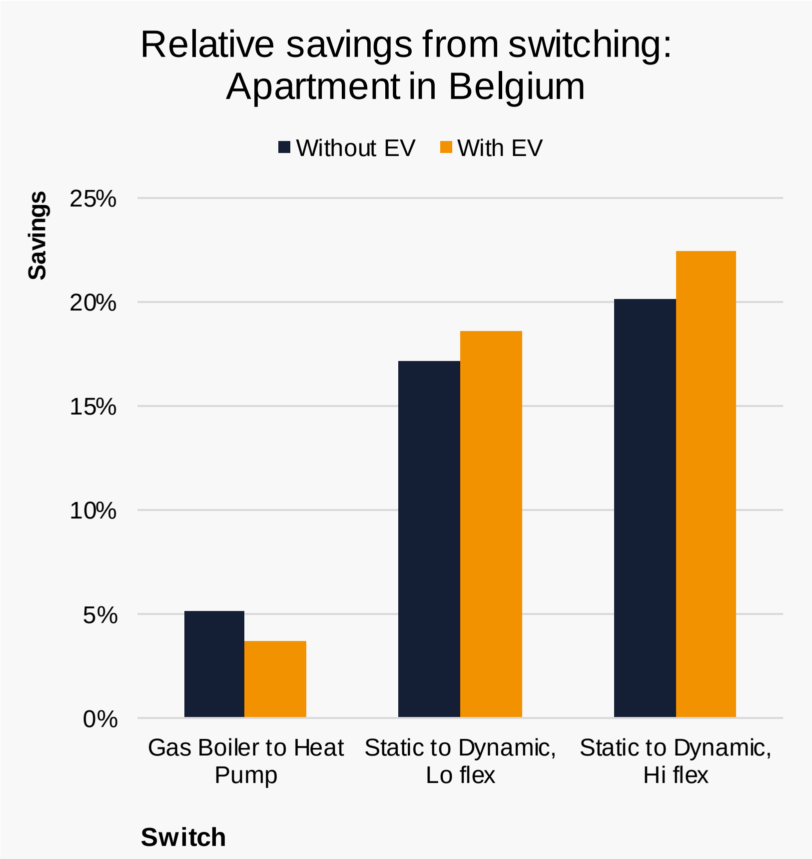


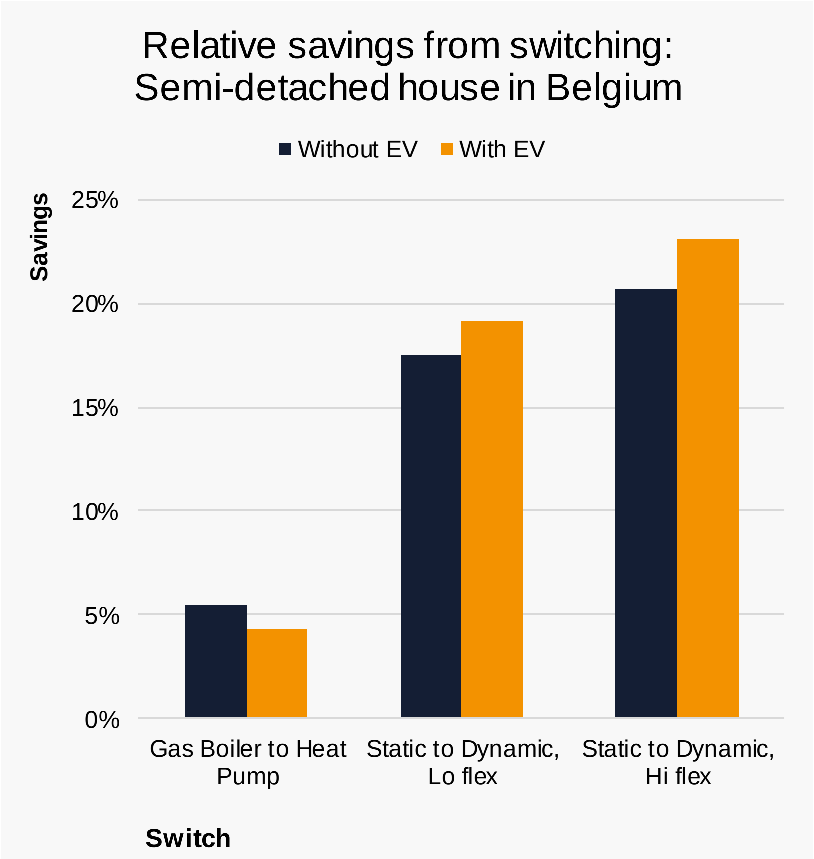



# *Results: Belgium*

## Average Relative Savings

**Switching to a dynamic tariff saved up to 23% of our modelled consumers' bills in this period**

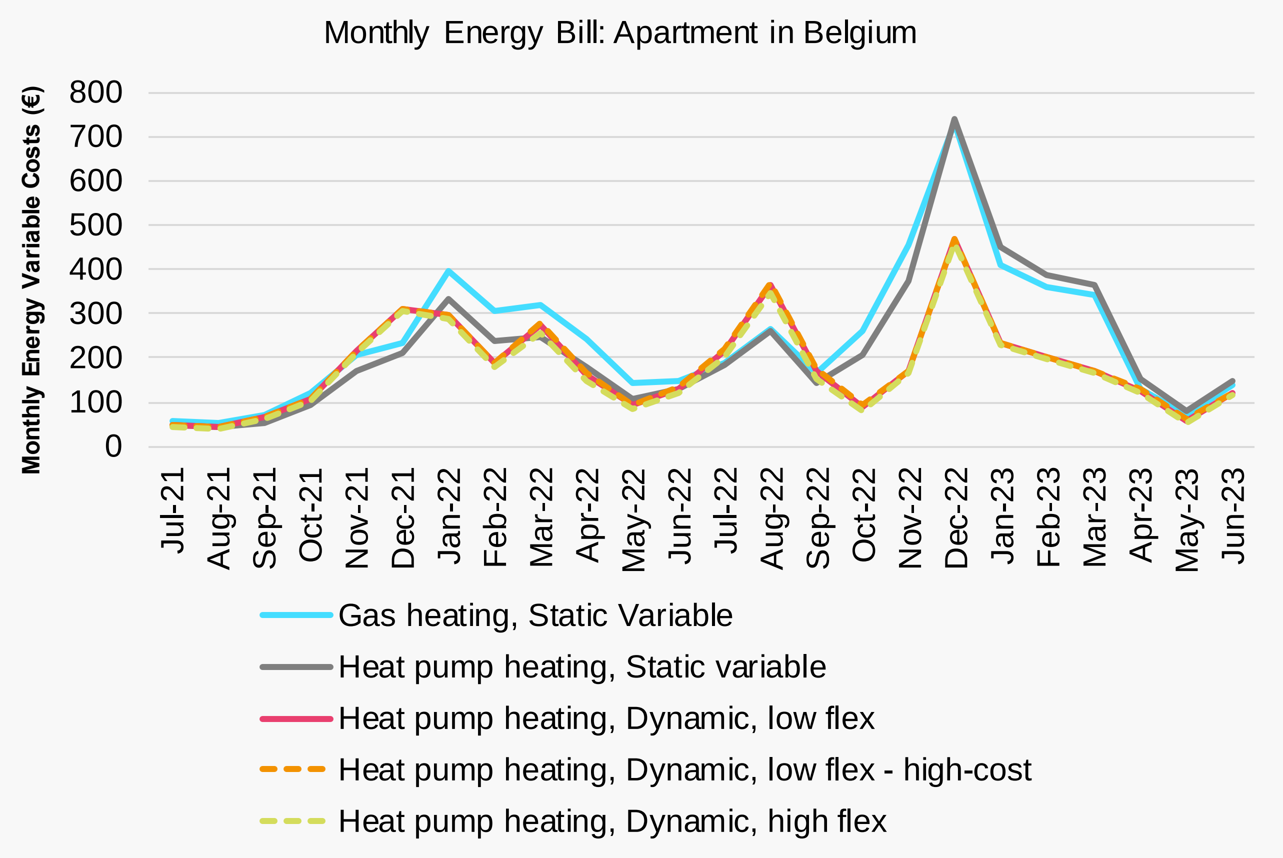


# *Results: Belgium*

## Energy Bill by Month

- Belgium has seen significantly lower dynamic tariff rates in the winter of 2022-2023 relative to static tariff rates
- The dynamic tariff modelled had higher rates earlier, in Summer 2022, however total demand at this time is significantly lower for heat pump owners in particular
- Hence overall we calculate savings for those on dynamic tariffs
- This behaviour of dynamic tariffs following rising (or lowering) prices first and static tariffs recovering costs later is expected
- A similar pattern is seen in November 2021 to March 2022
- The impact on the bill for heat pump owners will be sensitive to the timing in the year of volatility events in the energy markets

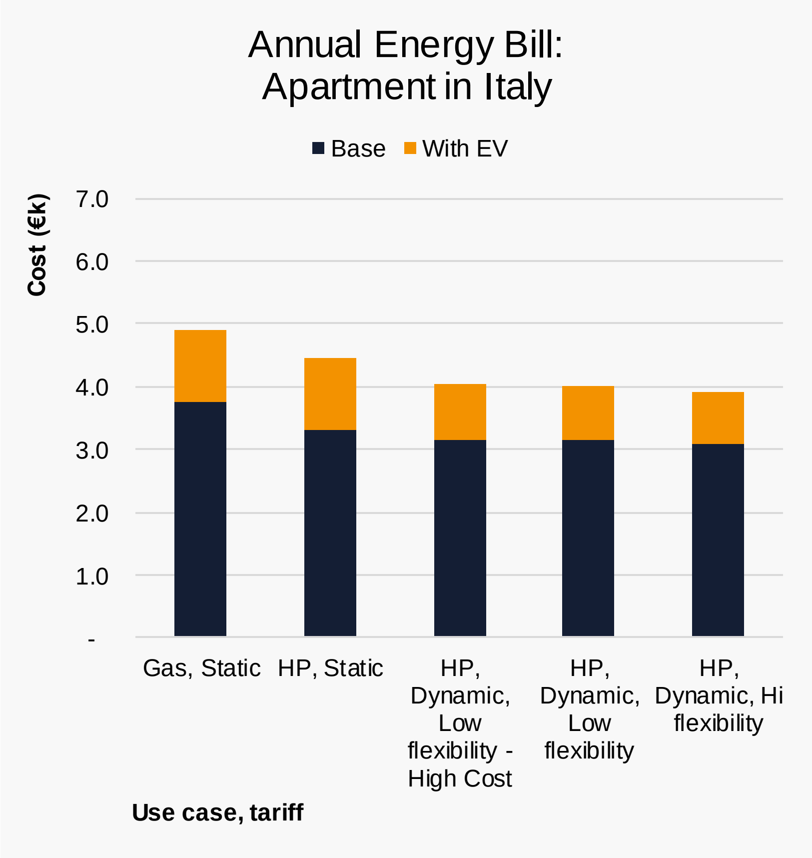


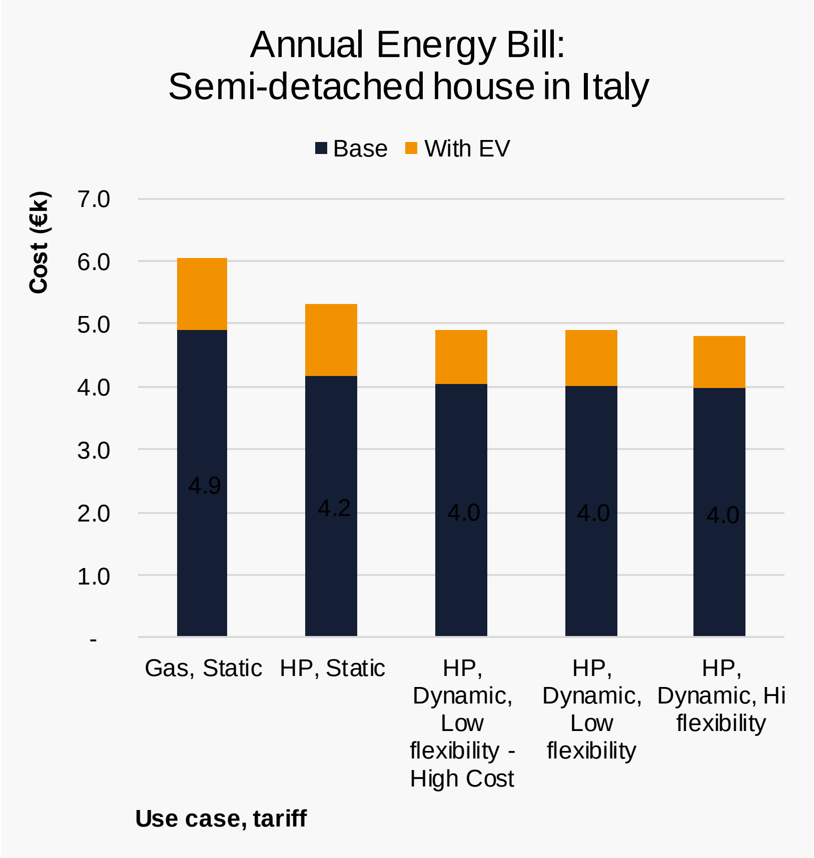
# *Italy*

# *Results: Italy*

## Average Annual Bill

**Savings of €160 - €530/year for switching to a dynamic tariff, and savings of €460 - €720/year for switching from a condensing gas boiler to heat pump**

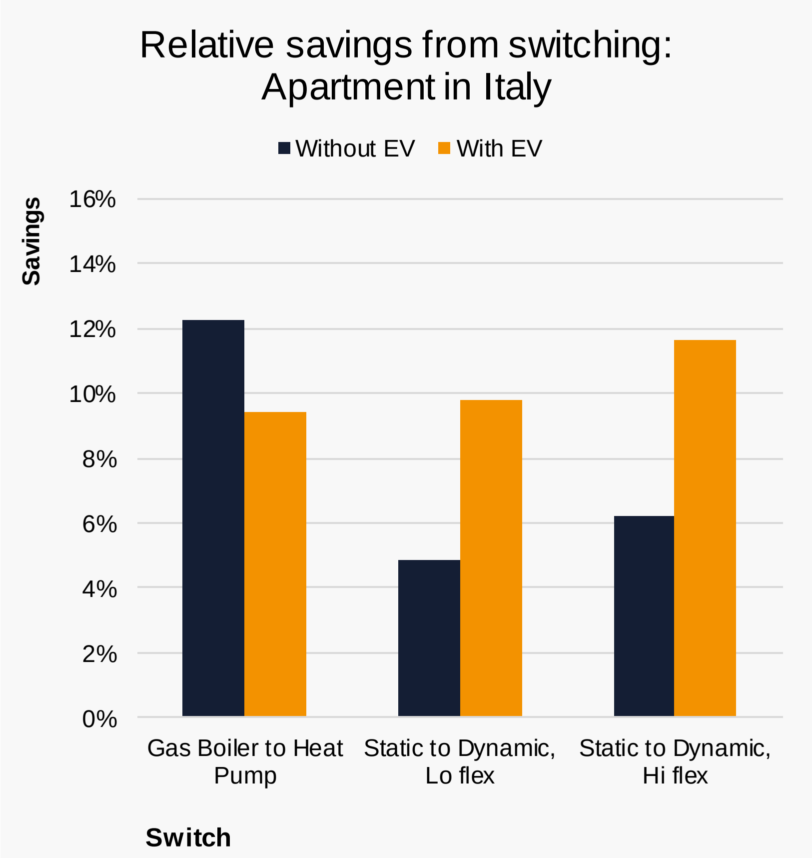


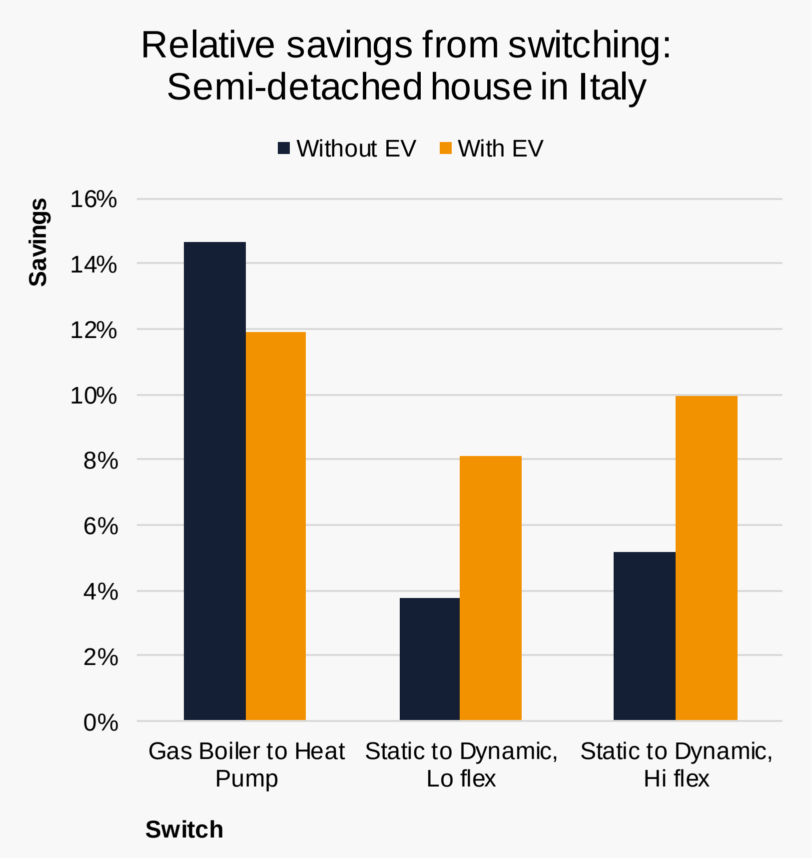



# *Results: Italy*

## Average Relative Savings

**EV owners stand to make approximately double the relative savings on their energy bill by adopting a dynamic tariff.**

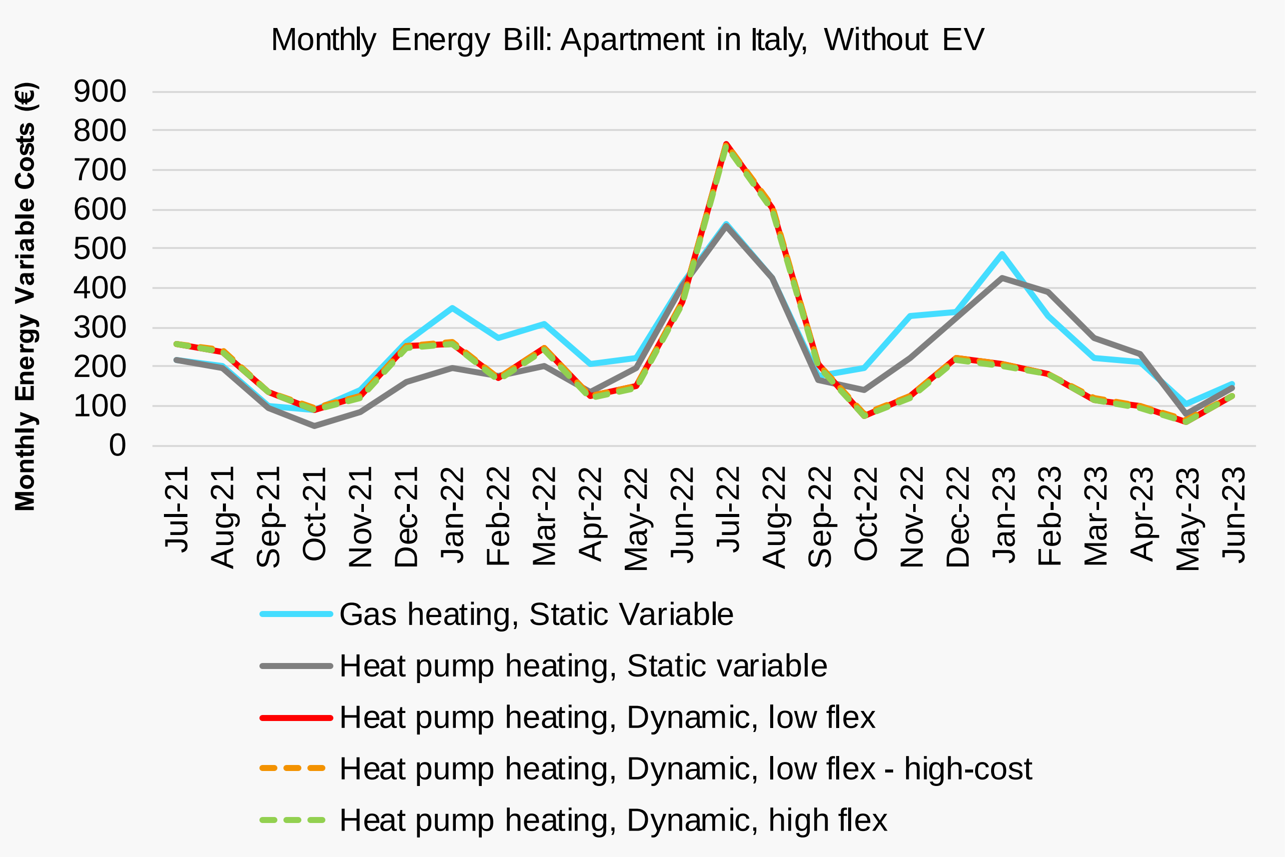


# *Results: Italy*

## Energy Bill by Month

- Higher electricity costs for static tariff customers in the winter of 2023 relative to dynamic tariff customers is responsible for absolute savings in switching to a dynamic tariff, even with low flexibility in demand
- The impact is less in this case because of greater summer air conditioning demand
- The higher costs in the summer of 2022 for dynamic tariff consumers therefore partly offsets the savings in the winter of 2022-23

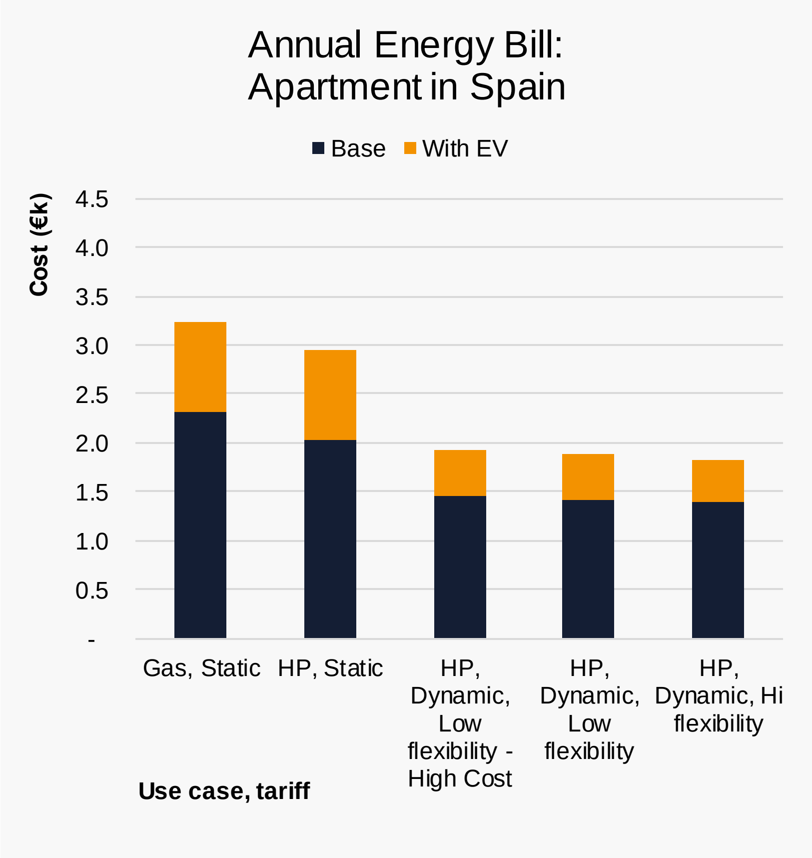


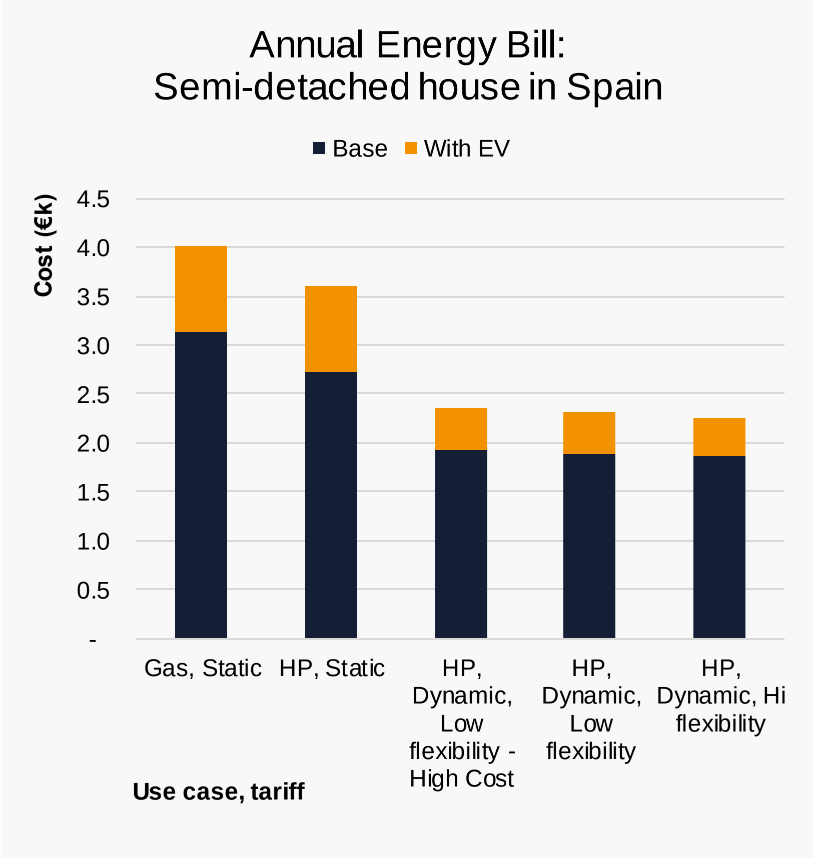
# *Spain*

# *Results: Spain*

## Average Annual Bill

**Savings of €620-1,350/year for switching to a dynamic tariff, and savings of €280 - €400/year for switching from a condensing gas boiler to a heat pump**

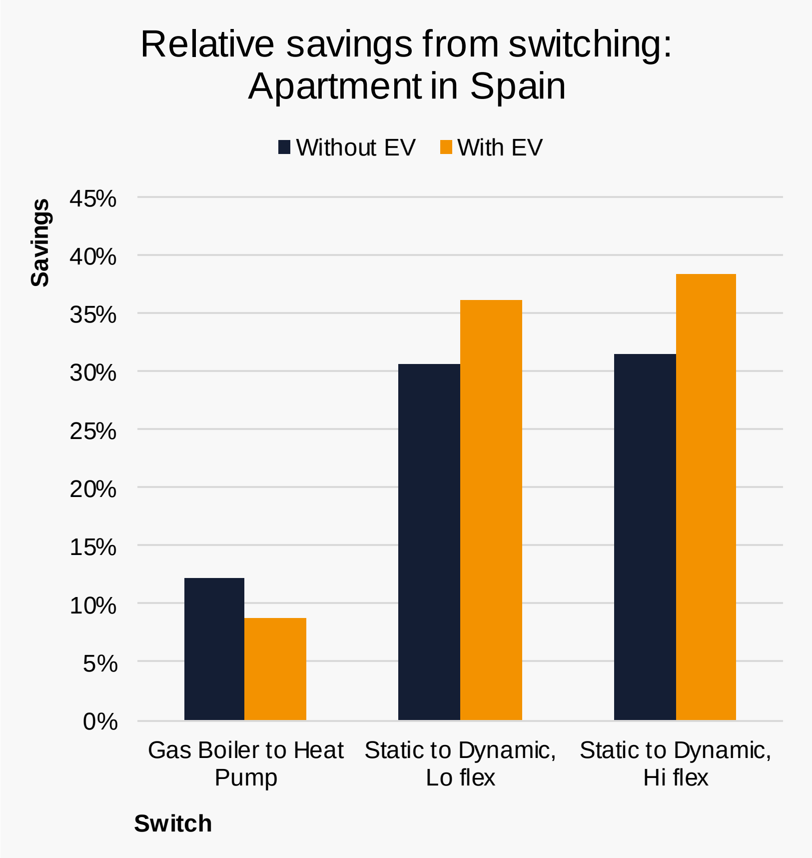


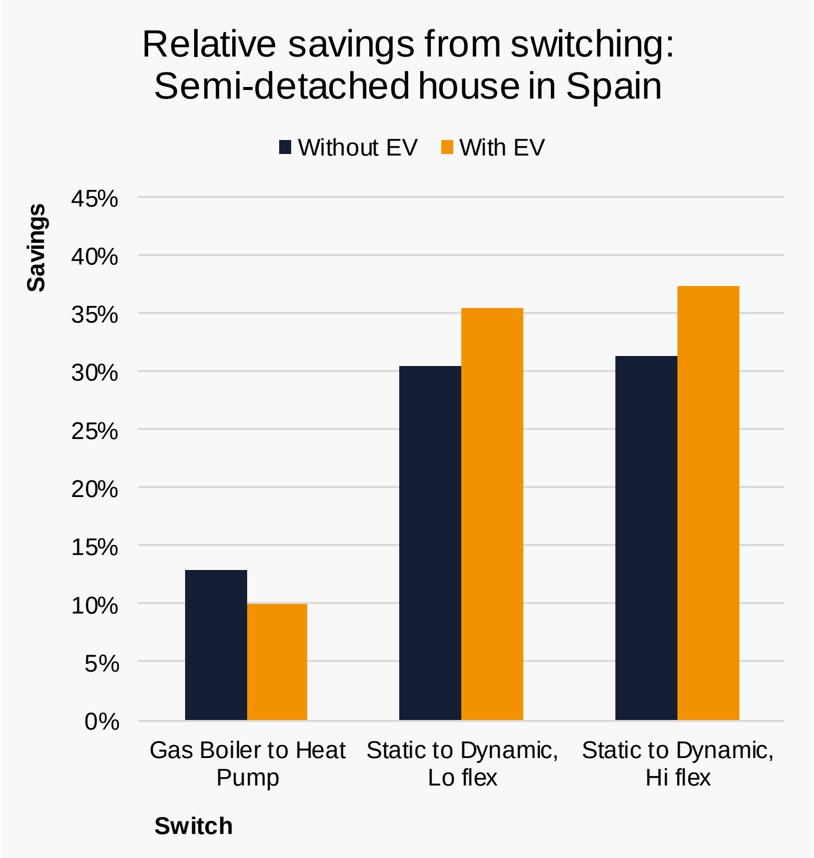



# *Results: Spain*

## Average Relative Savings

**Switching to a dynamic tariff saved up to 38% of our modelled consumers' bills in this period**

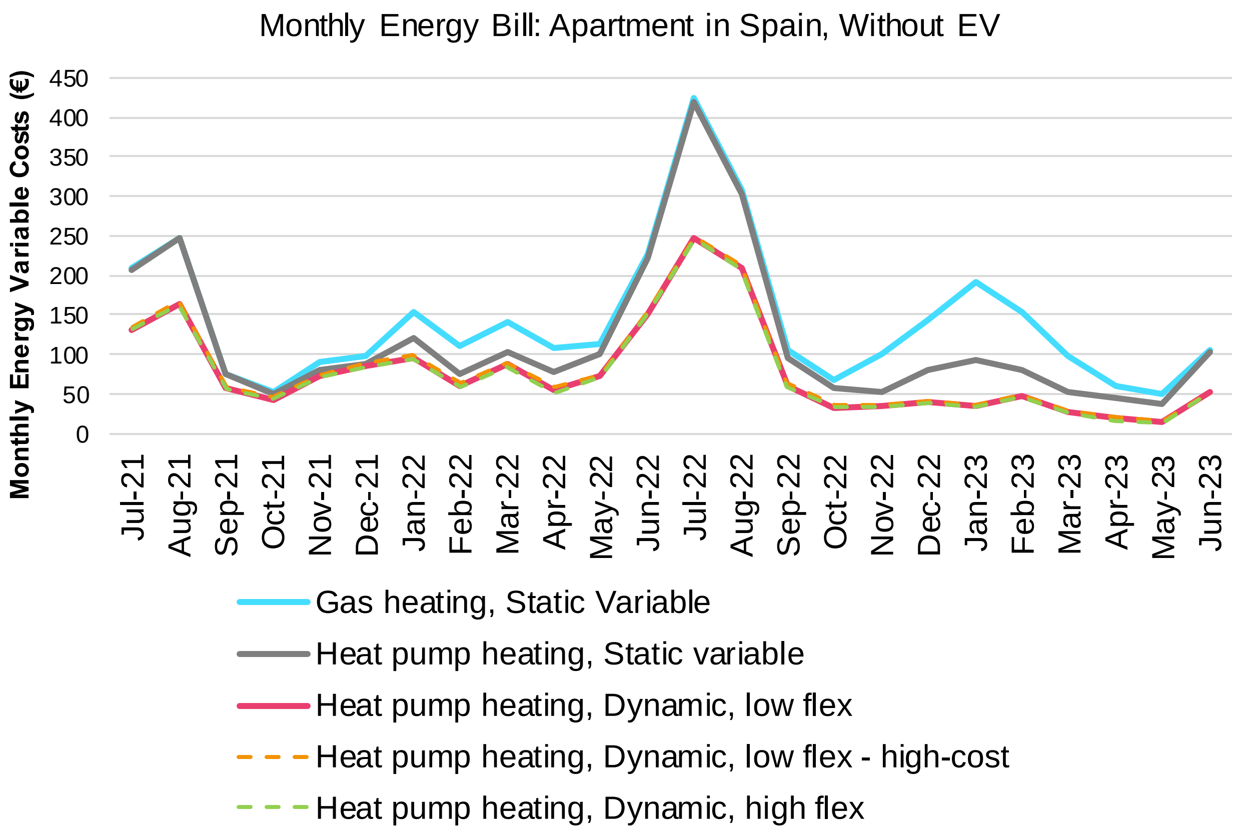


# *Results: Spain*

## Energy Bill by Month

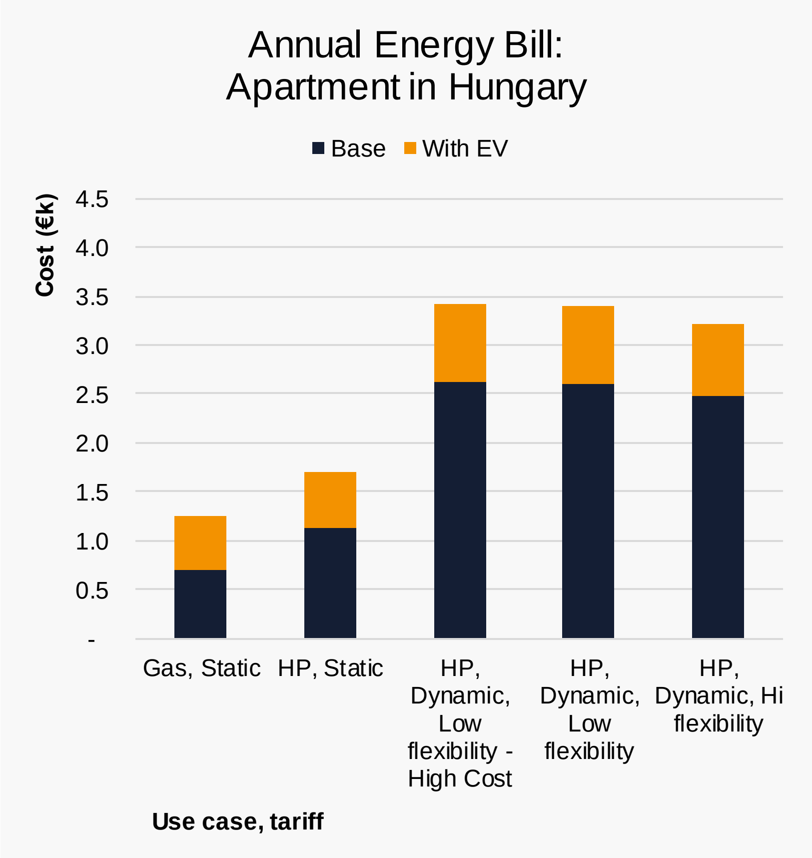
- Bills based on Static Variable Gas Tariff shows significant variation, with the highest costs recorded during the summer of 2022
- Heat pump energy costs are lower than gas heating from January 2022 onwards
- The overall energy bill based on Dynamic Tariffs has decreased when comparing the winter of 2021/22 to the winter of 2022/23
- Price for using heat pump on Static Variable Tariff seems consistent with exception for 2022 summer

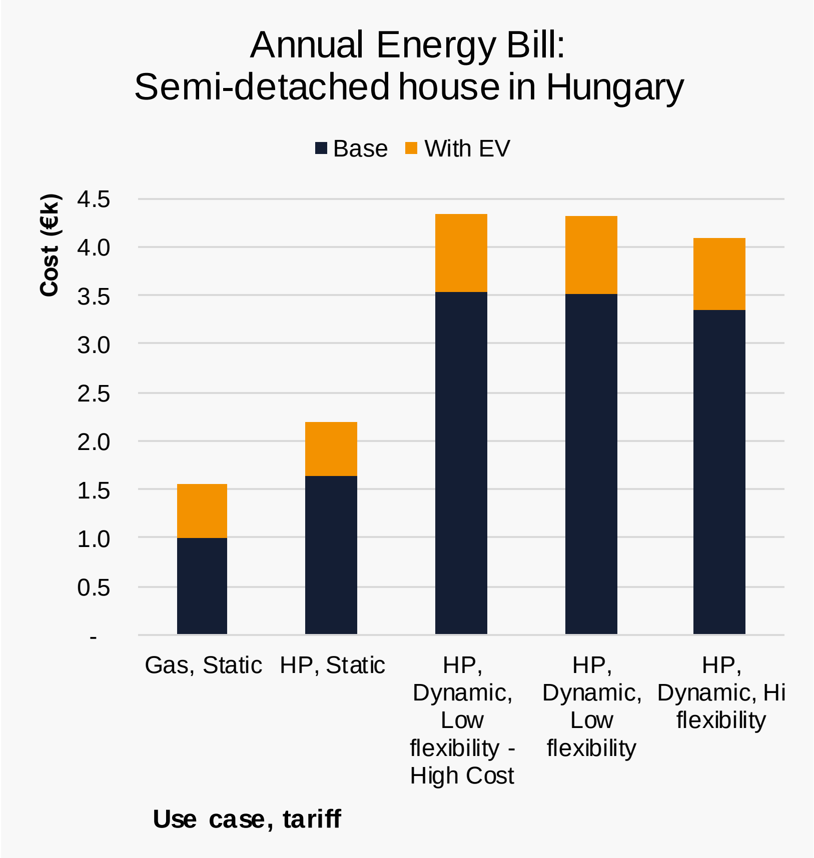


# *Hungary*

# *Results: Hungary*
## Average Annual Bill

**Dynamic tariffs do not lead to savings—instead, they result in additional costs between €1,460 and €1,900/year for our modelled consumers**

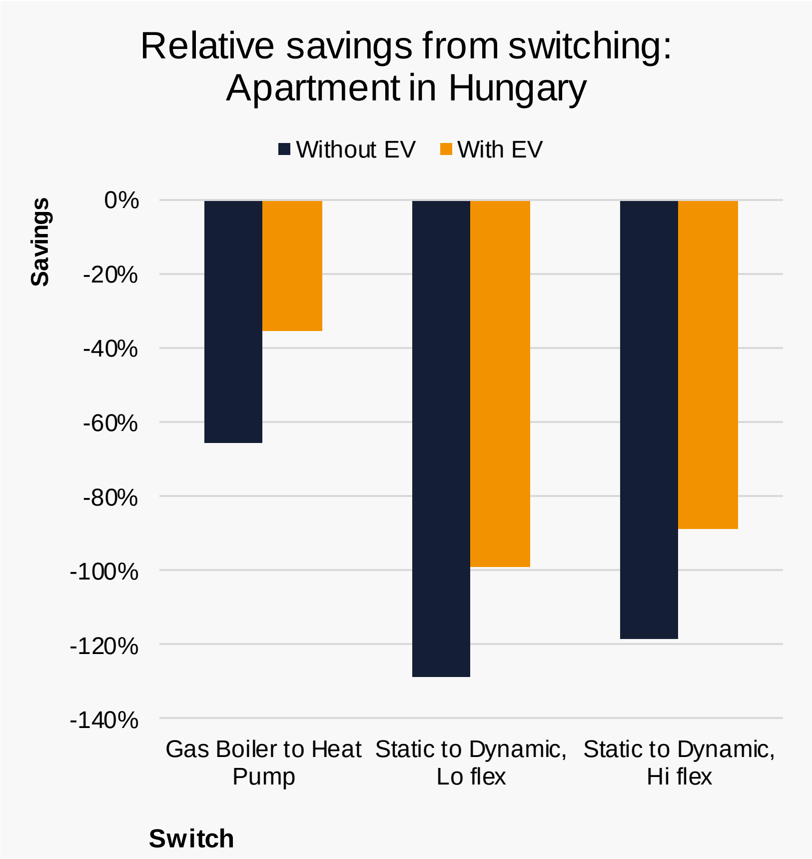


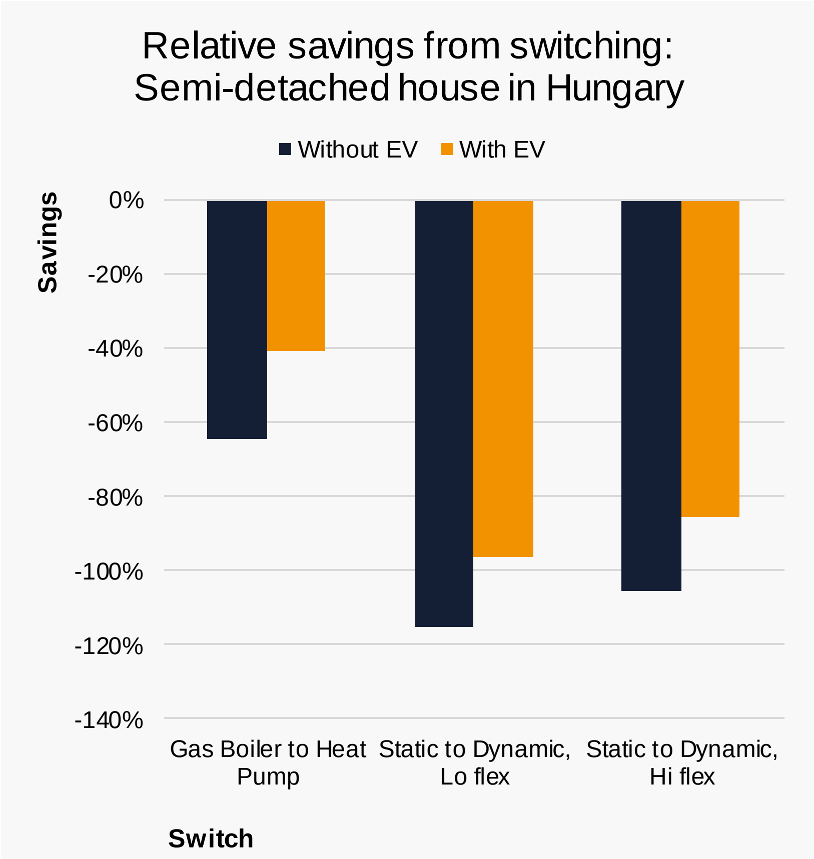



# *Results: Hungary*

## Average Relative Savings

**Both switching to a heat pump and switching to a dynamic tariff are expected to be more expensive for consumers in Hungary**

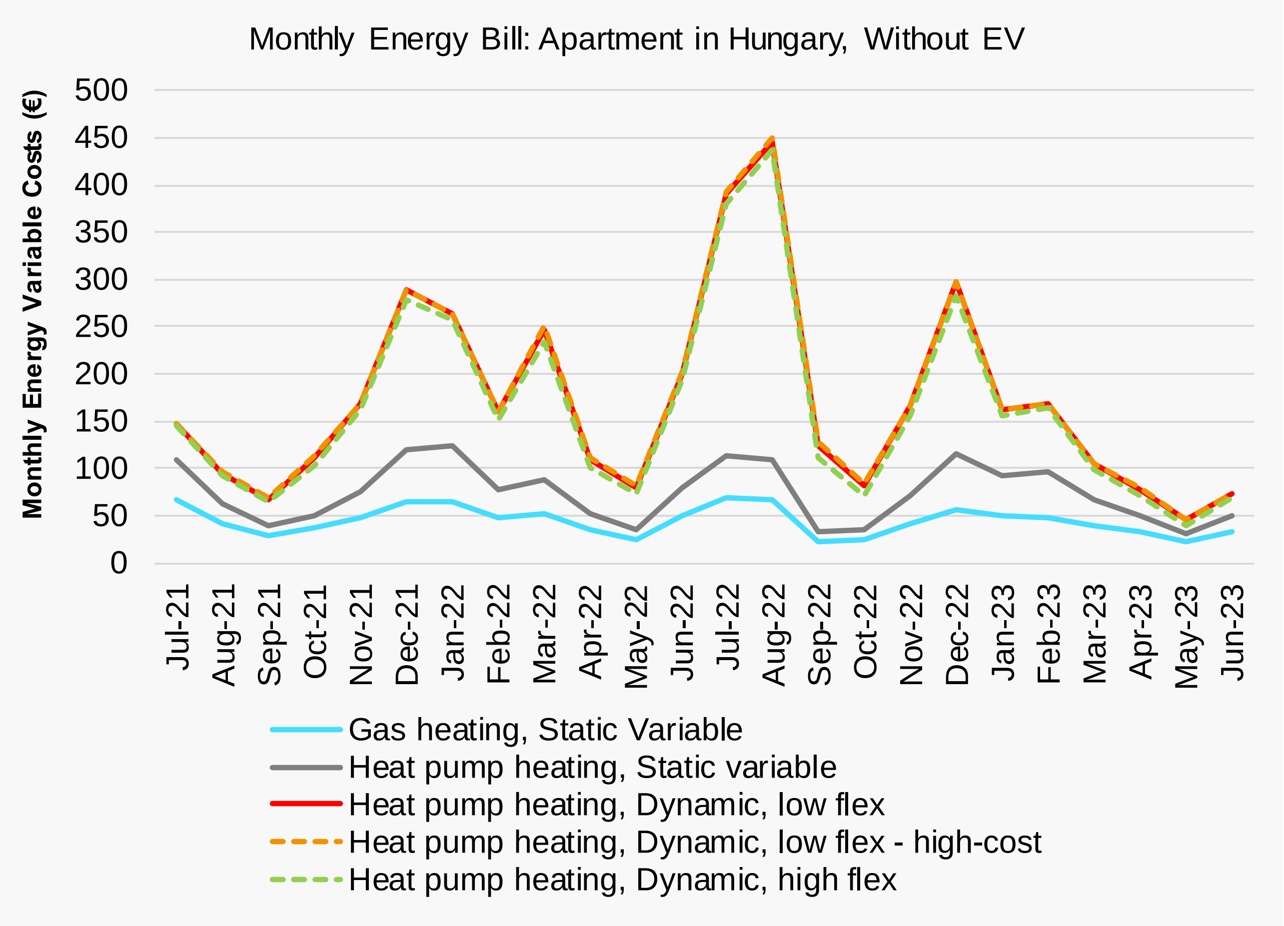


# *Results: Hungary*

## Energy Bill by Month

- In Hungary fixed price electricity tariffs have been heavily subsidised by the government, while dynamic tariffs remain pinned to wholesale prices
- Consequently, the energy bill for a consumer on a dynamic tariff is more than double for the period in some cases
- Persistently low gas prices have also meant that a heat pump is more costly to run than a gas boiler
- Flexing demand does not come close to compensating for these extra costs



# *Appendix - Methodology*

# *Our approach*

## Methodology by device

**Daily demands are aggregated by month to calculate costs for static variable tariffs.**

**Daily demands are used to scale hourly profiles to calculate costs for dynamic tariffs.**

| Load/Device | Daily demand approach | Daily demand source | Hourly profile approach | High flexibility approach |
|---|---|---|---|---|
| EV | Constant daily demand, downscaled to reflect less than daily usage | LCP Delta EV service | Constant demand for on duration | Cheapest consecutive hours chosen each day |
| Heat Demand | Annual heating demand in kWh/m$^2$ split between space heating and water heating. Daily space heating scaling with heating degree days; daily water heating assumed constant. | Annual heating demand from Heat Roadmap Europe. Country temperature data from European Environment Agency. | See heat pump and gas boiler | See heat pump and gas boiler |
| Heat Pump | Daily heat demand met with daily-varying heat pump efficiency, calculated from daily average temperature. | Temperature dependence of heat pump efficiency taken from National Grid (UK) Peak Heat project | Taken from National Grid (UK) Peak Heat project | Load allowed to vary within constraints |
| Gas Boiler | Daily heat demand met with constant gas boiler efficiency | Gas boiler efficiency from Trinomics paper | Not needed (not assessed for dynamic tariff) | Not needed (not assessed for dynamic tariff) |
| Air conditioning | Determined from total annual demand per country in W/m$^2$ of dwelling floor area and monthly demand profile, calculated from cooling degree days per country. | Heat Roadmap Europe | Taken from REMODECE project | Load allowed to vary within constraints |
| Electric room heater | Constant daily demand in winter only | Trinomics paper | Constant demand for on duration | Not flexible |
| Washing machine and dishwasher | Constant daily demand, downscaled to reflect less than daily usage | Trinomics paper | Constant demand for on duration | Cheapest consecutive hours chosen each day |
| 13 others | Constant daily demand | Trinomics paper | Constant demand for on duration | Not flexible |

# *Our approach*

## About our sources

**National Grid - Peak Heat Project** (Link)
A Network Innovation project by the distribution network operator for the Midlands, South West and Wales in the UK that looked at the impact of heat pumps on grid demand, conducted with LCP Delta. From this source we use intra-day heat pump demand profiles and heat pump efficiencies.

**Heat Roadmap Europe** (Link)
An EU-funded project to develop low-carbon heating and cooling strategies for Europe. From this source we use national average residential dwelling heating and cooling annual demands.

**Residential Monitoring to Decrease Energy Use and Carbon Emissions in Europe (REMODECE)** (Link)
A European Innovation Ecosystems-funded academic project that has monitored electricity demands in over 100 households in 12 European countries. From this source we use intra-day air conditioning demand profiles.

**Benefits of Ecodesign for EU Households 2023 Update, *'Trinomics paper'*,** (Link)
A valuation of the consumer savings due to EU Ecodesign and Eco labelling requirement, commissioned by BEUC from Trinomics. From this source we take annual demands of appliances and gas boiler efficiency, assuming best available technology.

# *Our approach*

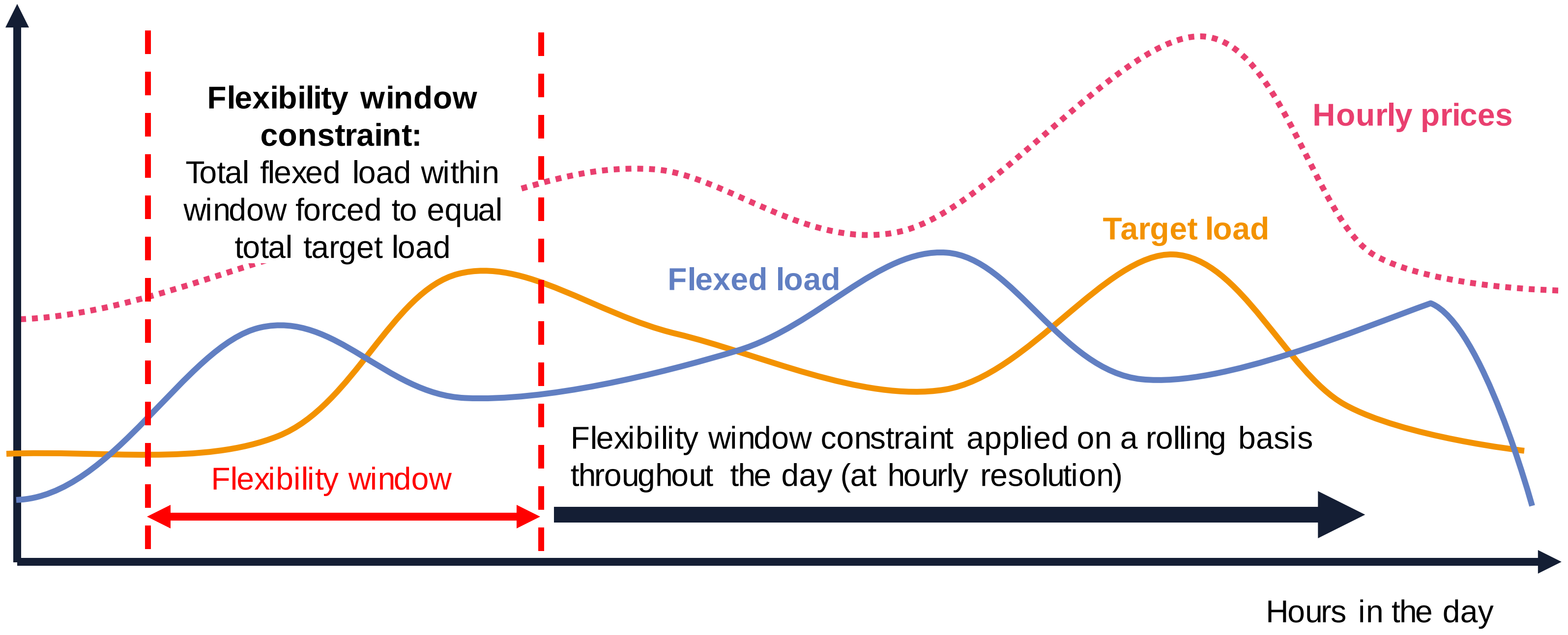
## Modelling flexible use of heat pumps and air conditioning

**This methodology is completed independently for air conditioning and heat pump demand for the 'high flexibility' use case scenario.**

### For heating and cooling we optimise a flexible demand profile daily

Our approach can be summarized by three steps:

1. A target load profile is defined – representing the typical demand from the asset without flexible use
2. Constraints are defined that require the flexed load profile to sum to the target load profile on a short-term basis, e.g. 5 hours – this ensures that building would remain at a similar temperature, while not implementing a full building physics model
3. The flexed load profile is optimised within the constraints to minimize the total cost for the day



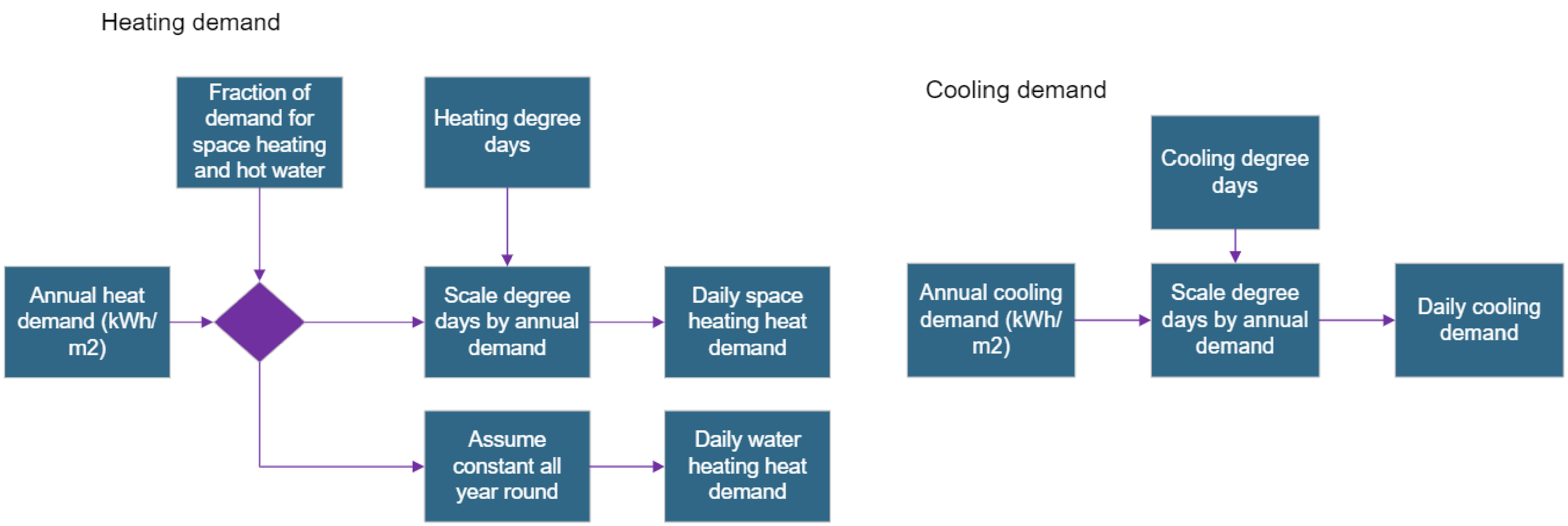

  

# *Our approach*

## Daily demand for space heating and cooling

### The following steps describe how we calculate daily heating and cooling demand

1. Average annual heat and cooling demand per m[2] of floor area, by country, are taken from the Heat Roadmap Europe project
2. Heat demand is split between space heating and water heating demand using ratios, by country, also from the Heat Roadmap Europe project
3. Daily space heating and cooling demand is calculated using the fraction of annual heating degree days and cooling degree days falling on a given day – degree days are calculated from European Environment Agency average national temperature data using EU standard baseline temperatures



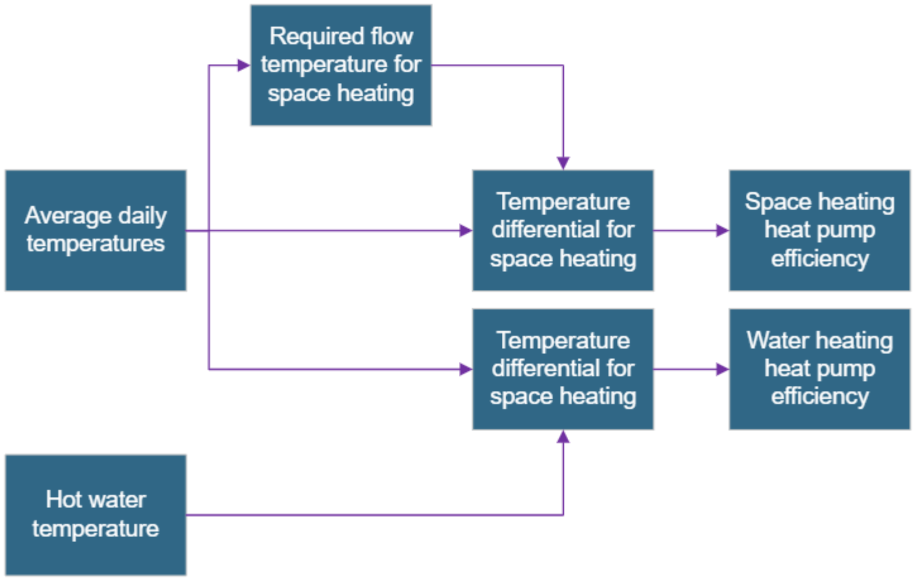
# *Our approach*

## Heating efficiency

### Heating efficiency varies by technology

- Gas boiler and air conditioning unit efficiency is assumed to be constant
- Heat pump efficiency is calculated from the temperature difference between the output temperature and the outside temperature. The output temperature:
  - For space heating increases as outside temperature decreases (to put out more heat)
  - For water heating is assumed to be a constant 60ºC

Heat pump efficiency

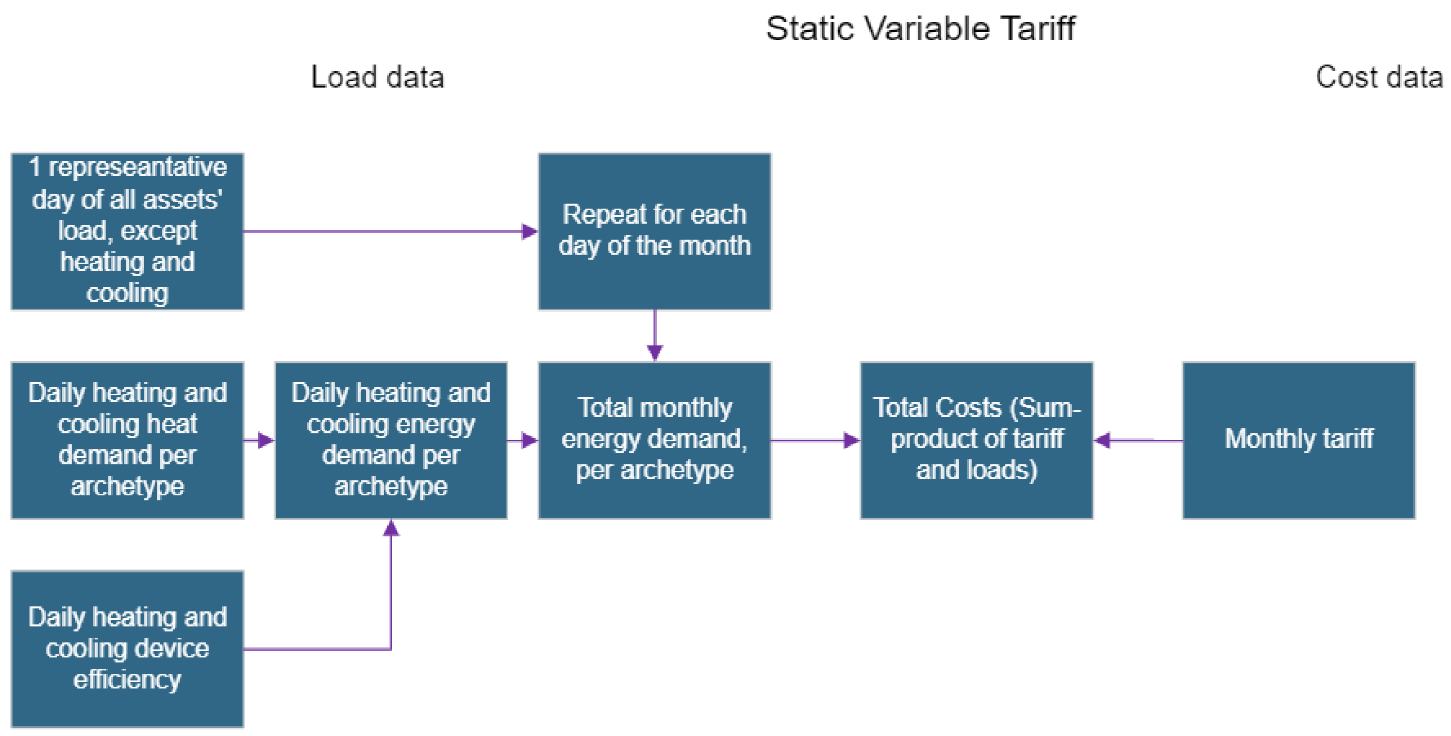


# *Our approach*

## Static variable tariff

**This process is followed for each dwelling archetype and for both condensing gas boiler and heat pump as the primary heat source**

Heating and cooling are considered separately from other loads to allow seasonal variation.



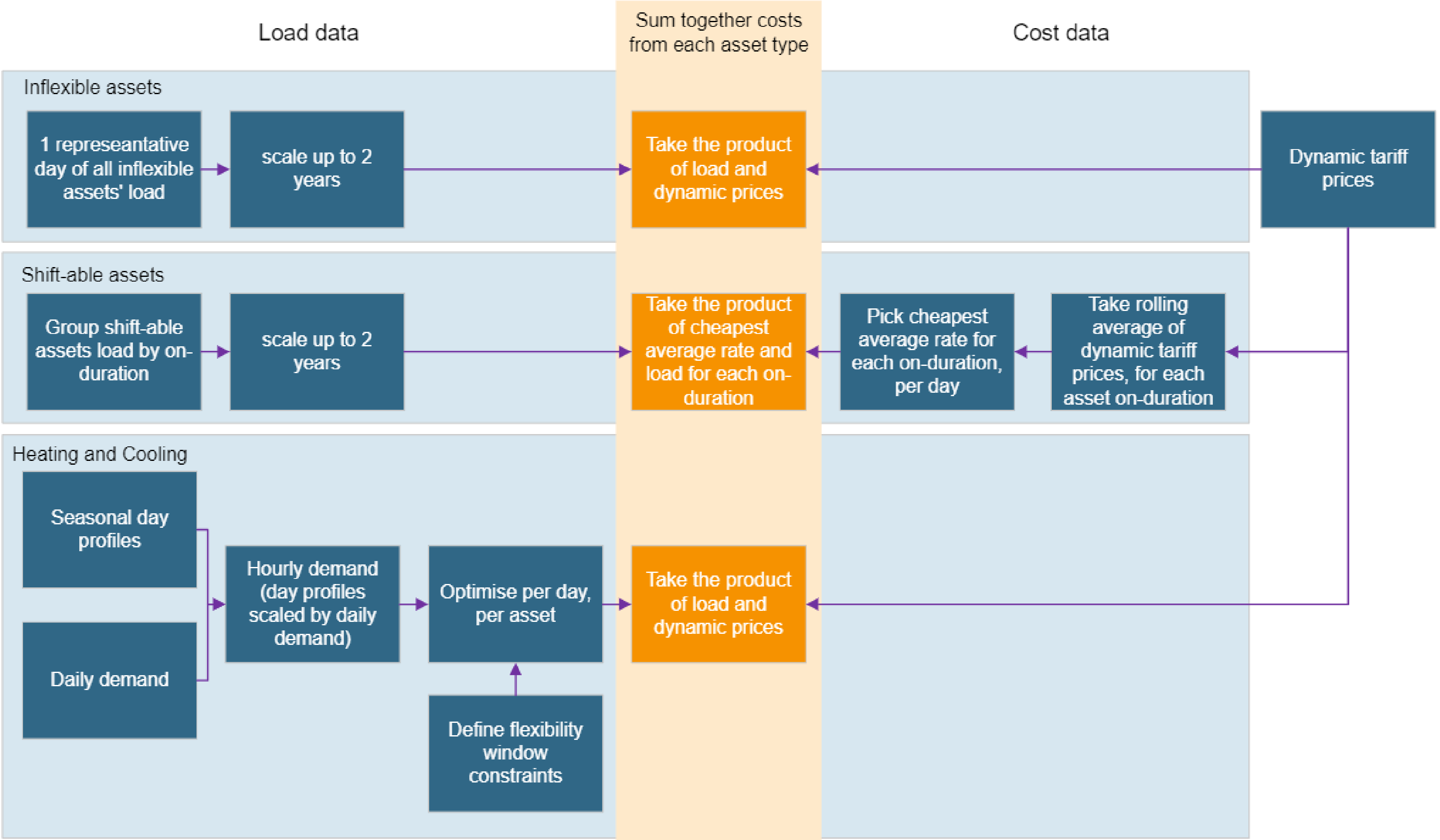
# *Our approach*

## Dynamic tariff with flexible use

**Inflexible assets are operated at the same time every day.**

**Shift-able assets use the cheapest average rate for the number of consecutive hours they are operated for.**

**Heating and cooling profiles are optimised daily, while preserving total demand.**



# *Appendix – Key Inputs*

# *Demand from Devices*

Devices type, true power, stock per household from Trinomics, EV data from LCP Delta EV Charging Service

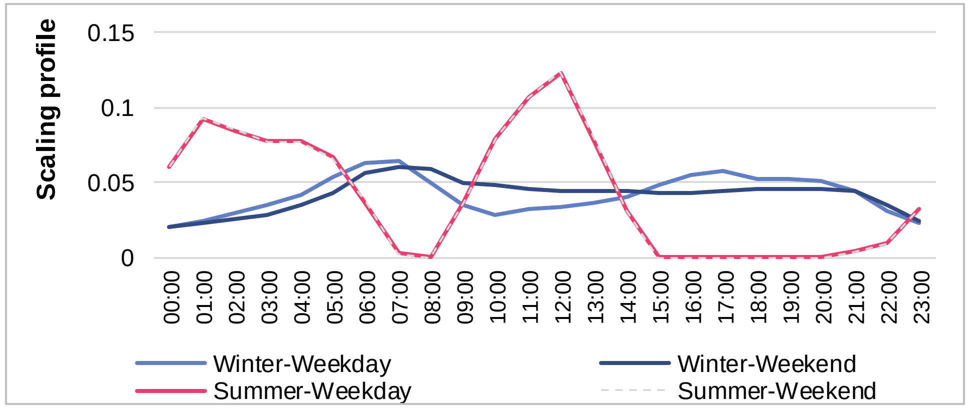
| Device name | Flexible scheduling? | Stock per household | Annual energy use (kWh) | True usage duration (hours) | Rounded-up usage duration (hours) | Daily average power with rounded-up duration (W) | Default/low-cost high-flex start-time | High-cost/low-flex start-time |
|---|---|---|---|---|---|---|---|---|
| Electric oven | Yes | 1 | 55.0 | 1.0 | 1.0 | 150.7 | 17:00:00 | 19:00:00 |
| Electric hobs | Yes | 1 | 209.0 | 0.5 | 1.0 | 572.6 | 17:00:00 | 19:00:00 |
| TV set | Yes | 1 | 67.0 | 4.0 | 4.0 | 45.9 | 18:00:00 | 18:00:00 |
| Monitor | Yes | 1 | 18.0 | 4.0 | 4.0 | 12.3 | 09:00:00 | 18:00:00 |
| Lightbulbs | Yes | 45 | 61.0 | 1.3 | 2.0 | 83.6 | 20:00:00 | 19:00:00 |
| Complex set-top box | Yes | 1 | 72.0 | 4.5 | 5.0 | 39.5 | 18:00:00 | 18:00:00 |
| Desktop PC | Yes | 1 | 14.0 | 2.0 | 2.0 | 19.2 | 09:00:00 | 19:00:00 |
| Notebook PC | Yes | 1 | 2.0 | 2.0 | 2.0 | 2.7 | 13:00:00 | 19:00:00 |
| Coffee maker | Yes | 1 | 30.0 | 1.7 | 2.0 | 41.1 | 08:00:00 | 19:00:00 |
| Tablet PC | Yes | 1 | 12.0 | 2.0 | 2.0 | 16.4 | 17:00:00 | 19:00:00 |
| Router | Yes | 1 | 37.0 | 7.0 | 7.0 | 14.5 | 08:00:00 | 17:00:00 |
| Printer | Yes | 1 | 18.0 | 0.2 | 1.0 | 49.3 | 13:00:00 | 19:00:00 |
| Vacuum cleaner | Yes | 1 | 26.0 | 1.0 | 1.0 | 71.2 | 14:00:00 | 19:00:00 |
| Fridge freezer | Yes | 1 | 111.0 | 24.0 | 24.0 | 12.7 | 00:00:00 | 00:00:00 |
| Electric room heater | Yes | 1 | 251.0 | 2.6 | 3.0 | 229.2 | 08:00:00 | 08:00:00 |
| Washing machine | No | 1 | 77.0 | 3.5 | 4.0 | 52.7 | 03:00:00 | 03:00:00 |
| Dishwasher | No | 1 | 123.0 | 2.0 | 2.0 | 168.5 | 03:00:00 | 03:00:00 |
| EV with smart charger | No | 1 | 2463.8 | 2.5 | 3.0 | 2250.0 | 03:00:00 | 03:00:00 |

# *Heating and Cooling Demand*

## Annual heating and cooling demands by country

| Country | Annual space heating and hot water demand per dwelling (kWh/m²) | Annual space cooling (A/C) demand (kWh/m²) |
|---|---|---|
| Belgium | 221 | 10.8 |
| Italy | 142 | 38.3 |
| Spain | 63 | 36.3 |
| Hungary | 155 | 19.8 |
| Source: Heat Roadmap Europe | | |

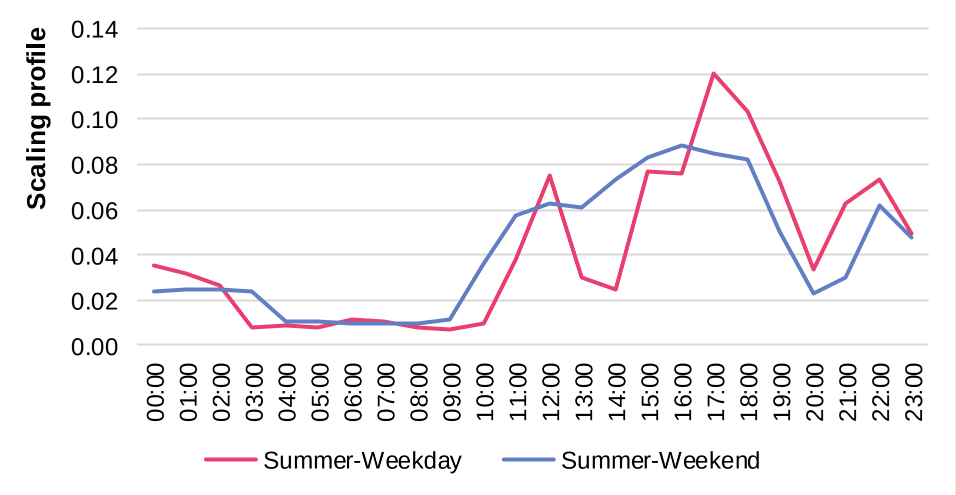
## Intraday hourly heating profiles




## Annual heating demand (this study)

| | Dwelling type | Country (kWh) | | | |
|---|---|---|---|---|---|
| | | Belgium | Italy | Spain | Hungary |
| Space heating | Apartment,70 sqm | 12,685 | 8,648 | 3,837 | 8,897 |
| Space heating | Semi-detached, 100 sqm | 18,122 | 12,354 | 5,481 | 12,710 |
| Hot water | Apartment,70 sqm | 2,785 | 1,292 | 573 | 1,953 |
| Hot water | Semi-detached, 100 sqm | 3,978 | 1,846 | 819 | 2,790 |
| A/C | Apartment,70 sqm | 756 | 2,681 | 2,541 | 1,386 |
| A/C | Semi-detached, 100 sqm | 1,080 | 3,830 | 3,630 | 1,980 |

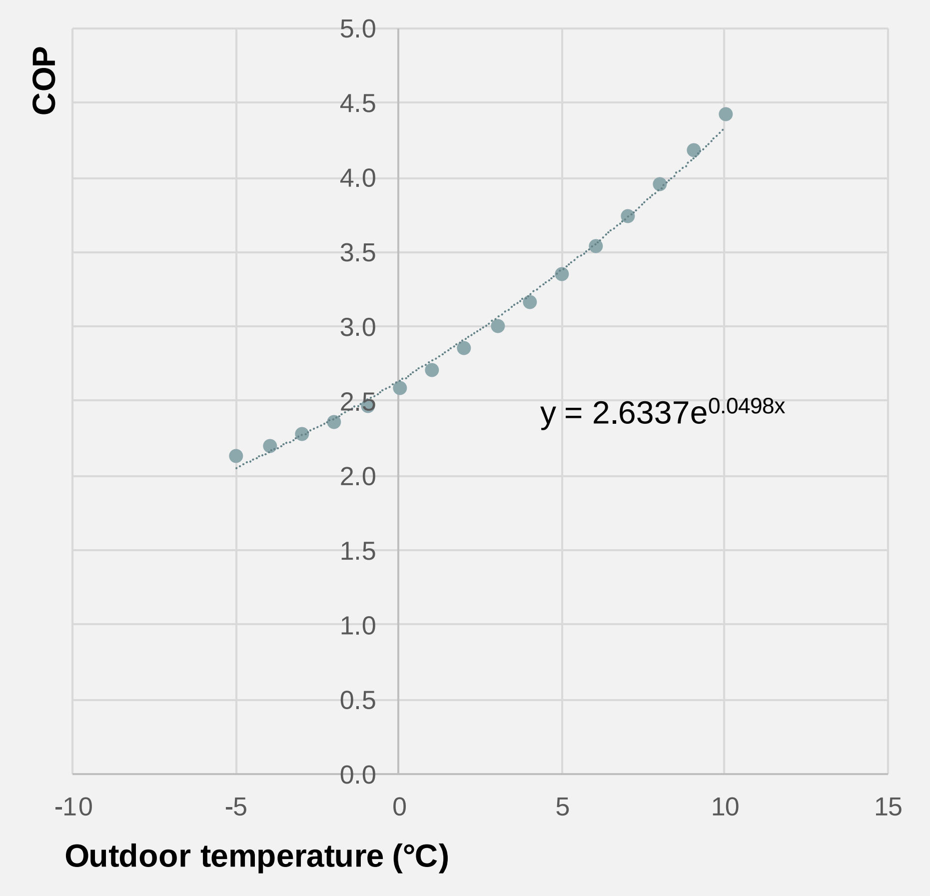
## Intraday hourly cooling profiles



# *Heat pump efficiency*

Calculated as a function of outdoor temperature based on lap COPs and MCS findings

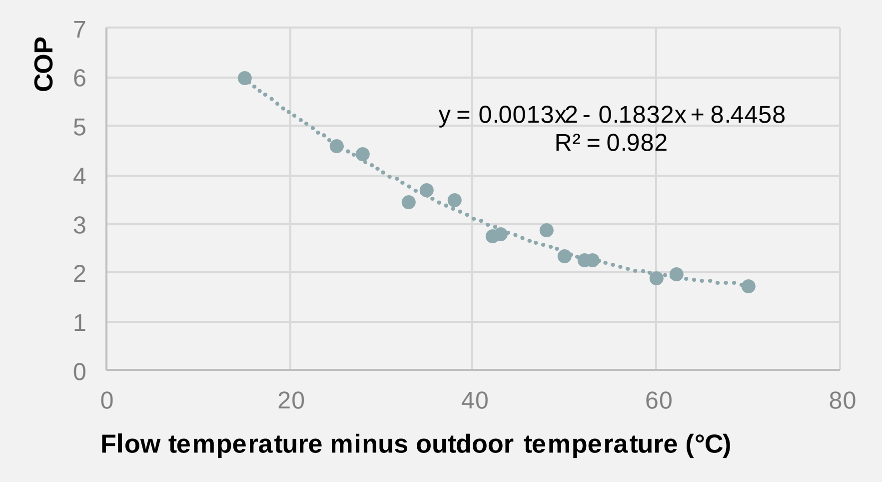
## Heat pump efficiency for space heating




## Heat pump efficiency for hot water

Heat pump efficiency for hot water is calculated based on formula:
COP = a * (ΔT)^2 + b * (ΔT) + c

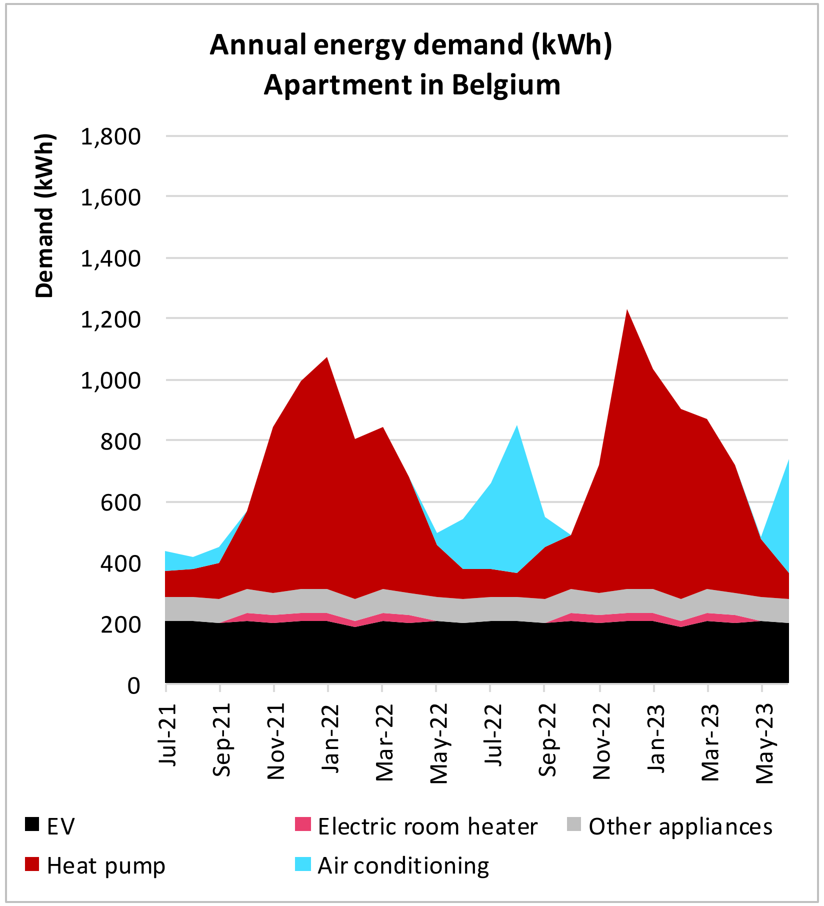
| Coefficient | Value | Remarks |
|---|---|---|
| a | 0.0013 | Lab HP COP |
| b | -0.1832 | Lab HP COP |
| c | 8.4458 | Lab HP COP |
| ΔT | Varies | Difference between the hot water output temperature (set as 60 °C) and the average outdoor temperature |



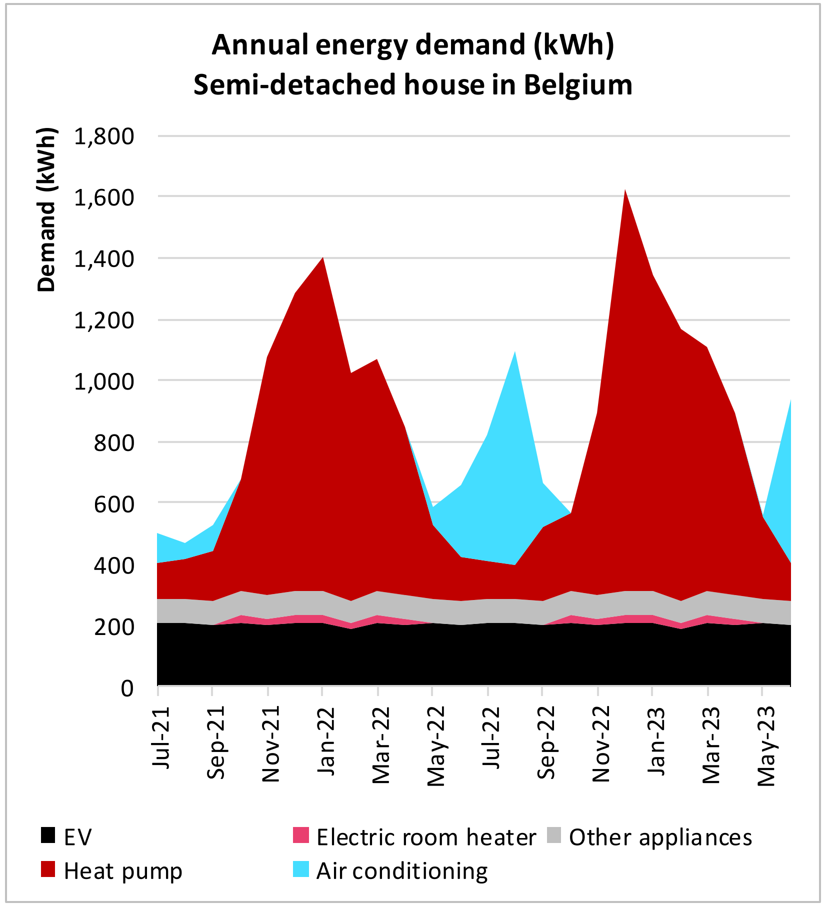
# *Annual Demand Profiles (1/4)*

## Belgium

### Apartment



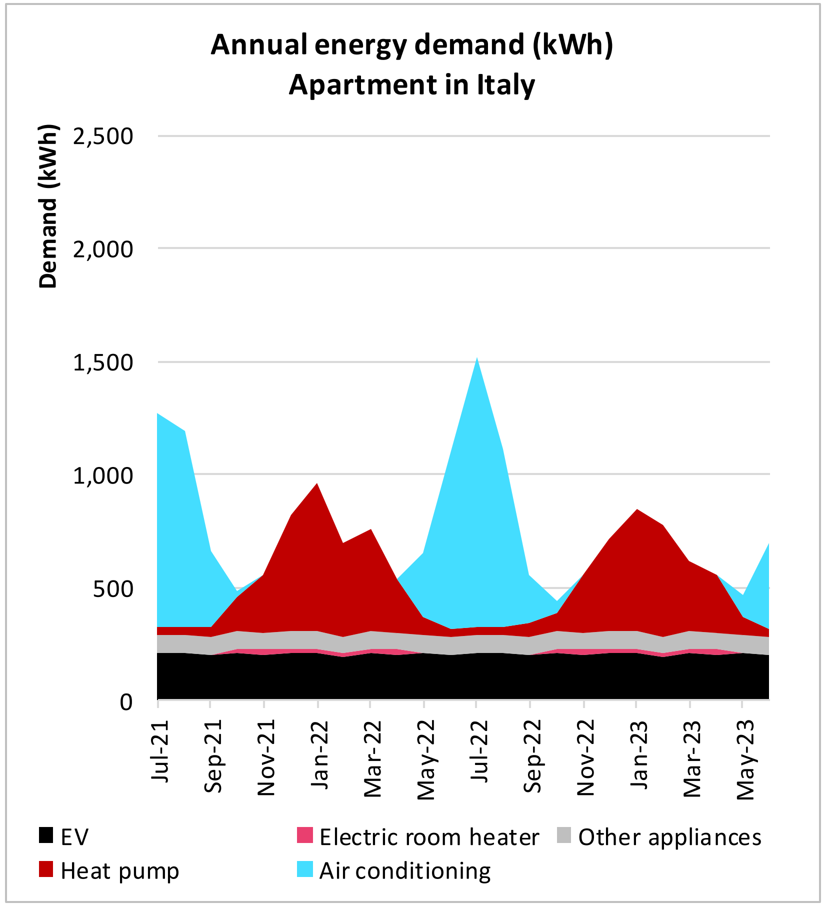

### Semi-detached house



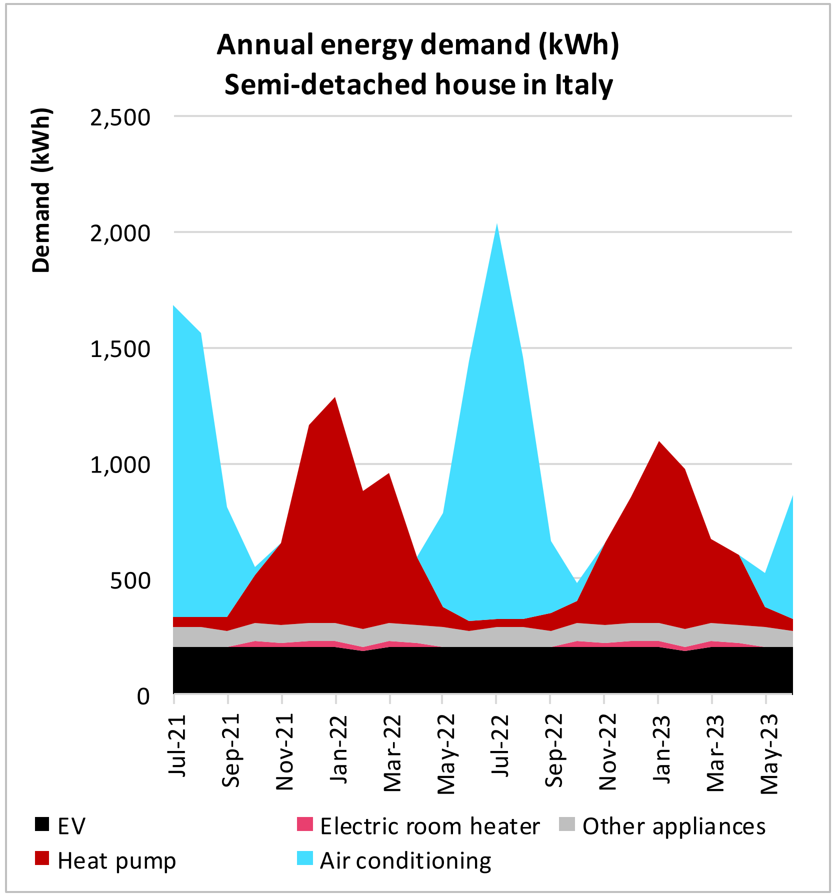
# *Annual Demand Profiles (2/4)*

## Italy

### Apartment



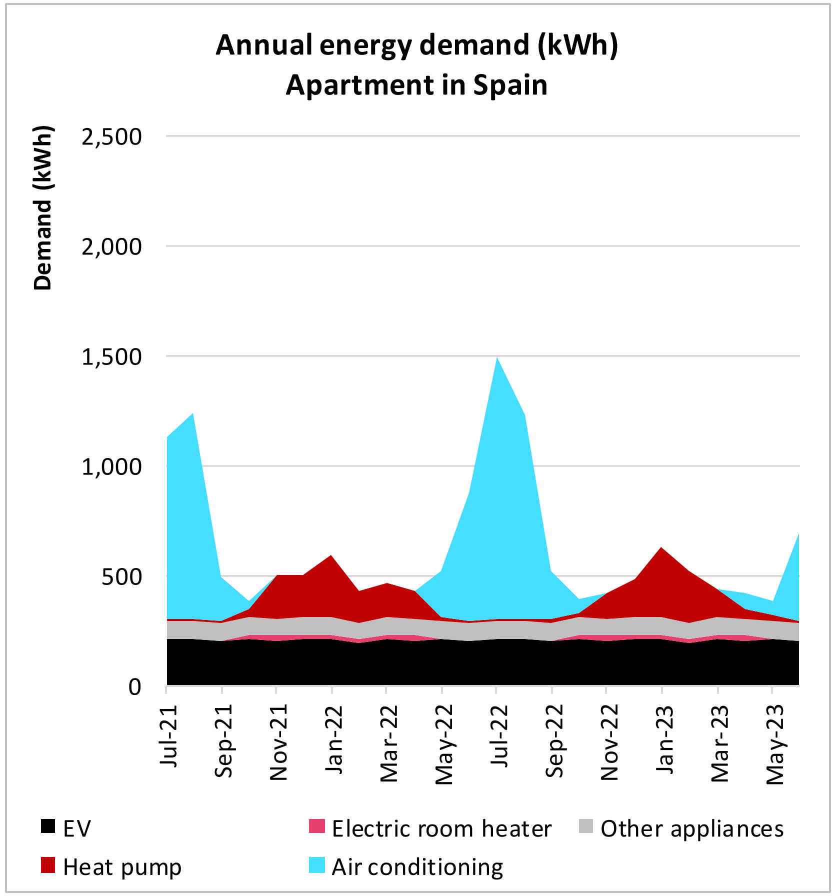

### Semi-detached house



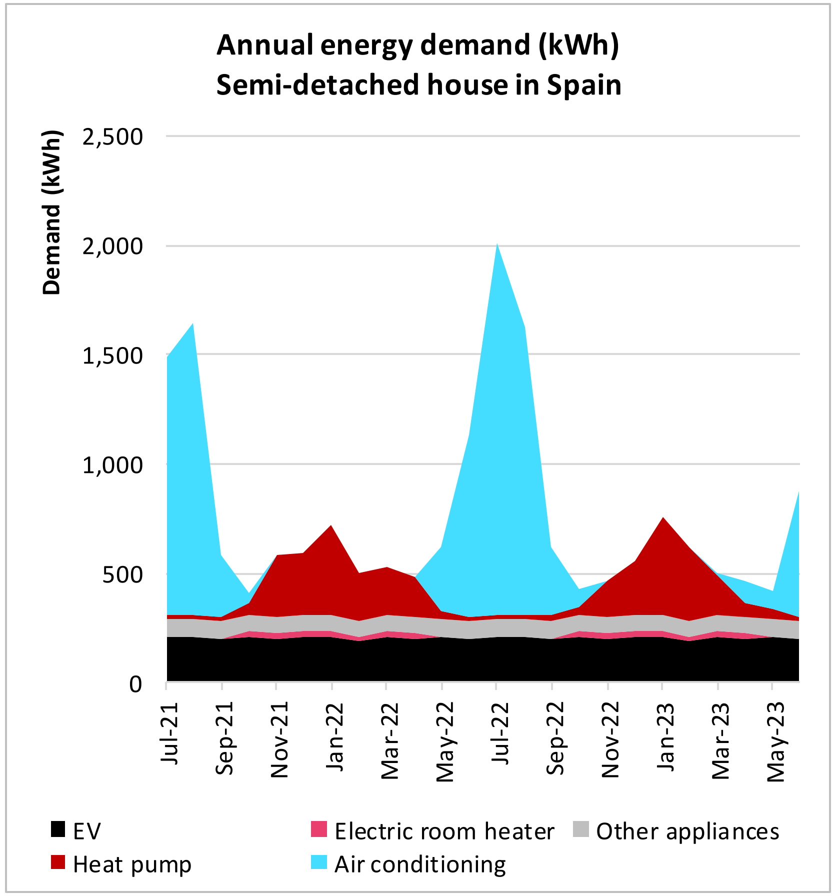
# *Annual Demand Profiles (3/4)*

## Spain

### Apartment



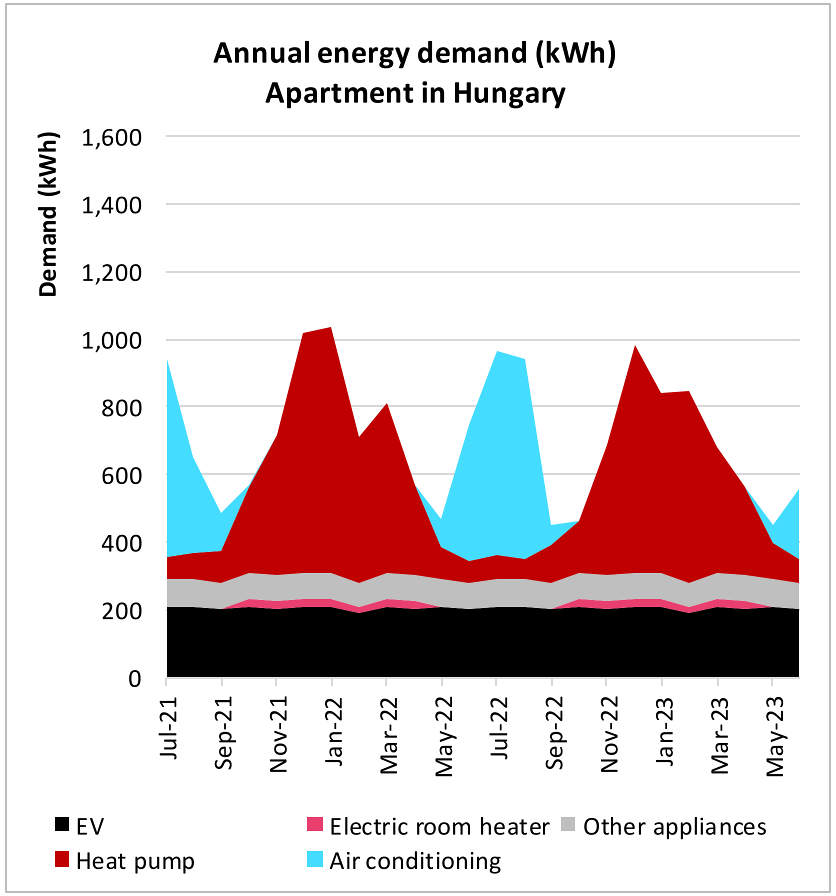

### Semi-detached house



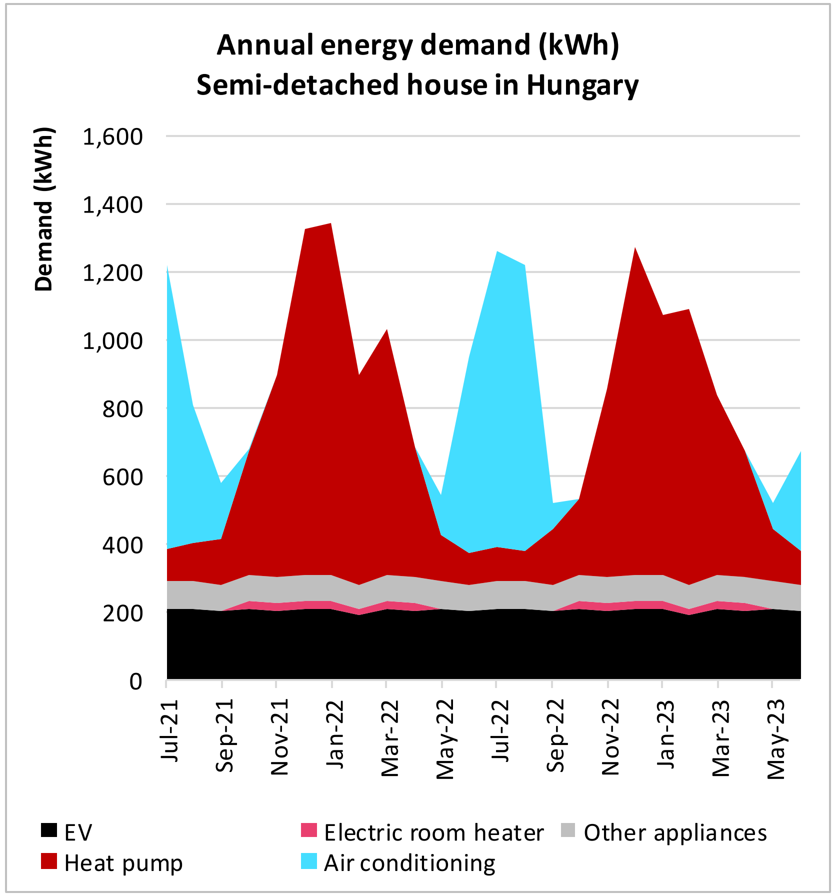
# *Annual Demand Profiles (4/4)*

## Hungary

### Apartment




### Semi-detached house

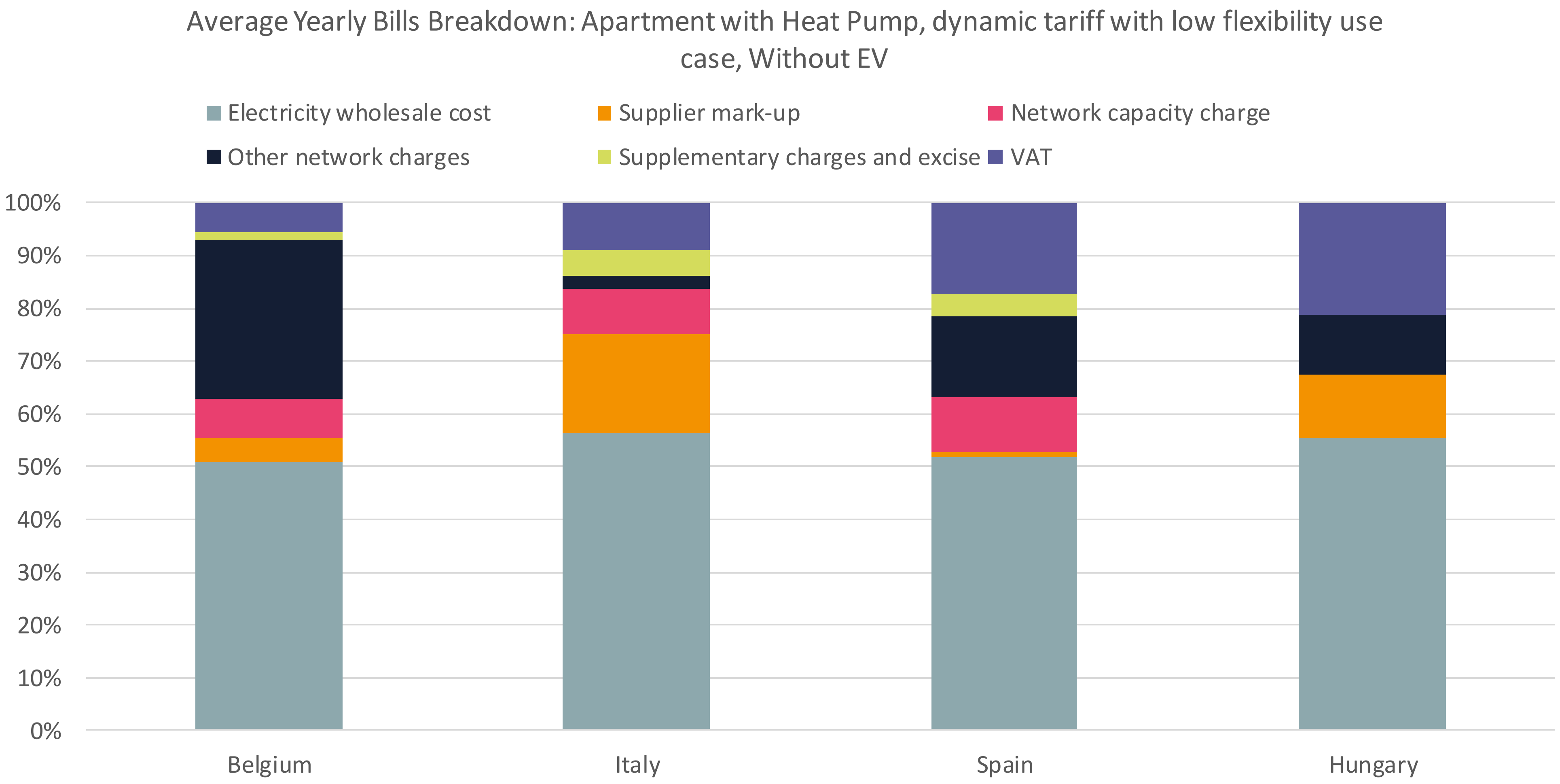


# Appendix – Tariff Analysis

# *Tariff breakdown*

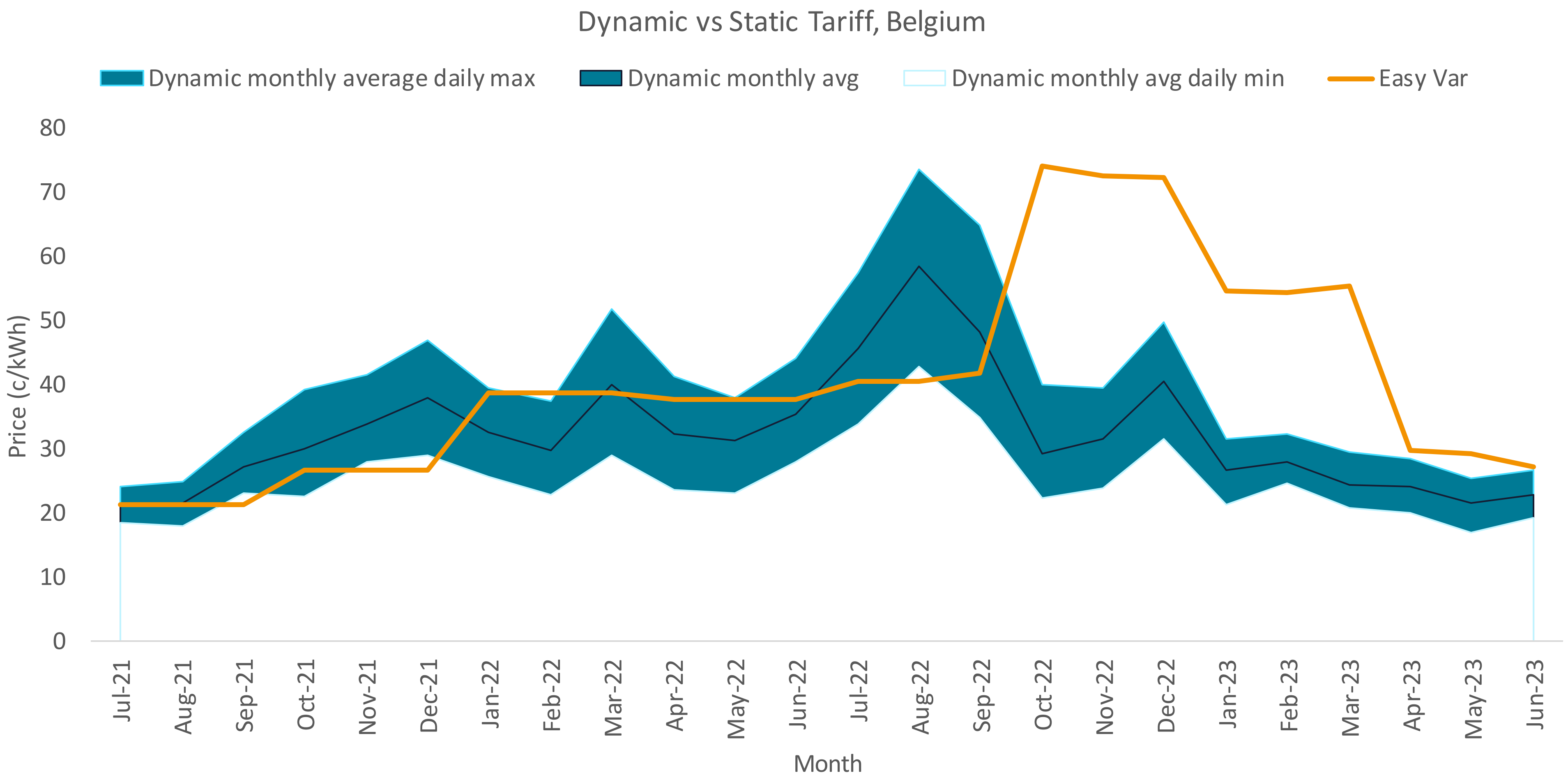
## Wholesale energy costs typically form 50-60% of total costs

**Note: there are some differences to how we have assigned distribution and metering charges between countries, falling either under either network charges or supplier mark-up**



# *Tariff Prices*
## Belgium

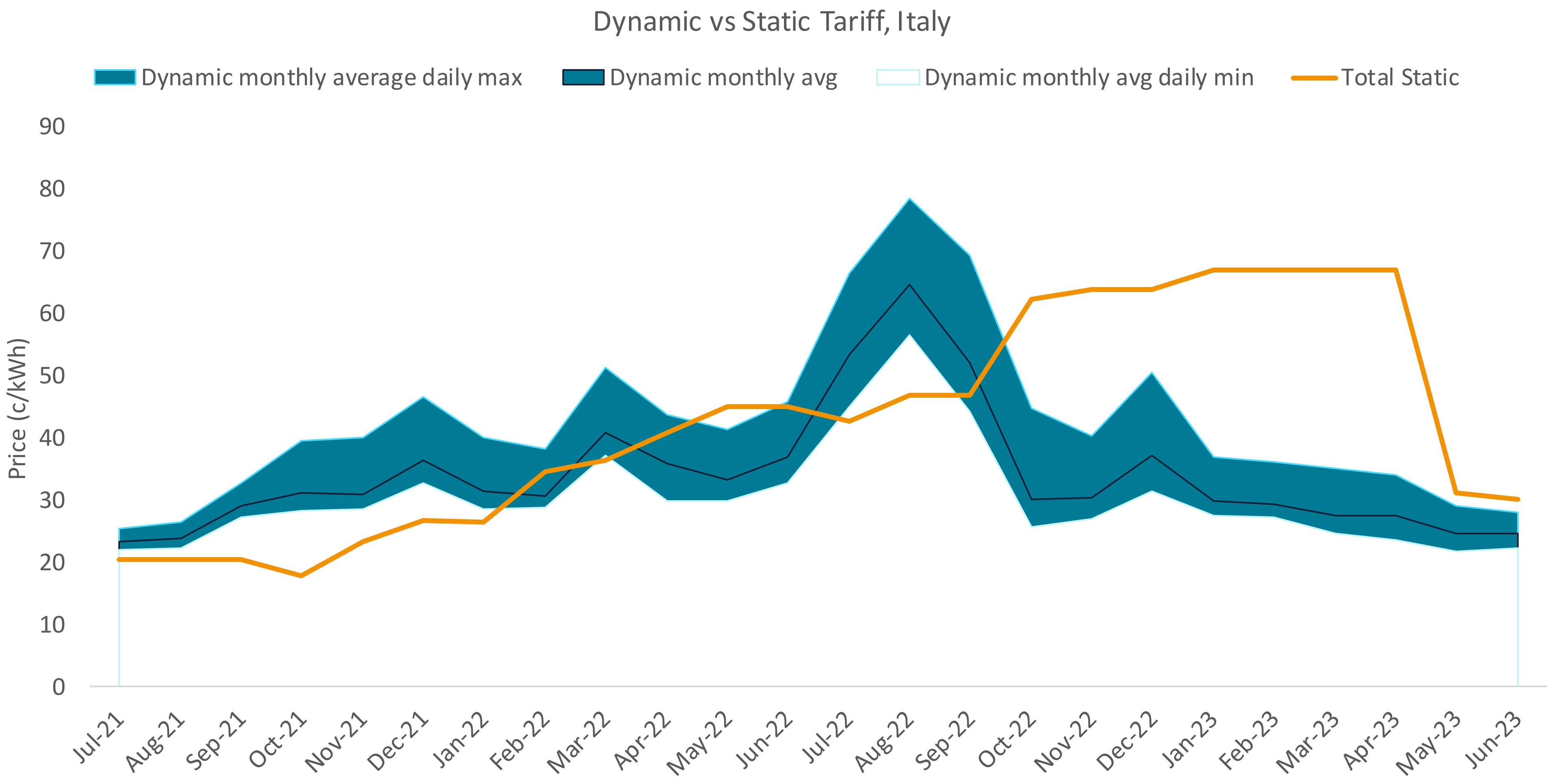
**Electricity unit charges only**



# *Tariff Prices*

## Italy

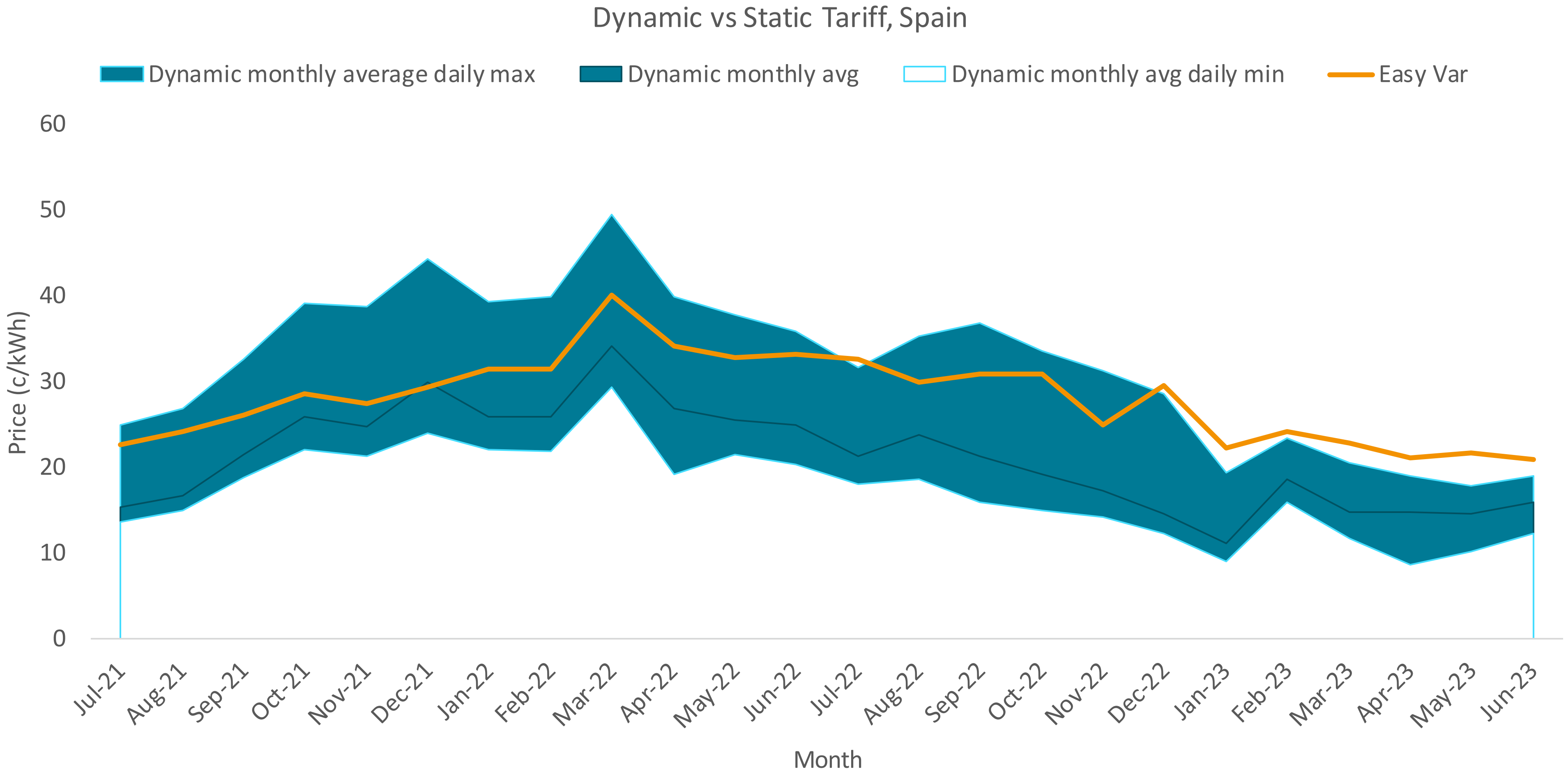
**Electricity unit charges only**



# *Tariff Prices*

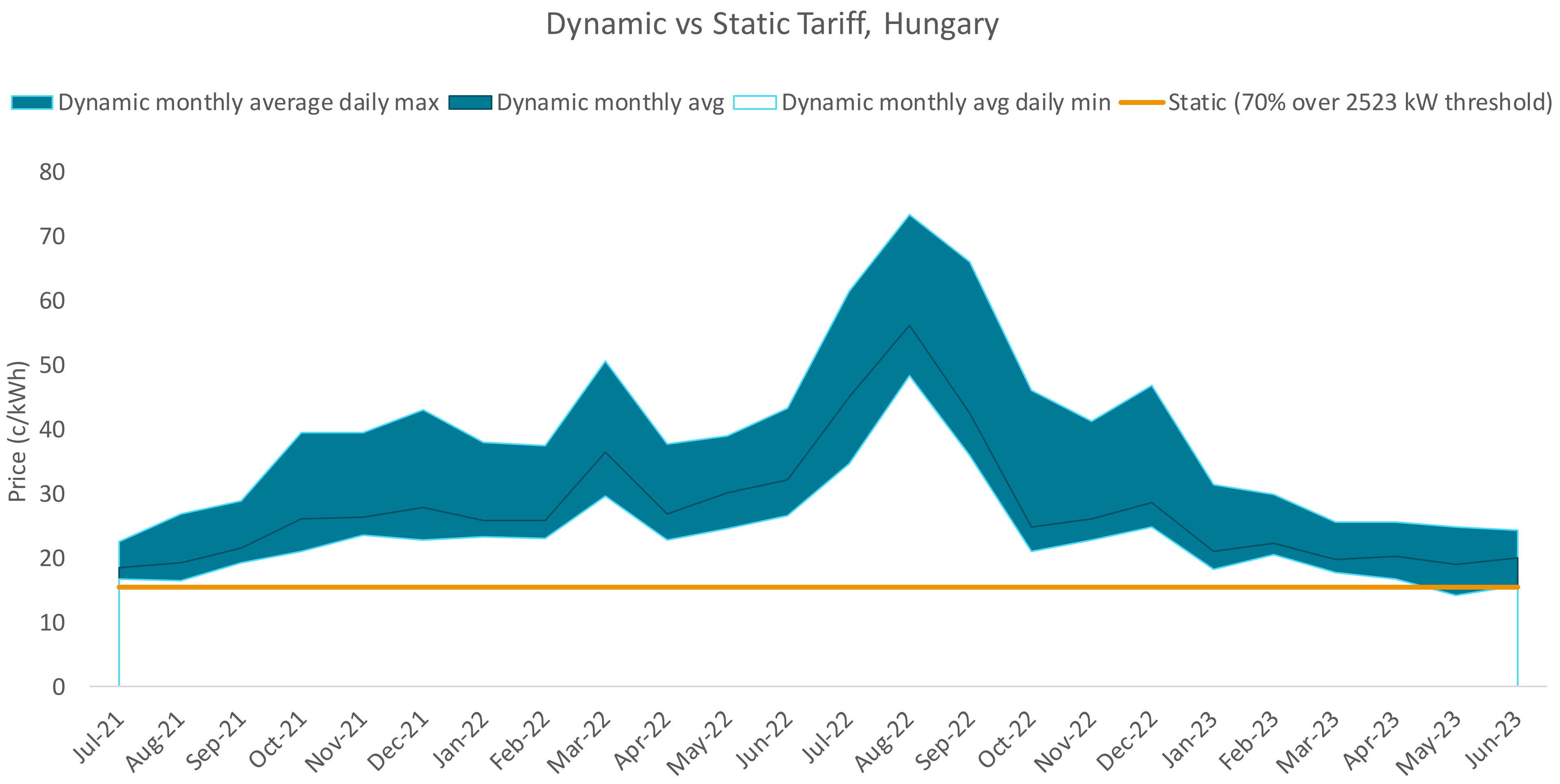
## Spain

**Electricity unit charges only**



# *Tariff Prices*
## Hungary

**Electricity unit charges only**



# *Limitations to our approach*

- By using average daily demands, the analysis reflects average costs when actual costs could be more variable, for example by charging an EV on some days but not on others
- By using average heating and cooling demands calculated per $m^2$ of floor area for all housing types, differences to the average for the archetypal dwellings considered (for example due to more or fewer external walls) are neglected
- By assuming that devices (apart from heating and cooling devices) draw a uniform power when operated, we neglect effects due to variations in their load profile, for example an oven draws more power when first turned on
- In the first instance we are considering only a single continuous period of usage for each device, whereas some such as an EV or lighting could be used at multiple times in a day
- The impact of temperature on air conditioning unit efficiency is not considered, resulting in peak summer demand being underestimated, and off-peak summer demand being overestimated
- The daily demand from the electric room heater is assumed to be constant in winter
- The impact of *hourly* temperature variations on heat pump efficiency is neglected
- The time of day of heating and cooling are modelled to change only once per season, for weekdays and weekends
- The temperature in the dwelling is not modelled directly, however the degree of flexibility allowed for space heating is designed to keep indoor temperature within 1.5ºC of the set temperature on a cold day, assuming an insulated dwelling that loses 0.5ºC or less per hour on a cold day, while preserving the total energy demand
- Similarly, the degree of flexibility allowed for cooling is designed to keep indoor temperature within 1.5ºC of the set temperature on a hot day, assuming an insulated dwelling that gains 0.5ºC or less per hour on a hot day, while preserving the total energy demand
- The impact of the thermal losses of storing hot water for more or less time, due to different water heating times is not considered

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