economie
FOD Economie, K.M.O., Middenstand en Energie

FlexMyHeat

D4.1a - White paper for decision makers

I. INTRODUCTION

The FlexMyHeat project aims at understanding the role that heat pumps and decentralized storage solutions will play in 2030 and 2050 as a source of flexibility for the national electricity system.

The extra need for electricity by shifting from fossil fuel based heating systems to heat pumps in the upcoming years will increase peak loads in the Belgian electricity grids (on top of increased peak loads caused by other domains that get electrified such as mobility and industry) and will thus lead to challenges with respect to the energy security of supply, the net balance and (on a more local level) to congestion of the grid infrastructure.

However, by properly controlling these heat pumps in combination with local storage solutions, unlocking the available flexibility, this challenge can be turned into an opportunity for the grid, contributing to the national and regional balance of the Belgian electricity system.

The goal of FlexMyHeat is to quantitatively analyze the impact and value of the increased deployment of heat pumps and decentralized electrical/thermal storage in 2030 and 2050 on the Belgian electricity system, including proposed control/coordination strategies at (a combination of) various timescales, ranging from day-ahead markets to imbalance markets.

This quantitative assessment is performed for different scenarios:

- *Business-as-usual:* considering the heat pumps and possibly associated local storage as independent devices, only optimized for local objectives, i.e., maximizing PV self-consumption. Thus, no dynamic interaction from the grid side to exploit their flexibility.
- *Individual smart control:* optimized control of the flexibility opportunities offered by the heat pump or storage devices individually, so assuming that any other devices are only optimized for PV self-consumption maximization.
- *Integrated smart control:* combined optimization of both the heat pump and storage devices for local and market objectives

Present document summarizes the results of this assessment.

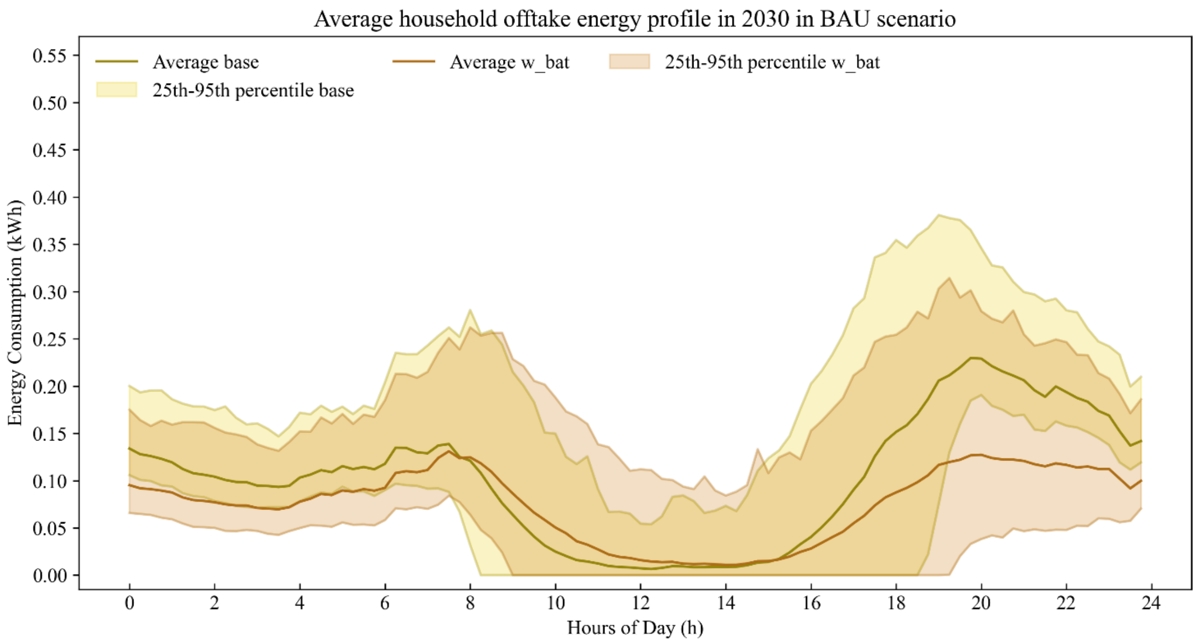
II. Results

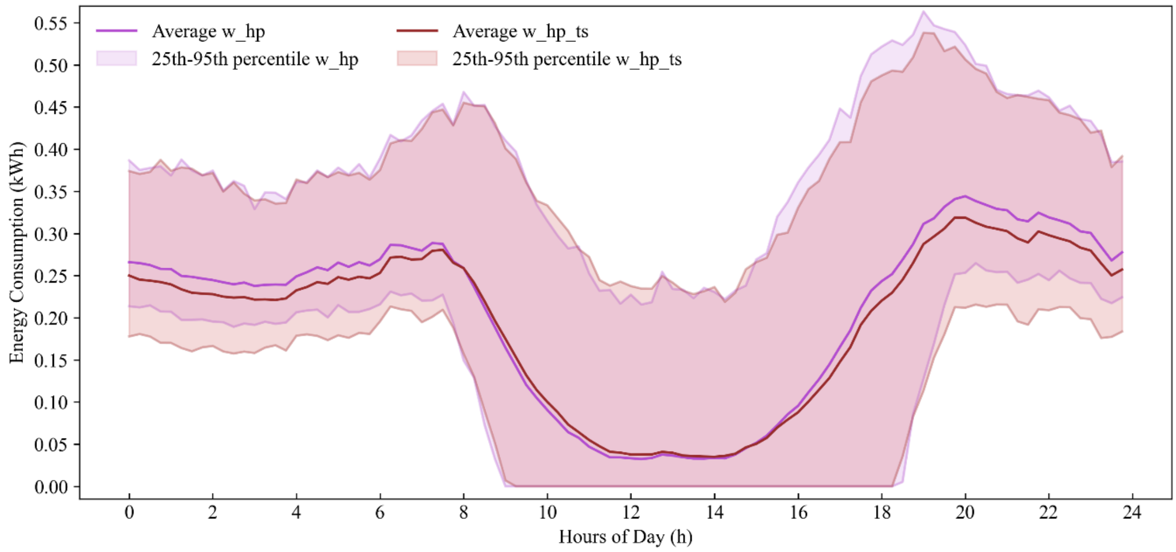
II.1. Characterization of flexible assets, adoption potential, grid constraints, and markets

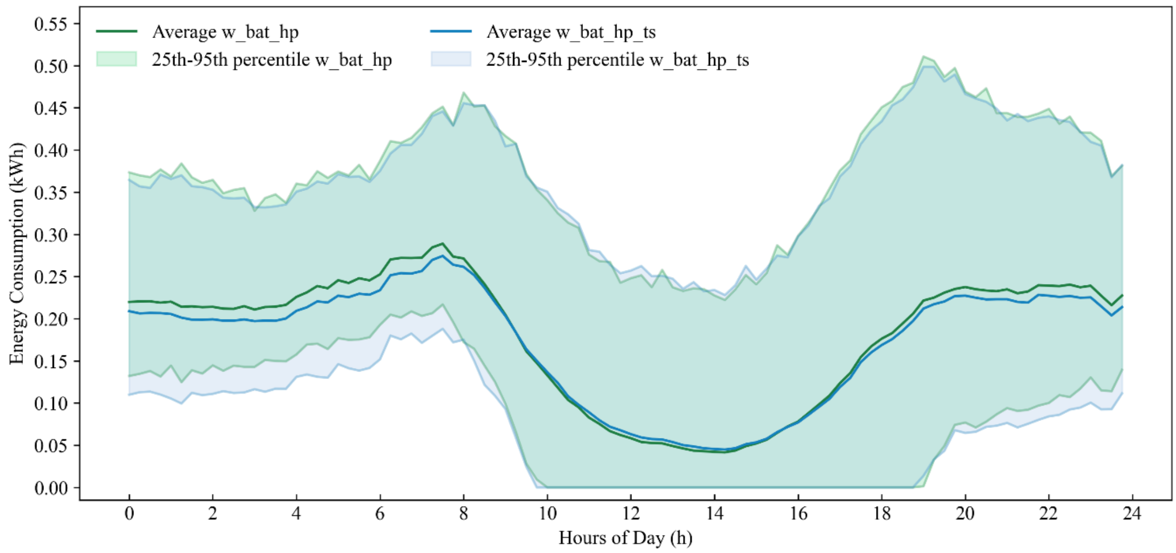
The project first focuses on the characterization of flexible assets such as heat pumps, batteries, and thermal storage, as well as their adoption potential and the constraints posed by the electricity grid and market structures.

The study evaluates a business-as-usual (BAU) scenario for the year 2030, in which these assets are controlled independently using simple rule-based logic that prioritizes local objectives like maximizing photovoltaic (PV) self-consumption. The findings show that while the widespread adoption of heat pumps significantly increases household electricity consumption and daily peak power, the integration of batteries and thermal storage can help mitigate these effects.

This can be observed from these average household offtake energy profiles in 2030:





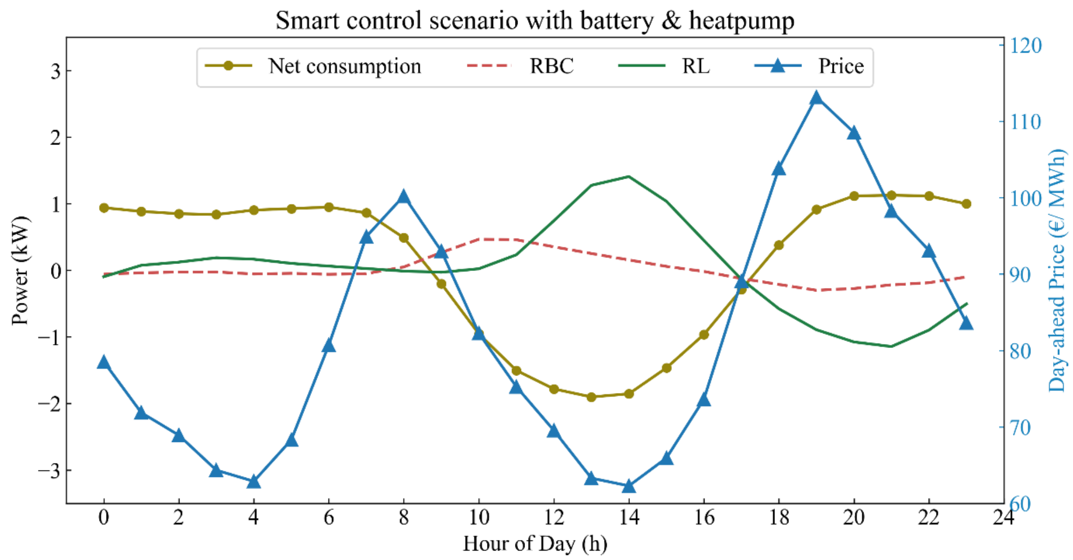


However, the BAU control logic proves to be insufficient, especially during winter months when PV generation is low, limiting the effectiveness of flexibility. This first part of the project concludes that more advanced control strategies are needed to fully unlock the potential of these assets, particularly under dynamic pricing and evolving grid conditions.

II.2. Smart control of batteries

Deliverable D2.1 builds on the previous analysis by introducing smart control strategies for home batteries using *reinforcement learning* (RL). The study evaluates battery performance in both the *day-ahead and imbalance electricity markets*.

In the day-ahead market, RL-based controllers are shown to reduce annual electricity bills by up to 4.88% compared to rule-based logic, by optimizing battery charging during low-price periods and discharging during high-price periods. This can be observed in figure below.



In the rule-based controller, the battery begins charging as soon as there is excess PV generation, leading to it being fully charged before the afternoon. As a result, peak battery consumption occurs in the morning. This means the household will miss the opportunity to charge the battery during the cheaper hours around early afternoon. In other words, the excess PV will be sold at lower prices. However, the RL agent charges the batteries around early afternoon, when the price is cheaper. In addition, the batteries will be charged more during cheap hours to avoid purchasing electricity from the grid in the evening when the price is more expensive.

In the imbalance market, which is more complex due to price volatility, the RL controllers achieve even greater cost savings—up to €735 annually depending on the revenue-sharing model. The results demonstrate that smart battery control not only reduces energy costs but also contributes to grid stability.

The deliverable concludes that RL-based control is significantly more effective than traditional methods and recommends extending smart control to other flexible assets such as heat pumps and thermal storage.

II.3. Smart control of heat pumps and thermal storage

Deliverable D3.1 extends the smart control approach to heat pumps and thermal storage, and also explores integrated control of all flexible assets.

Using a combination of Monte Carlo Tree Search (MCTS) and physics-informed neural networks, the study models and optimizes the operation of these devices to minimize energy costs and reduce peak power demand while maintaining user comfort.

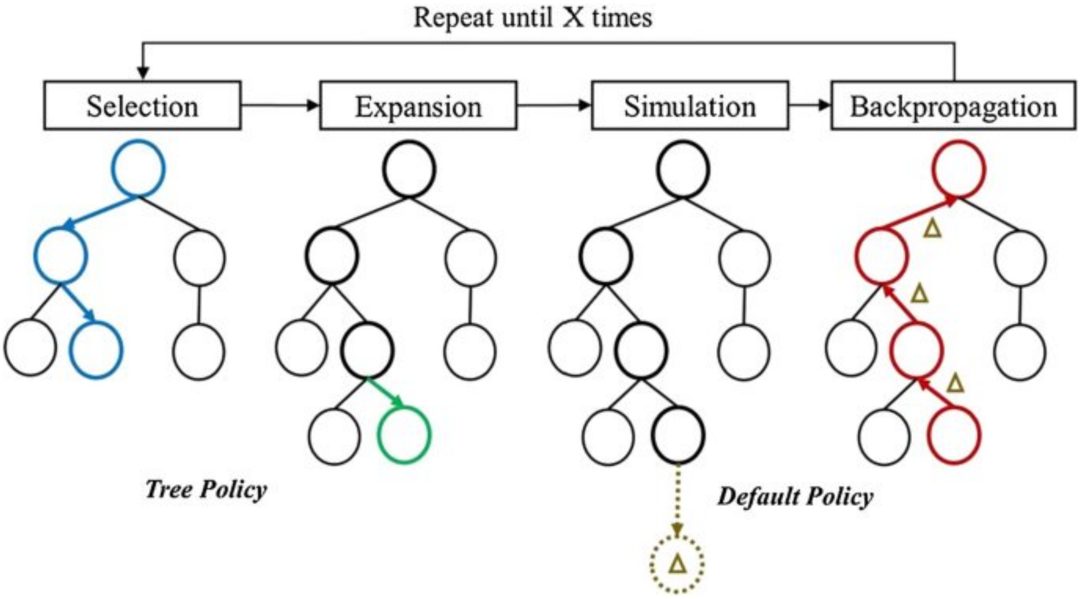


Figure - Monte Carlo tree search framework overview

The results show that smart control of heat pumps alone can reduce electricity bills by up to 13.22% and peak power by up to 13.3%. When thermal storage is added, the cost savings increase to nearly 30%, and peak power reductions reach 24.3%. The most significant benefits are observed when all assets—batteries, heat pumps, and thermal storage—are controlled together. In this integrated scenario, households experience up to a 35.1% reduction in electricity costs and a 26% reduction in peak power demand.

The study also finds that prioritizing battery use over thermal storage yields slightly better performance, particularly during sunny periods when PV generation is high. The deliverable concludes that coordinated, intelligent control of all flexible assets is essential for maximizing both economic and grid benefits.

II.4. Economical,social & environmental effects in Belgium

The goal of this project was to support and accelerate the energy transition in Belgium by identifying additional flexibility in energy consumption and analyzing how this flexibility can best be used to integrate additional renewable energy sources while at the same time keeping the cost of grid upgrades affordable. A faster electrification of our society whereby this electricity comes (mainly) from renewable energy sources will lead to a significant reduction of Belgian CO2 emissions.

A smart control of heat pumps can indirectly reduce Belgian CO2 emissions by using heat pumps mainly at times when the carbon intensity of the consumed electricity is low. Integration of heat pumps with storage can further decrease carbon emission by charging storage at low carbon intensity times and later using this stored energy for running heat pumps. In this way, heat pumps avoid consuming energy from the grid at times when the grid electricity is produced by fossil fuel-based power plants while still satisfying the user thermal comfort.

Indirectly, there will also be a positive effect on public health through lower emissions of combustion gases and because the increase in global temperature can (hopefully) be somewhat contained resulting in fewer natural disasters and heat waves.

The large-scale adoption of heat pumps will in any case lead to an increase in electricity consumption in Belgium, but for the management of the electricity system the increases in peak consumption are particularly relevant. If the heat pumps are installed without supporting systems, this will lead to a significant increase in peak consumption (+42% for an average household) which in turn will lead to large additional investments in grid upgrades and backup capacity. These costs will of course have an important societal cost, impacting grid tariffs and thus energy costs for consumers.

The goal of this project was to explore how this challenge can be turned into a solution for the energy transition. The combination of heat pumps with storage solutions and the smart and combined control of these assets in function of not only local objectives but also the needs of the grid can lead to a lower impact on the Belgian electricity system via lower peak loads (-26%) and lower electricity bills for the end users (-35%). This will hopefully accelerate the energy transition in Belgium.

There are however still a few challenges to be tackled to allow a large scale adoption of heat pump technology, and associated smart control services, i.e.,

- The economic incentive for households to switch to heat pumps is currently low because the cost difference between heat pumps and traditional fossil fuel-based heating systems remains small, or even unfavorable in some cases, especially when investment costs, electricity prices and current grid tariffs are taken into account.
- Realizing a smart control of heat pumps in combination with other flexible (and non-flexible) loads is also not straightforward nowadays due to interoperability issues with the control interfaces used across different types of assets and brands.