The potential contribution of heat pump flexibility to Belgian security of supply

Connecting electricity system and building physics simulations

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Executive summary

The increasing adoption of heat pumps in Belgium presents both challenges and opportunities for the country's electricity system, particularly concerning national security of supply. If all else remains equal, adding millions of heat pumps to the electricity system only makes it harder for supply to meet demand during every hour of the year. However, operating heat pumps in a flexible manner can partially compensate for this negative impact. While heat pump flexibility can thus contribute to security of supply, the extent of this contribution has remained unclear.

This report, developed under the FlexSys project funded by the Belgian federal government, investigates this in detail. The analysis combines advanced simulations of both electricity systems and building physics to explore how flexible heat pump operation can help alleviate potential electricity shortages.

Two approaches for evaluating the impact of heat pump flexibility are outlined: one focused on electricity system modelling and another on building physics. It was found that a combined approach integrating both domains offers new insights that are otherwise unattainable. However, significant challenges remain in fully capturing the complexity of both the electricity system and building physics in a single model.

Results indicate that heat pump flexibility can indeed help mitigate short-term scarcity events. These events are periods when the electricity supply cannot fully meet demand, typically occurring during extreme weather conditions or peak demand hours. When operated flexibly, heat pumps can reduce electricity demand during these critical times, helping to balance the grid without significantly compromising indoor comfort.

While a significant portion of scarcity events can be covered in this way, many scarcity events still cannot (fully) be dealt with – even under the highly theoretical assumptions made in our analysis, which include the fact that all residential heat pumps in Belgium would react, and 100% of users would allow indoor temperatures to drop at least somewhat. Heat pump flexibility represents a valuable tool for managing the evolving electricity system, but it clearly has limits as well.

Notably, the analysis also found that the effectiveness of flexibility does not significantly increase with more aggressive temperature setbacks. Allowing buildings to cool down by only two degrees can already provide substantial benefits, showing that a significant impact on comfort is not required for heat pumps to contribute to security of supply.

Policymakers are encouraged to continue promoting heat pump adoption alongside initiatives that enable and incentivize their flexible operation, ensuring that the benefits of this technology can be fully realized while mitigating its potential impacts on the electricity system.

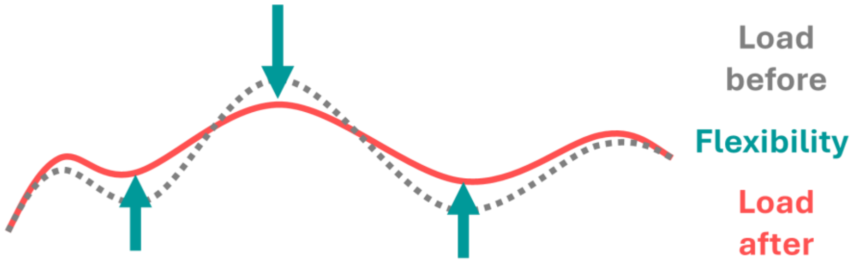
1. Introduction

The ongoing growth of the Belgian heat pump fleet is leading to an increase in electricity consumption, but this consumption is at least partially flexible in the sense that its timing is not entirely fixed or rigid. This *flexibility* can be exploited to help reduce the operational cost of running the heat pump, thereby also reducing the household electricity bill compared to a situation where the heat pump is operated in a “dumb”, inflexible manner. For example, by increasing the self-consumption of solar power, flattening consumption peaks from the perspective of the distribution grid (leading to lower grid fees), or concentrating electricity consumption into the hours with the lowest dynamic electricity prices. However, this report focuses on another potential purpose for which heat pump flexibility can be exploited, namely to contribute to Belgian national security of supply.

If the only thing that were to change in the electricity system going forward is the addition of more and more inflexible heat pumps, security of electricity supply would diminish. When electricity generation capacities are assumed constant but consumption increases, then – eventually – supply will no longer be able to meet demand in every hour of the year. The question then becomes: to which degree can heat pump flexibility *compensate* this initial negative impact on security of supply? If heat pumps all across the country would temporarily reduce their electricity consumption at times when electricity supply is struggling to meet national demand, then how much of a difference would that make?

A key limitation of contributing to security of supply with heat pump flexibility, is that flexibility is fundamentally different from producing additional electricity with a power plant. Flexibility does not add any new energy production to the system; energy consumption is only shifted across time. This means that flexibility can only “solve” a moment of scarcity – i.e. a situation in which supply struggles to meet demand – by temporarily reducing demand at this time, while increasing it at another time. By shifting electricity demand to another time – for example to a few hours later in the day –, a new moment of scarcity may be triggered. Flexibility therefore primarily has the effect of “tightening” the supply/demand balance throughout a given time period. It does not fundamentally “relax” periods with a tight supply/demand-balance, in contrast to adding production capacity to a system or permanently reducing demand.

Figure 1: Flexibility does not produce any new energy, it only shifts load around in time



Nonetheless, it is possible in theory that heat pump flexibility could still meaningfully contribute to security of supply, which is exactly what this report is trying to assess. To make this assessment, the rest of this report is structured as follows. In chapter 2, we explain that there are two possible approaches to make this assessment. One that focuses on simulating the electricity system, and another that focuses on simulating the buildings in which heat pumps are used. After examining both approaches, chapter 3 goes into detail about the methodology we developed to make our assessment – which is a combination of the two. Chapter 4 discusses the results of our assessment and chapter 5 concludes by formulating take-home messages and policy recommendations.

2. The two approaches to assess the potential security of supply contribution of heat pump flexibility

Estimating the security of supply contribution of heat pump flexibility requires an approach that considers both the operation of a country's electricity system and the operation of the heat pumps themselves in the context of the buildings they heat. This leads to a fundamental issue in terms of the modelling required to make the assessment. Namely the fact that both aspects require specialised models which cannot be easily linked with each other.

On the one hand, simulating the Belgian electricity system in a proper way requires a sophisticated "unit commitment economic dispatch" (UCED) model. Such a model focuses on the production, storage and transport of electricity – typically at a European scale, to accurately take international flows and exchanges into account.

On the other hand, simulating the operation of a heat pump requires specialised models focused on the building physics involved. Such models simulate the operation of a heat pump throughout the year, as it performs its function of maintaining comfortable indoor temperatures during certain hours of the day, while outside temperatures are constantly fluctuating.

To assess what would happen in the electricity system if a country's entire fleet of heat pumps were to operate in a flexible way, one would ideally use a model that can accurately capture *both* the operation of the electricity system *and* the operation of the heat pumps themselves. However, this is computationally infeasible, because electricity system models and building simulation models are both so complex that they cannot be meaningfully incorporated into a single model without oversimplifying one or the other.

As the real-world electricity system itself became more complex over time, so did the models that attempt to accurately simulate it. An example of such an evolution is the addition of flow-based market coupling in the European system, which could not be ignored in the world of modelling and was therefore incorporated. Meanwhile, the building physics dynamics involved in heating a building with a heat pump are highly non-trivial as well, leading to an entirely separate world of advanced simulation models.

The computational infeasibility of a fully integrated model incorporating both the complexity of the electricity system *and* the complexity of building physics leads to the fact that in practice, one must decide whether an approach will be chosen that focuses on one or the other.

2.1. The electricity-system-focused approach

A basic electricity system model specialises in accurately representing different electricity production technologies (wind, solar, nuclear, gas,...), storage technologies (pumped hydro, batteries,...) and transport technologies (HVAC, HVDC,...). It typically simulates a single entire year (e.g. 2030) at an hourly temporal resolution. In each hourly timestep of the year, there is a certain exogenous electricity demand that needs to be met. For example, the national electricity demand of Belgium. During execution, the model will typically seek to optimise the dispatching of different electricity generation and storage technologies in order to perfectly meet demand across the entire year in the cheapest way possible. During this optimisation process, all technical constraints of the different generation and storage technologies need to be respected, as well as the constraints related to the modelled transmission network.

The resulting model output tells you whether demand can in fact be met during all hours of the year – given the assumed generation capacities of different technologies – and how much each technology produces in every hour. These model outputs closely resemble the actual dispatch of electricity generators that takes place in the real world, as markets like the day-ahead market essentially aim to achieve the same thing: meeting electricity demand in the cheapest way possible.

Modern electricity system models include a variety of complex features on top of this basic architecture, although the general principles of the optimisation remain the same. One example of such an added feature – as mentioned before – is *flow-based market coupling*. This is a real-world mechanism to optimally determine the maximum flows that can be allowed to take place in different parts of the European transmission grid. Another example is the inclusion of unexpected outages. Specific production, storage or network assets can then become unavailable temporarily, according to predefined probabilities.

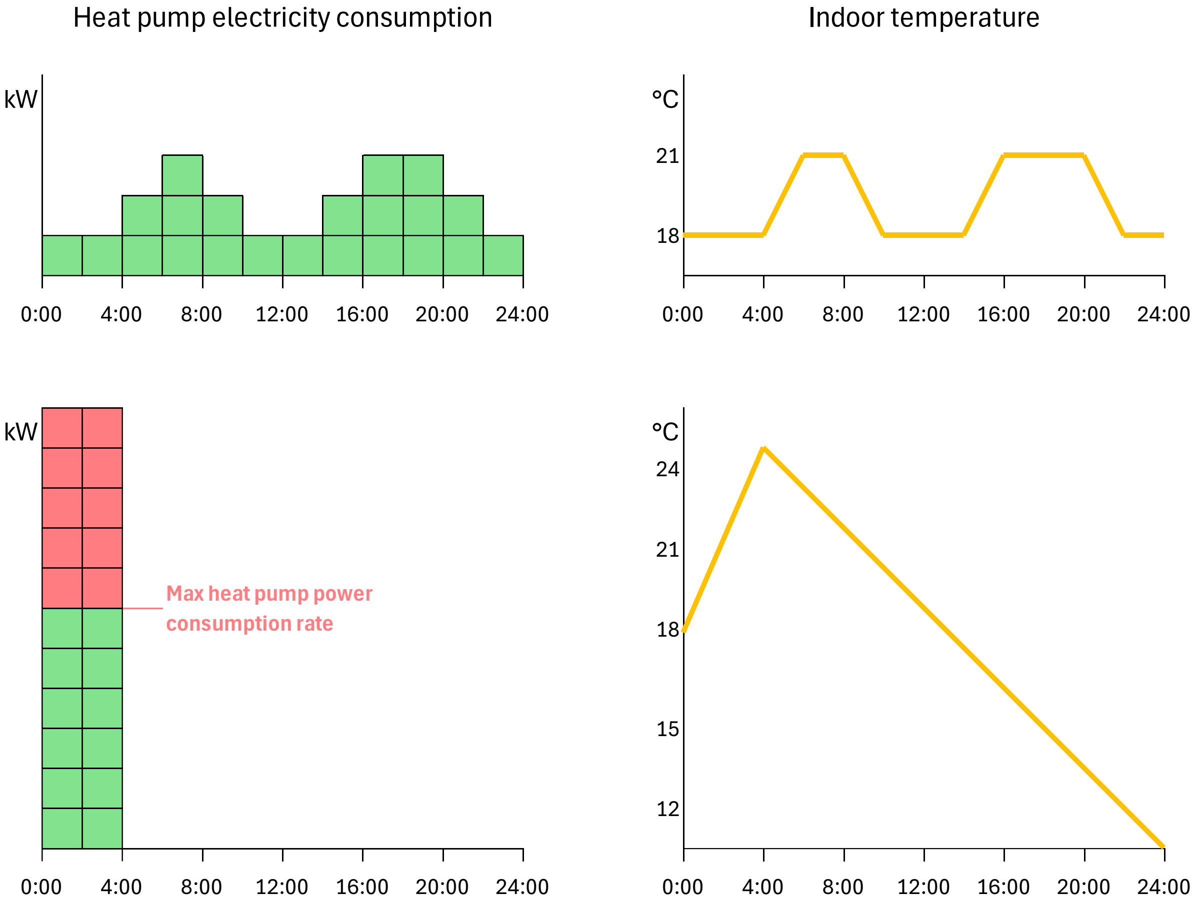
Historically, electricity demand was assumed to be fully exogenous and ‘fixed’ in electricity system models. Namely, in the sense that the hourly quantities of electricity demand 'are what they are' and simply need to be met by the available production and storage technologies. This has changed somewhat in today’s state-of-the-art models, in which it is sometimes assumed that certain loads are flexible.

For example, a country’s fleet of electric vehicles (EVs) may be assumed to charge in a “smart” way. The model can then endogenously optimise – as part of the overall cost minimisation objective – when cars are charged within a given time period. The total electricity demand of EVs may still be exogenously fixed at certain timescales (e.g. on a daily level), but the model can choose itself in which specific hours it wants to concentrate the electricity demand. Contemporary models can similarly include demand-side flexibility from electrolysers or industry – where, for example, electric boilers may be flexible to a certain degree.

When it comes to including heat pump flexibility in electricity system models, the key limitation lies in the fact that building physics cannot be endogenously captured in a meaningful way. Instead, heat pump flexibility needs to be radically simplified in one way or another in order to “fit” in the general architecture of electricity system models. How to optimally do this in a way that still resembles the real-world characteristics and limitations of heat pump flexibility is a matter of ongoing debate.

One conceivable way for a modeller to include heat pump flexibility into an electricity system model is to assume that the total electricity consumption of the heat pump fleet across a given day can be freely shifted around across the hours of the day (similar to EV flexibility through “smart charging”). However, this would completely ignore several real-world limitations of heat pump flexibility as indicated in **Figure 2**. If the model would endogenously choose to concentrate the heat pump electricity consumption into the first few hours of the day, then (a) this could easily exceed the maximum rate of power consumption possible with the heat pump(s) in question, and (b) it would lead to a radical deviation from the indoor temperatures that are desired by users from a comfort perspective.

Figure 2: Why heat pump electricity consumption cannot be freely shifted around at will



Note: this highly simplified representation of 'what would happen' if heat pump electricity consumption were to be radically concentrated into certain hours of the day is meant purely for illustrative purposes only.

Regardless of which simplifications are made in order to add heat pump flexibility to an electricity system model, the big advantage of including it endogenously is that it can be "dispatched" optimally, together with all the other assets in the system. Model results then show exactly how this flexible load can be optimally exploited to serve the goal of meeting overall demand in the cheapest way possible. Moreover, the impact of including the heat pump flexibility on any other model output parameter can be easily computed.

For example, if the Belgian electricity system is being simulated, the model results would first of all show when the heat pump flexibility is used the most and how the rest of the system responds to the shifts in electricity consumption that take place because of it. A simple "before and after analysis" could also reveal how the inclusion of heat pump flexibility impacted the electricity production of different technologies, flows on the transmission network, or specific security of supply KPI's like *Energy Not Served* (ENS) or the *Loss of Load Expectation* (LOLE).

It should nonetheless be noted that the electricity-system-focused approach has two important drawbacks in addition to the oversimplification of heat pump flexibility itself.

Firstly, the behaviour of a fleet of flexible heat pumps can easily “drown” in the broader dynamics that are at play in an electricity system model. Any analysis of how it is dispatched and what it’s overall contribution is to the broader system can be heavily influenced by the litany of boundary conditions and assumptions that inevitably go into electricity system models.

For example, in the case of a European model, assumptions have to be made about the energy generation capacities available in each country for a variety of technologies, about interconnection capacities between neighbouring countries, about the general electricity consumption profiles of each country, etc.. Each of these assumptions and especially the combination of them can co-determine which role there is left to play for a fleet of flexible heat pumps. Therefore, the answer in terms of “which contribution it can make to security of supply” can be heavily dependent on these many other assumptions as well. The question then becomes to which degree the answer to the research question can be trusted, given the fact that all of the other assumptions that go into electricity system models are essentially a source of “noise” for the analysis of heat pump flexibility.

Secondly, large electricity system models like the ones with a European scope inevitably have to deal with the fact that heat pump fleets exist in all countries and they could each become flexible at some point. In the ideal case, heat pump flexibility would be modelled equally well for all countries included in such a model, but this is unlikely to happen because of practical reasons. Even if models have a European scope, modellers sometimes only focus their efforts on including detailed heat pump flexibility for a single country of interest. Including heat pump flexibility for all countries in a European model would require a disproportionate amount of effort, because of the data collection and modelling work required to accurately portray the heterogeneous building stocks and heat pump fleets.

However, the fact that heat pump flexibility is typically only modelled for a single “focus country” – while all other countries in the model are assumed to have inflexible heat pumps – certainly has consequences for the analysis. In effect, such an analysis can only answer the purely theoretical and arbitrary question “which contribution can a Belgian fleet of flexible heat pumps make, if all other heat pump fleets in Europe are assumed to be inflexible?”. In reality, if it were to become the case that Belgium’s heat pump fleet would become highly flexible, then this would most likely coincide with the same thing happening in other European countries. This in itself would have its own second- and third-order effects rippling throughout the whole European system. It would change the dynamics in which the Belgian fleet needs to operate and it would therefore influence the answer that is ultimately formulated to the research question.

2.2. The building-physics-focused approach

In the alternative approach to assessing the security of supply contribution of flexible heat pumps, the focus lies entirely on the building physics instead of on the electricity system. Instead of simulating the electricity system, a whole range of individual buildings are simulated. Each individual building represents part of the building stock. Each simulation results in an individual electricity consumption profile for the heat pump in question. These individual profiles can then be added together and extrapolated in a bottom-up fashion to arrive at a country-level electricity consumption profile of a (flexible) heat pump fleet. Only after this work is complete – which represents the vast majority of the effort required in this approach – a rudimentary representation of the electricity system is introduced to assess how it could benefit from the quantified heat pump flexibility.

Building physics simulation tools are employed to model heat pump operations in individual buildings. Central to these simulations is the concept of a "heating profile," which dictates the target indoor temperatures at different times. These profiles can be simple, such as maintaining a constant 21°C, or more elaborate, varying temperatures based on specific hours of the day or days of the week.

At each (sub)hourly interval, the model calculates the heat pump's electricity consumption required to maintain the target indoor temperature. This calculation incorporates real-world variables such as changing outdoor temperatures, solar heat gain through windows and internal heat generated by occupants.

A comprehensive analysis of the building stock requires the creation and individual simulation of various "building archetypes." These archetypes capture the diverse range of building characteristics found in the stock, including different geometries (e.g., detached, terraced, apartments), sizes, insulation levels, and heating system specifications (such as heat pump types and heat distribution methods like underfloor heating or radiators).

The building-physics-focused approach offers two primary advantages. Firstly, it provides a more accurate estimation of heat pump electricity consumption during normal operation, aligning closely with actual building physics and user comfort requirements. Data is derived directly from empirically verified simulations, in contrast to the electricity-system-focused approach, which relies on high-level approximations to determine the electricity consumption profile of a country's heat pump fleet (e.g. in 2030 or 2034).

Secondly, the approach allows for a more comprehensive and realistic quantification of heat pump flexibility. Building simulations can accurately model temperature changes when a heat pump is turned off, including how quickly a building cools and when comfort thresholds are reached. This allows for explicit assumptions about which indoor temperature fluctuations are deemed acceptable, for example to let it cool down no further than 19°C, at which point the heat pump needs to reactivate. The simulations then also capture the increased electricity demand when restoring the indoor temperature back to the setpoint (e.g. 21°C). This detailed modelling enables a dynamic understanding of heat pump flexibility at both individual building and stock levels, precisely showing how electricity consumption profiles are affected – which is impossible in the electricity-system-focused approach.

The obvious drawback of focussing on the building physics is that all you are left with is a building-stock level electricity consumption profile of the entire heat pump fleet – either under “normal” or “flexible” operating conditions. Such profiles on their own do not yet answer the question of “which difference heat pump flexibility would make” in the broader electricity system. If, for example, you want to assess which contribution it could make to security of supply, then some kind of simplified representation of the electricity system still needs to be introduced in order to quantify this.

When this is done, the analysis bumps into a similar issue of oversimplifying part of the story, as we saw in the electricity-system focused approach, where – instead – the heat pump operation itself was oversimplified. This causes a number of issues, limiting the ability to truly answer the research question in a thorough and trustworthy way. Specifically, it may be difficult to trust any claims about a “security of supply contribution” when only the building physics were thoroughly simulated but the translation in terms of how the flexibility would impact the electricity system was done in an overly simplified way.

2.3. Summary of and reflection on both approaches

Ideally, a single “super model” would be able to simultaneously endogenize both the complexity of the electricity system and of the building physics involved in flexibly operating heat pumps. Such a model could simulate how to optimally dispatch a flexible heat pump fleet while at the same time it would (a) respect the limitations and dynamics associated with the building physics and (b) respect explicit constraints related to indoor temperature fluctuations. Without explicit assumptions about the acceptability of indoor temperature fluctuations – for example, only allowing temperatures to deviate by 2 degrees from the ideal comfort conditions –, any analysis about the security of supply contribution of heat pump flexibility is at least to some degree meaningless.

Given the practical hurdles and computational requirements which make it impossible to combine everything into a single model, we are forced to keep simulating the electricity system and the actual operation of heat pumps in separate, specialised models. Consequently, any person attempting to assess the security of supply contribution of heat pump flexibility is forced to make a choice. Either you focus entirely on one of the two aspects (the electricity system or the building physics) and take a highly simplified view on the other, -or-, you run a pure electricity system model and a pure building physics model and you somehow combine the results of both in order to come up with an answer. In the next chapter, we explain how we implemented the latter approach for the quantitative analysis in this report. Before we do so, **Table 1** presents a summarising overview of the essential dilemma which we are trying to overcome.

Table 1: Summary of the two possible approaches to assess the potential security of supply contribution of heat pump flexibility

	The electricity-system-focused approach	**The building-physics-focused approach**
What does the modelling focuses on	Accurately simulating the operation of the electricity system in all its complexity	Accurately simulating the operation of heat pumps, given all the complexity of the related building physics
How is the role of heat pumps in the electricity system assessed	By endogenously including heat pumps and their flexible operation in the electricity system model, albeit in an overly simplified way	By precisely quantifying what the electricity consumption profile of a fleet of heat pumps looks like, and how it is impacted when the heat pumps are operated in a flexible manner. This is done using specialised building physics simulations. Subsequently, an overly simplified representation of the electricity system is used to assess how the system may be impacted by this change in the electricity consumption profile
Biggest drawback/limitation	Heat pump flexibility constraints related to building physics are not accurately reflected Heat pump flexibility constraints related to the (un)acceptability of certain indoor temperature fluctuations are not accurately reflected	The electricity system needs to be looked at in such an overly simplified way that none of the second- and third-order effects that are triggered by a change in the electricity consumption profile are properly captured

3. Methodology

3.1. Overview of the methodological approach

The methodology employed in this report is based on the integration of two substantial bodies of work: (1) the findings from two earlier reports published in the context of the FlexSys project (D1.1 and D1.3)[1], which conducted extensive simulations of 66 individual building archetypes extrapolated to the Belgian building stock for 2030 and 2034, and (2) the latest Adequacy & Flexibility report published by Belgian TSO Elia in 2023, which included comprehensive simulations of the electricity system for those same future years[2].

By combining these two sources, we aim to assess the potential contribution of heat pump flexibility to security of supply in the Belgian electricity system. This approach allows us to leverage detailed building physics simulations and advanced electricity system modelling without the need for a single model integrating both – which is computationally infeasible.

3.2. Building stock simulations: recap of earlier FlexSys reports

3.2.1. Building archetypes and simulations

The FlexSys D1.1 and D1.3 reports form the foundation of our understanding of heat pump behaviour in the Belgian building stock. In these reports, a range of distinct building archetypes were simulated. They were each designed to represent part of the current and future Belgian residential building stock. The archetypes were categorized as follows:

- Detached houses (3 size variants)
- Semi-detached houses (3 size variants)
- Terraced houses (3 size variants)
- Apartment corner (1 size variant)
- Apartment enclosed (1 size variant)

For each of these 11 building types, 6 variations were made based on thermal insulation characteristics, ranging from labels A to F, resulting in a total of 66 archetypes.

Each archetype was simulated individually for a full year, modelling the operation of a heat pump maintaining an indoor temperature of 21°C (during specified hours). The simulations produced hourly outputs including heat pump electricity consumption and coefficient of performance (COP).

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[1] https://www.flexsys-project.be/deliverables/

[2] https://www.elia.be/en/electricity-market-and-system/adequacy/adequacy-studies

3.2.2. Extrapolation to the building stock level

The individual archetype simulations were then extrapolated to the building stock level for 2030 and 2034. This was done by forecasting the occurrence of each archetype in the future building stock and assuming that heat pump installations take place primarily in new builds and thoroughly renovated homes. The result was an hourly electricity consumption profile for the entire heat pump fleet under normal operating conditions.

3.2.3. Flexibility simulations

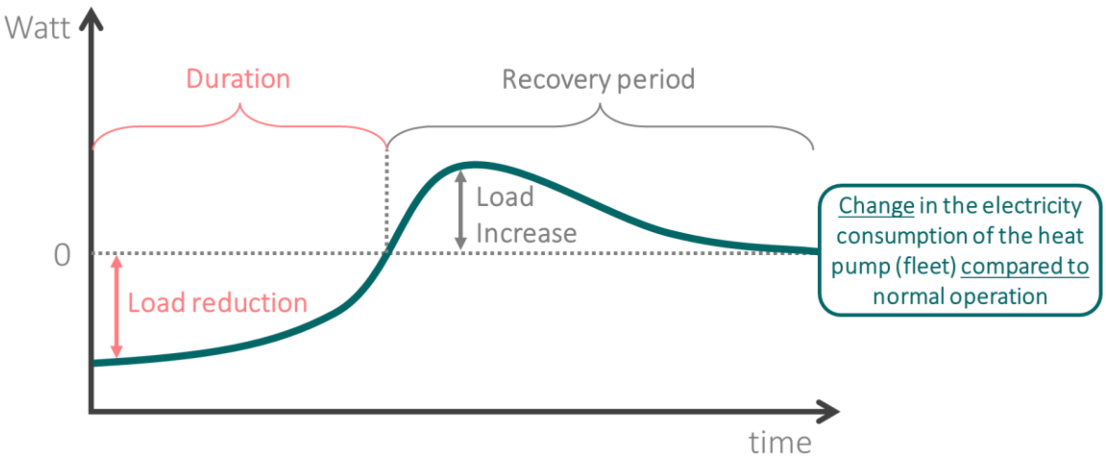
To assess the potential for flexibility, additional simulations were conducted for each archetype. These simulations modelled the effects of turning off the heat pump at specific times, after which the indoor temperature decline was observed until it reached a predefined "threshold temperature". Then, the heat pump was reactivated to restore the indoor temperature back to the setpoint (21°C). One such cycle of turning off the heat pump, letting the building cool down to a threshold temperature and then heating it back up to the setpoint temperature is called a “heat pump flexibility event”. To explore what happens under different possible assumptions for the threshold temperature, simulations were performed with 19°C, 18°C, and 17°C – representing increasing levels of acceptable comfort deviations.

For each case, 8760 simulations were performed to simulate what happens when a heat pump flex event is initiated during each of the potential hours of the year. For example, turning off the heat pump in the 1639th hour of the year, to then observe what happens in the 100 hours after that, as the building cools down to the threshold temperature and is subsequently recovered back to the setpoint temperature. This brute-force method of simulating “all possible heat pump flexibility events” enables an accurate view of how heat pump electricity consumption is affected under a wide range of varying boundary conditions. Each individually simulated heat pump flex event occurs under a different unique combination of outdoor temperatures and indoor temperatures which happen to be taking place (cf. “heating profiles” in section 2.2 and FlexSys report D1.1)[1].

These flexibility simulations were also aggregated to the building stock level, quantifying the potential impact on the total electricity consumption profile if all heat pumps in Belgium were simultaneously turned off at a given moment. Across the fleet, some buildings reach the threshold temperature faster than others, and initiate their recovery back to the setpoint temperature. The net effect at the fleet (building stock) level is a reduction in heat pump electricity consumption which shrinks as the hours go by, and ultimately turns into a net-increase in electricity consumption.

This moment when the “recovery period” kicks in at the building stock level determines the “duration” of the heat pump flex event. This is the amount of hours – after turning off the entire Belgian residential heat pump fleet – during which there is a net-reduction in electricity demand compared to the counterfactual situation in which the heat pumps would have remained untouched and had continued to operate normally.

Figure 3: Stylized representation of a heat pump flex event



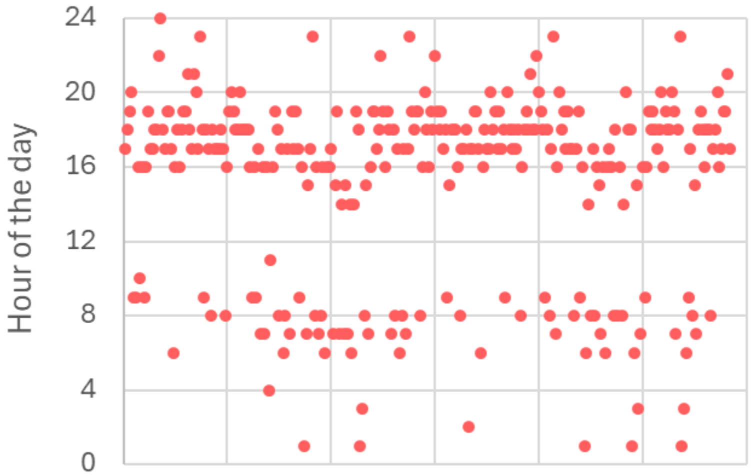
We assume in this report that allowing indoor temperatures to deviate from their setpoint (e.g. 21°C) is inevitable in heat pump flexibility is to be fully exploited. In theory, water buffer tanks could also enable a certain amount of heat pump flexibility to take place, without indoor temperatures being affected. The heat required to heat the building in the hours when the heat pump is turned off is then extracted from the pre-heated water buffer tank. However, as explained in Annex 7.1, we cannot reasonably expect water buffer tanks to be a reasonable substitute for indoor temperature fluctuations, because the buffer volumes required are highly impractical to install in many homes and require significant additional investments by the households in question.

3.3. Electricity system simulations: Elia's Adequacy & Flexibility report

The 2023 Adequacy & Flexibility report by Elia included detailed simulations of the Belgian electricity system for 2030 and 2034. For our analysis, we focused on the specific sensitivity simulations where heat pump flexibility was considered unavailable. This was done to avoid potential conflicts between heat pump flexibility activations that may have occurred in Elia simulations with those simulated by UGent on the basis of the building physics models and building-stock extrapolation presented in the D1.1 and D1.3 reports (cf. infra).

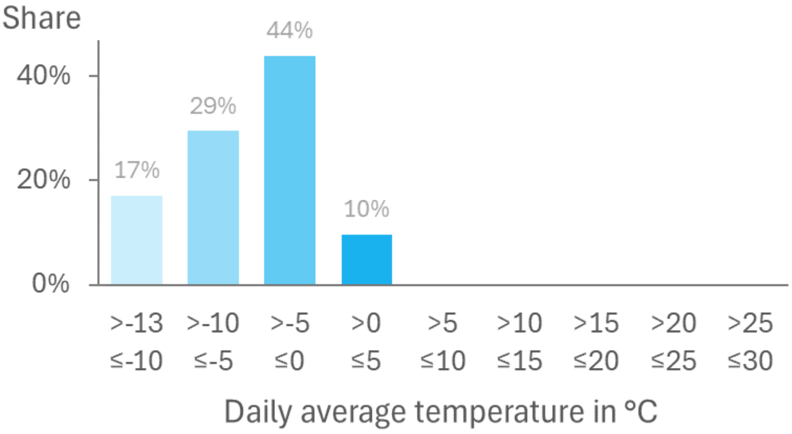
These Elia simulations, run across hundreds of Monte Carlo iterations, identified moments when supply could not meet Belgian hourly electricity demand, which we term "scarcity events". During these moments, a certain amount of "energy not served" (ENS) was recorded, measured in MWh. Every scarcity event also has a specific "duration", indicating the amount of subsequent hourly timesteps during which supply was unable to meet demand. Scarcity events typically take place during either the morning or evening peaks in national electricity demand (**Figure 4**) and exclusively when daily average temperatures are below freezing (**Figure 5**). The duration of scarcity events is usually limited to a few consecutive hours (**Figure 6**), while the amount of electricity demand that the system is unable to meet – also called the 'volume' of a scarcity event – is almost always below 5000 MWh (**Figure 7**).

Figure 4: Time of day when scarcity events occur



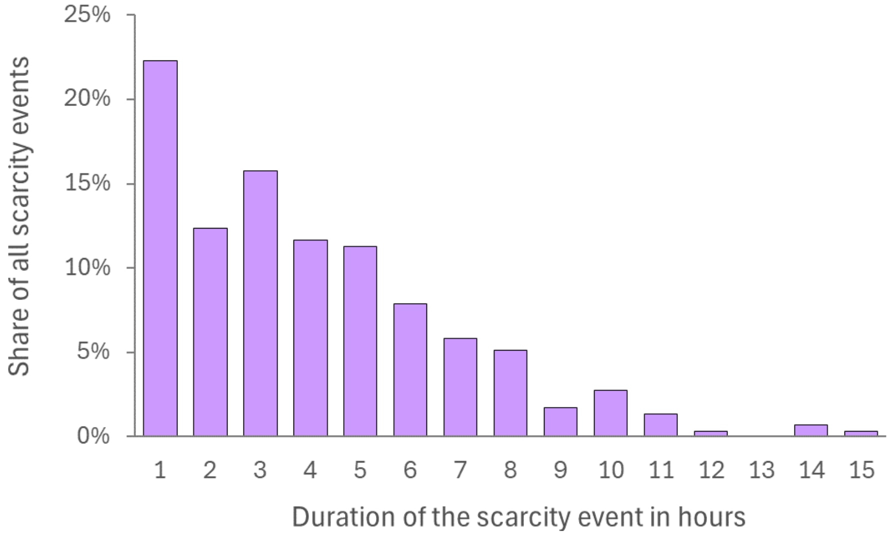
Note: each dot represents one scarcity event.
Dots are spread out horizontally for visual clarity.

Figure 5: Outside temperatures when scarcity events occur



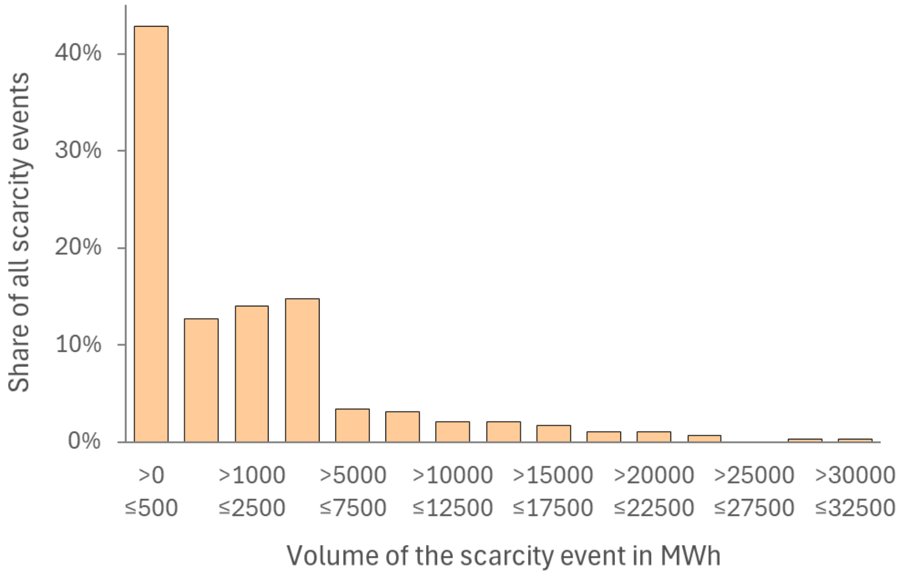
Note: data shown are for the electricity system simulations of 2030.
The distribution is almost identical in the case of 2034.

Figure 6: Duration of scarcity events



Note: data shown are for the electricity system simulations of 2030.
The distribution is almost identical in the case of 2034.

Figure 7: Volume of scarcity events



Note: data shown are for the electricity system simulations of 2030.
The distribution is almost identical in the case of 2034.

3.4. Integration of building stock and electricity system simulations

3.4.1. Matching scarcity events with heat pump flexibility

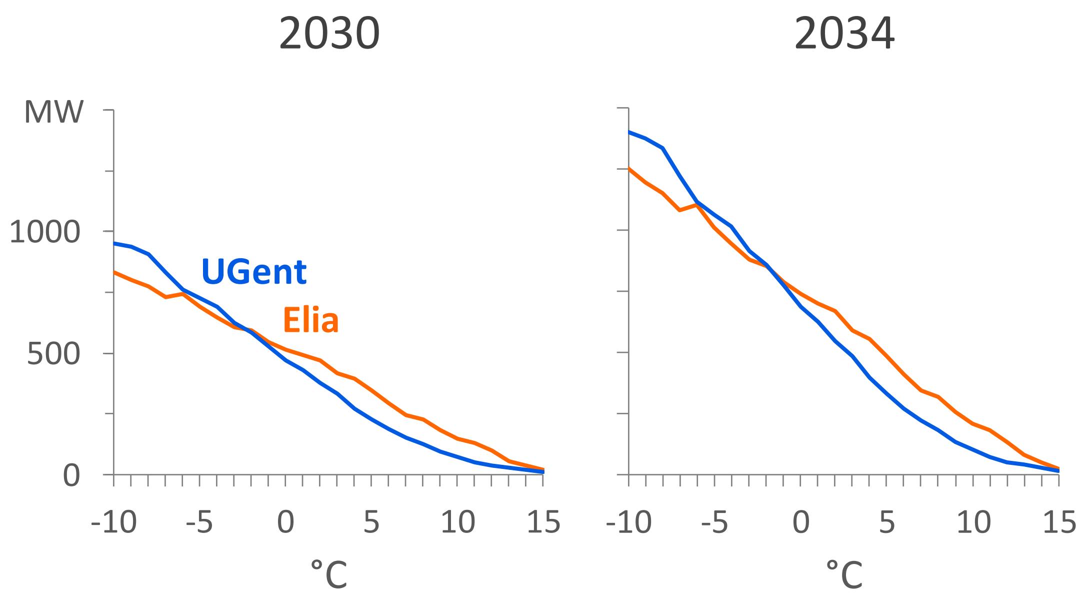
To assess the potential contribution of heat pump flexibility to security of supply, we matched each scarcity event from the Elia simulations with one or more heat pump fleet flexibility events from the D1.1 and D1.3 reports. This matching was done based on average daily temperatures, ensuring that:

- The total electricity demand reduction triggered by turning off the “UGent heat pump fleet” aligns as closely as possible with the electricity demand occurring in the “Elia heat pump fleet” at the start of the scarcity event.

- The rate of building cool-down, and consequently the duration of the heat pump flexibility event, is accurately reflected.

Figure 8 shows the alignment between the Elia and UGent building stocks and the subsequent heat pump electricity consumption that takes place at different outside temperatures.

Figure 8: Electricity consumption of the Belgian residential heat pump fleet



Note: the building stock and heat pump fleet projected by UGent for 2030 and 2034 were calibrated to those projected in the Elia Adequacy & Flexibility report. This was done to make sure that the electricity demand reductions triggered by heat pump flexibility events (as simulated by UGent) reflect the electricity demands that took place in the Elia simulations as closely as possible.

3.4.2. Synchronization of building stocks

It's important to note that efforts were made to synchronize the 2030 and 2034 building stocks envisioned in the D1.1 and D1.3 reports with those in the Elia simulations. This synchronization attempts to ensure to the best degree possible that the heat pump fleet whose flexibility is being exploited to address scarcity events is consistent with the heat pump fleet operating in the Elia simulations.

3.5. Limitations and considerations

3.5.1. Theoretical nature of the exercise

It should be emphasized that this analysis represents a highly theoretical exercise. In reality, if the future Belgian heat pump fleet were highly flexible, this flexibility would likely be exploited primarily for other goals mentioned in the introduction, such as reducing household electricity bills or increasing solar self-consumption. The impact of these other uses of flexibility on the potential for security of supply contributions is unclear and not considered in this analysis.

Moreover, two key notions underpinning the exercise are extremely unlikely in practice, namely that (a) the entire heat pump fleet would be fully controllable and react in its entirety to a scarcity event and (b) that all involved households would accept the resulting deviations from their ideal indoor comfort temperature. These assumptions are made to simplify the analysis, but they limit the scope to "how much could a flexible heat pump fleet contribute to security of supply in theory, under optimal conditions, i.e. *in the limit*?"

3.5.2. Recovery effects

A significant limitation of our methodology is the inability to account for the impact of the "recovery" phase (returning to 21°C indoor temperature) on the electricity system and security of supply. In reality, reducing Belgian electricity demand through a heat pump flex event could alleviate a scarcity event but potentially cause a new one during the subsequent recovery phase.

This limitation stems from two factors:

- The mismatch between the duration of simulated heat pump flexibility events (often more than 10 hours) and typical scarcity events (often only a 1 to 5 hours). In a real-world scenario, heat pumps would only be turned off for the duration of the scarcity event, resulting in a milder recovery phase than our simulations suggest.

- Methodological constraints: The output from the Elia simulations does not provide precise information about the degree to which the Belgian electricity system can cope with a particular increase in electricity demand during the recovery phase of a heat pump flex event. To assess this accurately would require re-running the Elia simulations with modified demand profiles, which is beyond the scope of this study.

As a result, our analysis focuses solely on the initial demand reduction phase of heat pump flex events and does not consider the potential secondary effects of the recovery phase on the electricity system.

In conclusion, while our methodology allows for a novel integration of building physics and electricity system simulations, it is important to interpret the results in light of these limitations and the theoretical nature of the exercise.

4. Results

4.1. Covering scarcity events with heat pump flex events

In the context of an electricity system, security of supply is sometimes referred to as *adequacy*. A traditional security of supply analysis quantifies the degree to which a certain mix of electricity production assets is *adequate* to make sure that electricity demand can (almost) always be met. More specifically, to make sure that the number of hours in which demand *cannot* be met is "sufficiently small".

An adequacy analysis performs hundreds of simulations, a few of which will contain a number of hours in which demand cannot be fully met. On average – across all simulations – this amount should be no higher than 3. When this "loss of load expectation" (LOLE) is lower than 3 hours, the system is seen as "capable enough" in terms of keeping the lights on – namely, during all but the rarest, most extreme moments.

Typically the rare moments when demand cannot be met are caused by one or more specific things happening at the same time. Namely: an extreme peak in electricity demand, exceptionally cold weather, exceptionally low renewable production, or 'forced outages' of other generators that are normally available to produce electricity when there is no wind or sun.

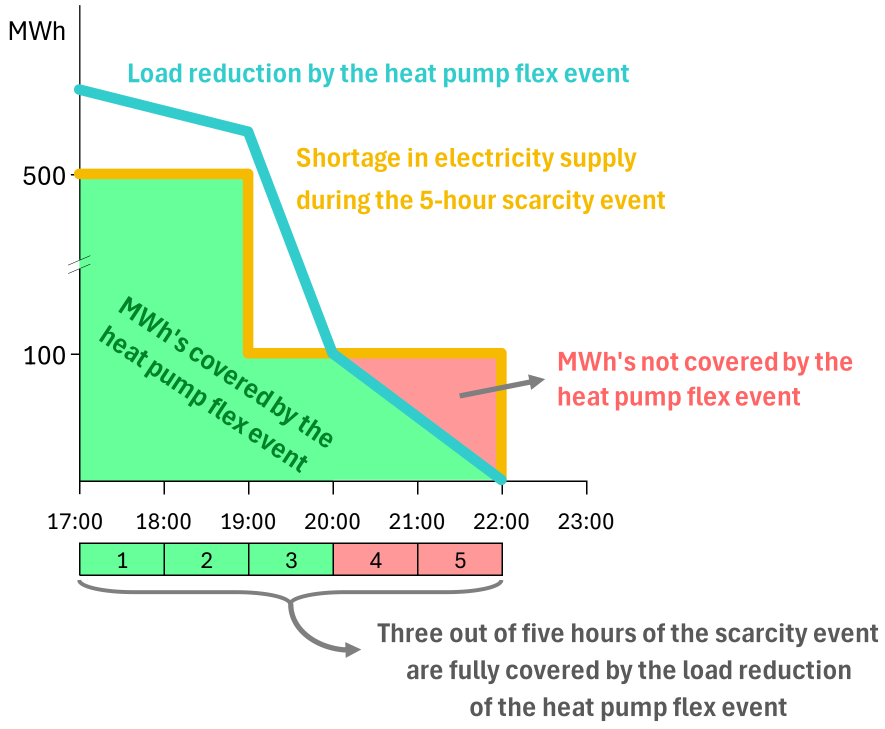
As explained in Chapter 3, we derived such "scarcity events" from electricity system simulations performed by Elia for the years 2030 and 2034. To assess the potential contribution to security of supply of the heat pump fleet, we consider how the reduction in national electricity demand that occurs during a "heat pump flex event" could help alleviate or "cover" the shortages of electricity supply that the system is faced with during these moments.

4.2. The two key metrics making up the results

In our analysis we focus specifically on two key metric. First of all, the degree to which each scarcity event's "**duration**" can be covered. By this we mean how many of the hours during which a shortage took place are "solved" by the load reduction from a heat pump flex event. If for example a specific scarcity event has a duration of 5 hours, it is possible that using a heat pump flex event (as envisioned in this report) to address it would lead to some but not all of these 5 hours being fully covered. This could happen when the load reduction caused by the heat pump flex event is large enough in 3 of the 5 hours, but not in the remaining 2.

The second metric we focus on is the degree to which each scarcity event's "**volume**" can be covered. The volume of a scarcity event indicates how large the shortage in cumulative megawatt-hours is across its full duration. If for example a 5 hour scarcity event consists of 2 hours with a 500 MWh shortage each and 3 hours with a 100 MWh shortage each, then the total volume of this scarcity event would be 1300 MWh. When an attempt is made to address a scarcity event with a heat pump flex event, our method checks – for each individual hour of the scarcity event – how many of the megawatt-hours that are needed can actually be "delivered". This results in a metric indicating which percentage of the total volume can be covered. **Figure 9** visualises in a simplified way the two key metrics focused on in the remainder of this results chapter.

Figure 9: Simplified representation of a heat pump flex event covering part of the duration (hours) and volume (MWh's) of a scarcity event



It should be noted that our focus on these two key metrics is not the only feasible way of "measuring" the security of supply contribution of heat pump flexibility. One alternative would be to estimate the degree to which the LOLE would decrease. For example, from an average of 3 hours down to an average of 1 hour (-66%). Another alternative is to calculate by how much the production capacity required in the system would decrease, assuming the LOLE can remain constant (e.g. at an average of 3 hours). It may for example be the case that heat pump flexibility enables one less gas power plant being necessary in the Belgian electricity system, for the same level of adequacy to be reached. However, such estimates are out of scope in this report due to the methodological limitations of the chosen approach.

4.3. Comparing the duration of scarcity events and heat pump flex events

To better understand the results presented in the next sections, we need to focus our attention on a key observation made when comparing scarcity events with heat pump flex events. Namely, that scarcity events typically last for a much shorter period, as shown in **Figure 10**. More than 70% of all scarcity events during which the electricity system is faced with a shortage in electricity supply last 5 hour or less. If we look within this duration category of 5 hours or less, we see that 20% of all scarcity events only last a single hour and approximately another 20% last only two to three hours. This stands in sharp contrast to the typical durations of heat pumps flex events, which can easily last more than 10 hours and even up to 40 hours and more – depending on the indoor temperature threshold that is assumed.

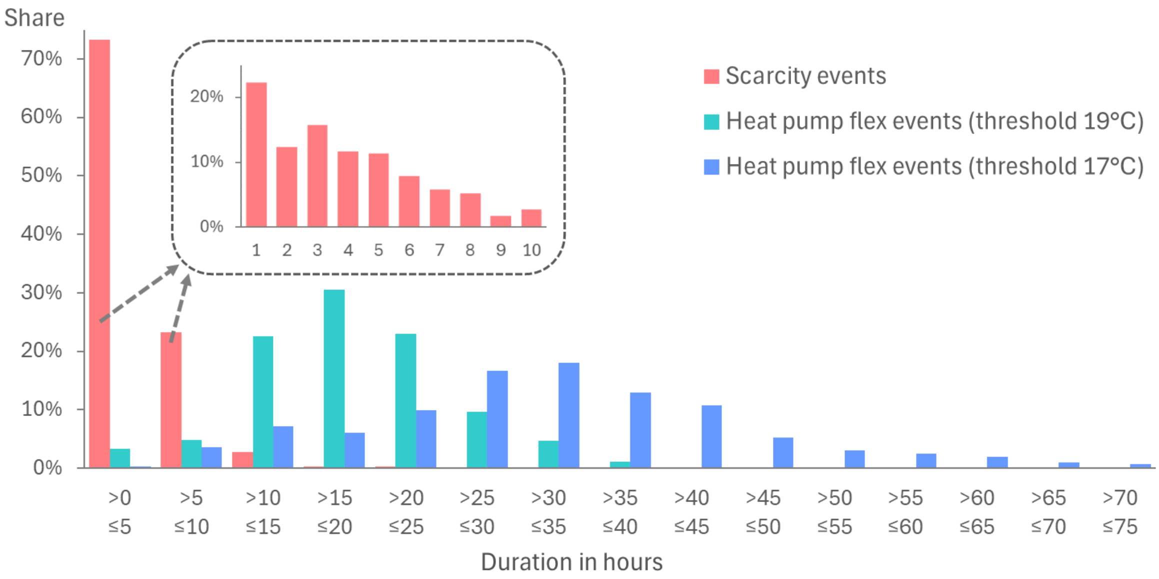
This unique comparison is enabled by our novel approach of bringing together a dataset of scarcity events – coming directly from a world-class electricity system adequacy simulation performed by Elia – with a dataset of heat pump flex events, generated by UGent on the basis of thousands of specialised individual building simulations.

What this comparison teaches us, is that heat pumps are in a unique position to contribute to security of supply. The buildings in which heat pumps are typically installed cool down very slowly when the heat pumps are turned off. Even if we assume that heat pumps need to reactivate as soon as the indoor temperature reaches 19°C – which implies a limited impact on thermal comfort – the electricity demand of the heat pump fleet can be reduced more than long enough to help deal with the vast majority of scarcity events.

Figure 10 also shows that if buildings would be allowed to cool down to 17°C before heat pumps are reactivated – which is unlikely in practice, but still a theoretical possibility – this further extends the duration of heat pump flex events in a nontrivial manner.

However, the question then becomes to which degree this additional duration is actually useful from a security of supply perspective, as long as the "problem" that needs to be dealt with only lasts for a few hours in most cases. This question is answered in the next section.

Figure 10: Duration of scarcity events and heat pump flex events

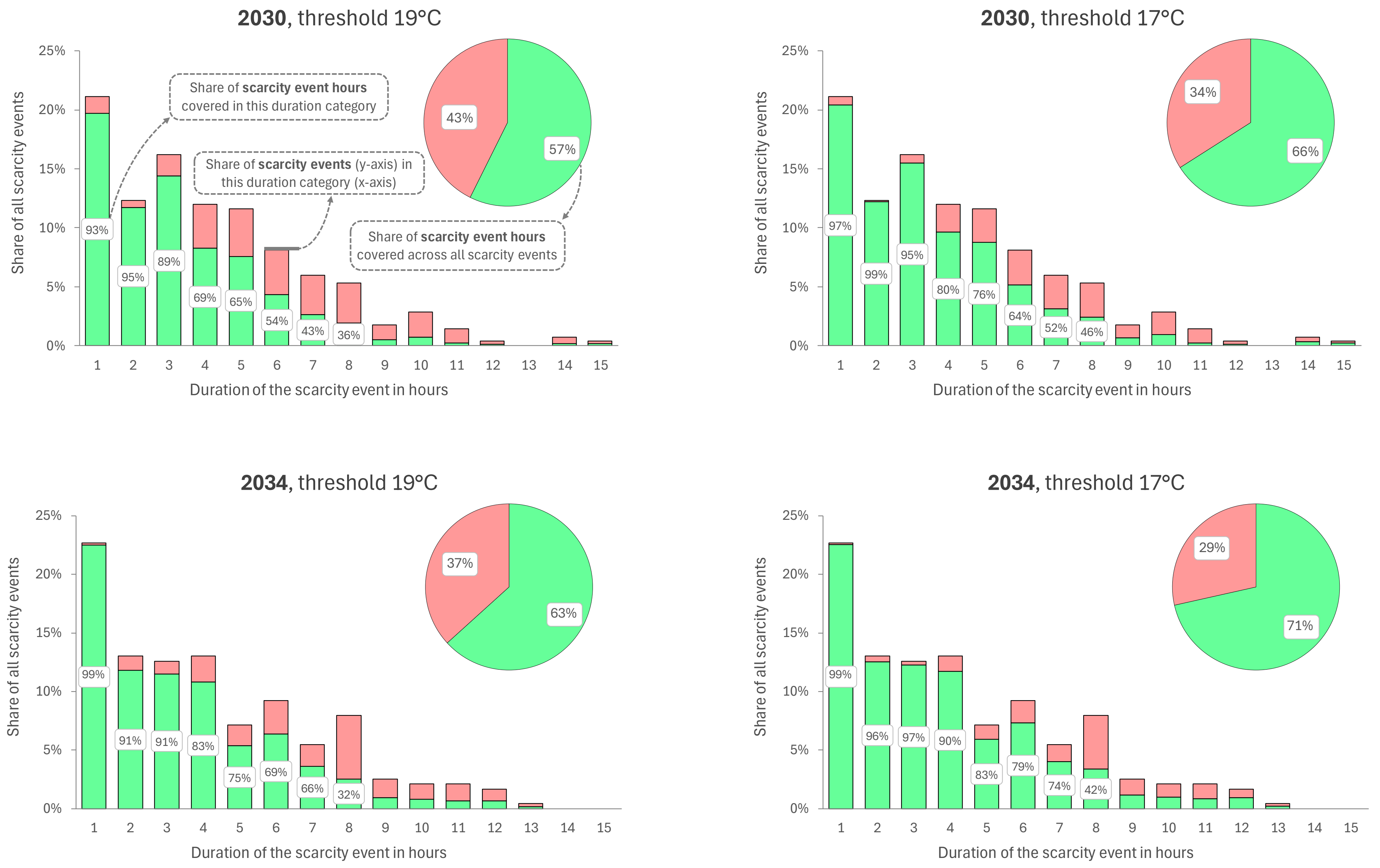


Note: scarcity events are moments when Belgian electricity demand cannot be fully met. Its duration expresses the number of consecutive hours during which this is the case. Heat pump flex events are moments when the entire Belgian heat pump fleet is turned off. Indoor temperature in each individual building is allowed to drop to a certain threshold, after which the heat pump reactivates and indoor temperature is recovered back to 21°C. Duration is expressed as the number of hours until the electricity demand reduction ends at the building stock level. The data in the figure represent the year 2030. The data for the year 2034 is quasi identical with respect to the visualized distributions. Given the fact that scarcity events only happen in January, February and December, the figure also only shows heat pump flex events taking place during these months of the year.

4.4. Results about covering the duration of scarcity events

Figure 11 gives an overview of results about the first key metric, namely to which degree heat pump flexibility can cover the **durations** of different scarcity events. When we look at scarcity events across different duration categories, we see that almost all scarcity events with a duration of one to three hours can be perfectly covered by heat pump flexibility. In the categories with longer durations of four hours and more, the vast majority of "scarcity event hours" can still be dealt with, but an increasing number of hours cannot. Across all scarcity events of all durations, approximately two thirds of scarcity event hours can be covered. While the number of scarcity events with a long duration is relatively small, they represent a outsized fraction of the total number of scarcity event hours.

Figure 11: Main results part 1 – share of scarcity event hours that can be covered by residential heat pump flexibility



When we compare the results for 2030 and 2034, we see that the security of supply contribution of heat pump flexibility improves over time, which can be explained by the fact that the number of heat pumps grows while the duration and magnitude of scarcity events more or less stays the same.

At the same time, we see that reducing the threshold temperature to 17°C instead of 19°C only makes a marginal improvement in terms of the security of supply contribution. As explained in the previous section, the duration of heat pump flex events is already "more than long enough" in the case of a 19°C threshold. This results in the fact that even longer durations – enabled by a lower threshold – hardly enable any additional scarcity event hours to be dealt with.

Certain scarcity events hours simply cannot be dealt with using heat pump flexibility, no matter how long and how far you allow buildings to cool down. For example, because the amount of load reduction required is simply too high. If the electricity system faces a shortage of more than 1 GW at a time when the electricity demand of the heat pump fleet is only 700 MW, there is simply no way for heat pump flexibility to solve the problem on its own. Once a heat pump is turned off, there is nothing more you can do.

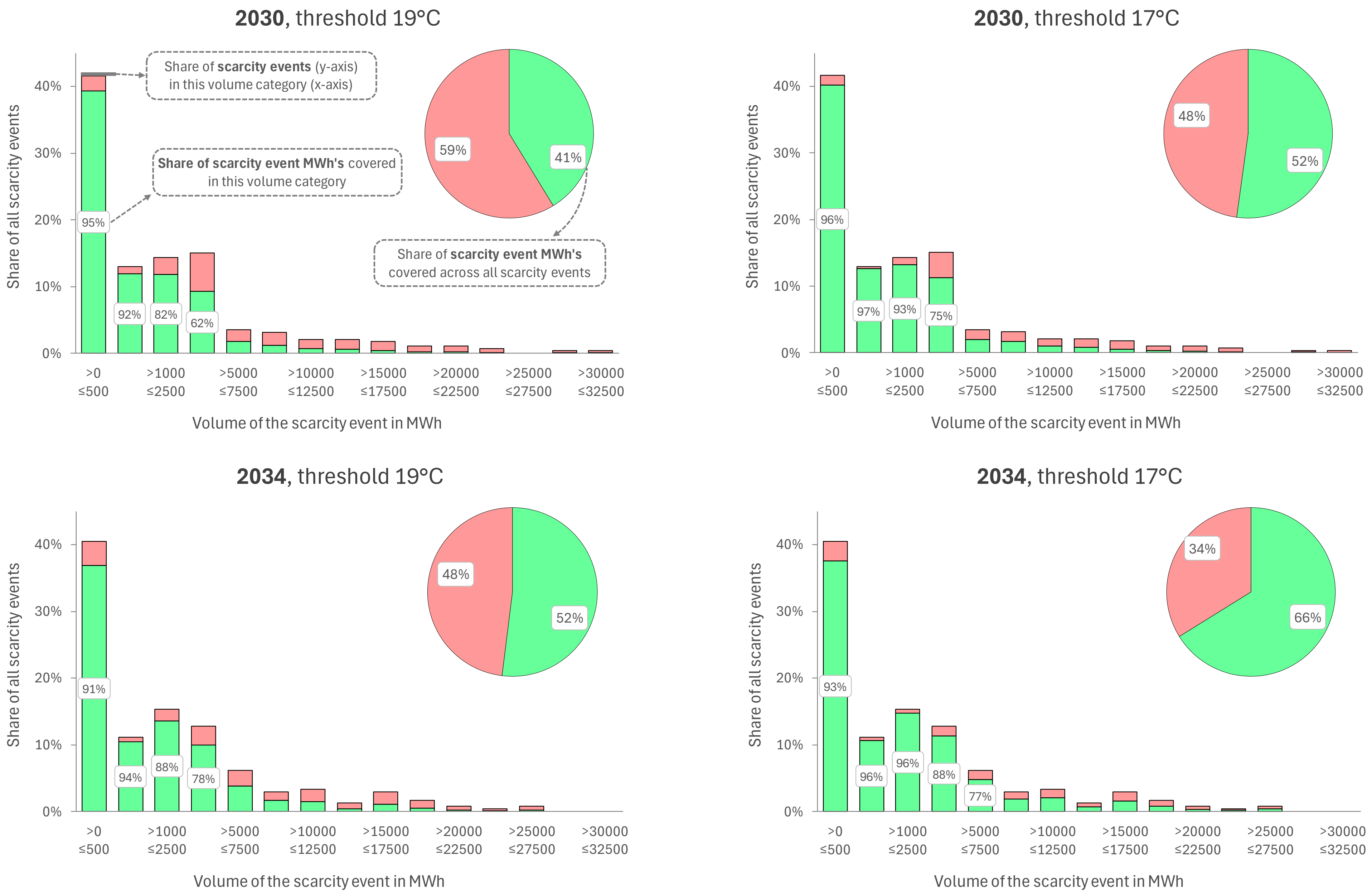
It should be noted that covering two thirds of all scarcity event hours can still be expected to result in a significant decrease of the average LOLE (for example from 3h to 1h). However, quantifying this in a precise manner would require a modeller to incorporate the heat pump flexibility envisioned in this report into a monte-carlo security of supply analysis of the electricity system. As explained in chapters 2 and 3, this is unfortunately computationally infeasible.

4.5. Results about covering the volume of scarcity events

A similar picture emerges when we take a look at the other key metric to evaluate the security of supply contribution of heat pump flexibility, namely the degree to which it can deliver the necessary amount of megawatt-hours. As shown in **Figure 12**, heat pump flex events can deliver a sufficient amount of load reduction to (almost) fully deal with scarcity events in the majority of cases.

While there are a fair number of scarcity events with a limited volume and thus a limited number of megawatt-hours required in order to "cover" them, there is a long "tail" of scarcity events with volumes that are larger than 5 000 megawatt-hours. In 2030 this tail represents 16% of all scarcity events, while it represents 20% of all scarcity events in 2034. As to be expected, heat pump flexibility can deal with many scarcity events in the smaller volume categories, but increasingly falls short as the volumes grow.

Figure 12: Main results part 2 – share of scarcity event megawatt-hours that can be covered by residential heat pump flexibility


2030, threshold 19°C

2030, threshold 17°C

2034, threshold 19°C

2034, threshold 17°C

Still, the same basic picture emerges as in the duration-focused results, whereby approximately two thirds of scarcity event megawatt-hours can effectively be dealt with. Moreover, the same differences also emerge when it comes to comparing the results for different future years or different indoor temperature thresholds. When the heat pump fleet grows as we proceed further into the future, more and more scarcity event megawatt-hours can be covered, while the marginal benefit of allowing buildings to cool down further is limited. Again we observe that a certain amount of scarcity events are simply “too hard to deal with” using heat pump flexibility alone. Regardless of how optimistic you want to be about the acceptability of lower thresholds and therefore increasing impacts on comfort.

It is important to know that the megawatt-hours shown in this figure only take place during the scarcity events themselves. Additional megawatt-hours could in theory be “delivered” during the many hours after a scarcity event has finished. As long as the indoor temperature threshold has not been reached yet in most buildings, the heat pump fleet can keep load reductions intact for many more hours. However, just like the longer durations themselves, additional megawatt-hours of load reduction that could in principle still be delivered in the hours after a scarcity event has occurred are irrelevant from the perspective of our analysis.

It *could* potentially help deal with a chain of several scarcity events that take place closely after each other. This is something that does occasionally happen in electricity system simulations, and potentially in the real world. However, analysing this is out of scope in our analysis, because the marginal security of supply value of being able to (partially) deal with multiple scarcity events in a row is presumably limited. Therefore, we do not expect that excluding this has a significant impact on the conclusions of this report.

4.6. Putting the results into perspective

The abovementioned results are dependent on a number of assumptions and boundary conditions unique to our analysis. The analysis is theoretical in nature, and explores what heat pump flexibility could do in the most extreme "best case scenario", namely by including the following elements:

- We assume that all residential heat pumps in Belgium respond to a scarcity event at the same time, and in the same manner – by fully turning themselves off until a certain indoor temperature is reached (19°C or 17°C). In reality, only a fraction of heat pumps will be able to react to scarcity situations. Of those who are able to react, only a further fraction actually *will* react. Moreover, only a fraction of heat pump owners whose heat pump reacts will allow the indoor temperature in their home to noticeably drop. Actual "amounts of reaction" could thus be more limited.

- We ignore the "recovery period" that takes place after a heat pump flex event, whereby electricity demand is inevitably *increased* relative to the counterfactual situation in which the heat pumps had continued to operate normally. These increases in electricity demand could – in some cases – potentially trigger new scarcity events of their own.

- We ignore the rare possibility of several scarcity events occurring shortly after each other, in which case the heat pump fleet could still be recovering from a previous flexibility activation.

- We do a pure "ex-post" analysis, whereby scarcity events that have already been simulated are now looked at separately to check whether they could be covered by heat pump flexibility. When our analysis indicates that a scarcity event would be reduced by a certain number of megawatt-hours through heat-pump flexibility, this does not fully align with what would happen in an electricity system model. Due to the so-called "Adequacy Patch", reducing the load in one country experiencing a scarcity event may counterintuitively not reduce the shortage in that country by this exact amount. Shortages taking place across the European system are shared and "spread out" according to predefined rules. In principle, it is possible for example that a 100 MW reduction in Belgian load to address a 100 MW Belgian electricity shortage, would (partially) end up alleviating a similar shortage taking place at the same time in another country, instead of fully going towards the alleviation of the Belgian shortage itself.

5. Conclusion

This report has examined the potential contribution of residential heat pump flexibility to security of supply in the Belgian electricity system. By combining detailed building physics simulations with comprehensive electricity system modelling, we've gained valuable insights into the capabilities and limitations of heat pump flexibility as a tool for addressing scarcity events.

Our analysis reveals that heat pump flexibility can indeed play a significant role in mitigating short-term scarcity events in the electricity system. The key finding is that heat pump flexibility durations are typically longer than scarcity event durations in the vast majority of cases. In practical terms, this means that buildings with heat pumps cool down so slowly that they can be safely turned off for several hours to help address critical situations on the grid without significantly impacting comfort.

Results indicate that in both 2030 and 2034, approximately two-thirds of scarcity event hours and megawatt-hours could potentially be covered by heat pump flexibility. This suggests that heat pump flexibility could make a meaningful contribution to security of supply, particularly for shorter-duration scarcity events. However, these results should be strictly interpreted in the light of the highly theoretical assumptions that were made for the sake of exploring what is possible “in the limit”. Namely, that 100% of heat pumps react, 100% of users allow their buildings to cool down, and ignoring several potential risks that can be relevant in practice. These are (a) several scarcity events happening shortly after each other, (b) the recovery period after a heat pump flex event increasing load and thereby causing a new scarcity event, and (c) the load reduction caused by the heat pump flex event not fully going towards the alleviation of the Belgian scarcity event, because of international electricity dynamics related to the ‘Adequacy Patch’.

Interestingly, we observed that allowing buildings to cool down to 17°C instead of 19°C did not significantly increase the security of supply contribution. The reason is that the flexibility durations achieved at 19°C are already long enough to address the majority of scarcity events. This suggests that more aggressive temperature setbacks may not provide substantial additional benefits from an electricity-system perspective.

While our analysis focused on scarcity events, it's important to note that heat pump flexibility may also prove valuable in managing variable renewable energy surpluses in the future. Although not quantified in this study, we can reasonably expect that the ability to increase heat pump consumption during periods with surplus wind or solar could be beneficial. This could be particularly relevant in winter months when surpluses in wind energy could be used to pre-heat buildings to temperatures slightly above standard comfort temperatures, enabling heat pumps to subsequently be turned off for an extended period of time while renewable production is lower. In summer, timing the production of domestic hot water can also help absorb surpluses in solar energy.

In addition to the abovementioned assumptions accompanying the main results, it is important to further put this report's findings into perspective and acknowledge further limitations of the analysis:

First and foremost, it's important for policymakers to recognize that on a net basis, adding millions of heat pumps to the Belgian energy system will likely have a negative impact on security of supply for electricity, assuming all else remains constant. The flexibility potential we've quantified can only partially compensate the impact of this increased electricity demand.

It's also worth noting that while our methodology represents a novel integration of building physics and electricity system simulations, there is still room for improvement in modelling heat pump flexibility within electricity simulation models. This remains an area of ongoing research, as we strive to more accurately represent the complex dynamics of building physics within the constraints of electricity system models.

Our analysis focused on the medium-term horizons of 2030 and 2034, and we do not make claims about the potential of heat pump flexibility in the very long term (e.g., 2050). However, the fundamental principles we've observed will likely remain relevant: a growing heat pump fleet will continue to increase overall electricity demand and flexibility can only partially offset the impact this has in terms of security of supply. A growing number of heat pumps unavoidably increases the firm production capacities required in order to keep the lights on, even if many scarcity events could be dealt with using flexibility. Certain situations that our electricity system has to deal with are fundamentally unaddressable with heat pump flexibility alone, and this will remain the case in the long term.

It's also important to note that our study did not consider the costs associated with implementing and activating heat pump flexibility at scale. We focused solely on quantifying the technical potential for security of supply contributions. While we can speculate that leveraging existing heat pump infrastructure might be cost-competitive compared to alternatives like building new peaker plants, the actual costs and necessary incentives for consumers remain open questions.

Despite these limitations, our analysis supports the continued pursuit of both heat pump adoption and enabling heat pumps to be operated in a flexible way. Even if flexibility can only partially compensate for the increased electricity demand, heat pumps remain crucial for reducing CO2 emissions from buildings. Furthermore, enabling flexibility is a no-regret strategy for policymakers to avoid that this additional electricity demand occurs at its fullest during the worst possible moments. The sooner we can reduce the electricity consumption of heat pumps at moments when supply struggles to meet national demand, the better.

Policymakers should not lose sight of the fact that the rollout of heat pumps and ensuring their flexible operation will both require additional interventions. This may include making heat pump installations more financially attractive by adjusting the relative taxation of electricity versus fossil fuels. Additionally, policymakers should address barriers that hinder flexible operation, as detailed in other reports of the FlexSys project.

In conclusion, while heat pump flexibility alone cannot solve all security of supply challenges, it represents a valuable tool in the broader toolkit for managing the evolving electricity system. By enabling this flexibility, we can mitigate some of the grid impacts of increased electrification while still reaping the environmental benefits of heat pump adoption. As we continue to decarbonize our energy system, such flexible resources will play an increasingly important role in maintaining a reliable and sustainable electricity supply.

6. Acknowledgments

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Any inquiries about or feedback on the report are welcome at Sam.Hamels@UGent.be.

7. Appendix

7.1. Heat pump electricity consumption and buffer tank size required for various archetypical buildings simulated

In the context of the FlexSys project, Ghent University's building physics group has simulated various archetypical residential buildings representative of the current and future building stock (cf. deliverable report D1.1)[1]. For each of these archetypes, advanced individual building simulations were performed in terms of heating the building with a heat pump for one entire year using an hourly temporal resolution. The output of these simulations included the total heat production required to maintain a setpoint temperature of 21°C, the heat pump COP and the electricity consumption of the heat pump – all available for each simulated hour.

This allows us to produce an overview table (**Table 2**) creating clarity about what the electricity consumption of heat pumps can be expected to be in various kinds of residential buildings for various outside temperatures.

Also included in this overview table is an estimate of how large a water buffer tank needs to be in order to be able to "take over the job of the heat pump" for one hour. More specifically, we show how large a buffer tank needs to be in order to store enough thermal energy to be able to deliver the necessary kWh's of heat, assuming a specific outside temperature (i.e. a specific building heat loss). In other words, the idea is to heat the building by using only the thermal energy stored in the buffer tank, enabling the heat pump to stay turned off for one or several hours. The estimates shown in the table assume that the buffer tank is heated to 20 degrees above the required supply temperature going to the heating delivery system (which can vary from .

What we learn from these buffer size estimates is that heat pump flexibility cannot be expected to come from using water buffers alone. To keep a heat pump turned off for several hours – which would be needed in practice in order to, for example, avoid an expensive evening peak with high prices – the values in the table need to be multiplied accordingly. For example, to be able to keep the heat pump turned off for five hours, the buffer volume in the table needs to be multiplied by five. When doing so for the volumes required when outside temperatures are below freezing, it becomes apparent that the required volumes are unrealistically large for most households and buildings. We cannot realistically expect every household with a heat pump to invest in and physically install water buffers that occupy several cubic meters of limited living space, especially considering the high value of housing real estate. Fully exploiting the technical potential of heat pump flexibility will hence inevitably involve deviations from ideal indoor comfort temperatures.

Table 2: Heating a home with a heat pump for one hour in various types of buildings and outside temperatures

Building Type	Building Volume (m^3)		Building Area (m^2)		Building Envelope Label	Heat pump electricity consumption (kWh$_e$)			Heat production (kWh$_{th}$)			COP (kW$_{th}$/kW$_e$)			Buffer size required (liters of water)		
						-5°C	0°C	5°C	-5°C	0°C	5°C	-5°C	0°C	5°C	-5°C	0°C	5°C
Appartment	300	M	100	M	A	0.8	0.6	0.2	1.8	1.6	0.9	2.3	2.8	4.8	78	71	41
Appartment	300	M	100	M	B	1.3	0.7	0.3	2.7	2.1	1.4	2.2	3.0	4.6	118	89	59
Appartment	300	M	100	M	C	1.4	0.8	0.3	3.0	2.1	1.3	2.1	2.6	4.3	128	92	55
Terraced	437	S	126	S	A	1.6	0.8	0.4	3.6	2.8	1.9	2.2	3.3	5.0	155	120	80
Terraced	437	S	126	S	B	2.3	1.4	0.6	5.2	4.1	2.9	2.3	3.0	4.6	226	178	126
Terraced	437	S	126	S	C	3.2	2.0	0.9	6.9	5.3	3.6	2.1	2.6	4.2	298	230	157
Terraced	475	M	160	M	A	2.0	1.0	0.4	4.5	3.3	2.0	2.3	3.4	5.1	193	143	86
Terraced	475	M	160	M	B	3.0	1.8	0.8	6.9	5.4	3.6	2.3	3.0	4.7	299	231	155
Terraced	475	M	160	M	C	4.2	2.4	0.9	8.8	6.5	4.0	2.1	2.6	4.3	380	279	171
Terraced	547	L	199	L	A	1.9	1.0	0.4	4.4	3.4	2.1	2.3	3.4	5.1	190	146	90
Terraced	547	L	199	L	B	2.9	1.8	0.8	6.8	5.3	3.6	2.3	3.0	4.7	293	229	155
Terraced	547	L	199	L	C	4.2	2.5	1.0	9.0	6.8	4.3	2.1	2.6	4.3	386	292	187
Detached	460	S	146	S	A	2.0	1.1	0.5	4.8	3.8	2.7	2.4	3.4	5.1	206	162	117
Detached	460	S	146	S	B	3.2	2.0	0.9	7.6	6.0	4.4	2.4	3.0	4.7	329	259	190
Detached	460	S	146	S	C	4.7	2.9	1.3	10.2	7.8	5.7	2.1	2.6	4.2	438	338	245
Detached	622	M	198	M	A	2.3	1.3	0.6	5.7	4.5	3.2	2.4	3.4	5.1	243	192	138
Detached	622	M	198	M	B	3.8	2.4	1.1	9.0	7.0	5.2	2.4	3.0	4.7	386	303	223
Detached	622	M	198	M	C	5.6	3.5	1.6	12.1	9.3	6.8	2.1	2.7	4.2	522	402	291
Detached	798	L	277	L	A	2.8	1.6	0.8	6.9	5.5	3.8	2.4	3.4	5.1	298	235	165
Detached	798	L	277	L	B	4.6	2.9	1.4	11.1	8.8	6.4	2.4	3.0	4.7	478	377	274
Detached	798	L	277	L	C	7.0	4.3	2.0	15.0	11.6	8.3	2.1	2.7	4.2	644	497	356

Example of what is in the table: If a medium-sized detached home with a building envelope label B wants to maintain an indoor temperature of 21°C for one hour, while it is 0°C outside, then: electricity consumption of the heat pump will be 2.4 kWh$_e$, the amount of heat released to the building will be 7 kWh$_{th}$ and the COP will be 3. Disclaimer: COP is not exactly equal to heat production divided by electricity consumption because the table shows values rounded up to one value behind de decimal point, leading to rounding errors. The values shown in the table assume that all building archetypes are heated using underfloor heating. An extended version of this table is available on request. It includes all 66 building archetypes simulated by UGent, an outside temperature range from -15°C to +15°C (instead of -5°C to +5°C), and values for both underfloor heating and radiators.

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