DemandFlex — Task 3.3

Retail Market:

The Potential of Time-of-Use Pricing

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Original deliverable: October 2025

Revised version: August 2026

This policy brief summarizes findings from:

The Welfare Effects of Time-of-Use Electricity Pricing
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Working Paper, 2026

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List of acronyms

Acronym	Definition
ACER	Agency for the Cooperation of Energy Regulators
CREG	Commission for Electricity and Gas Regulation (Belgium)
EU	European Union
EV	Electric Vehicle
MWh	Megawatt-hour
SPF	Federal Public Service (Belgium)
TSO	Transmission System Operator

Executive summary

Key messages

Simple prices can still guide demand in the right direction. Time-of-use prices often lead consumers to shift consumption toward similar parts of the day as under real-time pricing.

The direction of the signal is not enough, its strength also matters. By averaging real-time prices within periods, time-of-use pricing reduces the price difference between expensive and cheap hours. Even when consumers shift to appropriate hours, the financial reward is smaller than under real-time pricing.

The overall effect depends on how much demand responds. Because time-of-use pricing is only an approximation of real-time prices, it can sometimes direct demand to the wrong hours. When few consumers respond, these errors can outweigh the savings from leaving expensive hours. When many respond, the savings dominate.

Flexible consumers face the direct effects, while system costs affect everyone. The collective response of flexible consumers changes system costs, and these changes are passed through more broadly to consumers who remain on flat prices.

Highly flexible demand can create new peaks. When many consumers can shift consumption at very low cost, they shift to the same cheap hours. Because time-of-use periods are fixed and repeated across days, this synchronization can create new demand peaks more systematically.

Time-of-use and real-time pricing serve different purposes. Real-time pricing provides the most accurate signal of real-time system conditions. Time-of-use pricing offers a simpler and more predictable alternative, but its performance depends on how easily consumers can shift and on how many respond to the same signal at the same time.

The policy question

The energy transition is changing both *when* electricity is produced and *when* it is consumed. Solar and wind generation make low-cost electricity more variable across the day. At the same time, electric vehicles and heat pumps raise electricity demand but also create new opportunities to shift some of that demand in time.

This flexibility is valuable only if consumers receive useful signals. A flat price gives no reason to avoid expensive hours. Real-time pricing gives the most precise signal, because prices follow wholesale conditions hour by hour, but real-time prices are less predictable and harder to act on without automation. Time-of-use pricing sits between the two: the day is divided into a small number of periods, each with a stable price. The signal is easier to follow and shielded from extreme market events, but a simpler price cannot reflect every change in system conditions.

The policy challenge is to design a time-of-use price that (i) tracks the broad real-time price pattern of the wholesale electricity market, (ii) offers a large enough incentive to shift flexible consumption, and (iii) directs that consumption toward hours where it actually lowers the cost of supplying electricity.

Extension of the analysis

An earlier stage of the DemandFlex research asked whether a simplified time-of-use price can preserve the *direction* of the real-time signal for multi-hour activities such as EV charging. The answer was often yes. The completed research keeps that result but goes further, asking two questions that the direction result alone cannot answer:

- Is the price difference large enough to make shifting worthwhile for consumers?
- Once many consumers respond together, does their combined response actually reduce the cost of supplying electricity, and who bears the resulting costs and savings?

The central lesson is that **a price signal cannot be judged on its own**. It must be evaluated together with the response it produces. The attached research paper develops the full economic framework, data, and simulations. This brief focuses on the intuition and the implications for retail pricing.

1 Context and background

1.1 The empirical puzzle: why real-time pricing disappoints

In theory, real-time pricing should align electricity consumption with supply conditions. When consumers face the true, moment-by-moment cost of electricity, they should shift usage toward lower-cost periods. However, empirical studies consistently find a limited response to real-time prices: many consumers keep their usual electricity consumption patterns despite substantial intraday price variation.

Three factors help explain this. First, the cognitive burden can be high. Tracking prices that change every hour and every day requires attention that many consumers cannot or are not willing to provide. Second, the individual financial reward can be small, making manual hour-by-hour optimization unattractive even when shifting would benefit the system. Third, real-time pricing exposes consumers directly to periods of very high wholesale prices. The 2022 energy crisis illustrated how sharply prices can rise under market stress, reinforcing concerns about bill volatility. These limitations create a potential role for simpler price structures that preserve useful incentives while reducing complexity and exposure to short-term price fluctuations.

1.2 Time-of-use pricing: why simplification may still work

Time-of-use pricing divides the day into a small number of periods, typically two to four, each with its own price. By design, it cannot reproduce every price movement in wholesale prices. Its performance instead depends on whether the information lost through simplification is important for flexible consumption decisions.

For many flexible uses, consumers do not choose electricity consumption hour by hour. An EV charging session, for example, runs for several consecutive hours. What matters is the cost of the whole session rather than the price of any single hour. A simpler price design can discard some real-time detail while still identifying broadly attractive and unattractive times to consume.

Therefore, time-of-use pricing can preserve the broad direction of the real-time signal with substantially less information. Simplification, however, also compresses price differences and cannot identify the lowest-cost hours on every day. The analysis examines whether the resulting signal remains sufficiently strong and accurate to induce shifts that benefit consumers and the electricity system.

1.3 Belgian context: flat pricing leaves value uncaptured

Belgium currently maintains predominantly flat-rate electricity pricing for residential and small electricity consumers. Retail electricity prices have three components: energy (the cost of generation), network (transmission and distribution), and taxes. This deliverable focuses on the energy component, which retailers can structure as flat, time-of-use, or real-time pricing.

Figure 1 shows the evolution of the energy component of conventional residential electricity prices in Belgium over 2023: a single-rate price and the peak and off-peak prices. While their level varies substantially over the year, the price difference between peak and off-peak hours remains relatively limited.

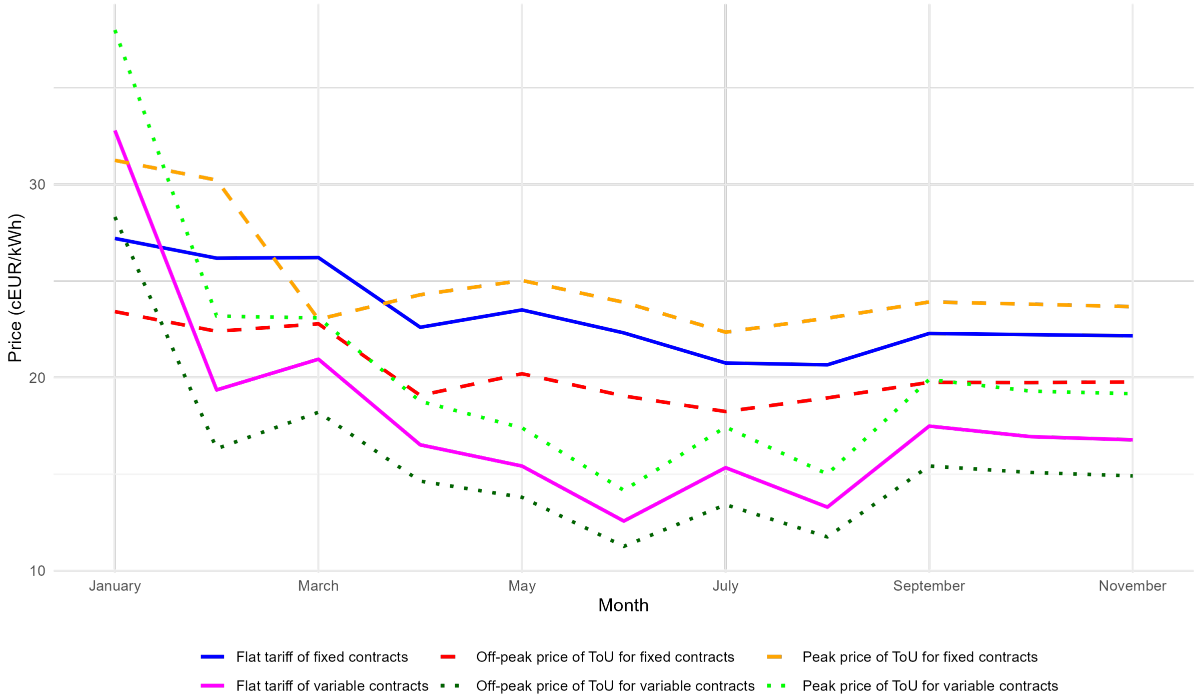

Figure 1: Average retail electricity prices by contract type in 2023 in Belgium - prices displayed for contract entry

Note: The graph shows weighted average retail electricity prices for residential contracts in Belgium in 2023. Data are from the monthly "cartes tarifaires" of MonEnergie, which report supplier-level contract prices across regions. Missing monthly values were filled using the previous month's data, and if missing for more than two months, by linear interpolation. Weighted averages were computed using yearly supplier market shares from CREG. Full data (2019–2023) are available in the Appendix but excluded from the main analysis to maintain comparability with the counterfactual time-of-use designs.

These relatively flat retail prices contrast sharply with growing wholesale price volatility. Figure 2 shows daily wholesale price patterns in 2023, illustrating increasing intraday variation that retail prices fail to transmit to consumers. During high solar generation hours (typically 11:00-15:00), wholesale prices often drop below €50/MWh, while evening peaks (18:00-21:00) regularly exceed €150/MWh, a 3:1 ratio that flat pricing completely suppresses.

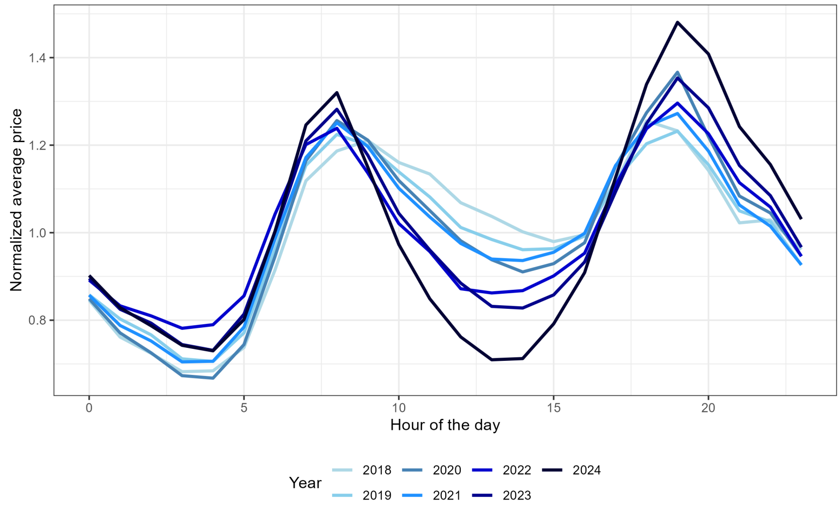

Figure 2: Rising intraday volatility in wholesale electricity prices (2018–2024, normalized by year)

Note: Hourly day-ahead prices are averaged by year using weekday data. Each year's curve is normalized by its own annual mean to highlight changes in intraday price patterns over time. Data from Belgian wholesale markets illustrate broader trends in systems with growing renewable penetration. **Source:** ENTSOE Transparency Platform: Day-ahead prices, Belgian bidding zone (2018–2024), weekdays only.

Belgium's existing time-of-use structure divides the day into two periods: peak hours (7am–10pm on weekdays) and off-peak hours (weekends and 10pm–7am on weekdays). This structure was designed initially to incentivize nighttime consumption when nuclear baseload capacity exceeded demand. Most meters in use are bi-horaire meters that track consumption separately for these two periods. While this metering infrastructure represents a technological legacy from pre-renewable era, it simultaneously provides an opportunity: Belgium can implement optimized two-period time-of-use pricing using existing meters, avoiding the delays and costs associated with comprehensive smart meter deployment required for real-time pricing.

More granular time-varying prices are also emerging in Belgium, both in network pricing and in retail energy contracts. These two developments should be distinguished. In Wallonia, the CWaPE introduced the optional *Impact* network tariff in 2026 for consumers with a communicating meter. Impact is a **distribution-network tariff**: it divides the day into five time blocks charged at three network-price levels (ECO, MEDIUM, and PIC) according to typical conditions on the distribution grid [1].

Separately, electricity suppliers are introducing more granular **energy contracts**. ENGIE's Empower Flextime, for example, uses fixed peak, off-peak, and super-off-peak energy prices, while Luminus offers a similar time-of-use structure through SmartFlex. Some suppliers also align their energy pricing with the new Walloon network structure:

TotalEnergies' Impact product, for instance, applies the same ECO, MEDIUM, and PIC periods to both the energy and distribution components. Together, these developments illustrate an expanding range of price designs between conventional peak/off-peak tariffs and fully real-time pricing.

Real-time pricing contracts, introduced in 2023, link retail prices directly to hourly wholesale market prices. However, adoption remains minimal with only 0.2% of residential and small business consumers in Flanders by Q4 2024 (VREG Dashboard). This low uptake reflects both limited smart meter penetration and the behavioral barriers discussed above. Smart meter deployment varies by region: Flanders achieved nearly 44% penetration by December 2022 with a target of 80% by 2025, while Wallonia reached only 5.7% coverage and Brussels has set a 2040 target (ACER, 2023, p. 94; Sibelga). The availability of the infrastructure required for real-time pricing remains uneven across Belgium.

This pricing landscape exists against a rapidly transforming electricity system aligned with Belgium's climate objectives. Renewable generation reached 29.8% of Belgium's electricity mix in 2024, up from 28.2% in 2023, with solar alone accounting for 11.9% and becoming the largest renewable source, overtaking offshore wind ([2]). Solar generated 8.3 TWh with cumulative installed capacity reaching close to 11 GW by end of 2024, achieving 924 Watts per capita penetration. Battery electric vehicles achieved a record 28.5% market share in 2024 with 127,750 new registrations representing a 37% increase compared to the previous year ([3]). By end of 2025, Belgium aims to reach or exceed 100,000 public charging points and put 400,000 electric vehicles on the road ([4]). In the heating sector, air-source heat pumps led with 70% revenue share in 2024, driven by subsidy packages covering as much as 70% of upfront system costs and a reduced 6% VAT on installations, alongside regional bans on new gas connections from 2025 ([5]). Elia calculated that in a scenario with high flexibility of heat pumps and electric vehicles, the adequacy gap could be reduced by 500 MW by 2028, 700 MW by 2030 and 1,100 MW by 2034 compared to the central scenario.

2 Methodology

The attached research paper compares three retail price designs for Belgian residential consumers under 2023 market conditions: **flat pricing** (constant throughout the day), **time-of-use pricing** (two, three, or four periods), and **real-time pricing** (varying hourly). Real-time pricing is the efficiency benchmark, time-of-use is evaluated as a second best.

The simulation captures the feedback loop between retail prices, consumer response, and the wholesale market (Figure 3). Consumers respond to a price signal by changing the timing of flexible use such as EV charging. These changes reshape total hourly demand, which changes wholesale prices. Under time-of-use pricing, the updated wholesale pattern is used to re-optimize the periods and prices. The process repeats until demand and prices stabilize.

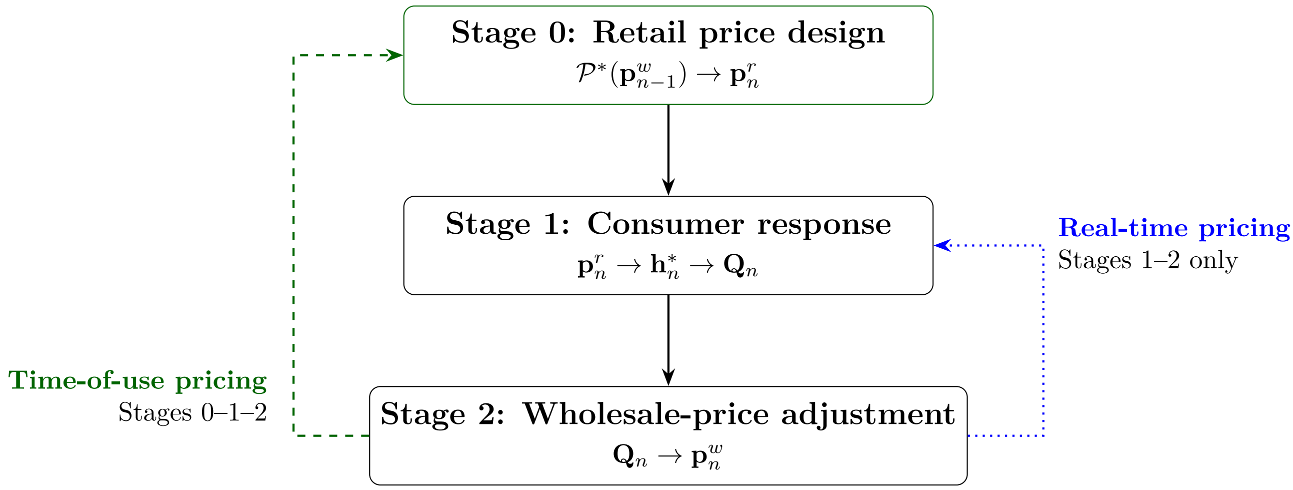

Figure 3: Simulation workflow under alternative retail price designs

Note: Stage 0 re-optimizes the time-of-use periods and their prices using the previous iteration's wholesale prices $\mathbf{p}^w_{n-1}$, it is bypassed under real-time pricing. *Stage 1* solves consumers' discrete start-hour choices given the prevailing retail price ($\mathbf{p}^r_n$ under time-of-use, $\mathbf{p}^w_{n-1}$ under real-time pricing). *Stage 2* maps the resulting demand Q_n into counterfactual wholesale prices through a non-parametric supply model estimated on 2023 Belgian data. *Flat pricing:* one pass, with no iteration and no shifting. *Time-of-use (green loop):* Stages 0–1–2 iterate until the design and demand stabilize. *Real-time pricing (blue bypass):* Stage 0 is skipped ($\mathbf{p}^r_n = \mathbf{p}^w_{n-1}$), Stages 1–2 iterate until prices and quantities converge.

2.1 Time-of-use optimization

Rather than imposing Belgium's traditional peak/off-peak split, the model searches for the period boundaries that best preserve the *ordering* of cheap and expensive hours in wholesale prices. Each period contains at least four consecutive hours, and all hours in a period share one price equal to the consumption-weighted average of wholesale prices in that period. The goal is to retain as much as possible of the information consumers need to tell attractive from unattractive times.

2.2 Consumers and flexible demand

Electricity use is split into two categories: consumption that does not respond to short-term prices (lighting and cooking), and flexible consumption whose timing can change within the day (EV charging and heat-pump operation). Flexible demand is *shifted*, not curtailed: consumers choose *when* to consume, not *whether* to consume.

Flexible demand is not free to shift. Each consumer has a preferred time to charge or heat, and shifting further from that time is increasingly inconvenient. Consumers change their schedule only when the bill saving is large enough to justify the inconvenience. The paper summarizes this inconvenience in a single **scheduling-cost** parameter. To fix ideas, its highest calibrated value implies that an EV owner needs a wholesale price saving of roughly €20/MWh, about 40% of the average intraday spread, before a three-hour shift becomes worthwhile. The simulations vary two economic parameters:

- **Scheduling cost**: how hard it is for an individual to reschedule. This governs how strongly a single consumer responds to any given signal.
- **Exposure**: the share of flexible demand facing the time-varying price design, varied from 20% to 100%. This governs what happens when the *same* signal reaches many consumers at once.

Consumers are assumed to understand and respond to time-of-use and real-time prices in the same way. The analysis gives simpler price designs *no* extra advantage for being easier to follow, any difference in results comes from the price signal itself, not from differences in the ability to act on it. This is a deliberately conservative choice: in reality, simplicity is one of time-of-use pricing's main practical strengths.

2.3 The wholesale market

When consumers change when they use electricity, the wholesale market changes too. Removing demand from one hour lowers the cost of supply in that hour, adding it elsewhere raises the cost in the receiving hour. The analysis does *not* hold wholesale prices fixed after consumers respond.

Instead, it estimates how Belgian wholesale prices react to a new hourly demand profile. The wholesale market is treated as competitive, and prices are predicted with a non-parametric model estimated on 2023 data: each counterfactual hour is matched to observed hours with similar conditions, taking into account demand, wind and solar generation, cross-border flows, weather, and the time of day and year. The predicted price is built from those comparable observations. This keeps the simulation anchored to the Belgian system observed in 2023 while letting wholesale prices respond to demand. The full estimation and its validation are in the accompanying paper.

3 Key findings

Time-of-use often reproduces the direction of the signal. Among consumers who shift under *both* designs, time-of-use pricing tends to send them to similar hours as real-time pricing. This alignment is stronger for less flexible consumers, whose scheduling constraints make them respond mainly to broad and persistent differences between cheap and expensive parts of the day. These are precisely the patterns that a time-of-use price can preserve. A simpler price can guide consumption toward similar hours without reproducing every real-time price movement. However, a similar shift does not imply a similar economic benefit.

The same shift yields a smaller saving under time-of-use. Real-time prices preserve the full gap between expensive and cheap hours, time-of-use averages several hours into one price and compresses that gap. This shows up in two ways. First, some consumers who would shift under real-time pricing no longer find it worthwhile. Second, and more important, those who *do* shift generally save less. In the simulations this second effect dominates: most of the gap between the two designs comes from weaker rewards among shifters.

Peak reduction must be large enough to offset imperfect reallocation. Under flat pricing, flexible demand is initially concentrated in costly peak hours. Time-of-use pricing can reduce this peak, but it only approximates the hourly price signal and may reallocate some demand inefficiently. When only a small share of flexible demand responds, the reduction in peak demand is limited, while the costs created by this imperfect reallocation can be relatively important. When a larger share responds, much more demand leaves the costly peak, so the savings from peak reduction become large enough to outweigh the costs of imperfect reallocation.

The effects are distributed across consumers. Flexible consumers are affected directly by time-of-use pricing because they can change when they consume and may gain or lose from doing so. Their collective response also changes the cost of supplying electricity. Under competitive pass-through, these cost changes are shared across all consumers, including those who remain on flat prices. As a result, time-of-use pricing can benefit some flexible consumers while increasing costs for others who do not respond. Since access to electric vehicles, heat pumps, and automation is uneven, these effects also have a distributional dimension.

Very flexible demand can create new peaks. Shifting demand away from the original peak can create a new peak elsewhere. Under time-of-use pricing, many consumers face the same cheap periods. When demand is highly flexible, they may all shift to the same hours, creating a "shadow peak." This problem is more systematic under time-of-use pricing because the cheap periods are fixed and repeated across days. Real-time prices vary with daily conditions and are better able to spread demand across hours, although they can also lead to concentration on a particular day. This risk becomes especially important as EV charging and other flexible uses become increasingly automated.

4 Policy implications

Treat time-of-use as a practical tool, not a universal substitute for real-time pricing

The results do not support replacing real-time pricing with time-of-use pricing across the board. Real-time pricing remains the most accurate way to communicate changing system conditions, and it becomes especially valuable when consumers or automated devices can act on detailed information. However, consumers differ in how much detail they can use. For consumers with limited flexibility or no automation, a stable, predictable price design can be a far more usable signal than a different price every hour. The regulatory objective should be to *enable useful price signals* across a range of consumers, not to impose a single design on every consumer. Allowing time-of-use and real-time pricing to coexist, and letting each be used where it performs best, is the right frame.

Preserve both the timing and strength of the price signal

Choosing when cheap and expensive periods begin and end remains important, and wholesale prices should guide those choices: growing solar output can make midday increasingly cheap, while evening demand keeps other hours costly. However, boundaries alone are not enough. The *difference* between prices must be large enough to motivate a shift. A price design can correctly label one period cheaper than another yet compress the gap so far that consumers have little reason to shift. Regulators and suppliers should ask two questions of any design: Does it identify the right broad parts of the day? Is the price difference between them large enough to encourage a useful change in behavior?

Establish periodic review and updating

Time-of-use periods should be stable enough to stay understandable, but they should also evolve as the electricity system changes. More solar can make midday increasingly attractive, EV growth can reshape evening and nighttime demand, storage, interconnection, and generation changes all shift when electricity is cheap. Designs should be reviewed periodically. Crucially, the review should not stop at how well a design reproduced *historical* wholesale prices. It should also ask whether consumers are responding as expected and whether the resulting demand pattern continues to lower supply costs. A design that looked right five years ago may no longer send the right signal after major changes in generation or flexible demand.

Communicate pricing clearly and consistently

Simple communication is one of time-of-use pricing's main advantages: consumers should not need to understand wholesale markets to know how to respond. Rules such as "avoid the evening peak" or "midday power is cheaper when solar is high" turn a complex system problem into an actionable message. However, communication must track actual conditions. Traditional day/night designs were built for a very different system, with more solar, the cheapest hours may increasingly fall during the day rather than at night. Clear, consistent messaging across suppliers helps consumers learn the new patterns and helps manufacturers design smart appliances around them.

Coordinate automation to avoid synchronized demand

Automation, smart chargers, and home energy management systems can make it much easier for flexible demand to respond to price signals. At the same time, they can also synchronize consumption. If thousands of chargers are set to start at the beginning of the cheapest period, a new peak appears immediately. This synchronization is relevant not only for wholesale-market costs but also for distribution networks. A new local peak can increase congestion and network stress even when shifting is beneficial from a production cost perspective. Distribution-network effects are outside the scope of the simulations in this study, but they reinforce the importance of coordinating automated demand. Possible approaches include staggered start times, randomized delays, aggregator control, or charging algorithms that account for the response of other devices. The analysis does not compare these solutions, but it highlights why coordination becomes increasingly important as automated flexibility expands.

Evaluate effects beyond the consumers who actively shift

Policy evaluation should not stop at the bills of EV or heat-pump owners. Their combined response changes system costs, and those changes reach a much wider group. If they shift consumption away from expensive hours, the resulting lower costs can benefit everyone, if they create costly new peaks, the opposite can happen. Because flexible technologies and access to automation are unevenly distributed, real-time pricing policies should be judged from a broader perspective than the savings of participants alone. The present analysis does not compare effects by income group, future work should, but the results already show why this broader view is necessary.

5 Limitations and future research

- **Calibration to Belgium in 2023.** The simulations reproduce one system, generation mix, and demand pattern. The exact numbers should not be read as forecasts, renewable deployment, electrification, and storage will change both wholesale prices and the value of flexibility.

- **Exposure is imposed, not predicted.** The analysis asks what happens when different shares of flexible demand respond, it does not model which consumers choose time-of-use or real-time contracts. In practice, the consumers best able to benefit may also be the most likely to enrol.

- **No behavioural advantage is given to simple price designs.** Consumers are assumed able to understand both designs equally. The simulations do not credit time-of-use pricing for simpler communication, lower attention costs, or greater bill predictability, real advantages in practice.

- **Focus on the energy component.** Distribution networks can face local congestion that does not line up with wholesale-price patterns. Energy and network price designs should be considered together in future work.

- **No comparison across consumer groups.** Consumers differ in income, housing, technology ownership, and ability to shift. Future research should examine how alternative designs affect these groups differently.

- **Automation is stylized.** The model captures that consumption can become easier to shift but does not compare specific smart-charging or coordination technologies, an important next step as automated flexibility expands.

6 Conclusion

Time-of-use pricing remains a promising tool for residential demand response, but the case for it is more nuanced than the idea that a few daily prices can stand in for real-time prices. The earlier DemandFlex work established that a simple design can preserve much of the **direction** of the real-time signal: for multi-hour activities, well-chosen periods often guide consumers toward similar parts of the day as real-time pricing. The completed research explains why that is not the whole story.

The financial reward must also be large enough to make consumers willing to change their routine, and once thousands of them respond, their combined behavior must genuinely shift electricity toward hours where it is cheaper to supply. When little flexible demand responds, the savings from leaving expensive hours can be too small to compensate for imperfect shifts elsewhere. When exposure is high, much more demand leaves costly hours and time-of-use pricing performs substantially better. And when demand becomes very easy to shift, highly responsive consumers can create new peaks by all shifting together. The performance of time-of-use pricing depends on the interaction between the **price signal**, the **amount of flexibility responding**, and the **way that demand is coordinated**.

For policymakers, the implication is not a permanent choice between time-of-use and real-time pricing. Simple, predictable price designs stay valuable where consumers need stable, actionable signals, as automation spreads, the extra information in real-time prices becomes easier to use and more valuable, while coordinating automated demand becomes increasingly important. A retail price design should ultimately be judged not by how closely it resembles wholesale prices, but by what happens after consumers respond: whether enough electricity leaves costly hours, where it shifts, whether new peaks appear, and whether the system becomes cheaper to operate.

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The accompanying research paper contains the complete academic references used for the theoretical framework, empirical motivation, and simulation methodology.

Acknowledgments

This research received funding from the SPF Économie through the Belgian Energy Transition Fund as part of the DemandFlex research project. The views expressed in this policy brief are those of the author and do not reflect the official position of the SPF Économie.

About this deliverable

This policy brief summarizes findings from the research paper attached to the deliverable, *The Welfare Effects of Time-of-Use Electricity Pricing.* The full paper provides the technical framework, data, calibration, simulation methodology, detailed results, and robustness checks.