DemandFlex - Task 3.3

Retail Market:

The Potential of Time-of-Use Pricing

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This policy brief summarizes findings from:

Do Consumers Need Hourly Prices? Simulation in Belgian Electricity Markets
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Working Paper, 2025

Contents

List of acronyms

Acronym	Definition
ACER	Agency for the Cooperation of Energy Regulators
CREG	Commission for Electricity and Gas Regulation
CWaPE	Commission wallonne pour l'Énergie
ETS	Emissions Trading System
EU	European Union
EV	Electric Vehicle
JRC	Joint Research Centre
kWh	Kilowatt-hour
MWh	Megawatt-hour
RTE	Réseau de Transport d'Électricité (France)
SPF	Federal Public Service (Belgium)
TSO	Transmission System Operator
TTF	Title Transfer Facility (natural gas hub)
VREG	Vlaamse Regulator van de Elektriciteits- en Gasmarkt

Executive summary

Key Messages

Simplicity works for simple load shifting: Well-designed two-period time-of-use pricing captures nearly 100% of real-time pricing efficiency from residential load-shifting.

Optimize design: Focus regulatory (or commercial) resources on determining optimal period boundaries of time-of-use based on wholesale cost patterns, not increasing price granularity.

Lower costs, equivalent results: Time-of-use requires modest analytical capacity rather than expensive smart meter infrastructure, while delivering comparable demand response from simple residential load shifting.

Policy question

Decarbonizing electricity systems requires two parallel transformations: shifting generation toward intermittent renewables and electrifying end uses such as heating and transport. These changes fundamentally alter wholesale electricity price patterns. Renewable penetration lowers average prices but increases hour-to-hour volatility, while electrification raises aggregate demand and intensifies peak-period price pressures. This growing price variation creates significant opportunities for demand-side flexibility to shift consumption to low-cost hours can reduce system costs, avoid infrastructure investments, and prevent renewable curtailment. However, prevailing retail pricing structures in Belgium fail to transmit these price signals to consumers. Most households and small businesses face flat pricing or poorly informative time-of-use. This misalignment suppresses efficient consumption decisions. As electrification accelerates, with electric vehicles and heat pumps, the costs of this disconnect will grow. Without time-varying retail prices, residential flexible loads operate without regard to system conditions, necessitating excess generation capacity, curtailing available renewable energy, and increasing overall costs. The policy challenge is bridging this gap: translating wholesale price variation into retail signals that drive efficient demand response without compromising consumer protection or market accessibility.

The academic motivation

The economic literature on electricity pricing exhibits tension between theoretical predictions and empirical evidence. Real-time pricing should theoretically induce the best demand response possible by exposing consumers to true costs. However, empirical studies consistently find minimal consumer response to real-time prices, with demand elasticities near zero in residential settings. Meanwhile, simpler time-of-use pricing structures generate stronger behavioral responses despite providing less precise price signals.

This paradox has generated substantial academic debate, with researchers approaching the question from multiple angles. Some evaluate time-of-use designs by measuring statistical correlations with wholesale prices, finding that even complex structures explain only 13–43% of price variation. Others focus on rank correlation metrics, arguing that preserving relative price rankings matters more than matching absolute levels. A third strand uses structural models to simulate welfare outcomes, though results vary widely depending on assumptions about demand elasticity and generation technology.

Yet two critical gaps remain in this literature. First, existing research largely ignore feedback effects: when consumers shift loads in response to retail prices, demand patterns change, altering wholesale prices and the optimal design of time-of-use periods afterwards. Second, most research evaluates pricing structures by comparing price series statistically, rather than modeling the complete chain from pricing design through consumer behavior to wholesale market outcomes and back.

The *attached research paper* develops extensively the literature debate and addresses both gaps by developing an integrated framework that captures feedback loops between retail pricing, consumer response, and wholesale market clearing ([Viadere, 2025]). This approach provides new evidence on how much efficiency is lost by simplifying 24 hourly prices into fewer daily periods.

Key findings

Well-designed two-period time-of-use pricing captures nearly 100% of the efficiency gains achievable with real-time pricing. The key is optimization: when time-of-use periods group hours by typical wholesale costs—separating systematically cheap hours from expensive ones—they preserve the price ranking that drives efficient load-shifting. Consumers facing these simplified signals make nearly identical decisions to those under real-time pricing, shifting flexible loads to the same hours on average. This result likely understates time-of-use's practical advantages. The analysis assumes consumers respond equally to all price structures, when simpler signals may actually elicit stronger responses than complex hourly prices. It also ignores stability benefits: fixed periods enable simple device automation and eliminate bill volatility that deters real-time pricing adoption. These factors suggest time-of-use may outperform real-time pricing in practice, not merely match it.

Policy implications

The analysis yields a clear regulatory strategy: focus resources on optimizing, updating, and communicating simple time-of-use prices rather than implementing complex real-time pricing for residential and small consumers. This approach maximizes load-shifting efficiency while minimizing implementation costs and consumer complexity and risk expose.

Design simple, optimized pricing structures. Regulators should prioritize getting period boundaries right over increasing price granularity. A well-designed two- or three-period structure captures nearly all available efficiency gains from consistent simple residential load shifting. The optimization task is determining which hours systematically experience low versus high costs, based on renewable generation patterns and demand peaks.

Establish regular review and updating processes. As renewable penetration grows and demand patterns evolve, optimal period boundaries will shift. Regulators should commit to periodic reviews (annually or biennially) to ensure time-of-use structures remain aligned with actual cost patterns. These updates maintain pricing effectiveness without requiring continuous real-time adjustments or consumer re-education.

Communicate pricing structures clearly. Simple, stable period definitions enable straightforward consumer communication: "electricity is cheap overnight and mid-day, expensive during morning and evening peaks." This clarity facilitates both manual shifting decisions and automated responses through smart devices. Clear communication costs far less than the complex billing systems and consumer education required for real-time pricing.

The cost advantage. This regulatory approach requires modest analytical capacity to optimize period boundaries and standard communication channels to inform consumers: far less expensive than real-time pricing infrastructure, smart meter requirements, and ongoing price volatility management. The policy delivers comparable efficiency gains from daily load shifting at a fraction of implementation cost.

1 Context and background

Belgium's energy policy context frames the urgency of retail pricing reform. The country targets climate neutrality by 2050, requiring substantial renewable integration and electrification of transport and heating. CREG, Belgium's federal energy regulator, oversees retail electricity market design in coordination with regional regulators: VREG (Flanders), CWaPE (Wallonia), and Brugel (Brussels). Regional regulators manage distribution network tariffs and regional implementation. This multi-level governance structure creates both coordination challenges and opportunities for coherent pricing reform. Belgium's widespread bi-horaire metering infrastructure, while a legacy technology, provides an immediate platform for refined time-of-use pricing without requiring complete smart meter deployment—a constraint that can become an advantage with proper optimization.

1.1 The empirical puzzle: Why real-time pricing disappoints

Economic theory predicts that real-time pricing should align consumption with supply conditions. Ideally, when consumers face the true cost of electricity at each moment, they should respond by shifting usage to lower-cost periods. However, empirical evidence consistently contradicts this prediction. Most studies of residential real-time pricing find minimal demand response. Consumers continue their usual consumption patterns despite substantial hourly price variation.

Why does real-time pricing fail in practice? Three interconnected factors emerge from the literature. First, the cognitive burden is severe: tracking hourly prices that change daily requires constant attention that most households cannot or will not provide. Second, individual incentives are misaligned with social efficiency: the typical household might save only a few euros monthly through hour-by-hour optimization, making the effort economically irrational even when system-wide efficiency gains would be substantial. Third, financial risk becomes unmanageable during supply disruptions. The 2022 energy crisis exemplified this problem when Belgian wholesale prices spiked to unprecedented levels, exposing real-time pricing customers to extreme bill volatility.

The theoretically optimal pricing mechanism proves empirically ineffective, raising the question: What alternative pricing structures might bridge this gap between theoretical efficiency and practical implementation?

1.2 Time-of-use pricing: simpler but effective

In contrast to real-time pricing, time-of-use pricing shows more promise. Time-of-use divides the day into a small number of periods, typically two to four, each with a fixed price that remains constant over extended periods (weeks, months, or even years). Though time-of-use cannot, by definition, adapt to real-time supply conditions, it proves relatively effective at influencing consumer behavior. The reasons for time-of-use's performance relate directly to its simplicity. Two or three stable periods are easy to remember and act upon, with consumers able to learn patterns like "*charge my EV overnigh*t" without continuous monitoring. Stable periods enable simple automation, as an EV charger or heat pump controller needs only basic programming to shift loads to cheap periods. Fixed period prices eliminate volatility, addressing consumer risk aversion while still providing price signals, while clear differentiation between "*cheap*" and "*expensive*" periods provides more actionable information than 24 different hourly prices. This creates the policy opportunity: time-of-use pricing appears to strike a better balance between theoretical efficiency and practical implementation than real-time pricing.

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.

As Figure 1 illustrates, the energy component of most residential contracts in 2023 follows either flat pricing (a single rate regardless of time) or time-of-use pricing with peak and off-peak periods. The level of retail prices varies across months, reflecting wholesale market conditions and the frequency at which retailers update their contract offers.

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.

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 deploy-

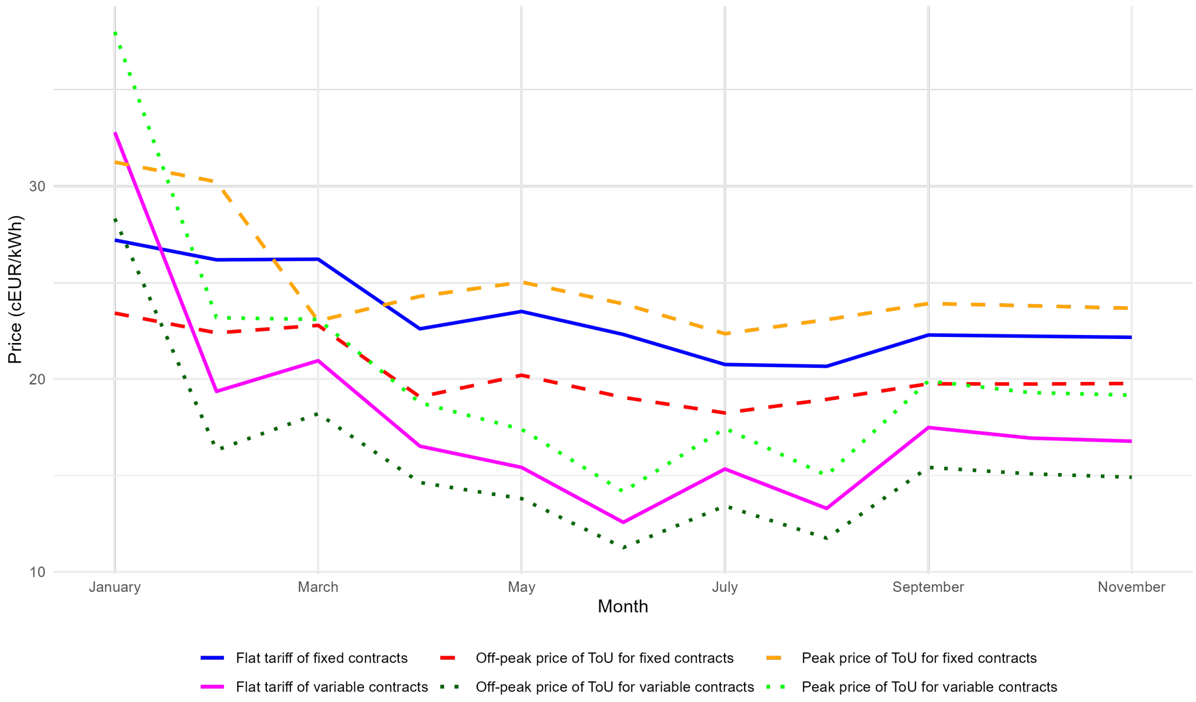

Figure 1: Average retail electricity prices by contract type in 2023 in Belgium - prices displayed for contract entry
Note: The graph shows weighted average retail electricity prices for residential contracts in Belgium in 2023. Data are from the monthly "cartes tarifaires" of MonEnergie, which report 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 ToU designs.

ment required for 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 dramatically 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). These divergent regional trajectories complicate coordinated pricing policy but also suggest that time-of-use approaches workable with existing bi-horaire meters may enable faster, more uniform progress 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 ([Elia Group, 2025]). Solar generated 8.3 TWh with cumulative installed capacity reaching close to 11 GW by end

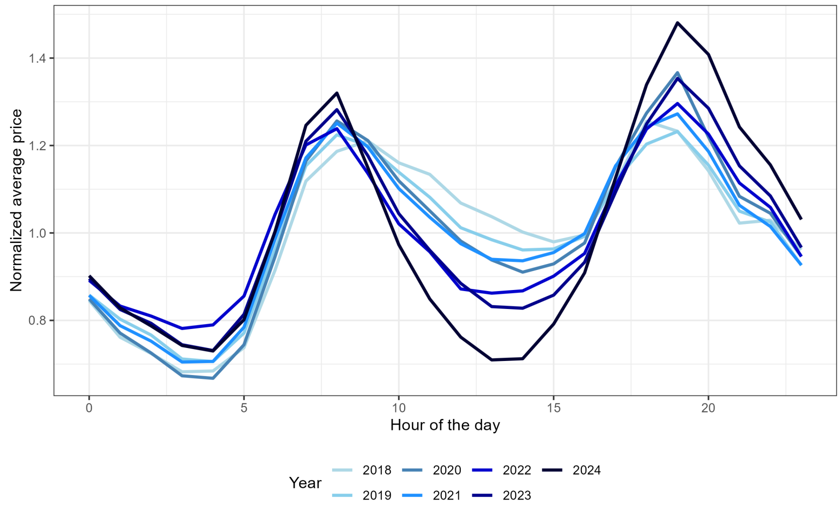

Figure 2: Rising intraday volatility in wholesale electricity prices (2018–2024, normalized by year)

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.

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 ([European Alternative Fuels Observatory, 2025]). By end of 2025, Belgium aims to reach or exceed 100,000 public charging points and put 400,000 electric vehicles on the road ([Mobility Portal Europe, 2024]). 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 ([Mordor Intelligence, 2024]). 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 overview

The *research paper attached* to this deliverable compares three types pricing structures for residential electricity in Belgium during 2023: flat pricing that remains constant throughout the day, time-of-use pricing with two, three and four periods, and real-time pricing that varies hourly. The central question is which approach most effectively incentivizes electricity consumption toward cheaper and cleaner hours.

The simulation captures the feedback effect of time-varying prices: optimized time-of-use prices faced by consumers will incentivize them to shift EV charging or heat pump operation, but that change in consumption patterns will reshape hourly demand and consequently wholesale market prices, which will then influence how time-of-use periods are optimized in the next iteration. The simulation runs iteratively until three components stabilize at equilibrium: consumer demand patterns, wholesale prices, and time-of-use period definitions. Figure 3 illustrates this iterative process, showing how time-of-use pricing (green dashed loop) cycles through retail price optimization, consumer response, and wholesale clearing, while real-time pricing (blue dotted bypass) skips the optimization stage by directly passing through wholesale prices to consumers.

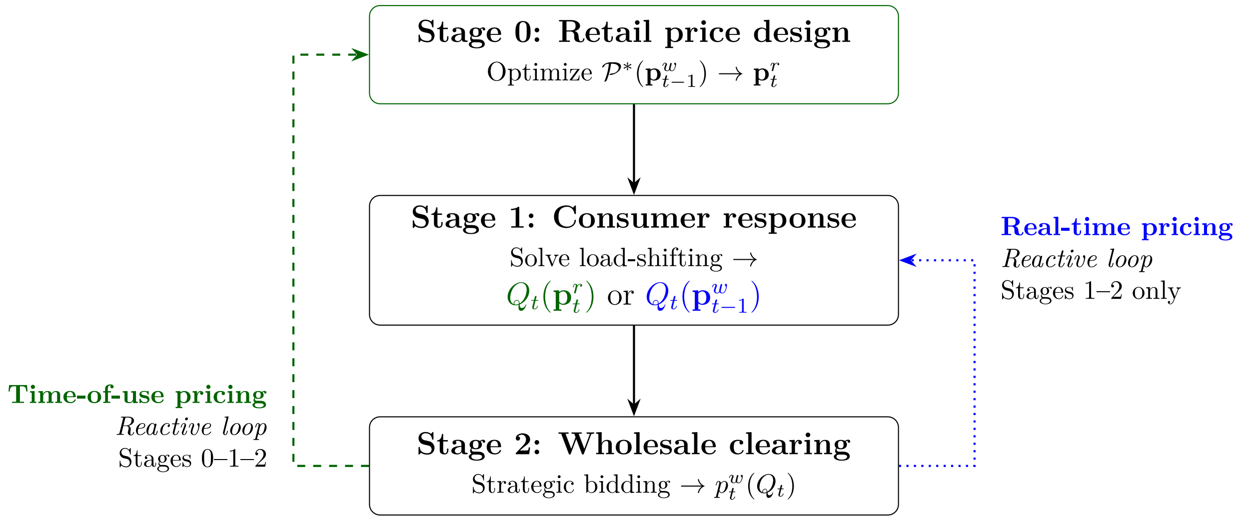

Figure 3: Simulation workflow under alternative retail pricing

Note: The figure depicts how the simulation is executed under three retail time-of-use pricing regimes. *Stage 0* optimizes time-of-use prices design based on previous period wholesale prices p^w_{t-1}. *Stage 1* computes load shifting given those prices p^r_t simulation on optimized time-of-use prices or p^w_{t-1} if real-time pricing. *Stage 2* determines wholesale prices via strategic bidding based on the results total demand Q_t. *Baseline (flat pricing):* one pass through Stages 1–2 with fixed flat retail prices (no iteration, no load shifting fed back to Stage 0). *Time-of-use (green dashed loop):* Stages 0–1–2 iterate—wholesale outcomes feed back to redesign the ToU partition, until the partition stabilizes. *Real-time pricing (blue dotted bypass):* Stage 0 is bypassed ($p^r_t = p^w_{t-1}$); only Stages 1–2 iterate until prices/quantities converge.

2.1 Time-of-use optimization

The model optimizes time-of-use pricing by determining how to divide the 24 hours of each day into distinct price periods—testing structures with 2, 3, or 4 periods. Rather than using Belgium's current fixed division (7am–10pm weekday peak), the algorithm searches for the period structure that best reproduces wholesale market price variation. The optimization groups hours with similar wholesale costs into the same period, creating the largest feasible price differences across periods.

2.2 Electricity consumers

In the simulations, household electricity use is split into two categories: inflexible consumption that does not respond to price signals (such as lighting and cooking) and flexible consumption that can shift timing within the day (notably EV charging and heat pumps). Consumers are assumed to minimize their electricity bills while also maximizing utility based on their usual consumption timing: they prefer their habitual consumption patterns but will deviate when price differentials make shifting worthwhile. The model makes a critical behavioral assumption: consumers always react to time-varying prices and fully understand price structures regardless of complexity. This assumption is used to isolate the effect of pricing design from behavioral frictions. In practice, cognitive limitations could reduce consumers' ability or willingness to process 24 prices per day, potentially making simpler structures more effective despite being theoretically suboptimal. In the simulations, responsiveness is calibrated so that 20% of the identified stock of EVs and heat pumps shifts consumption in response to time-varying prices, while the remaining 80% maintains normal consumption timing. This calibration reflects both technical constraints (not all devices can shift easily) and behavioral inertia (not all consumers actively optimize).

2.3 Electricity wholesale market

On the supply side, the model estimates how Belgium's wholesale market sets hourly prices. The foundation is a new dataset gathering all publicly available information about every power generating unit in Belgium from TSO Elia. The marginal cost of each power plant is estimated using: technology-specific thermal efficiencies from the Joint Research Centre database; daily natural gas prices from TTF futures; EU ETS carbon allowance prices for 2023; and emission factors by fuel type from RTE (French TSO). Each power generation unit in the dataset thus has an estimated marginal cost. For instance, wind and solar are assumed to have zero marginal cost.

Based on these costs, the merit order can be approximately reconstructed. On the wholesale electricity market, prices are set where supply meets demand each hour. In a perfectly competitive wholesale market, this marginal cost framework would accurately predict observed prices. However, the competitive merit order systematically underpredicts observed prices, reflecting strategic behavior. Three firms (Electrabel/ENGIE, Luminus, and TotalEnergies) control 87.5% of dispatchable thermal capacity, creating substantial market power. The model accounts for this by estimating firm-specific and condition-specific market power parameters that better predict prices set on the wholesale market.

3 Key findings

The central finding is that **a well-designed two-period time-of-use pricing captures almost 100% of the efficiency and welfare gains achievable with real-time pricing.** This equivalence holds despite substantial differences in pricing granularity. Real-time pricing provides 24 distinct hourly price signals per day, updated daily based on wholesale market outcomes. Whereas, time-of-use provides just two constant prices that remain fixed across days.

How can such different pricing structures yield similar efficiency outcomes? The answer lies in how time-of-use pricing is optimized. When time-of-use periods are designed to replicate the relative price incentives of real-time pricing, they can guide consumers toward nearly the same load-shifting decisions. The optimization algorithm assigns hours to periods based on their typical wholesale costs, grouping cheap hours together and expensive hours together. This creates price signals that, while simpler than hourly prices, preserve the essential pattern: which hours are systematically worth avoiding and which hours are systematically attractive for flexible consumption. A consumer facing optimized time-of-use prices receives a simplified but accurate signal about when to shift their EV charging or heat pump operation: one that leads to consumption patterns similar to those under real-time pricing. The key insight is that optimal consumer behavior under time-of-use pricing approximates optimal behavior under real-time pricing when the period structure accurately reflects the underlying cost ranking. Both pricing structures incentivize shifting flexible loads to the same hours on average, even though real-time pricing provides more granular information.

The finding that time-of-use matches real-time pricing efficiency should be interpreted cautiously. The model makes several assumptions that favor real-time pricing and likely understate time-of-use's practical advantages. The simulation assumes consumers respond equally to all price structures and process information costlessly, when in reality simpler time-of-use signals may elicit stronger responses than complex hourly prices. The model also ignores time-of-use's stability benefits: stable periods enable simple device automation for EVs and heat pumps, and eliminate the bill volatility that makes many consumers reluctant to adopt real-time pricing. Each of these omitted factors would improve time-of-use's relative performance, suggesting the analysis provides a lower bound on time-of-use effectiveness.

4 Policy implications

The analysis yields clear guidance for electricity market regulation: regulators should focus resources on optimizing, updating, and communicating simple time-of-use prices to drive residential and small consumer load-shifting, rather than implementing complex real-time pricing systems. This approach delivers comparable efficiency gains at substantially lower implementation cost.

4.0.1 Prioritize time-of-use implementation over real-time pricing

Primary responsibility: CREG in coordination with regional regulators

Belgium should move decisively toward time-of-use pricing rather than pursuing real-time pricing for residential and small consumers. A well-designed two- or three-period structure can capture nearly all available efficiency gains from consistent residential load-shifting while being substantially easier to implement, more likely to elicit consumer response, and less costly to administer.

This recommendation reflects both the theoretical findings and practical considerations. Real-time pricing requires extensive smart meter deployment, complex billing systems, consumer education about volatility management, and ongoing support infrastructure. Time-of-use pricing works with existing bi-horaire meters, requires straightforward billing, and presents consumers with simple, stable price signals they can understand and act upon.

4.0.2 Focus design effort on optimizing period boundaries

Primary responsibility: CREG with technical input from Elia

The critical regulatory task is determining when each period begins and ends. This optimization requires systematic analysis of Belgian wholesale price patterns to identify when electricity is systematically cheap versus expensive. Unlike real-time pricing, which requires continuous price updates, this analysis needs to be conducted only periodically, making it a manageable regulatory investment.

Key factors for determining optimal period boundaries include:

- **Renewable generation patterns:** Solar generation peaks mid-day, creating systematically low prices during these hours. Wind generation is less predictable but contributes to overnight low-price periods.

- **Demand patterns:** Morning peaks (07:00–09:00) and evening peaks (18:00–21:00) on weekdays systematically correspond to high wholesale prices.

- **Seasonal variation:** Winter heating loads and summer cooling loads shift the timing and magnitude of demand peaks.
- **Weekend versus weekday differences:** Weekend demand profiles differ substantially from weekdays, potentially warranting distinct period definitions.

Based on 2023 Belgian wholesale price patterns, a starting structure might include:

- **Super-off-peak:** Overnight hours (roughly 23:00–07:00) when demand is low and baseload generation dominates
- **Off-peak:** Mid-day hours (roughly 10:00–16:00) when solar generation increasingly depresses prices
- **Peak:** Morning and evening hours (roughly 07:00–10:00 and 16:00–23:00) when demand peaks and dispatchable fossil generation sets prices

4.0.3 Establish salient price differentials between periods

Primary responsibility: CREG (regulatory framework); Retail suppliers (implementation)

For time-of-use pricing to induce substantial load-shifting, price differences between periods must be large enough to overcome consumer inertia and make shifting economically worthwhile. The evidence suggests price ratios of at least 2:1 between peak and super-off-peak periods are necessary to generate significant response. Higher ratios—reflecting actual cost differences—will induce stronger responses.

Critically, these differentials should be grounded in actual wholesale cost differences between periods, not arbitrary markups. Regulators should establish principles requiring retail suppliers to use wholesale market data when setting period prices, ensuring that retail price differentials reflect underlying cost variation. This approach maintains cost-reflective pricing while providing consumers with economically meaningful signals. When wholesale patterns show that overnight electricity costs half as much as evening electricity, retail time-of-use prices should reflect this difference.

4.0.4 Establish periodic review and updating processes

Primary responsibility: CREG in coordination with regional regulators

While time-of-use periods should remain stable over extended periods to provide predictability and enable consumer adaptation, they must be reviewed and updated periodically as the electricity system evolves. Growing renewable penetration, changing demand patterns from electrification, and infrastructure developments will gradually shift when electricity is systematically cheap or expensive.

Regulators could establish a regular review process—annually or biennially—to re-assess optimal period boundaries. This review could analyze whether wholesale price patterns have shifted sufficiently to warrant adjusting period definitions. Small changes in average prices within periods do not require updates, but systematic shifts in which hours experience high versus low costs could trigger period boundary adjustments.

This periodic updating represents a modest regulatory cost—requiring analytical capacity and stakeholder consultation—but ensures time-of-use structures remain aligned with actual cost patterns. The alternative gradually loses effectiveness as the system transforms, undermining the efficiency gains time-of-use pricing is intended to deliver.

4.0.5 Communicate pricing structures clearly and consistently

Primary responsibility: Regional regulators (standards); Retail suppliers (implementation)

Simple time-of-use structures enable straightforward consumer communication: "Electricity is cheap overnight and during sunny mid-day hours; expensive during morning and evening peaks." This clarity facilitates both manual consumption adjustments and automated responses through smart devices. Clear communication requires standard utility channels like utility bills, websites, mobile apps—not the extensive consumer education campaigns that real-time pricing demands.

Regional regulators (VREG, CWaPE, Brugel) could establish communication standards that retail suppliers must follow, ensuring consistent messaging across suppliers within their jurisdictions. CREG could coordinate across regions to promote alignment where appropriate. Standards could cover clear labeling of periods, accessible explanations of the cost basis for differentials, and practical guidance on shifting common flexible loads (EV charging, heat pump operation, major appliances).

4.0.6 Consider complementary policies

Shared responsibility: Multiple actors depending on policy type

While optimized time-of-use pricing can drive load-shifting on its own, complementary policies enhance effectiveness:

- **Default enrollment structures** *(CREG regulatory framework; Retail suppliers implementation):* Making time-of-use pricing the default option (with flat-rate alternatives available for consumers who prefer predictability) likely increases adoption substantially compared to opt-in structures. However, this could be implemented carefully, with clear communication and straightforward opt-out mechanisms to maintain consumer choice.

- **Coordination with network tariffs** *(CREG coordination with regional DSO regulators):* Distribution network operators are increasingly implementing time-of-use network charges. Coordinating retail energy time-of-use periods with network tariff periods simplifies the price signals consumers face and reinforces load-shifting incentives. CREG could facilitate coordination between energy pricing and network pricing where system benefits are substantial.

4.0.7 Implementation costs and feasibility

Relevant for: Budget planning across all responsible actors

A significant advantage of this regulatory approach is its modest cost. Optimizing time-of-use periods requires analytical capacity but this is a one-time investment with periodic updates, not continuous operation. Communication requires standard utility channels, not specialized infrastructure. Billing systems already accommodate Belgium's existing bi-horaire structure, so extending to optimized multi-period pricing requires incremental rather than wholesale system changes.

This contrasts sharply with real-time pricing, which requires: comprehensive smart meter deployment (still incomplete in Belgium with regional disparities); real-time billing systems; sophisticated consumer interfaces; ongoing price risk management; and extensive consumer support infrastructure. The cost differential is substantial, while the efficiency gains, as this analysis demonstrates, are comparable.

The regulatory resources required are manageable within existing institutional capacities: CREG and regional regulators possess the analytical expertise for period optimization; retail suppliers have billing infrastructure that can accommodate refined time-of-use structures; and consumer communication can leverage existing utility channels.

5 Limitations and future research

While these findings provide policy direction, several caveats merit consideration. Several limitations should be considered when interpreting these results:

- **Calibration to 2023 conditions:** The analysis uses Belgian electricity market data from 2023, a year characterized by specific generation mix and demand patterns. Results may differ as the system evolves, particularly with continued renewable expansion, nuclear capacity decisions, and accelerating electrification. Future research should examine whether the near-equivalence between optimized time-of-use and real-time pricing holds under alternative generation scenarios, including higher renewable penetration rates and different baseload configurations.

- **Simplified consumer heterogeneity:** The model assumes a representative consumer with standardized load-shifting capabilities and preferences. In reality, households differ substantially in their flexible load potential (EV ownership, heat pump adoption, appliance stock), willingness to adjust consumption timing, and responsiveness to price signals. Future work should incorporate heterogeneous consumer types to examine whether optimal time-of-use structures vary across consumer segments and whether differentiated pricing approaches could improve welfare outcomes.

- **No network considerations:** The analysis focuses on energy pricing and wholesale market efficiency, abstracting from distribution network constraints and network tariff design. In practice, local network congestion may create additional incentives for temporal load-shifting that differ from wholesale price patterns. Distribution system operators increasingly implement time-of-use network charges to manage grid constraints. Future research should integrate energy and network pricing optimization to determine whether coordinated versus independent tariff structures better serve system-wide efficiency.

- **Static generation capacity:** The analysis treats generation capacity as fixed, appropriate for evaluating short-run efficiency but omitting long-run investment effects. Time-of-use and real-time pricing may have different implications for generation investment incentives, particularly for peak capacity and storage. Future work should examine how alternative retail pricing structures affect long-run capacity adequacy and investment efficiency.

- **Ignore retailers:** The analysis abstracts from retail market structure. The model assumes regulators can directly implement optimal period structures, whereas actual implementation depends on retailer incentives and competitive dynamics in Belgium's liberalized retail market.

These limitations suggest valuable directions for extending this research framework while not fundamentally undermining the core finding: that well-designed time-of-use pricing can closely approximate real-time pricing efficiency for residential demand response.

6 Conclusion

This analysis demonstrates that well-designed time-of-use pricing captures nearly all efficiency gains of real-time pricing while maintaining simplicity. Efficient demand response requires preserving relative hour rankings not tracking 24 hourly prices. Optimized time-of-use periods guide consumers toward load-shifting decisions that approximate real-time pricing outcomes. For regulators, this suggests allocating resources to optimize simple time-of-use structures: analyzing wholesale patterns to determine period boundaries, establishing meaningful price differentials reflecting actual costs, implementing periodic reviews, and communicating clearly. This approach requires modest analytical capacity rather than comprehensive smart meter infrastructure and sophisticated billing systems: comparable efficiency at substantially lower cost. These results are conservative. The analysis assumes equal consumer response across pricing structures, abstracting from behavioral frictions favoring simpler designs. Real implementation would likely show stronger time-of-use performance through higher participation and more consistent response.

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About this deliverable

This policy brief summarizes findings from the *research paper* attached to the delivrable "Do Consumers Need Hourly Prices? Simulation in Belgian Electricity Markets." The full paper provides detailed technical methodology, and empirical validation.

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