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Causal Greedy Pair Scheduling for Residential Battery Storage under Day-Ahead Electricity Prices

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INTRODUCTION & AIM

Dynamic, exchange-linked tariffs expose households to hourly wholesale price variation. A battery can charge at low prices and discharge to cover demand at high prices — consumption-side arbitrage.

Nord Pool publishes next-day hourly prices after the 12:00 CET gate closure, so a household controller has deterministic price knowledge for at least the full next day, and longer right after publication.

Causality is the core difficulty: every kWh discharged must have been charged in a strictly earlier interval. When the daily minimum price falls AFTER the daily maximum, naive price-ranking heuristics produce infeasible plans.

Aim: a deterministic, solver-free scheduler that guarantees charge-before-discharge causality by construction, plus two practical sizing methods.

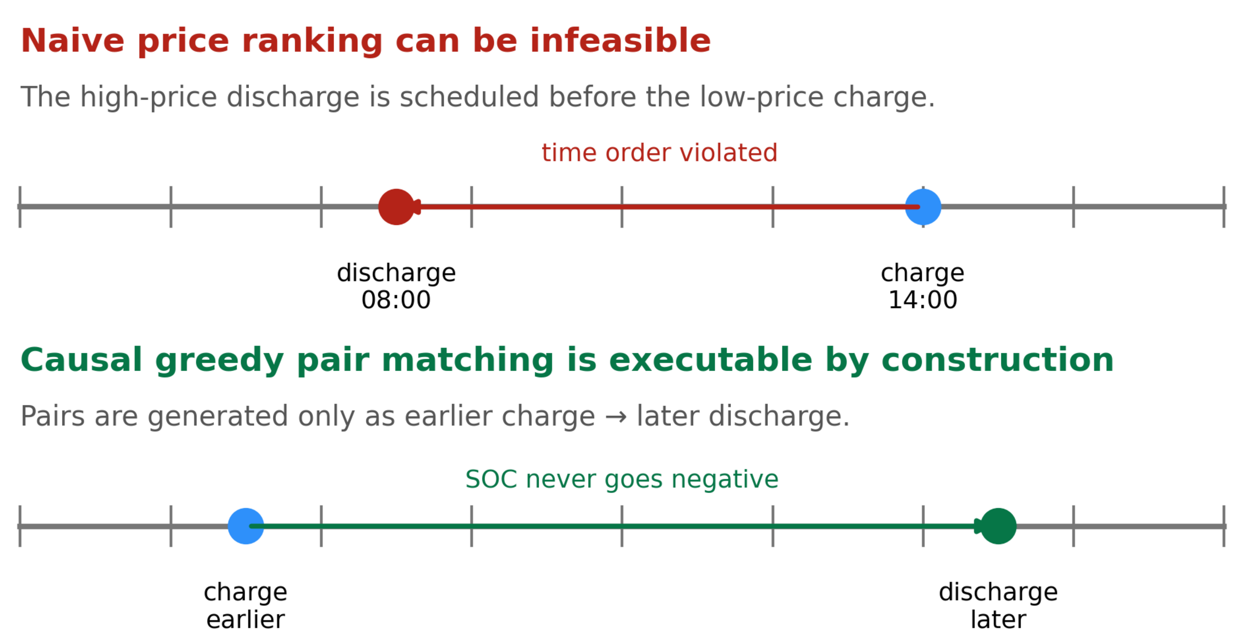

Figure 1. Causal feasibility problem.

METHOD

Data: full-year 2025 smart-meter consumption from four Estonian households (H1–H4, 8.3–13.1 MWh/a) + Nord Pool Estonian day-ahead prices. Native hourly / 15-min resolution retained.

Causal greedy pair-matching, two phases per 24 h window:

- Phase 1 — generate only ordered pairs (i, j) with $i < j$; profit $\pi = p_j \cdot \eta_{rt} - p_i$; discard $\pi \le 0$; sort by profit. Charge always precedes discharge → causality guaranteed.
- Phase 2 — process greedily; commit Δc = min(charge power, SOC headroom, discharge power, unmet load).
- Sizing Method 1 — marginal threshold: largest capacity whose last kWh still earns its annualised capital cost (15–30 €/kWh/a).
- Sizing Method 2 — saving-per-kWh slope g(C)=S(C)/C: user sets the steepness (% of initial decline) at which extra capacity is no longer justified.

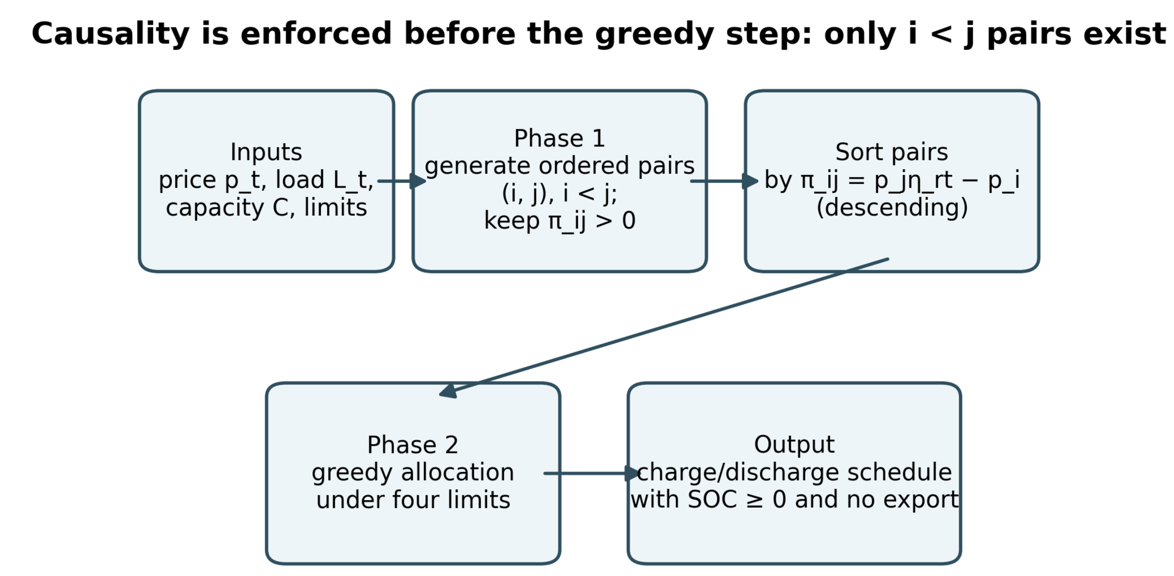

Figure 2. Workflow of the causal greedy pair-matching scheduler .

RESULTS & DISCUSSION

Across the four households a 10 kWh battery saves 332–446 €/a (34.6–45.2% of the spot-energy bill). Marginal value falls steeply: the 1st kWh returns ~ 73–80 €/a, the 30th only ~ 1.5–3.6 €/a (Fig. 3–4). At 20 €/kWh/a the optimal size is 7–10 kWh (Method 1); a conservative 50% slope gives 5 kWh, a permissive 20% gives 12–15 kWh (Method 2, Fig. 5). The 24 h day-ahead horizon is best for the residential range; longer horizons help only above ~ 25 kWh.

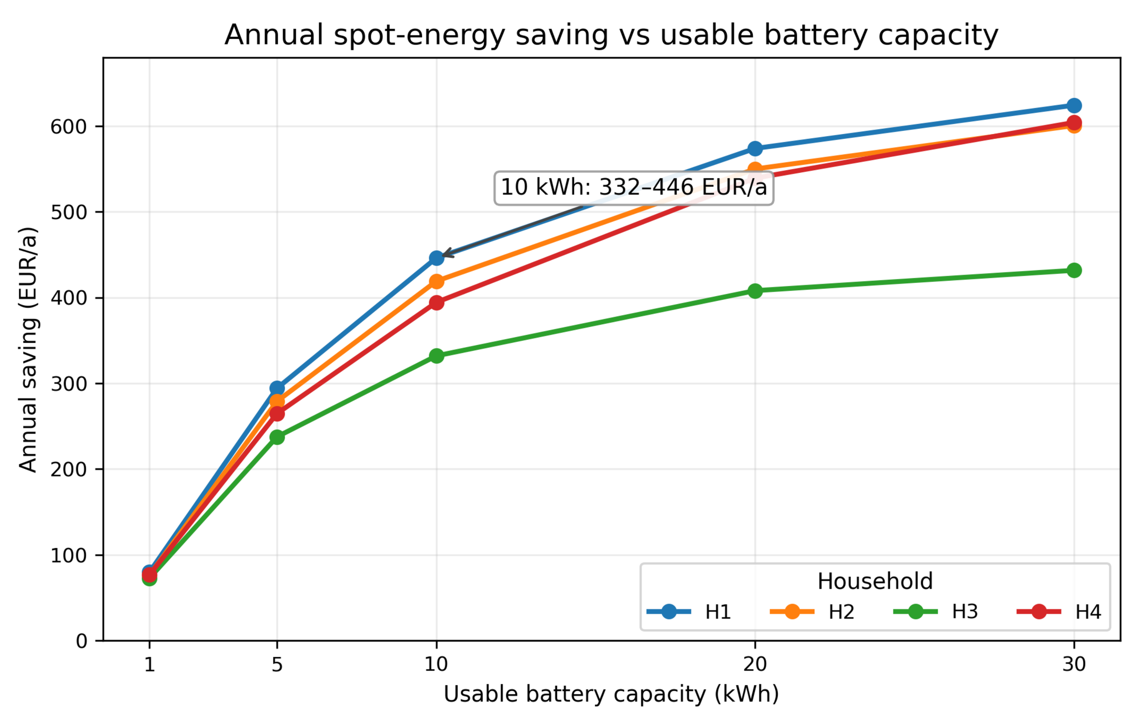

Figure 3. Annual gross spot-energy saving as a function of usable battery capacity

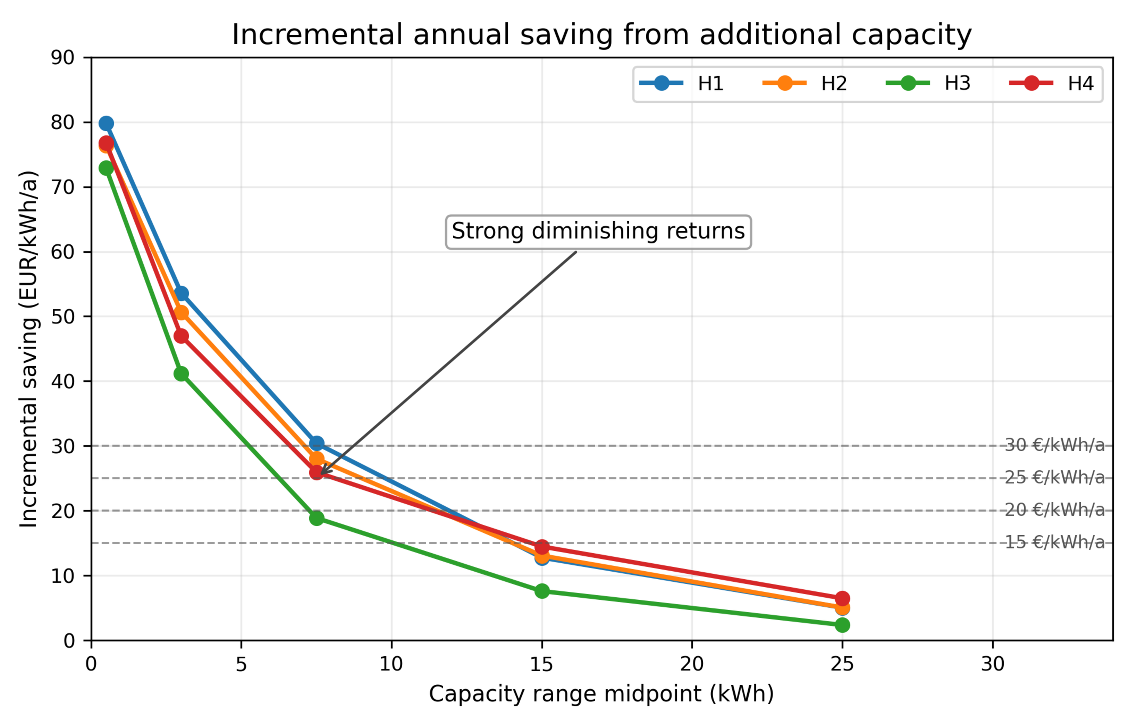

Figure 4. Incremental annual saving from additional capacity, shown as interval-average marginal values between evaluated capacities. Dashed lines mark annualised capital-cost thresholds used in Method 1.

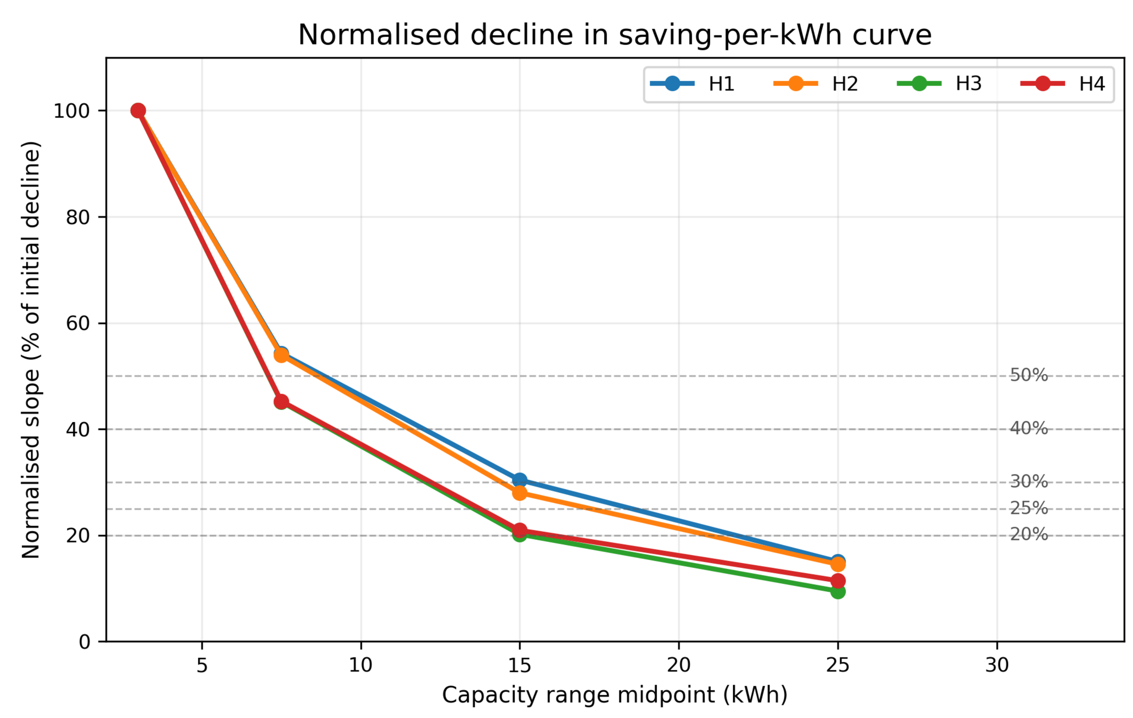

Figure 5. Normalised decline in g(C) with user-defined thresholds for Method 2. The threshold is a transparent tuning parameter rather than a fixed cost assumption.

CONCLUSIONS

A causal, solver-free greedy scheduler captures a substantial share of day-ahead arbitrage value while guaranteeing physically executable schedules by construction.

At a representative 20 €/kWh/a capital cost both sizing methods place the economically sensible capacity at 7–10 kWh — well below where the saving curve flattens.

Reporting both methods makes diminishing returns explicit and discourages oversizing. Reported values are gross spot-component savings, not net profitability.

FUTURE WORK/ REFERENCES/ACKNOWLEDGMENT

Future work: (1) battery degradation & per-cycle cost → net benefit and a wear-aware dispatch rule; (2) PV coupling and grid export; (3) more years and households; (4) a consumer-facing web tool where a household loads its own data and tunes the slope threshold.

Selected references:

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Keskküla et al., Energies 2025, 18, 4405.

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