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Energy Scheduling for Industries under Real-Time Tariffs: Effects of On-Site PV and Battery Storage

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Content

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Motivation

Motivation

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Manufacturing is energy & carbon intensive

- 30% of global energy use.
- 24% of global GHG emissions.

Industrial decarbonization relies on

- Shifting production to low energy-price hours and low-carbon emissions.
- Increasing the share of on-site renewables and battery storage.

Production scheduling must still respect

- Operating states of production lines.
- Labor and facility cost constraints.

Current integrated scheduling models often

- Difficult to implement and adapt.
- Less adaptable to new assumptions.
- Computationally challenging.

Goal: A Simple, Systematic & Actionable Framework

Integrates industrial scheduling + PV + BSS under real-time tariff, remaining adaptable to process changes

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Research Gap

ESTABLISHED LITERATURE FINDINGS

- Production scheduling under Time-of-Use (TOU) tariffs shows consistent cost savings.
- Emerging Real-Time-Pricing (RTP)-based models capture short-term price volatility.
- Integration of PV and BSS improves energy cost and emissions performance.

KEY LIMITATIONS IN CURRENT RESEARCH

- RTP models remain scarce and are mostly evaluated over short horizons.
- Seasonal effects, multi-day energy price, and PV patterns are rarely considered.
- Market-facing outputs missing: absence of flexibility offers, activation costs, and settlement-ready results.
- PV and BSS are often treated in isolation or under single configurations.
- Limited industrial realism: lack of shift plans, operating modes, and labor/facility constraints

RESULTING GAP

There is a lack of market-oriented, industrially realistic scheduling framework that jointly optimizes production, Photovoltaics (PV), and Battery Storage System (BSS) under RTP over multi-day horizons and seasonal variations.

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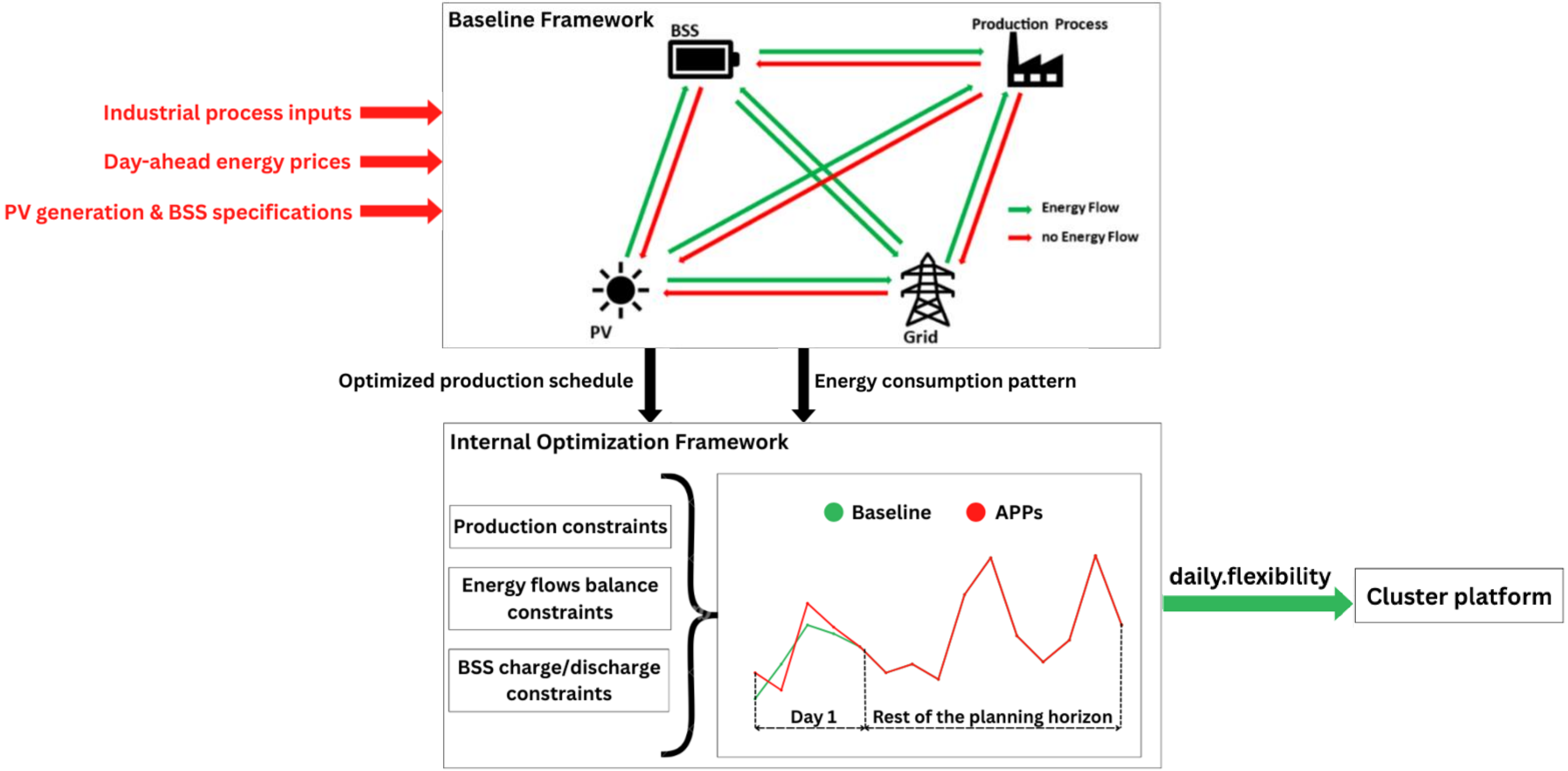
Concept Approach

Concept Approach



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Mathematical Model

Stage 1: Baseline Framework as a mixed-integer quadratically constrained programming (MIQCP)

$$\min \left\{ \sum_{t \epsilon T} E_t^{grid,in} \cdot C_t^{da} \quad \sum_{l \in L} \sum_{t \in T} Aux\_Costs_{l,t}^{op} \quad \sum_{t \in T} E_t^{grid,out} \cdot rem^{PV} \right\}$$

GRID ENERGY COSTS

- Energy covering production demand.
- Resulting load of process after subtracting PV and BSS supply.
- Day Ahead (DA) energy prices.

+

AUXILIARY COSTS

- Captures labor + facility/lighting costs.
- Linked to production line status and operating modes

-

PV REVENUE

- Revenue from PV energy exported to the grid.
- Valued at a fixed PV remuneration rate.

Stage 2: Alternative production profiles (APPs) Framework (Internal Optimization)

- Production is shifted only within the day-ahead window (first 24 hours).
- All decisions beyond the day-ahead window remain fixed to the baseline.
- APPs are cost-ordered to avoid identical or dominated solutions.

Evaluation criteria: Economic and environmental impacts (Key Performance Indicators KPIs)

DAILY ENERGY FLEXIBILITY

measures the maximum flexible energy volume provided by the APPs in the day-ahead time horizon.

ENERGY COST REDUCTION

quantifies energy cost savings of the optimized baseline schedule compared to the current production planning.

CO2 EMISSIONS REDUCTION

measures the percentage decrease in emissions achieved bythe optimized schedule compared to the current operation.

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Case Study Setup

Case Study Setup

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Industrial Case

- Electronics manufacturing.
- Soldering lines, assembly units and buffer areas.
- Major energy consumers: Soldering lines.

Scheduling & States

- Production line operating states: Long & short standby mode.
- Operating mode depends on soldering liquid temperature.

Simulation Scenarios

- 7-day planning horizons (Jan-June 2025).
- Winter, spring/fall, summer seasonality.
- High vs low production variance.

Energy & Data

- **Daily Consumption:** a few thousand kWh
- **PV:** 116 kWp | **BSS:** 50-600 kWh.
- SMARD & CO2Map integration.
- PV generation data: Factory energy digital twin (FLEX4FACT).

Case Study Setup

Key Performance Targets:

> 30 kWh	> 5%	> 5%	25%
DAILY FLEXIBILITY	COST REDUCTION	EMISSION DECREASE	PV SELF-CONSUMPTION

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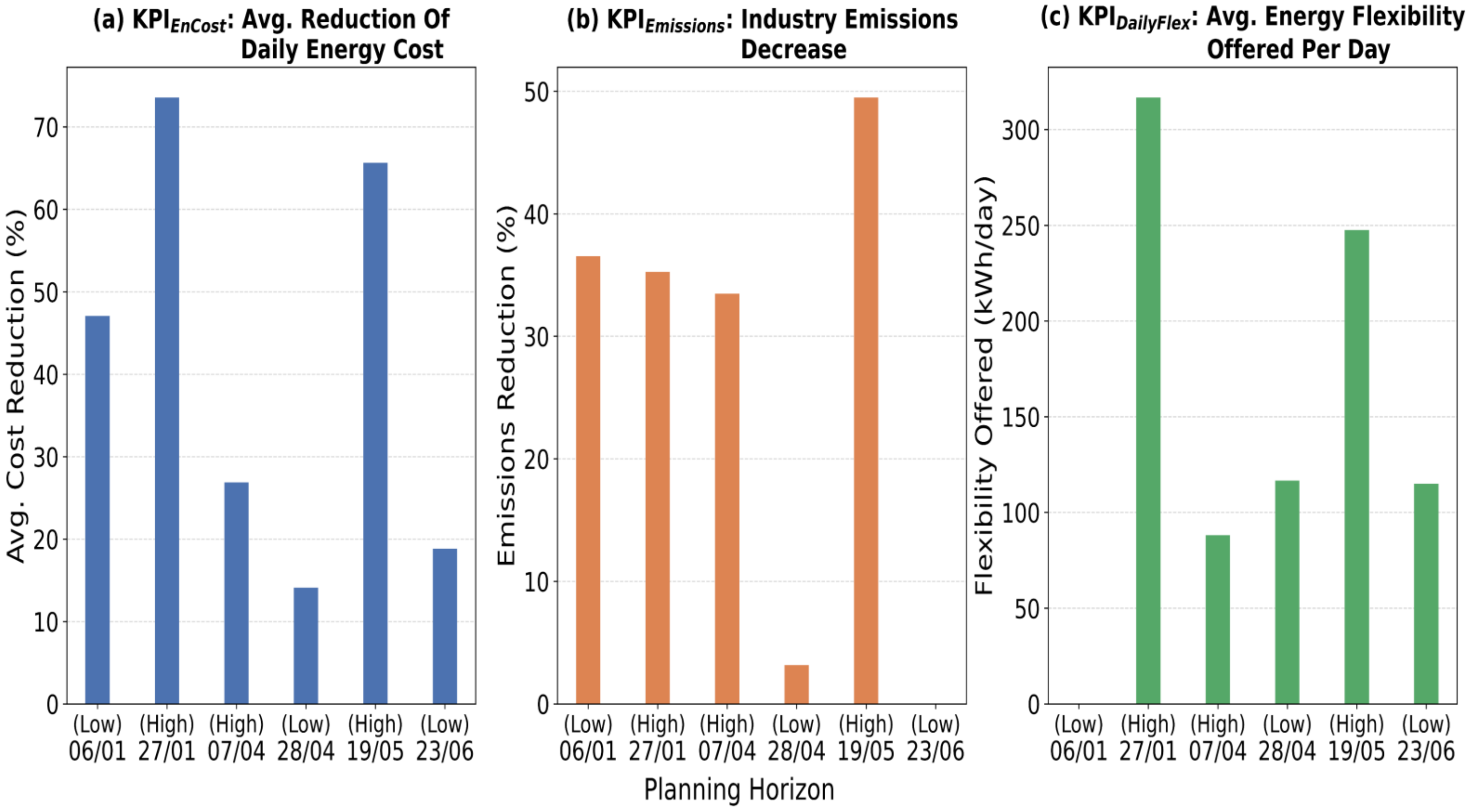
Results and Interpretations

Seasonal and production-volume performance of energy cost savings, CO_2 reduction and offered daily flexibility (Without BSS).



Energy Cost Reduction

Strong savings from energy-aware scheduling driven by energy tariff spread + PV generation.

Reduced CO_2 Emissions

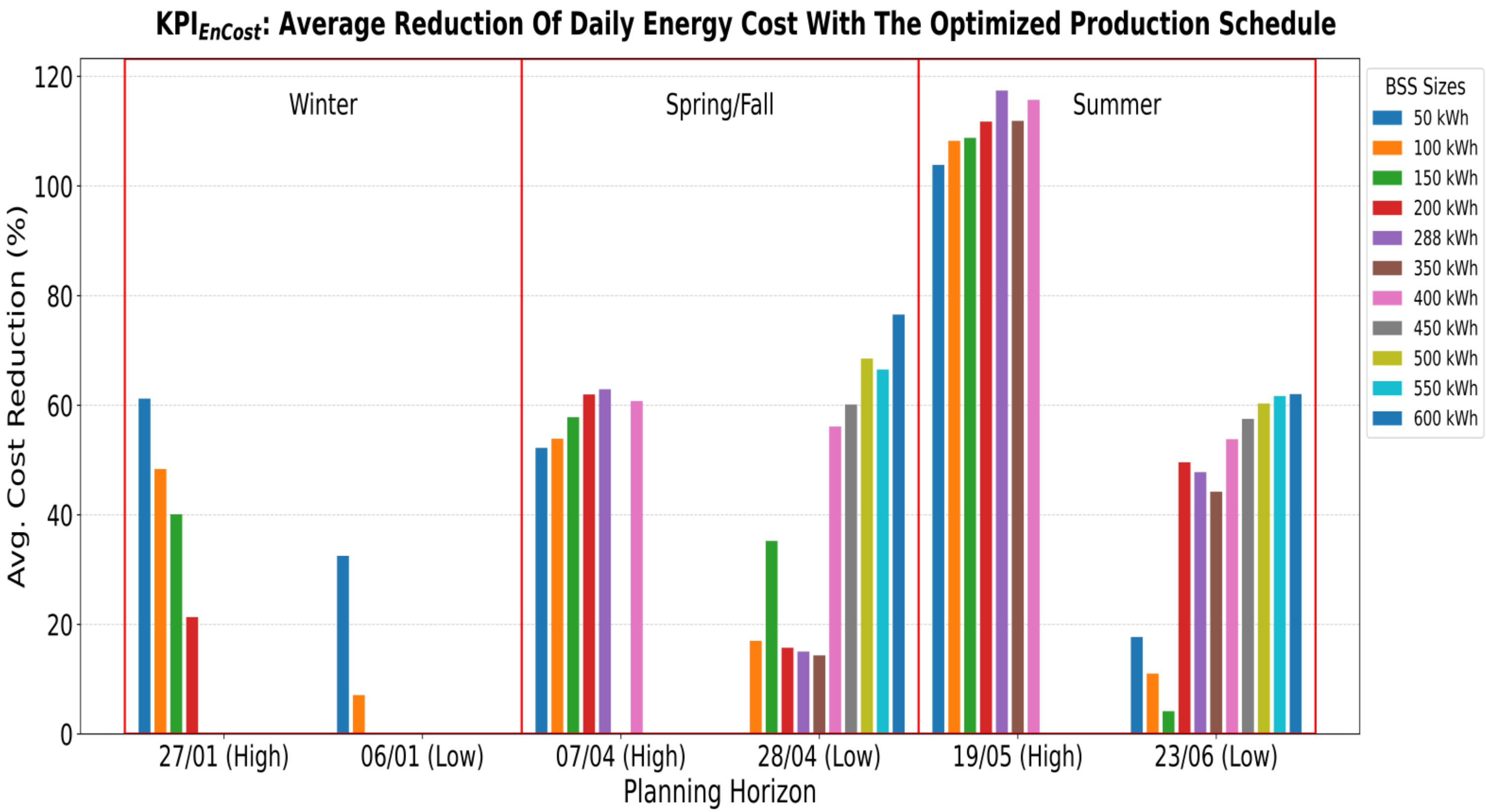
- Reductions achieved due to shifted low energy prices and higher hours of PV availability.
- Cost reductions ≠ CO_2 reductions. Low energy prices can coincide with high emissions factors (planning week 23/06).

Daily Flexibility

- Daily flexibility exceeds target in most of the planning horizons.
- No flexibility in the week starting on 06/01 indicates that there is no feasible shift within the baseline solution. Hence no APPs are generated.

Results and Interpretations

Seasonal and production-volume performance of energy cost savings for different BSS sizes.



Strong Seasonal Variation

Limited values in winter, higher values in spring/summer.

Winter BSS sizes Threshold

Small BSS is sufficient during winter. Additional capacity does not yield significant cost improvements.

Spring/Summer Optimization

BSS enables major reductions via PV surplus management and leveraging stronger energy price spreads.

Reduced Savings

Limited savings for BSS sizes beyond **(350-400 kWh)**. Additional storage capacity adds marginal extra savings.

Results and Interpretations

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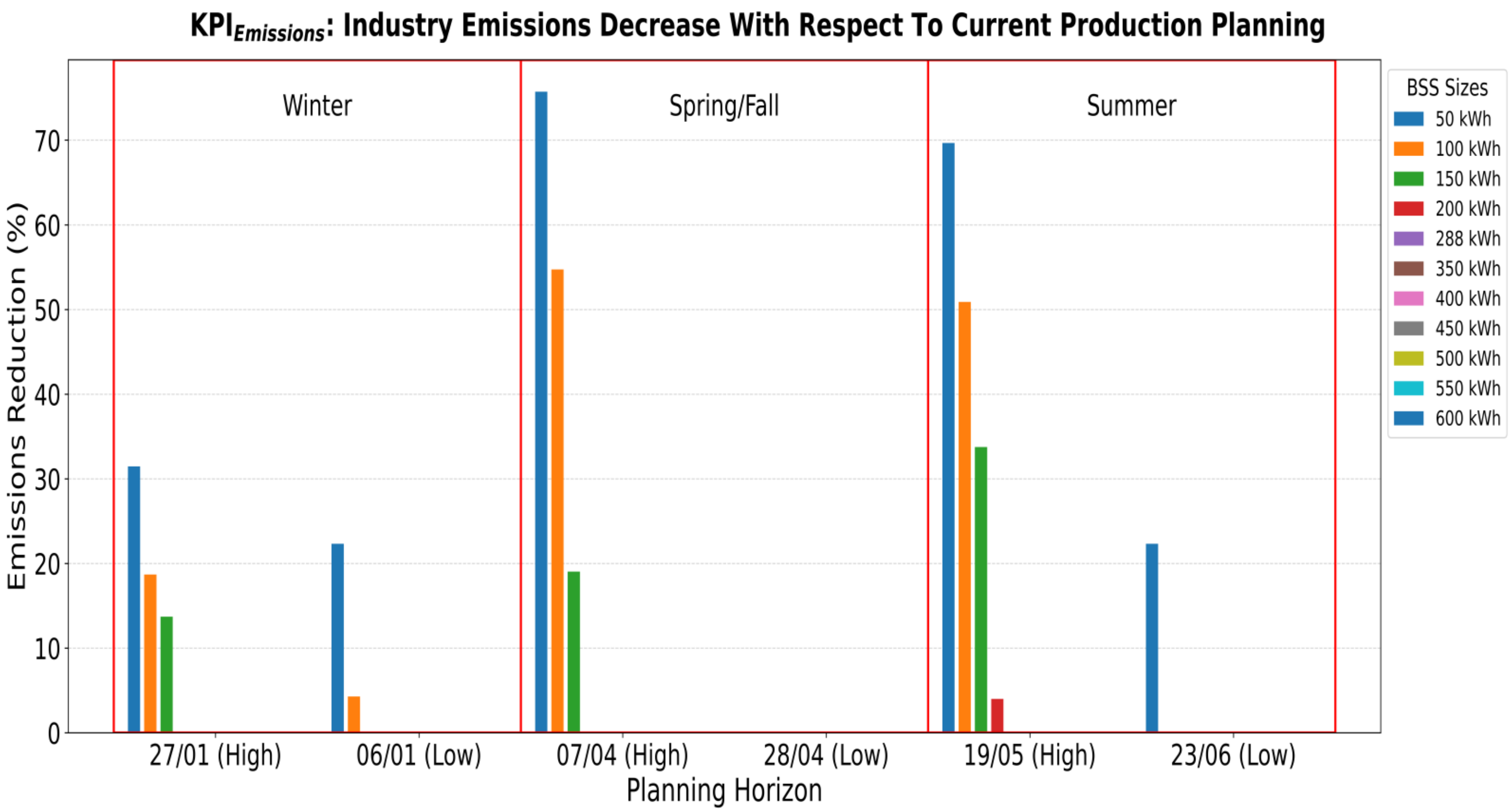
Seasonal and production-volume performance of CO_2 reduction for different BSS sizes.



Seasonal Sensitivity

Emission reductions are highly dependent on season and battery capacity optimization.

BSS sizes Sweet-spot

Small BSS **(50–150 kWh)** yields the largest gains, reaching up to **75%** reduction in spring/summer.

Storage Oversizing Risk

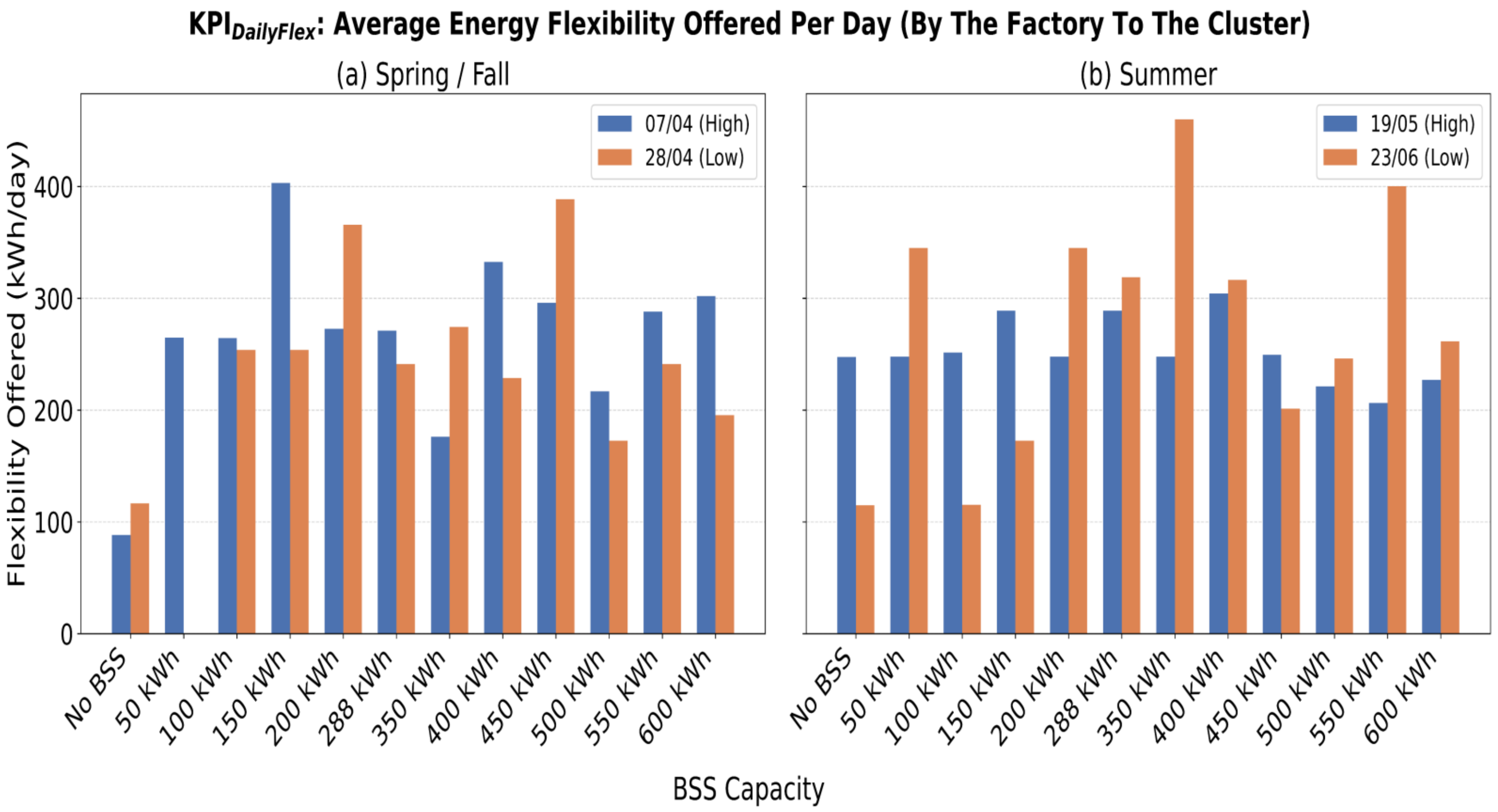
Larger storage can neutralize gains by charging during high-carbon grid intensity hours.

Emissions Factors

This KPI is primarily driven by PV-surplus utilization, rather than battery size alone.

Results and Interpretations

Seasonal and production-volume performance of the offered daily flexibility to the cluster for different BSS sizes.



Significant Capacity Uplift

BSS strongly increases daily flexibility. Values rise from **(88 to 400 kWh/day in spring/fall scenario)** across high-production horizons.

Non-Linear Performance

Medium BSS sizes **(200–400 kWh)** deliver the highest relative flexibility gains before reaching diminishing returns.

Flexibility Factors

Flexibility depends heavily on PV surplus and baseline production schedules rather than storage size alone.

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Conclusion

Conclusion

❖ Summary:

- This work presented an Energy-Flex scheduling framework that jointly optimizes industrial production, PV generation, and battery storage under time-varying tariffs.
- Validation on a real manufacturing case across multiple 7-day seasonal horizons shows that price-aware scheduling alone already delivers important cost savings, daily flexibility as well as CO_2 reduction.
- Battery storage acts as a flexibility multiplier, increasing both offered flexibility and savings when PV availability and price spreads are favorable.
- Storage benefits are seasonal and non-linear, with diminishing returns beyond medium capacities (300- 400 kWh).

❖ Further research:

- Multi-objective scheduling for combined cost and CO_2 reduction.
- Testing multiple electricity price scenarios and volatility cases.
- Full cost-benefit analysis of PV+BSS sizing and payback under RTP.

Kontakt

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Thank you for your attention!

We are looking forward to your questions.