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ICT4SS
Information and Communications Technologies for Smart Societies

Home Energy Management System

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1 Topic overview

Problem

The growing complexity of energy management, driven by fluctuating grid demand and the integration of renewables, makes cost optimization and constraint adherence increasingly challenging.

Solution

To develop an advanced energy scheduling system that balances grid demand, photovoltaic generation, electricity pricing, and EV charging, achieving cost optimization while respecting user-defined constraints.

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2 Framework and Players actions

Prosumer

Consumes energy as per the optimized schedule provided.
Study case: worker who lives alone and own an EV.

PV System

Generates solar energy during daylight hours and feeds energy into the grid.
Study case: five photovoltaic panels

Grid (Energy Market)

Sets dynamic electricity prices to encourage consumption during specific time slots.

3 Sequence of Events

Input Collection

Gather user preferences, electricity prices, and PV generation estimates.

Optimization models

Apply optimization algorithms to balance user preferences, PV usage, and grid interaction.

Optimized Schedule

Generate a schedule allocating energy usage across time slots to minimize costs and maximize efficiency.

Energy Usage Plan

Provide the prosumer with a detailed time-based energy schedule.

Plan Implementation

The prosumer follows the schedule, using it to plan energy consumption for the day.

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4.1 Mathematical model

Objective function

$$\min \sum_{h=0}^{23} [P(h) \cdot \max(E(h) - G(h), 0) + P(h) \cdot d \cdot \min(E(h), G(h))]$$

- $E(h)$: Energy scheduled (decision variable).
- $G(h)$: Energy generated (PV panels).
- $P(h)$: Electricity price.
- d: Discount for solar immission $(0 < d < 1)$.

Constraints

- **Total Energy Demand**
  The sum of scheduled energy for all hours must equal the total daily demand: $\sum_{h=0}^{23} S(h) = E_{\text{total}}$
- **Hourly Energy Bounds**
  The scheduled energy for each hour must respect minimum and maximum limits: $E_{\text{min}}(h) \leq S(h) \leq E_{\text{max}}(h)$
- **EV Energy Total**
  The total energy for electric vehicle (EV) charging must meet the required demand: $\sum_{h \in H_{\text{EV}}} S_{\text{EV}}(h) = E_{\text{EV-total}}$

4.2 Goodness function

Prioritizes hours with lower scheduled energy relative to their maximum capacity while preventing over-allocation in already saturated hours

Balances the contribution of electricity price, photovoltaic energy, and time-of-day preferences defined by hyperparameters

$$\text{Goodness}(h) = \left(1 - \left(\frac{S(h)}{E_{\max}(h)}\right)^2\right) \cdot \left(\frac{\text{PriceScore}(h)}{2} + \text{PVFactor}(h) + \text{HPFactor}(h)\right)$$

Variables:

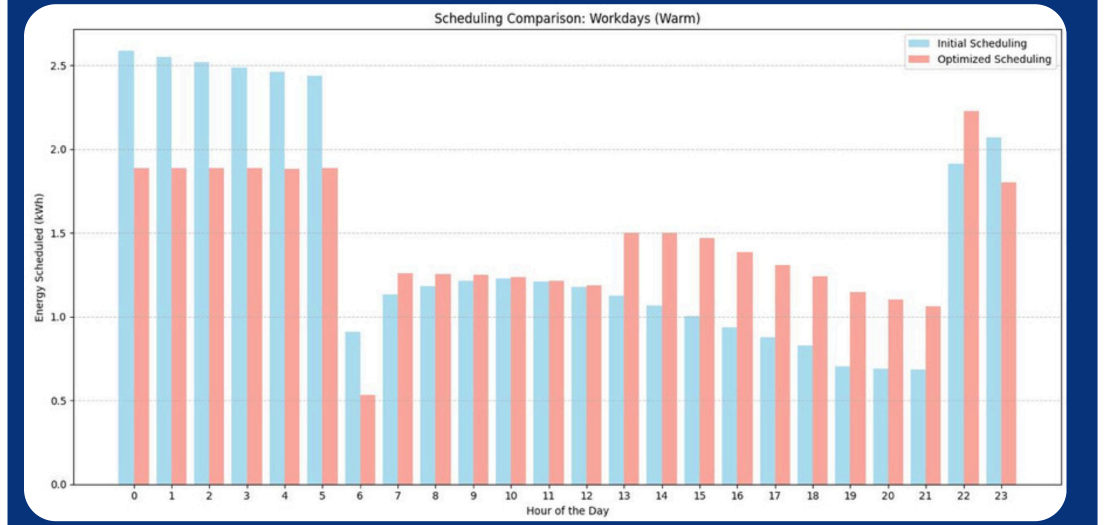
- $S(h)$: Scheduled energy for hour h.
- $E_{\max}(h)$: Maximum energy allowed for hour h.
- $\text{PriceScore}(h)$: A score based on the electricity price for hour h
- $\text{PVFactor}(h)$: A normalized factor indicating PV energy generation.
- $\text{HPFactor}(h)$: A weighting factor based on Hyperparameters for four specific periods of the day.

4.3 Pseudocode

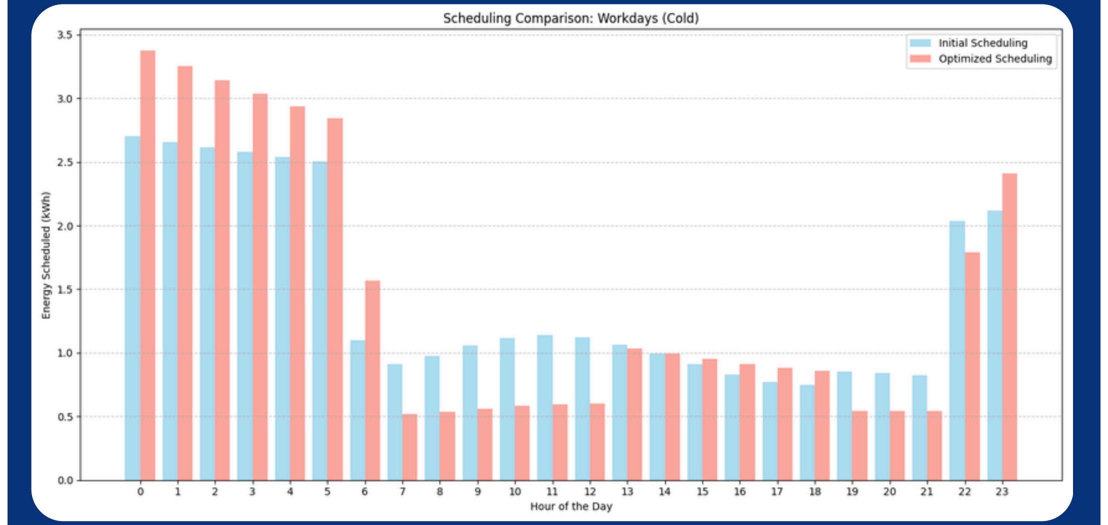
1. **Initialize Scheduling**:
   - Set $S(h) = E_{\text{min}}(h)$ for all h.
   - compute $E_{\text{remaining}} = E_{\text{total}} - \sum S(h)$.
2. **Define Hyperparameter Ranges**:
   - Define ranges for Hyperparameters.
3. **Perform Grid Search**:
   - For each combination of Hyperparameters values:
     (a) **Compute Goodness Factors**: Calculate $\text{Goodness}(h)$ for each hour h.
     (b) **Normalize Goodness Factors**: Ensure $\text{Goodness}(h)$ values sum to 1.
     (c) **Allocate Remaining Energy**:
       - Allocate $\Delta S(h)$ based on $\text{Goodness}(h)$ and constraints.
       - Update $S(h)$ and reduce $E_{\text{remaining}}$.
     (d) **Simulate Total Cost**: Calculate the cost for $S(h)$.
4. **Select Best Hyperparameters**:
   - Pick set of Hyperparameters that minimize cost.
5. **Final Allocation**:
   - Use the best hyperparameters and repeat step 3a–3c.

5.1 Initial vs Optimized schedule

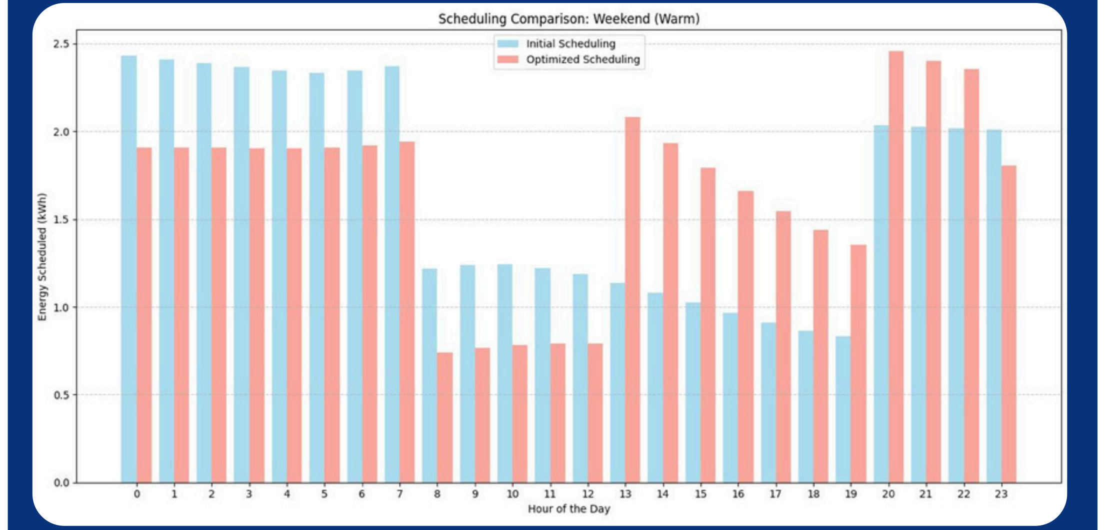
Workday (Warm)



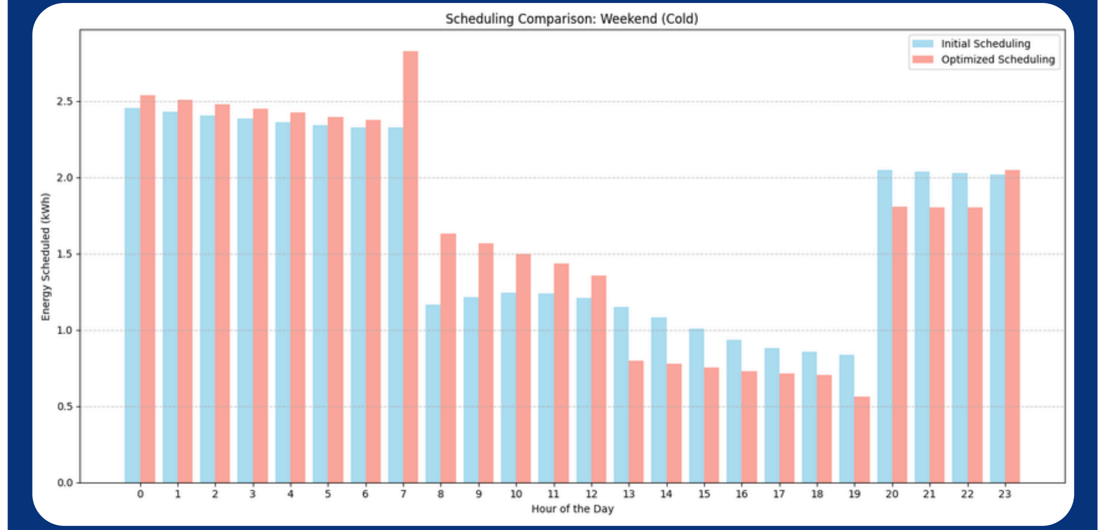
Workday (Cold)



Weekend (Warm)



Weekend (Cold)



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5.2 Cost Optimization

Workdays (Warm)

- **Initial Expenses (€):** 1.4554
- **Optimized Expenses (€):** 1.1113
- **Savings (%):** 23.64

Weekend (Warm)

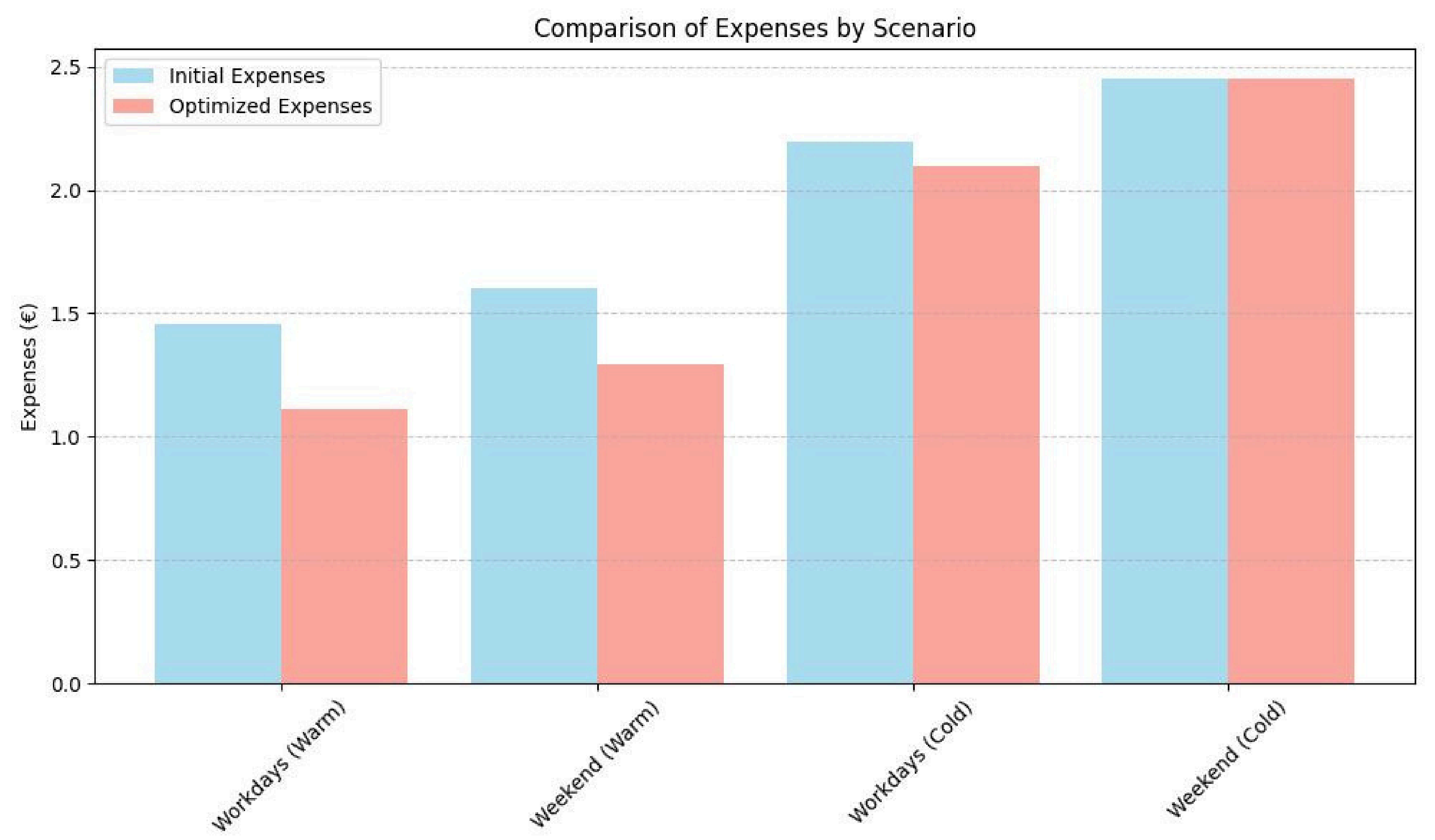
- **Initial Expenses (€)**: 1.6022
- **Optimized Expenses (€)**: 1.2944
- **Savings (%)**: 19.20

Workdays (Cold)

- **Initial Expenses (€)**: 2.1960
- **Optimized Expenses (€)**: 2.0950
- **Savings (%)**: 4.60

Weekend (Cold)

- **Initial Expenses (€)**: 2.4498
- **Optimized Expenses (€)**: 2.4497
- **Savings (%)**: 0.0002



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Thank You!

Data References:

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