Prosumer Community Energy Trading Simulator

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Problem statement

Challanges

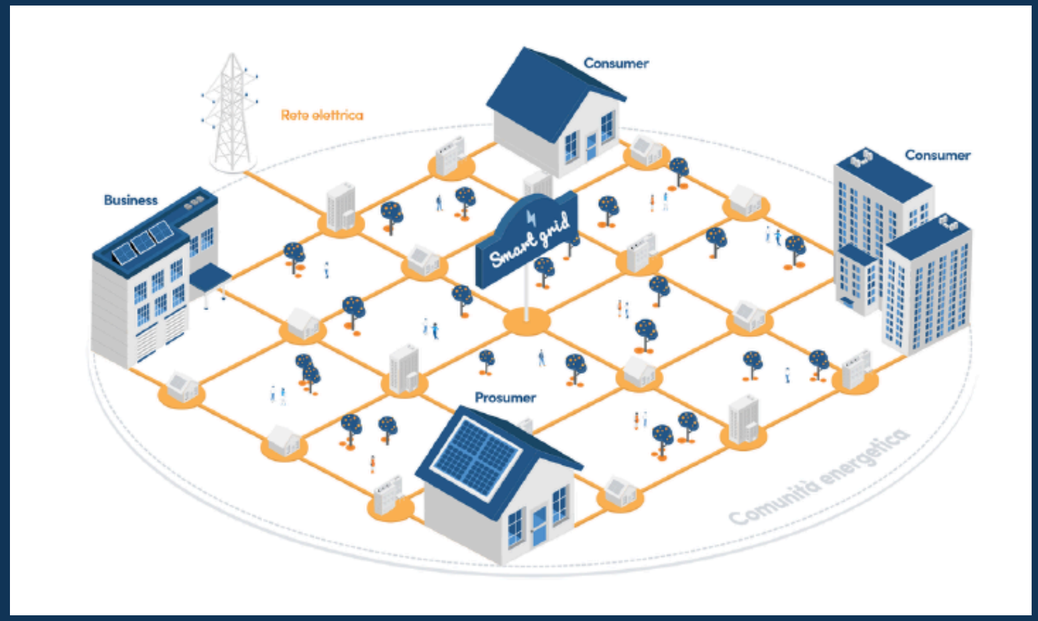
- Traditional grids are centralized and inefficient
- Prosumers sell exceeding energy at low prices
- Consumers buy from grids at high prices
- 60% price spread captured by intermediaries

Objectives

- Simulate a 100 prousmers community exchanging energy with hourly timestamps
- Register each transaction in a Blockchain with PoW logic
- Explain how P2P can optimize the renewable energy usage

Opportunities

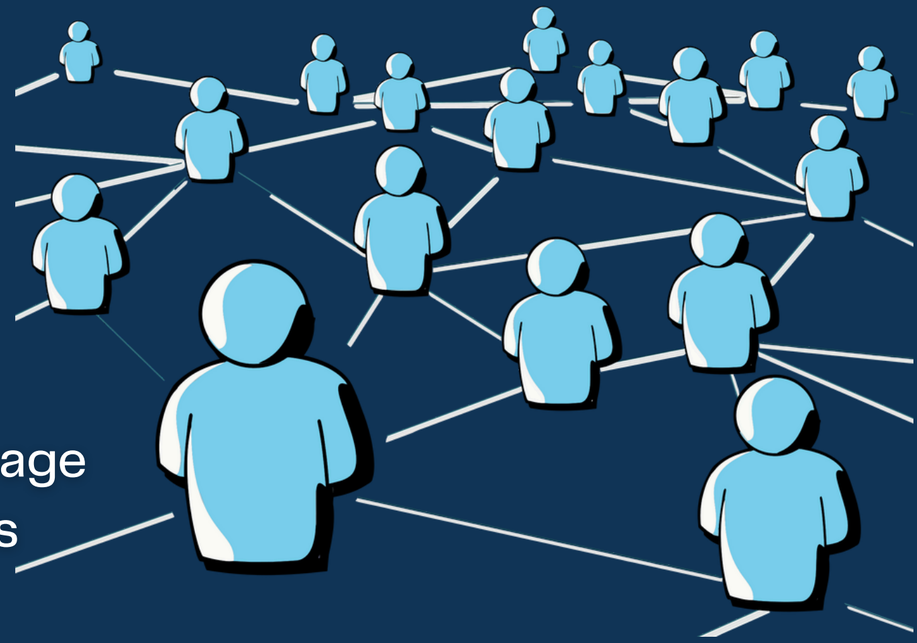
- Enable direct p2p trading between prosumers
- Reduce dependency on the central grid
- Maximize renewable energy consumption
- Fair pricing through competitive markets



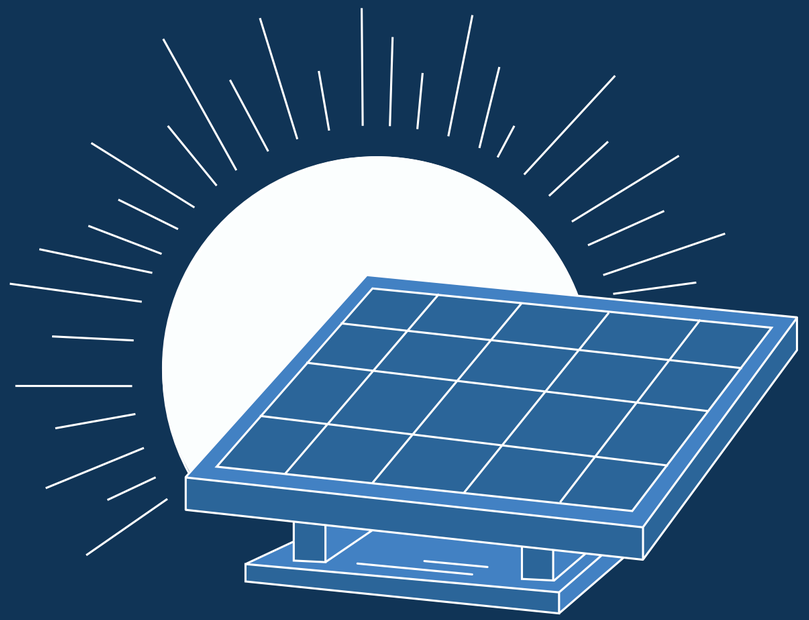
Community overview

System architecture

- 100 prosumers
  - 10 types of houses
    - PV Capacity: 2.5–7 kW
    - Base Consumption: 0.35–1.5 kWh/hour
    - Battery storage: 5–20 kWh
- 3-Step Energy Balancing Process
  - Self-Balancing: Use own PV generation and battery storage
  - P2P Trading: Bilateral negotiations with other prosumers
  - Local Market: Trade through central market
- Blockchain Network: 15 miners using Proof-of-Work
- Regulator: Enforces rules to maximize renewable energy usage
- Assumptions: 24hrs simulations, realistic PV generation, realistic consumption trend, Price forecast based on demand patterns



PV generation



Realistic PV generation (6AM 6PM)

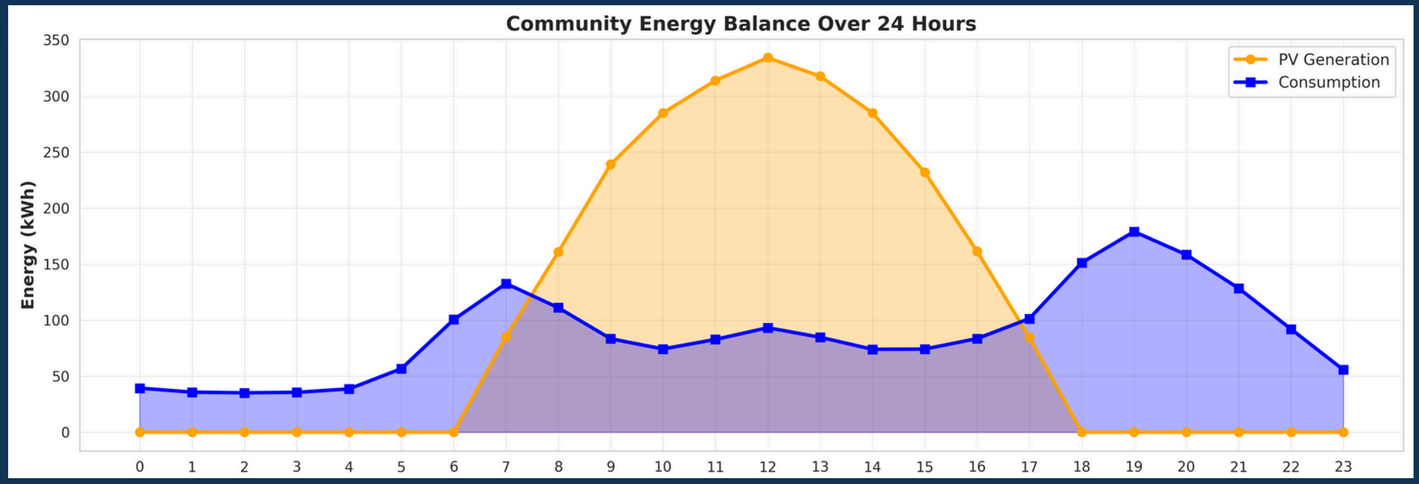
- Sinusoidal curve peaking at noon
- 88% panel efficiency with weather variability (0.5–1.0)
- 21% capacity factor (industry standard for residential PV)

Consumption patterns

- Morning peak at 7AM (1.4x base consumption)
- Evening peak at 7PM (1.9x base consumption)
- Nighttime low consumption from 1 to 4AM (0.35x base consumption)

Battery performance

- 80% of prosumers have their own battery
- 95% round-trip efficiency (5% energy loss)
- 10–95% SOC limits (battery protection)
- Use battery to compensate imbalances. Remaining disparity is than solved with trading.



Trading algorithm

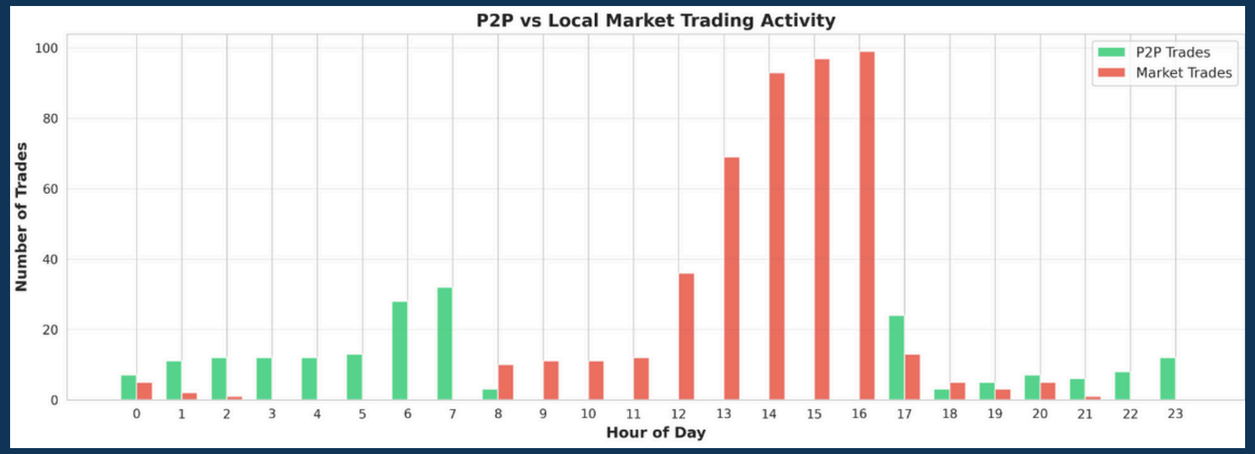
Peer–to–Peer Trading

Double action matching algorithm where the system, finds the compatible matches between buyers bids and sellers asks.
Prices are determined by prosumer urgency (quantity needed) and are bounded between Grid Sell and Buy prices.

Local Market (Grid)

Alternative when P2P fails, price are higher.

- Buy Price: €0.15 + €0.03 = **€0.18/kWh**
- Sell Price: €0.15 – €0.03 = **€0.12/kWh**
- €0.06 aggregator spread (33% profit margin)



Price comparison

Method	Buy Price	Sell Price	Spread
P2P	€0.139	€0.139	€0.00
Grid	€0.18	€0.12	€0.06

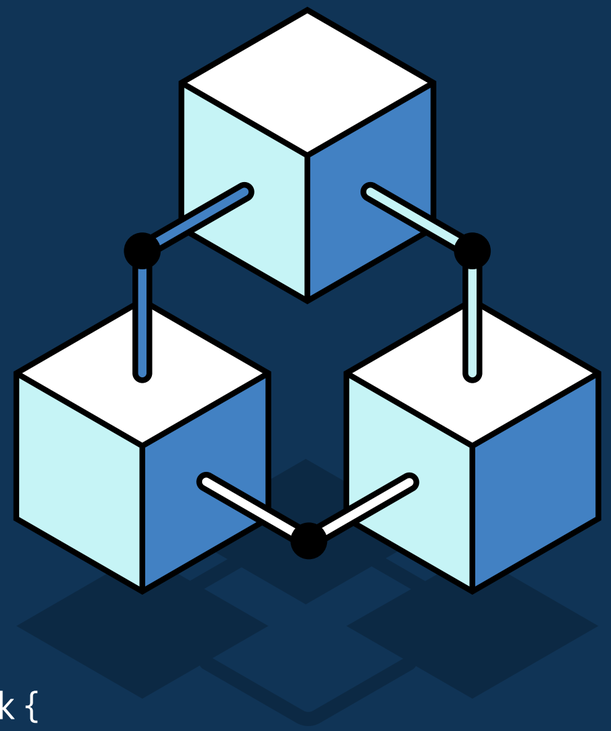
Blockchain implementation

Architecture

- Proof of work consensus mechanism
- 3 leading zeros in block hash
- 15 miners competing to validate blocks
- €0.1 reward per mined block

Results

- around 26 blocks mined per 24 hours simulation
- 100% chain validity (all the runs pass validation)
- Immutable transaction history for audit trail



```
Block {
    index: int
    timestamp: datetime
    transactions: List[Trade]  # Max 50 trades
    previous_hash: str
    nonce: int  # Found through mining
    hash: str   # SHA-256(block_data + nonce)
}
```

Regulator strategy

The regulator sets the market rules in order to guide the prosumers behaviour

Objective

Maximize the usage of renewable energy

Bonus

€0.02/kWh of renewable energy consumed

Cumulative bonuses grow throughout day

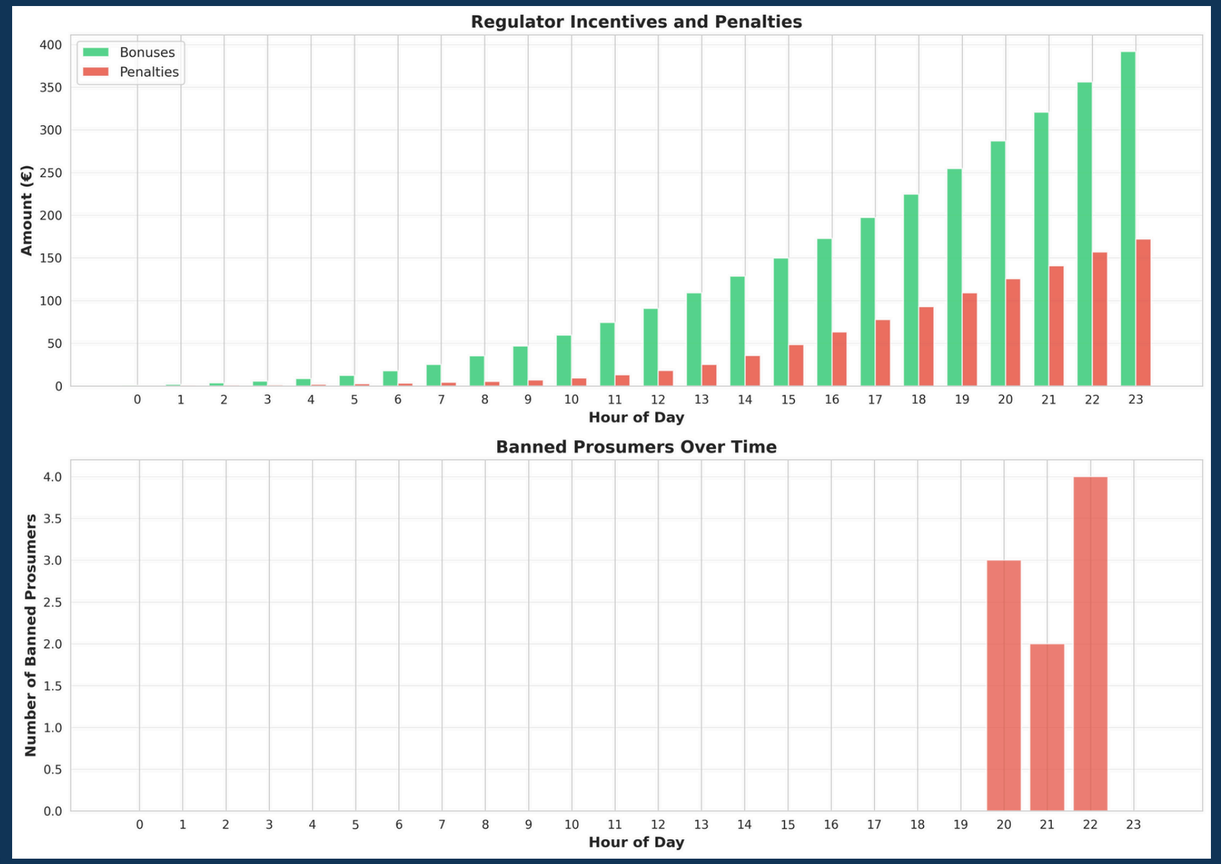
Malus

€0.01/kWh of local market energy consumed discourages excessive grid reliance

Ban system:

- Market abuse: 2hrs ban for penalties >€2 and bonus< €2
- Negative balance: 3hrs ban for balance < -€20
- 5 timestamp cooldown to prevents immediate re-ban

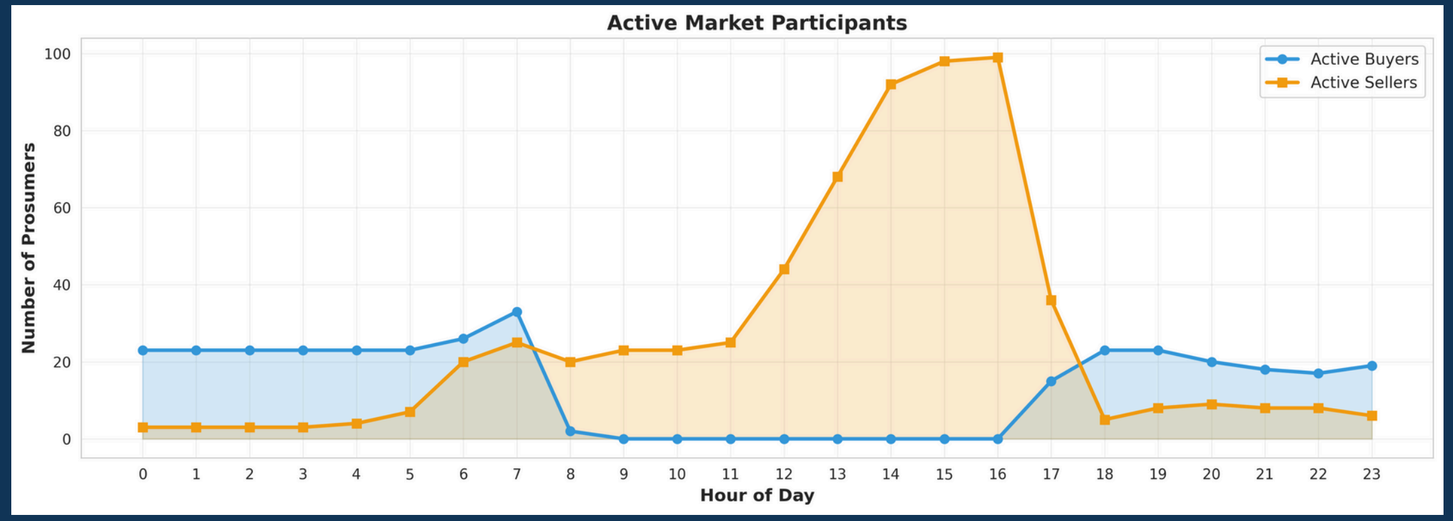
Results: 13 prosumers banned per run (1.3%)



Simulation Results & Key Metrics

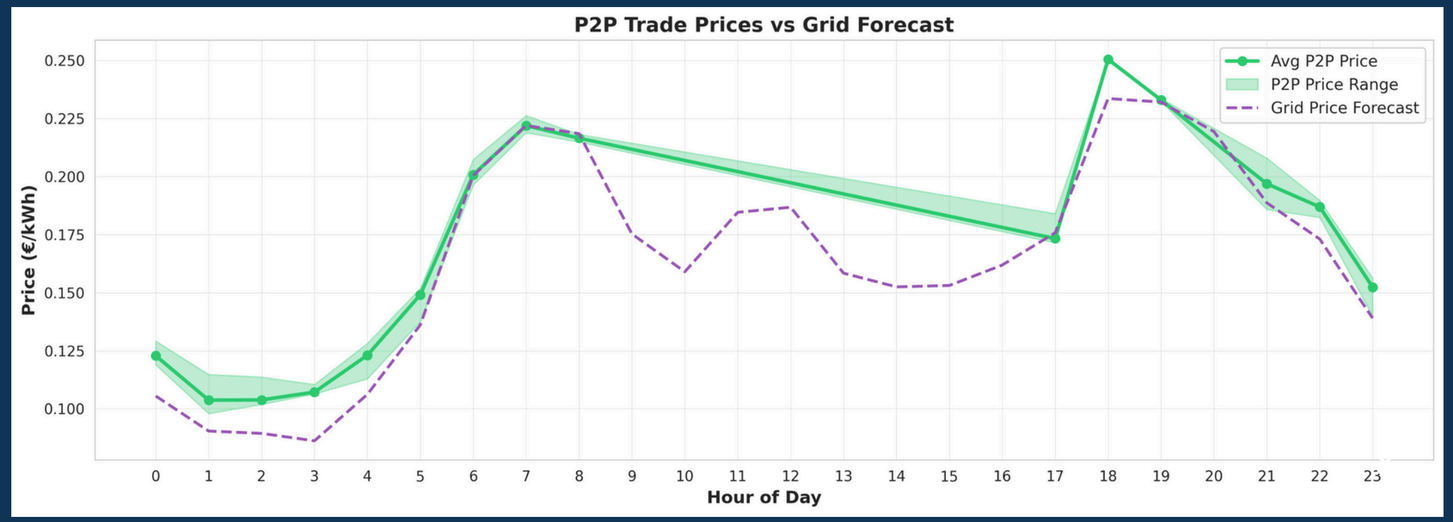
Market participation

- Buyer–seller dynamics closely follow daily production and demand cycles.
- Sellers dominate during PV peak hours, while buyers prevail in evening.
- Active participation confirms effective role switching of prosumers across the day.



Price dynamics

- During peak demand, P2P prices slightly exceed forecasted prices, reflecting scarcity.
- Price smoothing emerges from local matching between prosumers.



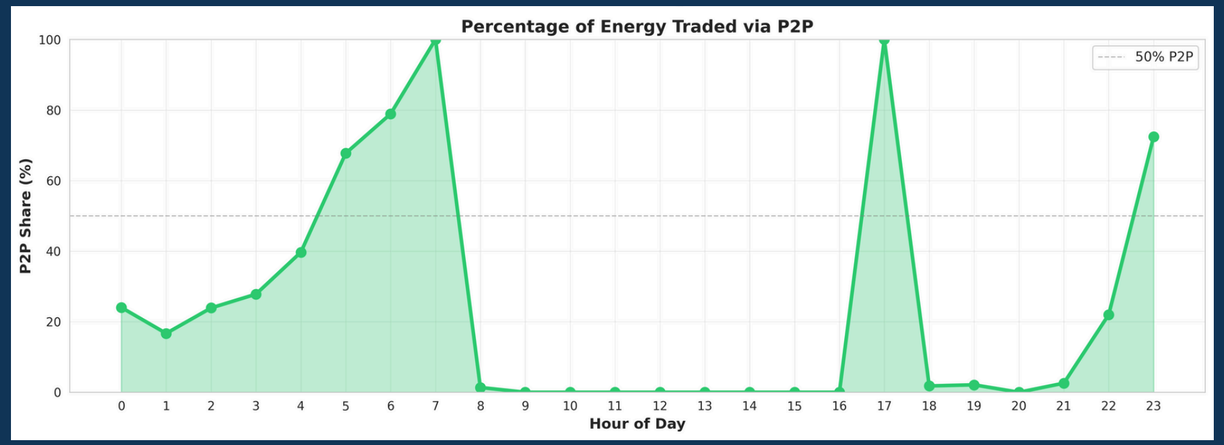
System Behavior & Dynamics

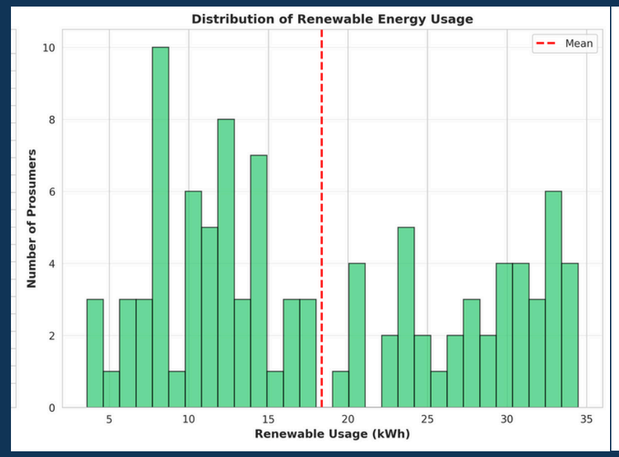
P2P trading

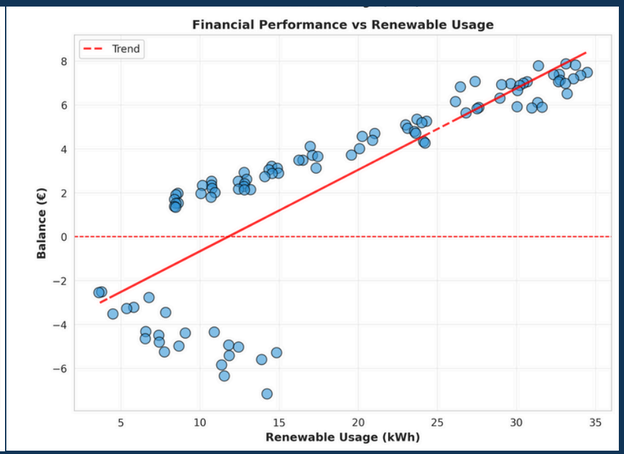
- Peak during transition periods (morning and late afternoon) when both surplus and deficit coexist.
- Midday energy surplus reduces P2P relevance.
- Night trades through battery storage.
- Market mechanisms complement P2P trading, when bilateral matching is not feasible.

Financial performance

- Higher renewable usage correlates with better financial performance.
- Prosumers benefiting from PV generation achieve higher balances.







Conclusions

System effectiveness

- The simulator successfully models a decentralized energy community with realistic trading dynamics.
- P2P trading emerges naturally when local surplus and deficit coexist.

Prosumer behavior

- Prosumers with higher P2P participation achieve better financial outcomes.
- Excessive reliance on the local market is associated with negative balances.

Role of regulation

- Incentives effectively promote renewable usage and cooperative behavior.
- Penalties limit opportunistic strategies without destabilizing the system.

Overall outcome

- The system increases renewable self-consumption while maintaining economic fairness.
- Results confirm the feasibility of regulated P2P energy markets as a complement to traditional grids.

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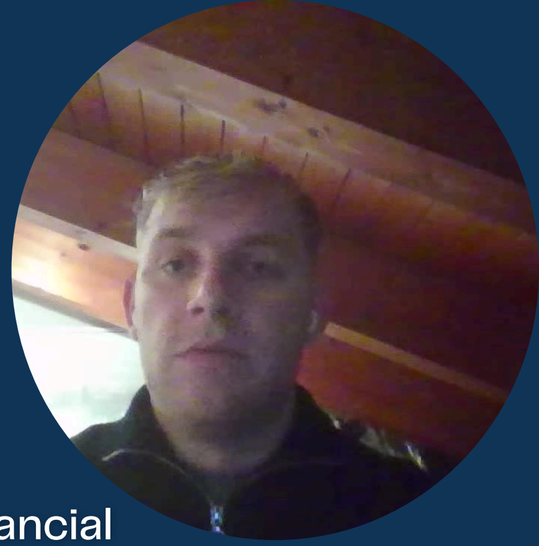

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Thank **You!**