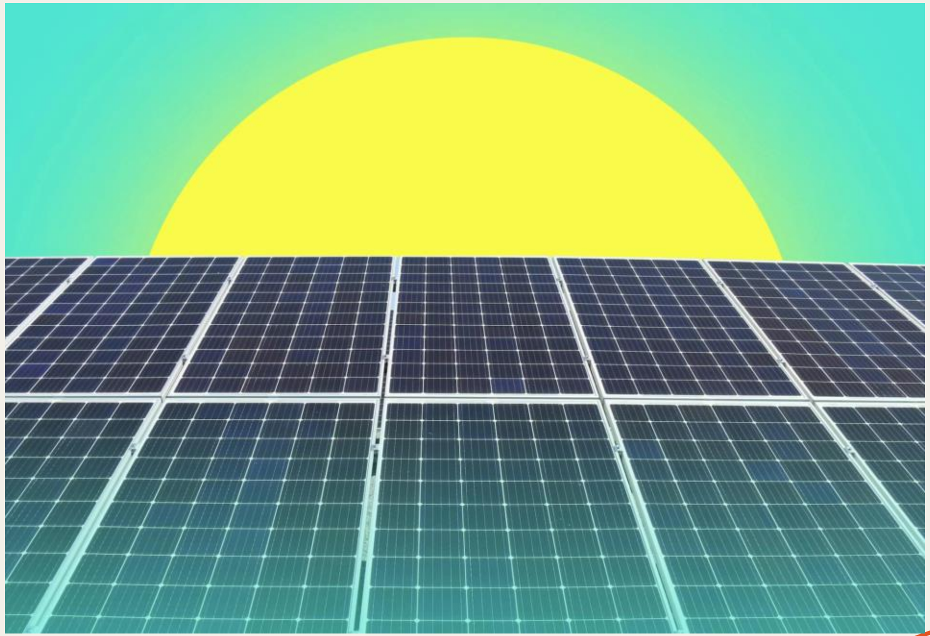
Simulation of a regulated prosumer community from self-balancing to local markets

Smart Grids – Professor Tao Huang



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Introduction – Prosumer community

+ Achieving energy flexibility, affordability and sustainability
+ Self-sustainable **prosumers** with their own PV generation
+ Distributed decision making → maximising **individual utilities**
+ **Regulation** influence the behaviour of players
  + Incentives / penalties
+ **Blockchain** to support self-organised trading
  + Can be proof-of-work or proof-of-stake

Framework and players of the community

+Prosumers

+ Bidirectional power flow: power injection or withdrawal
+ Participation to P2P market is price elastic
+ Individual attitudes on comfort and profit

+The Distribution System Operator

+ Maintains the physical connection between the community and the national grid
+ Provides energy as the “lender of last resort”
+ Purchases excess solar energy from the community at FiT price

+The load aggregator

+ Participates to the local open market on behalf of prosumers
+ Act as a clearing layer for prosumers whose P2P offers weren’t fully matched
+ Maximize social benefit with cap prices

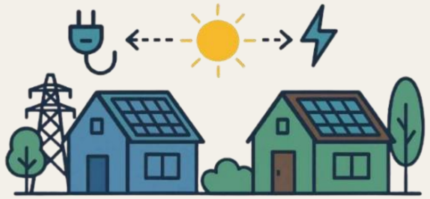
+Regulators and policy makers

+ Enforce public policies to achieve sustainability
+ Sets energy tariffs frameworks and financial incentives / penalties
+ Monitors markets operations, system performance

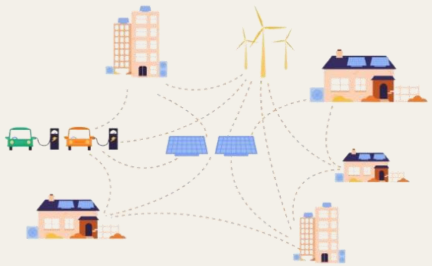
Community assumptions and objectives

+ 200 selfish prosumers balance their energy through consecutive steps:

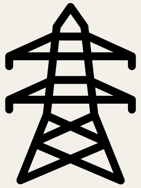
Self-balancing



Self-organized negotiation (P2P trading)



Local market



National grid

+ Transactions are secured by **blockchain** (proof-of-work, 10 minors)
    + Proof-of-work: blocks with 000 difficulty targets
    + The minors validate the transactions by changing the nonce until the hash is valid
    + Consensus mechanism: separate nodes distribute the right to update the blockchain

+ **Objective:** To maximize social benefit, affordability and sustainability

Regulation & control strategies

2 regulation objectives to promote "good" prosumers behaviours:

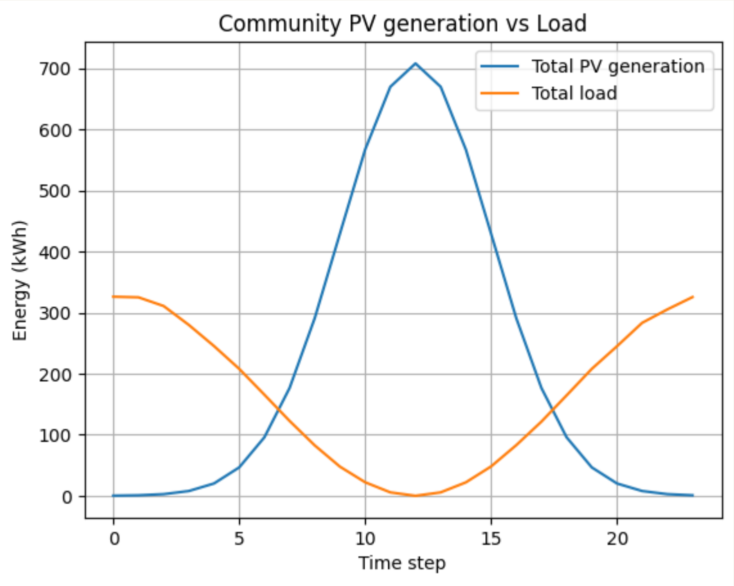
- **Maximize self-organized trading**
  - **Incentive**: **Balancing Premium** → Stepwise regulation, ≠ rewards per P2P participation ratio
  - **Penalty**: A fine is given to the prosumer if he's not participating enough
- **Maximize chaos**
  - **Incentive:** the prosumer is encouraged to keep more energy for him
  - **Penalty:** randomly banning prosumers and increasing prices

POVERTY

POLLUTION DEATH

Local communities grid stability Energy flexibility

Mathematical models



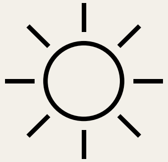
+ **Total solar energy production** of prosumers

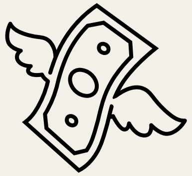
$$E = P_{peak} \times S \times (1 - L) \times \Delta t$$

With:

- *P the peak power in kWp of the solar panels. Pure consumer has* $P_{peak} = 0kW$ *('capacity' in the code)*
- *S the normalized solar irradiance* $\in [0,1]$ *to include the sunlight intensity ('base_capacity_shape' in the code)*
- *L the system loss factor* $\in [0,1]$ *due to inverter inefficiencies, cable losses, snow, shading… ('noise' in the code)*
- $(\Delta t = \frac{24}{h}\ hours\ per\ time\ step)$ *the amount of time for the energy production, with h the number of simulation steps*

+ **Price forecasting**





  + Simulation of **grid prices** as a squared sinusoidal curve.
    Cheap at night, expensive in the evening. Prices $\in [0.12,\ 0.45]$ €/kWh

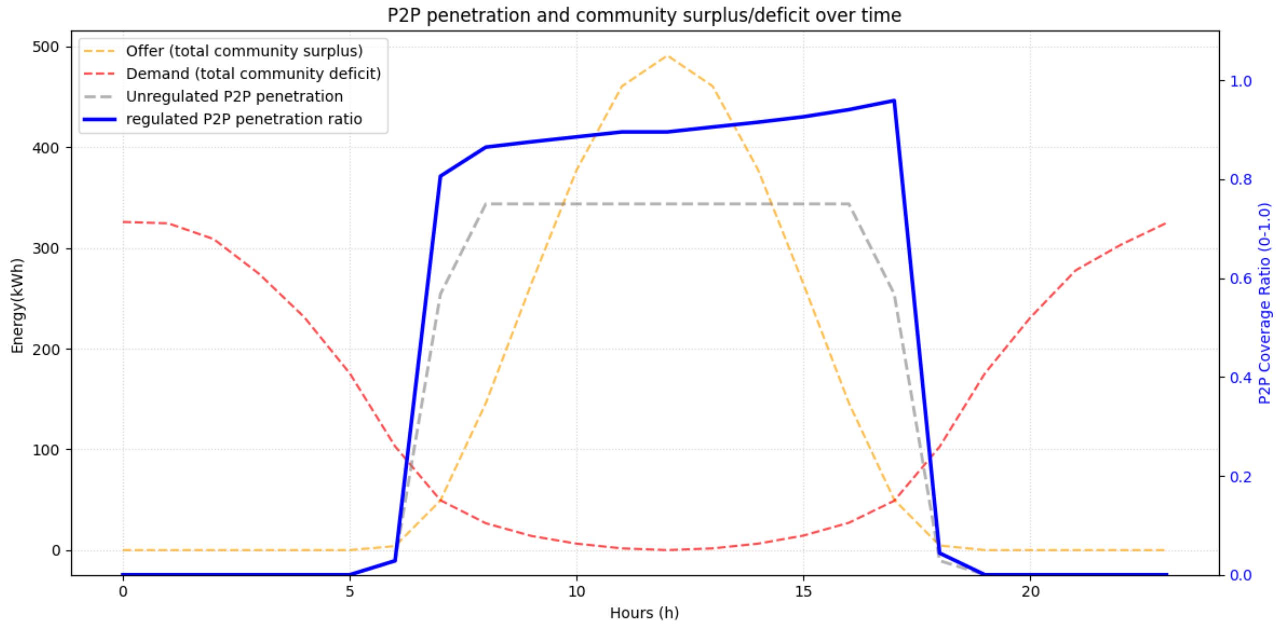
  + **FIT rate (feed-in-tariffs)** of 0.08 €/kWh. Price paid to prosumers for each unit of solar electricity fed back to the grid => fixed to encourage solar production

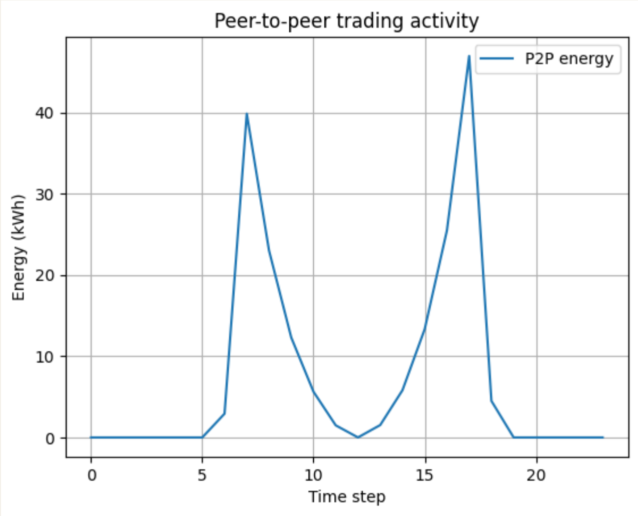
P2P market modelling

+ **Imbalance** = PV generation (t) – load (t)
  + >0: **surplus**, the prosumer is a potential seller
  + <0: **deficit**, the prosumer is a potential buyer

+ Sell and buy offers determined by:
  + Quantity = |imbalance| × **trade fraction**
  + Price: - Sell price = β × grid_price → **undercut factor**
    - Buy price < grid price → **price cap**

+ Asks ranked by ascending price, bids by descending price
+ Possible exchange if **price (buyer) > price (seller)**
+ **Clearing price** = mean (price buyer, price seller)

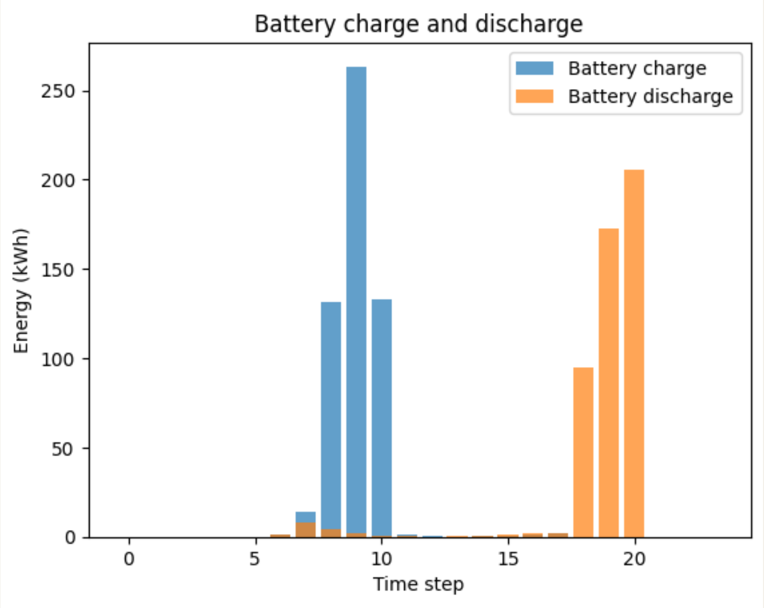


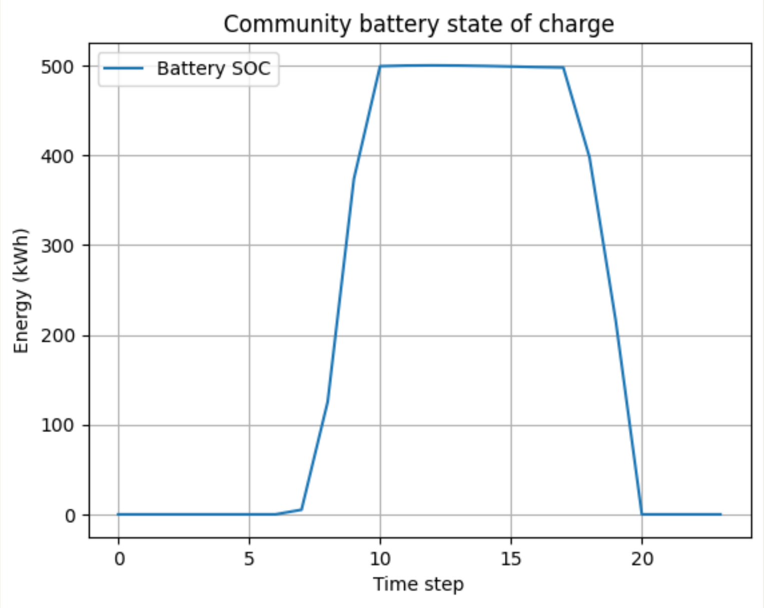


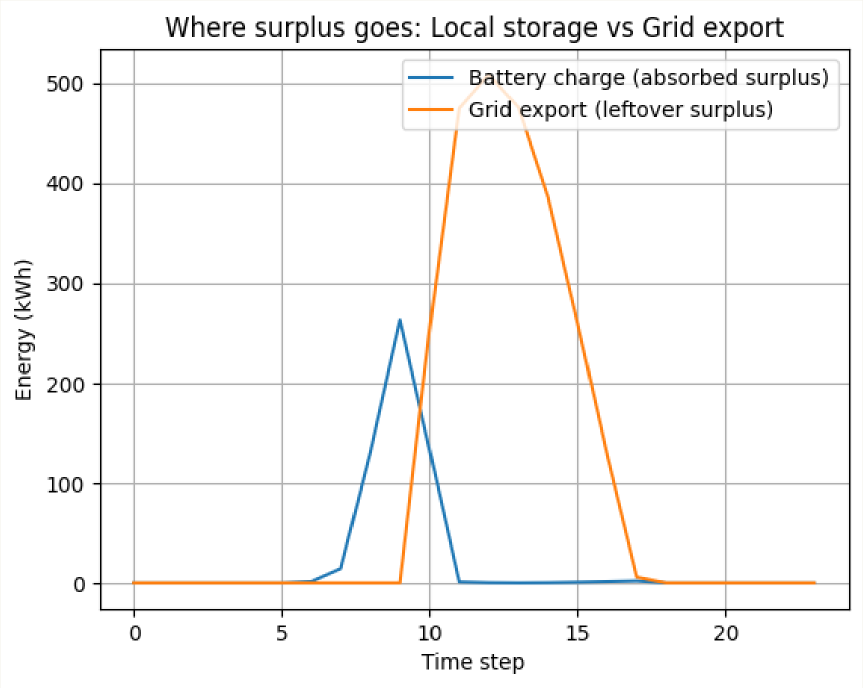
At the heart of flexibility: the community battery

+ After P2P & local markets, before grid settlement
+ Stores extra surplus generated by solar panels not bought by the markets
+ Battery capacity: 500 kWh, charge/discharge efficiency of 95%

$$\textit{Available charge capacity}\ (kWh) = \frac{\textit{Max Capacity} - SOC}{\textit{Charge efficiency}}$$

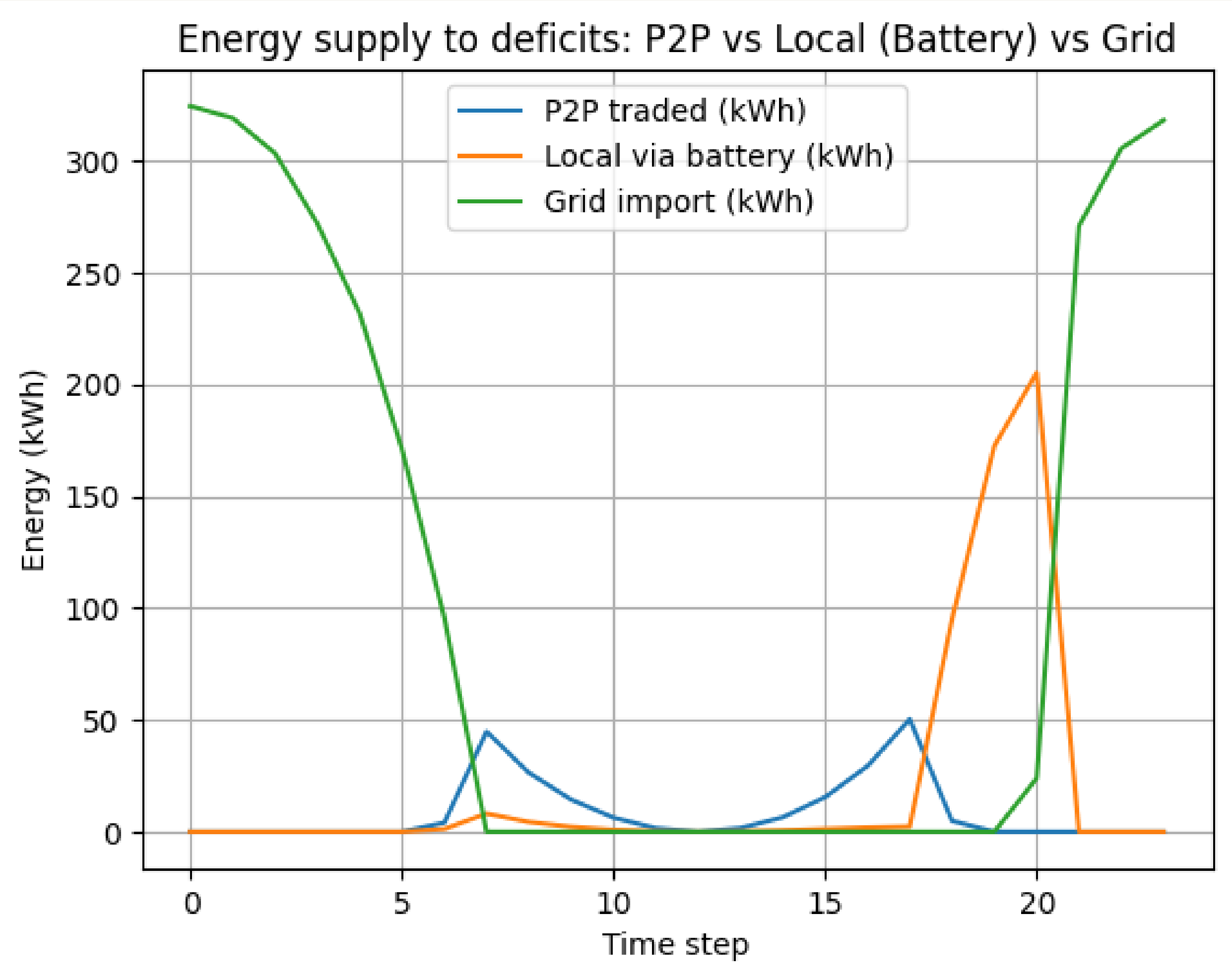


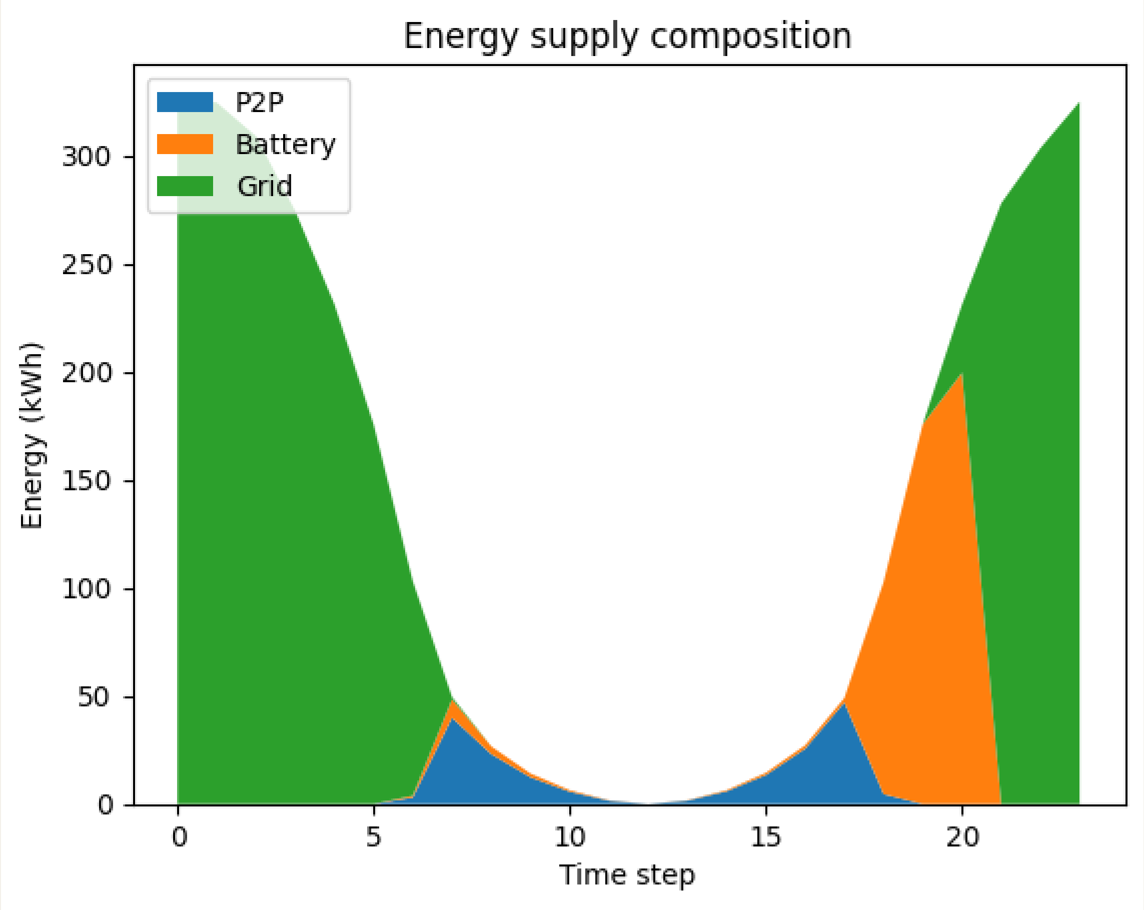




Simulation – energy supply composition

+ Community goal to minimize grid utilization during the day achieved…





Conclusion: towards a more sustainable grid

Energy communities bringing together prosumers and consumers could be at the heart of Smart Grids:

- Rooftop PV panels and battery storage allows self consumption, leveraging **sustainability** and **affordability.**
- P2P trading & local markets allow a **decentralized, more democratic energy system.**
- **Blockchain** ensure secure energy exchanges on the grid. **Regulation** can be used to achieve desired goals.