

# Markets for integrated energy systems

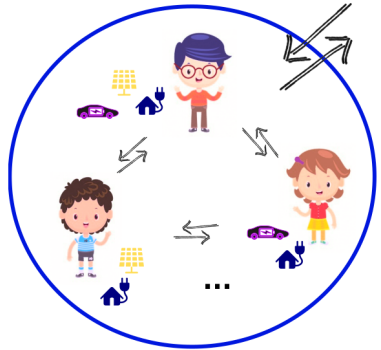
Loose coupling, business models and consumer-centric proposals

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(Ackn. to **L. Mitridati, C. Ordoudis, J. Kazempour, L. Bobo, E. Sorin, F. Moret, etc.** - also supported IF, EUDP and ForskEL through '5s', EnergyLab Nordhavn and The Energy Collective)

- ① Two key ideas first regarding renewables in electricity markets...
- ② Higher level perspective: integrated energy markets
  - from complete to loose coupling
  - heat and gas
  - heat and electricity
- ③ Consumer-centric and community driven electricity markets
  - background and motivations
  - it is already happening in Denmark (or bound to happen)
  - how will that work?

## Dispatch under uncertainty



- **The narrative fallacy:** Do we really believe we can offer renewables deterministically with lead times of 12-36 hours ahead?
- Why not adapting market designs to reveal and accommodate the true cost of renewables' uncertainty?

- Write ( $t + k$  omitted)

$$\mathbf{y}_i = [y_{i,t_1} \ y_{i,t_2} \ \dots \ y_{i,t_n}]$$

the sample *power profile* for market participant  $i$

- The energy delivered is

$$E_i = \frac{1}{n} \sum_j y_{i,t_j} = (t_n - t_1) \bar{y}_i$$

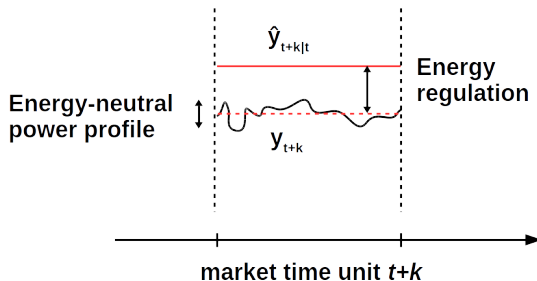
- and the *energy neutral power profile* is

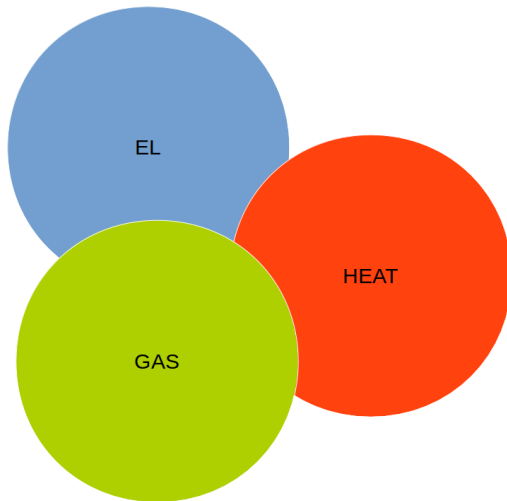
$$\tilde{\mathbf{y}}_i = \mathbf{y}_i - \bar{y}_i$$

- The revenue of a producer in the electricity market is then generalized as

$$R_i = \pi_s \hat{y}_i + \pi_b (\bar{y}_i - \hat{y}_i) + R_i^P$$

where  $R_i^P$  is a revenue (most likely, negative) related to **variability in power delivery**.





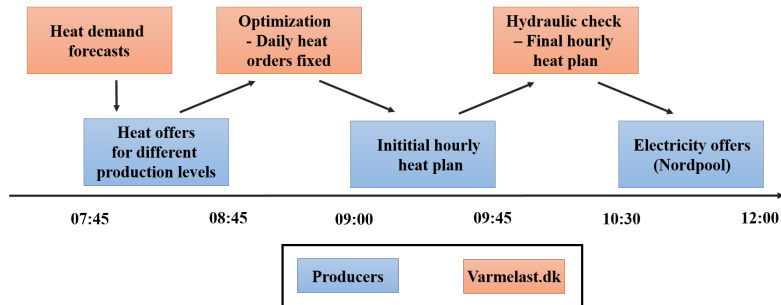
For a mathematical point of view, we can write and solve fully integrated markets for el-gas, el-heat, el-gas-heat... **but...**

What do we mean by loose coupling?

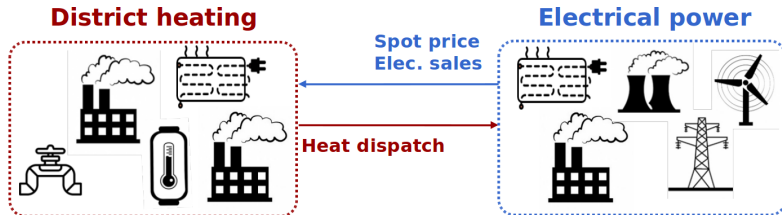
## What do we mean by loose coupling?

- *respecting organizational aspects of the energy system*, e.g., heat and el management are separated, the system operator is not taking care of day-ahead electricity market clearing, etc.
- *profit of existing levies* for impacting dispatch, costs, etc.

## A practical example: heat and el interaction through Varmelast



One may respect the leader-follower structure of the market sequence, though optimally dispatching heat in view of future electricity dispatch!



**Sequential:**

1) Heat dispatch

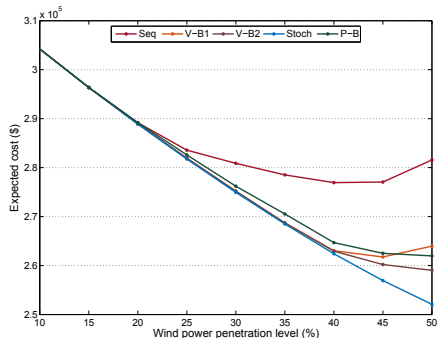
- **Anticipate** electricity market clearing
- Explicitly formulated as a **constraint** of the heat dispatch
- **Stochastic:** scenarios of wind production, rival participants bids, elec. and heat demand

2) Electricity dispatch



A great thing in Denmark is that Energinet is system operator for both el and gas networks!

- *Beware of the gas network modelling* since the potential buffer (offered flexibility) is to be well represented
- Market coupling setups *accommodate renewable uncertainty*
- We have proposed and compared:
  - sequential coupling as of today (**Seq.**)
  - complete coupling of gas and el markets (ideal- **Stoch.**)
  - loose coupling through price premiums (with 'fairness' constraints - **P-B**)
  - loose coupling through gas volume availability (**V-B**)





[Taken from [moneycrashers.com](http://moneycrashers.com), Brian Martucci]

- *Sharing* is part of human nature and a source of happiness
- *Sharing* is a basis for the development of new business models ('*access economy*' and '*collaborative commons*')
  - crowdfunding
  - crowdsourcing
  - car pooling, shared property, etc.



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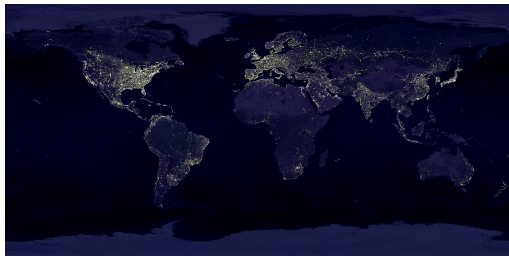
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There are things we might never have thought of sharing... e.g., **electric energy (!)**

## Why would you think one might share electric energy?

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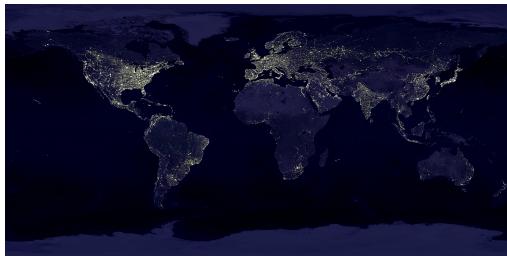
We tend to *interconnect* ourselves  
through *electric power networks*



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# Why would you think one might share electric energy?

We tend to *interconnect* ourselves through *electric power networks*

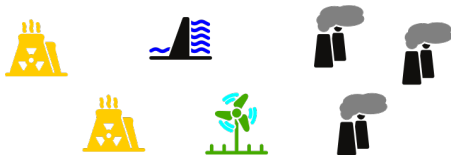


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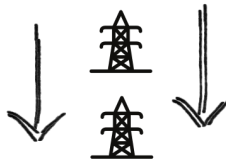


The Internet of Things (IoT – cloud-based, blockchain) gives the promise of *remote sensing and actuating* in a smart energy future...

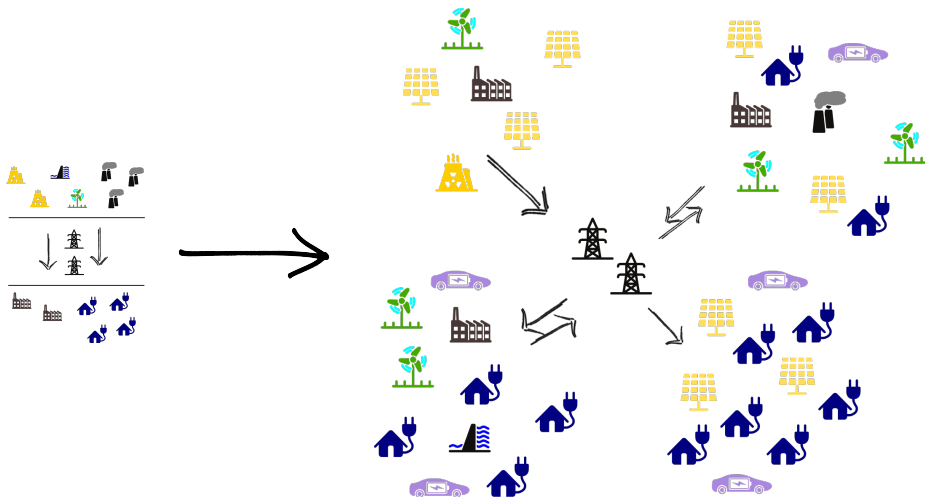
## From a supplier-centric model...



Actors of the electric power network are traditionally organized in a *hierarchical* and *supplier-centric* manner

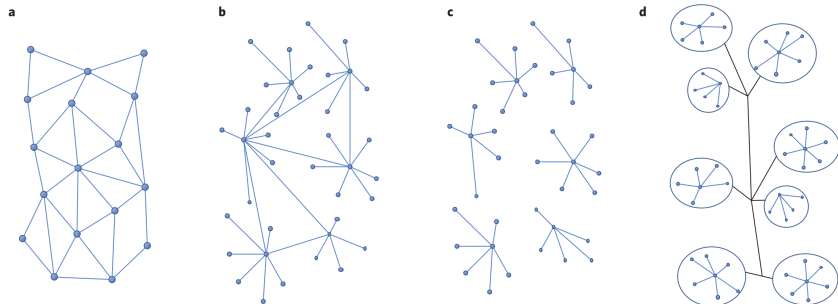


# From a supplier-centric model to a more decentralized setup



Eventually, electricity markets need to adapt to this new decentralized setup(!)





**Figure 1 | Structural attributes of three prosumer markets.** **a**, Peer-to-peer model, in which prosumers interconnect directly with each other, buying and selling energy services. **b, c**, More structured models involving prosumers connected to microgrids. These entail prosumer-to-interconnected microgrids, in which prosumers provide services to a microgrid that is connected to a larger grid (**b**), or prosumer-to-islanded microgrids, in which prosumers provide services to an independent, standalone microgrid (**c**). **d**, Organized prosumer group model, in which a group of prosumers pools resources or forms a virtual power plant. Dots represent prosuming agents; lines represent a transaction of prosuming service; circles represent an organized group of prosumers.

[Reproduced, with authorization, from:

Parag Y, Sovacool BJ. Electricity market design in the prosumer era. *Nature Energy* 1, art. no. 16032, 2016]



[*Svalin* - a boffællesskab in Roskilde - The Energy Collective]

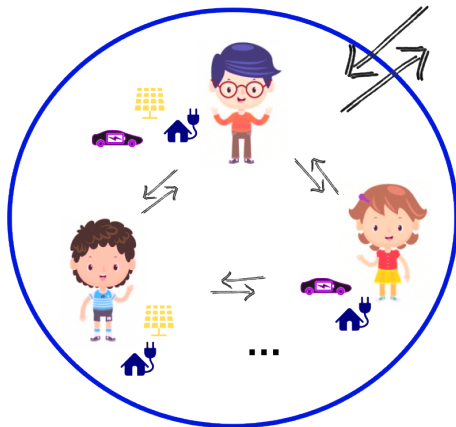


[*Nordhavn in Copenhagen* (?) - generalizing to multi-carrier energy markets (heat and electricity, mainly) - EnergyLab Nordhavn]



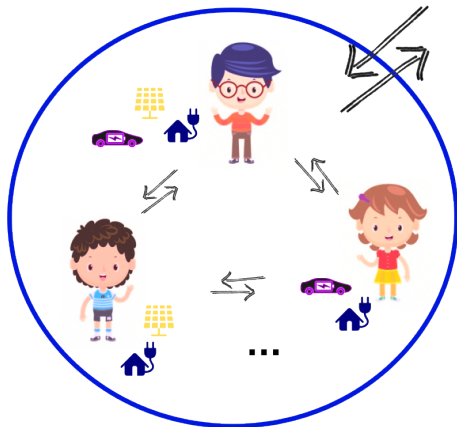
[*København NV* - social experiment - EnergyBlock]

# Introducing 'Energy Collectives'



[Characters designed by [freepik.com](https://www.freepik.com)]

- Aidan, Eamonn, Niamh, etc., chose to gather in an *Energy Collective*
- They traditionally bought energy from the grid and sold their production back at a disadvantageous rate...
- They work at optimally matching their production and consumption
- They decide on how to share costs and benefits from import/export
- Exchanges within the community do not have to be settled against monetary transactions, but e.g., against a service or simply for free



[Characters designed by [freepik.com](https://www.freepik.com)]

- The base concept relies on p2p exchanges
- One ends up with a negotiation problem on a network, of potentially very large dimension
- In practice, consensus-based optimization and Lagrangian relaxation-decomposition techniques can be used
- The negotiation problems can be made sparse by market design (russian doll principle for energy collectives) or through trading bots accounting for preferences
- Many mathematical challenges ahead of us, but direct applications also readily possible!



- making the most of state-of-the-art IoT capabilities
- proposing a collaborative commons model for electric energy
- allowing for the proposal of new business models (substitution, collaboration...)
- multi-attribute exchange of energy ("greenness", localization, reputation...)
- localization of exchanges and potential redefinition of grid tariffs
- **placing consumers at the centre of the game**, resulting in increased awareness and engagement!

