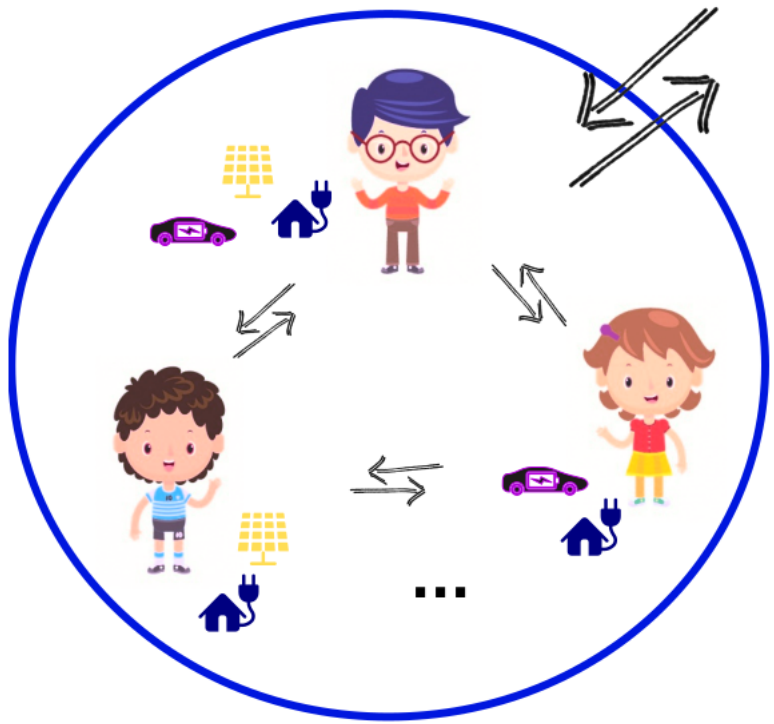
A vision for future electricity markets

From coupling of energy markets to consumer-centric market design

Pierre Pinson



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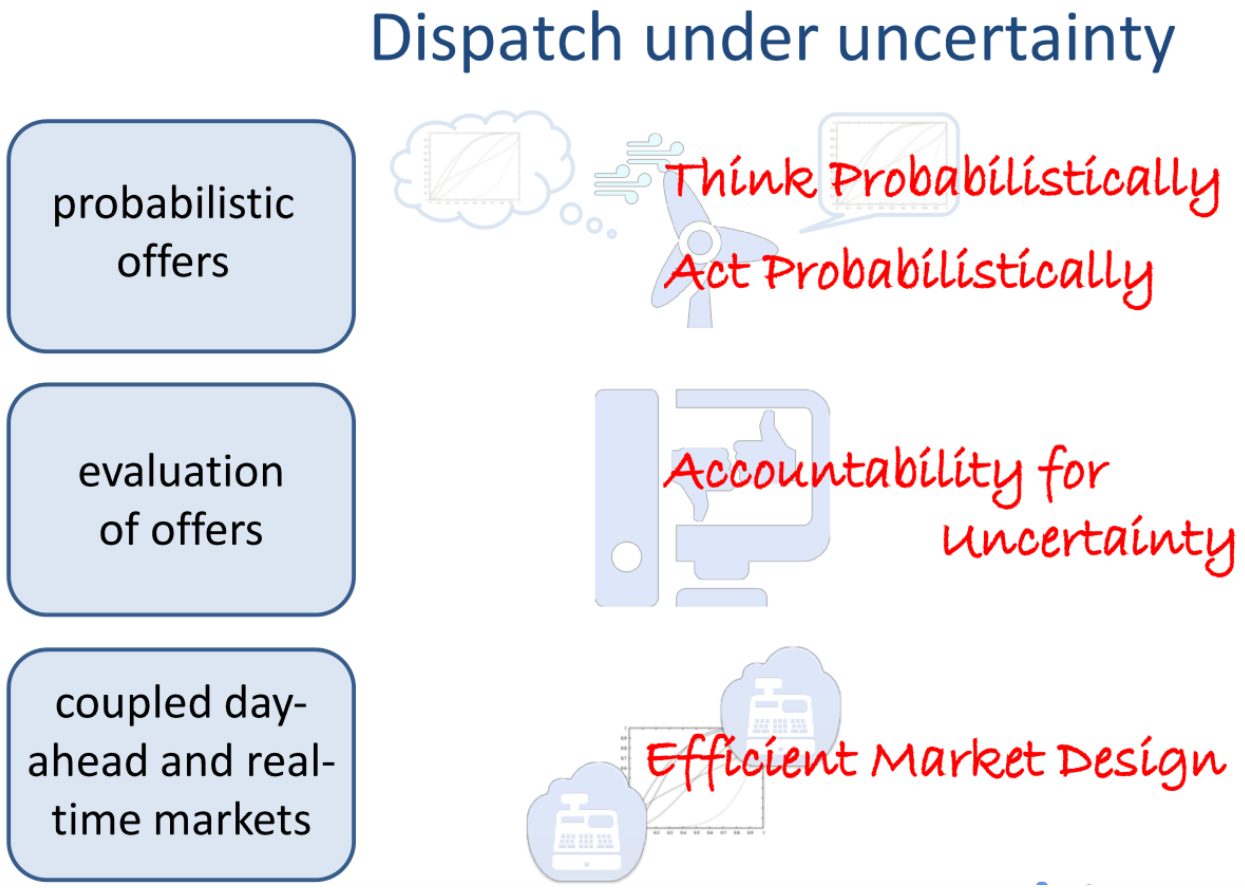
(Ackn. to **L. Mitridati, C. Ordoudis, J. Kazempour, L. Bobo, E. Sorin, F. Moret** -
partly funded by IF, EUDP and ForskEL through '5s', CITIES, EnergyLab Nordhavn and The Energy Collective)

Outline

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?

Reveal and accommodate the true cost of 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?

Papakonstantinou A, Pinson P (2015). Information uncertainty in electricity markets: Introducing probabilistic offers. *IEEE Transactions on Power Systems*

Attributing costs from variability

- Write ($t + k$ omitted)

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

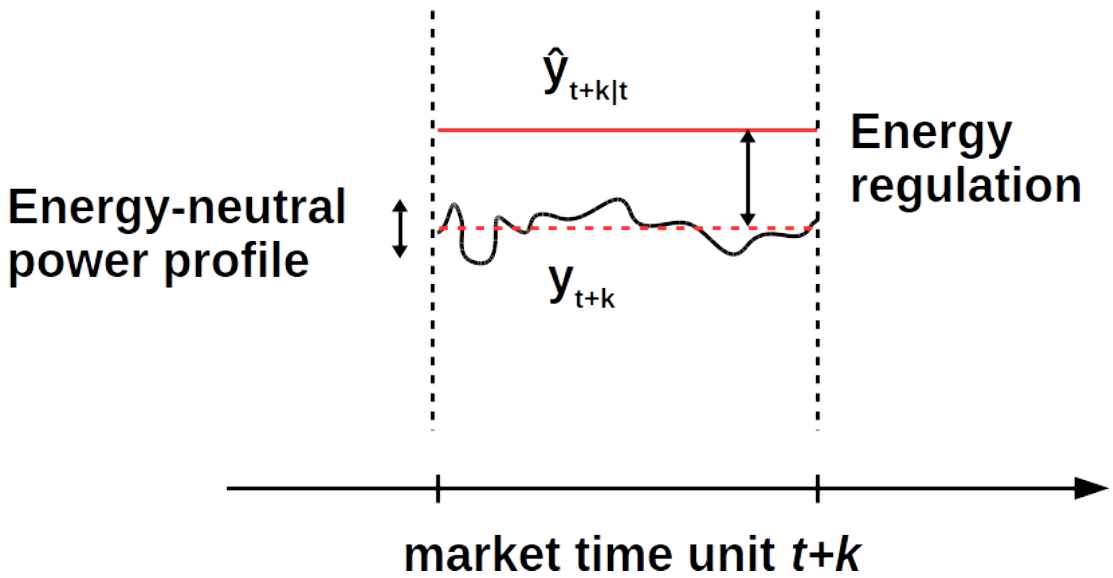
the sample *power profile* for market participant i

- 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

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



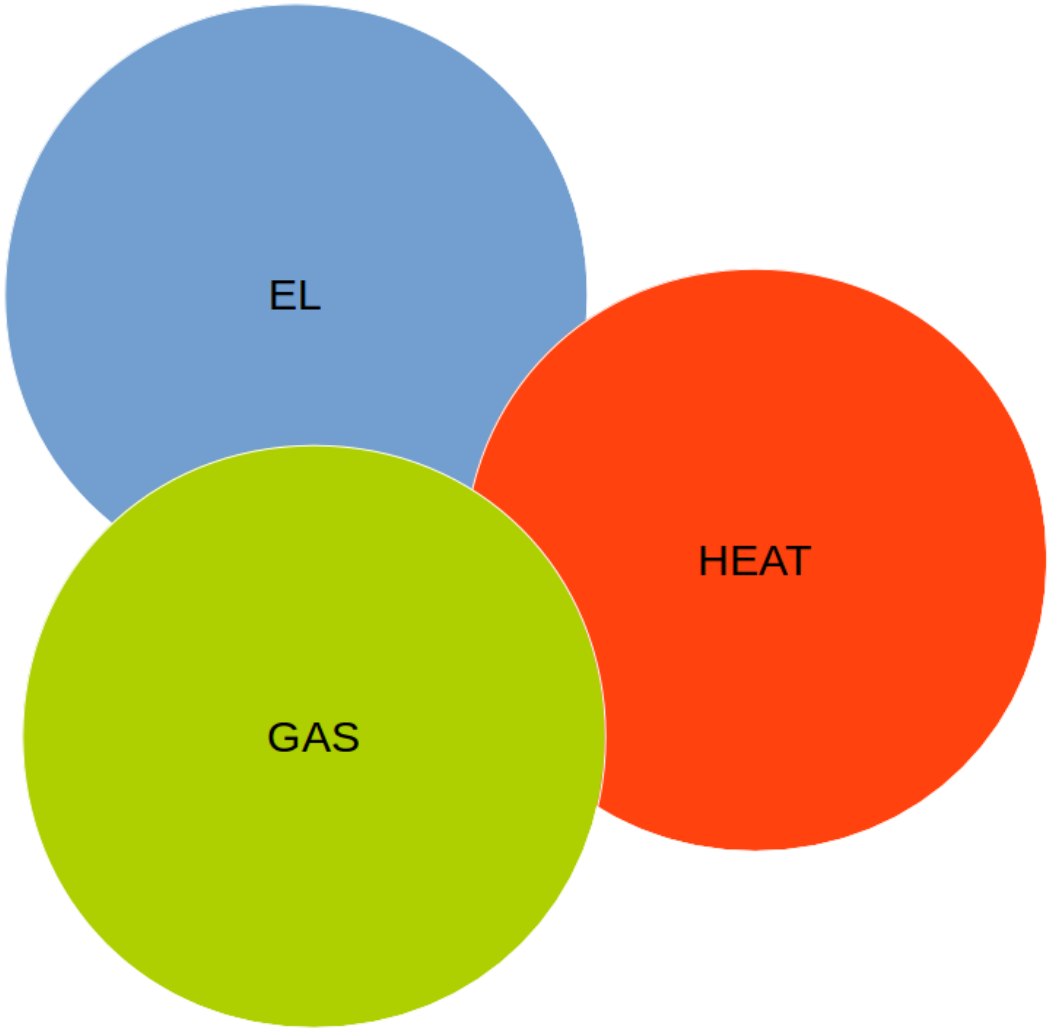
- The revenue of a producer in the electricity market is then generalized as

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

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

Bona F et al. (2015). Attribution mechanisms for ancillary service costs induced by variability in power delivery. *IEEE Transactions on Power Systems*

Integrated energy markets: complete coupling



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

Integrated energy markets: loose coupling

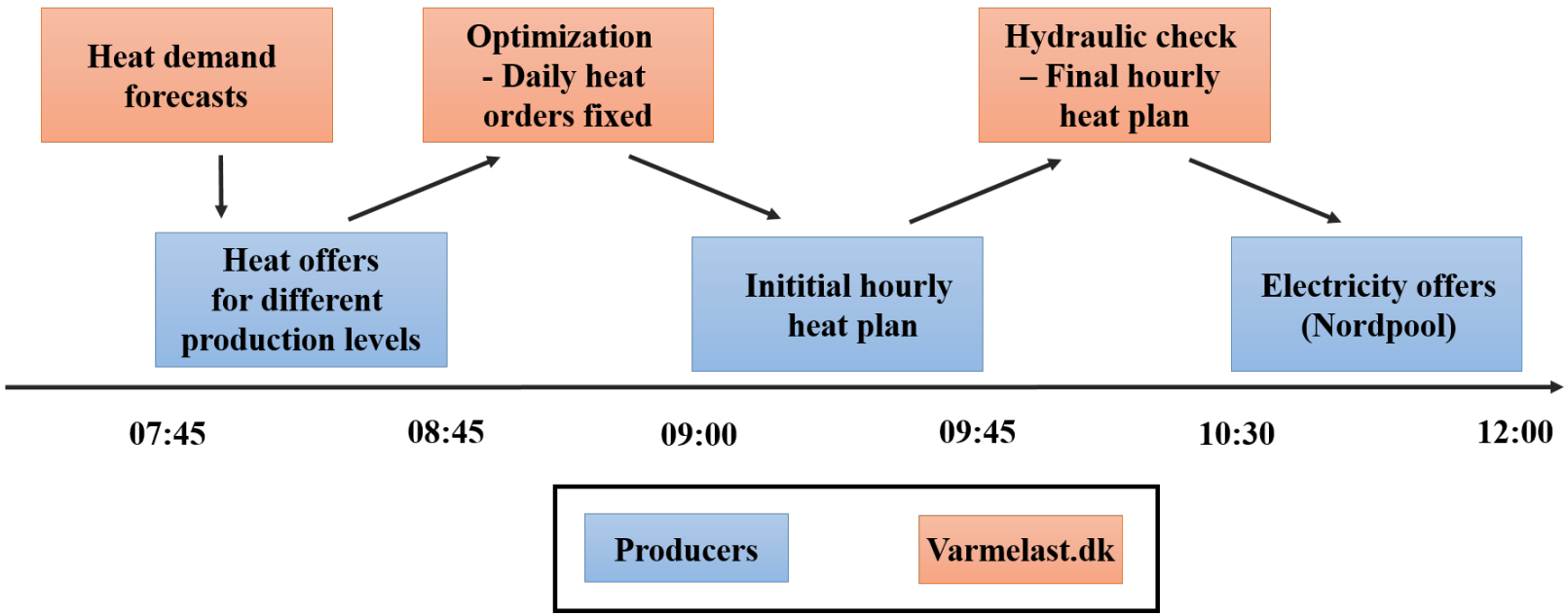
What do we mean by loose coupling?

Integrated energy markets: loose coupling

What do we mean by loose coupling?

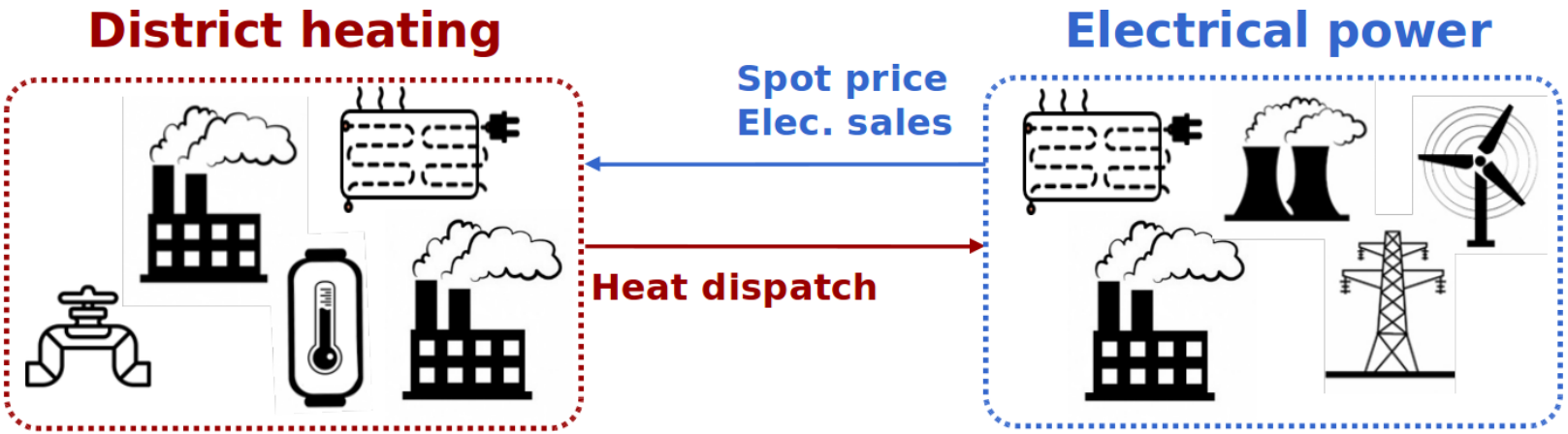
- *respecting organizational aspects of the energy system*, e.g., heat and el management are separated, the system operator is not taking care of day-ahead electricity market clearing, etc.
- *profit of existing levies* for impacting dispatch, costs, etc.

A practical example: heat and el interaction through Varmelast



Loose coupling of el and heat markets

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

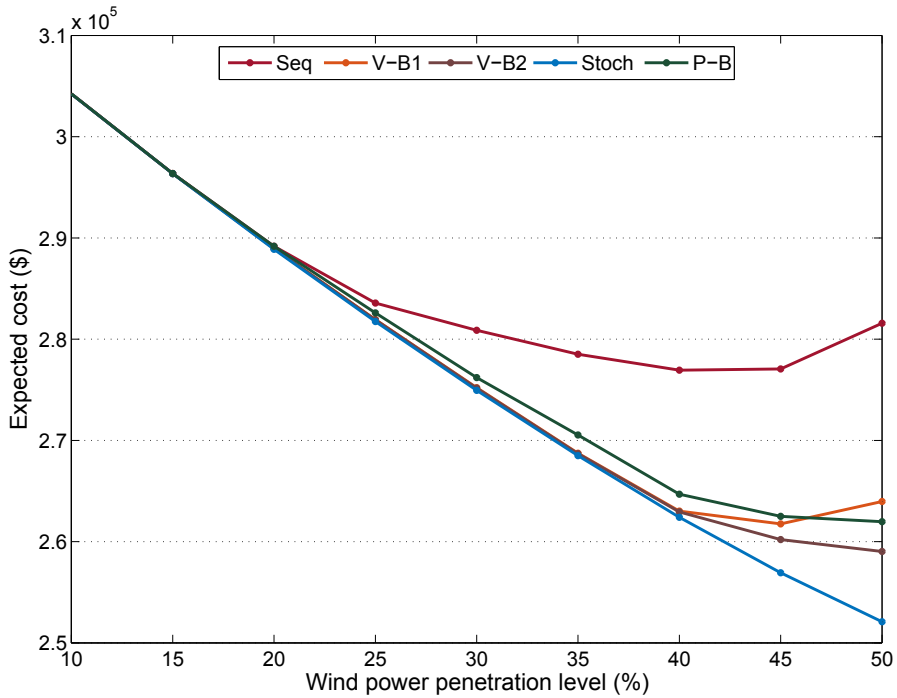
- **Anticipate** electricity market clearing
- Explicitly formulated as a **constraint** of the heat dispatch
- **Stochastic:** scenarios of wind production, rival participants bids, elec. and heat demand

2) Electricity dispatch

Loose coupling of el and gas markets

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**)



Sharing is caring...

[Taken from 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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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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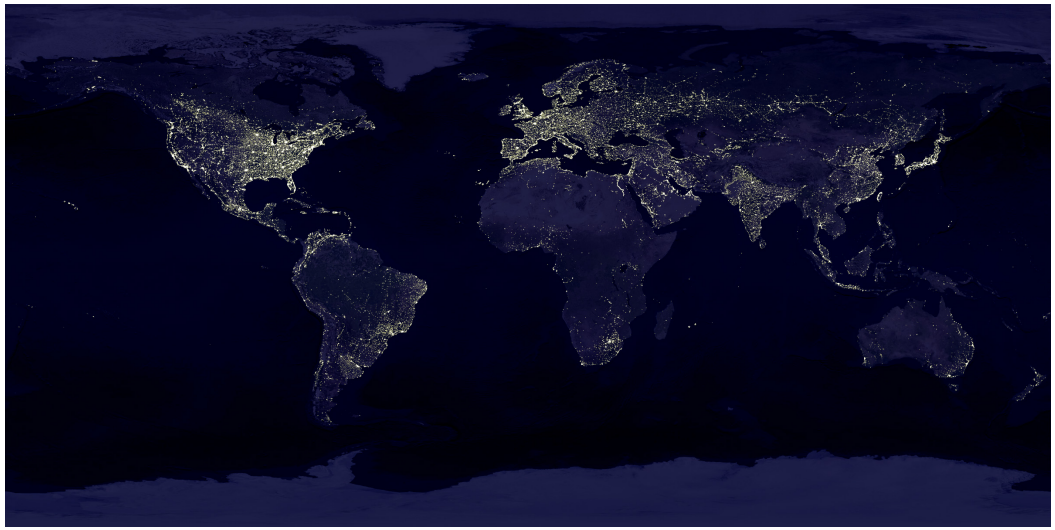
We tend to *interconnect* ourselves through *electric power networks*



[Credits to Nasa Visible Earth]

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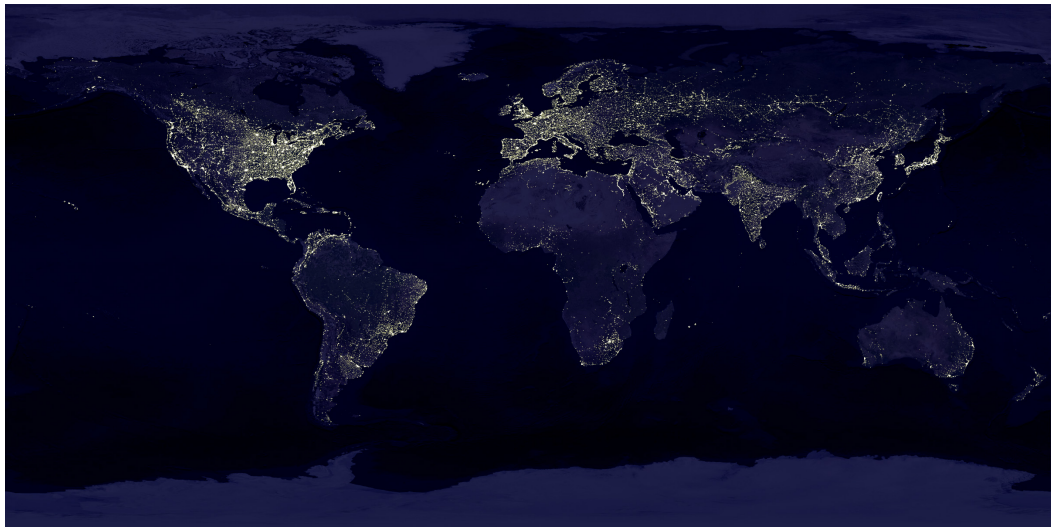


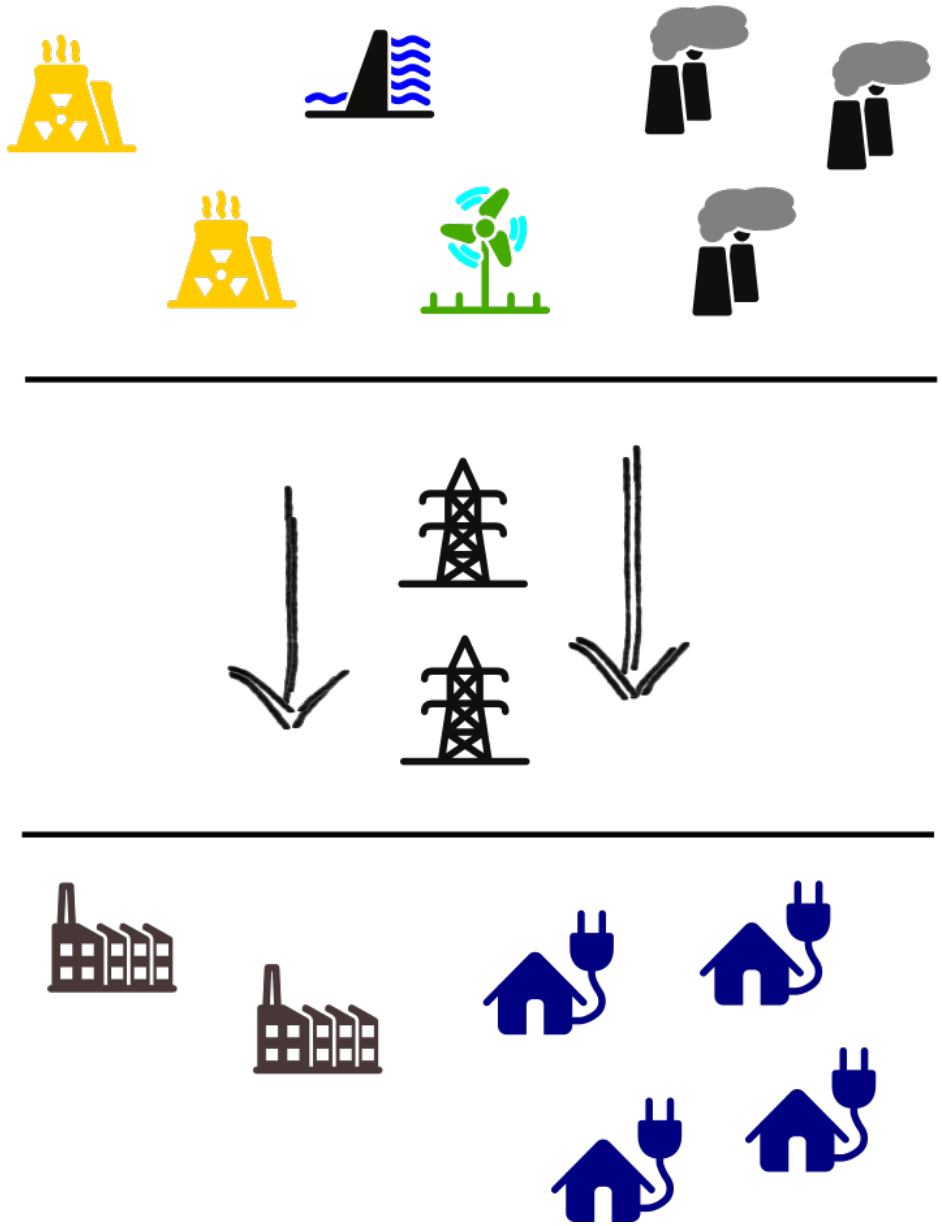
[Credits to Nasa Visible Earth]

[Taken from www.telecomstechnews.com]

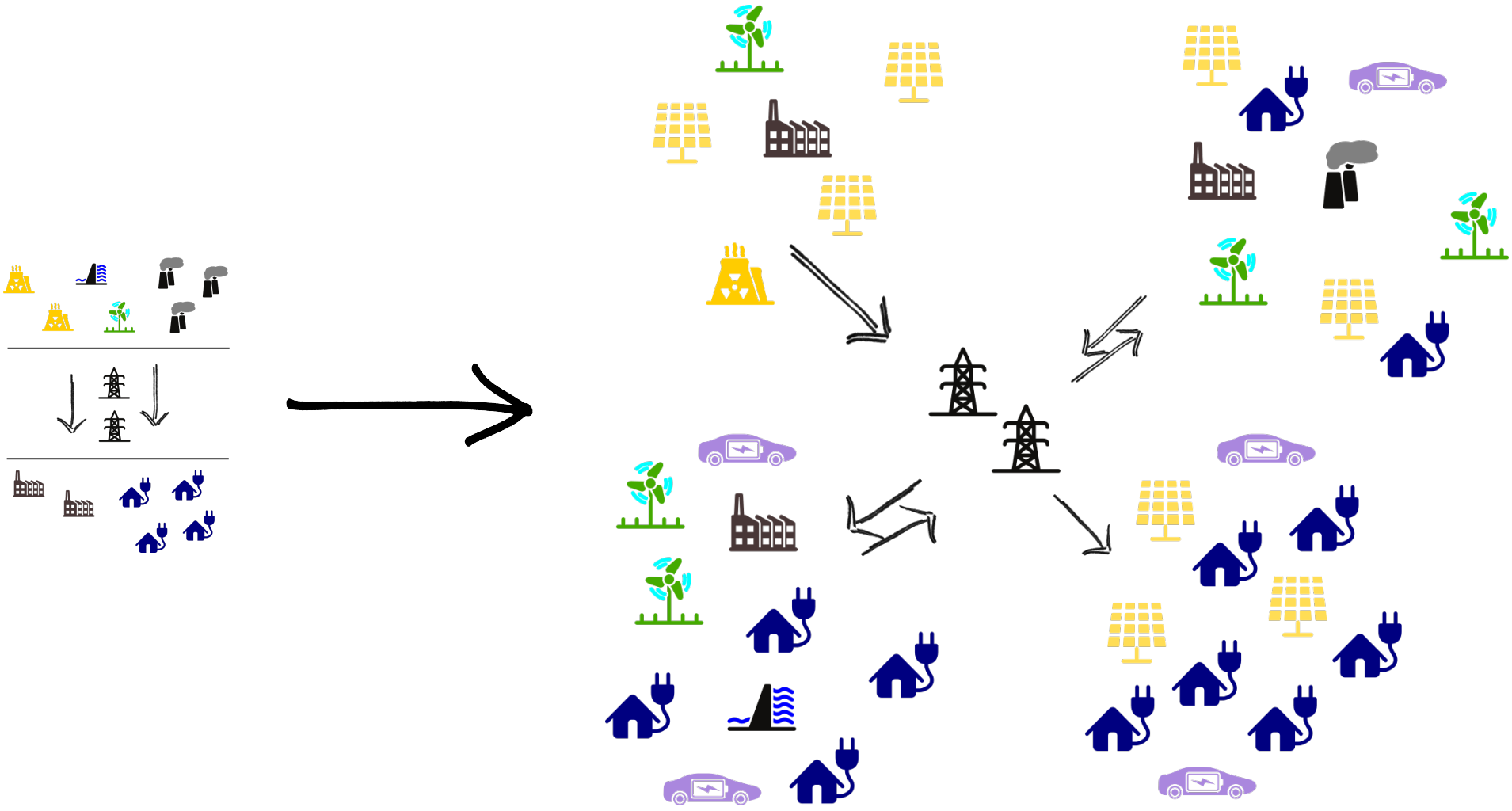
The Internet of Things (IoT – cloud-based, blockchain) gives the promise of *remote sensoring and actuating* in a smart energy future...

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(!)

Organization of consumer-centric electricity markets

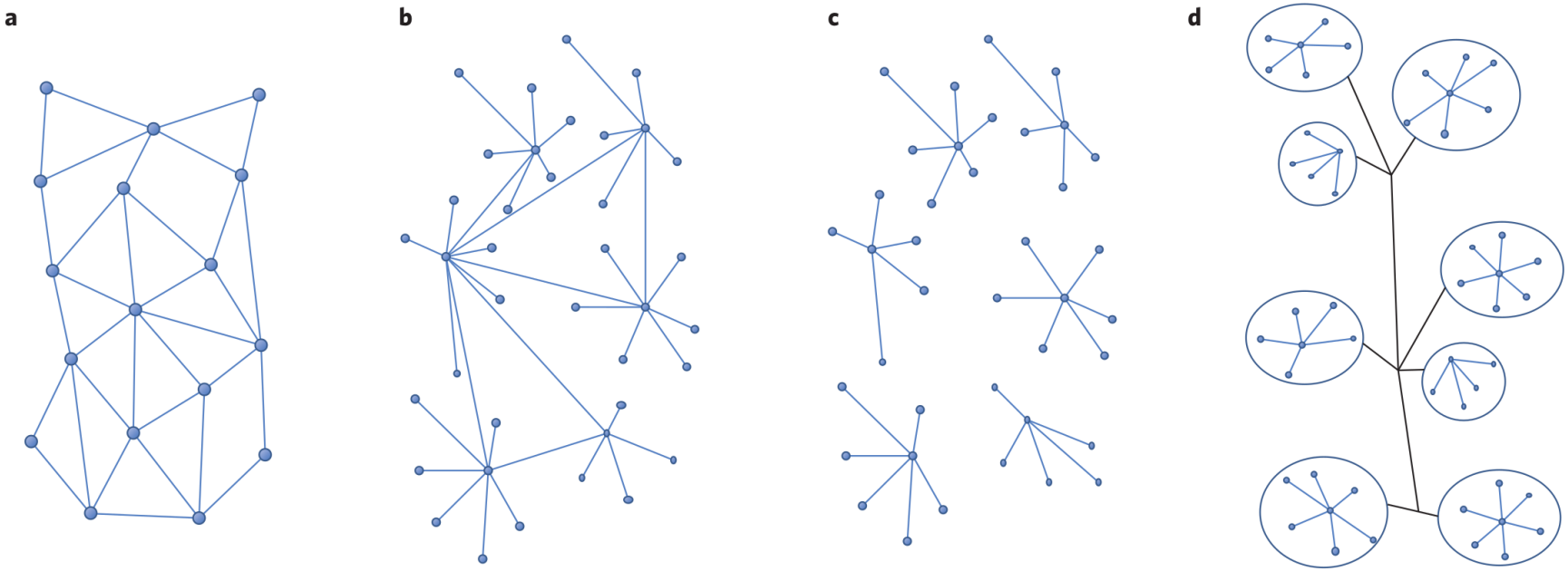


Figure 1 | Structural attributes of three prosumer markets. a, Peer-to-peer model, in which prosumers interconnect directly with each other, buying and selling energy services. **b**,**c**, More structured models involving prosumers connected to microgrids. These entail prosumer-to-interconnected microgrids, 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]

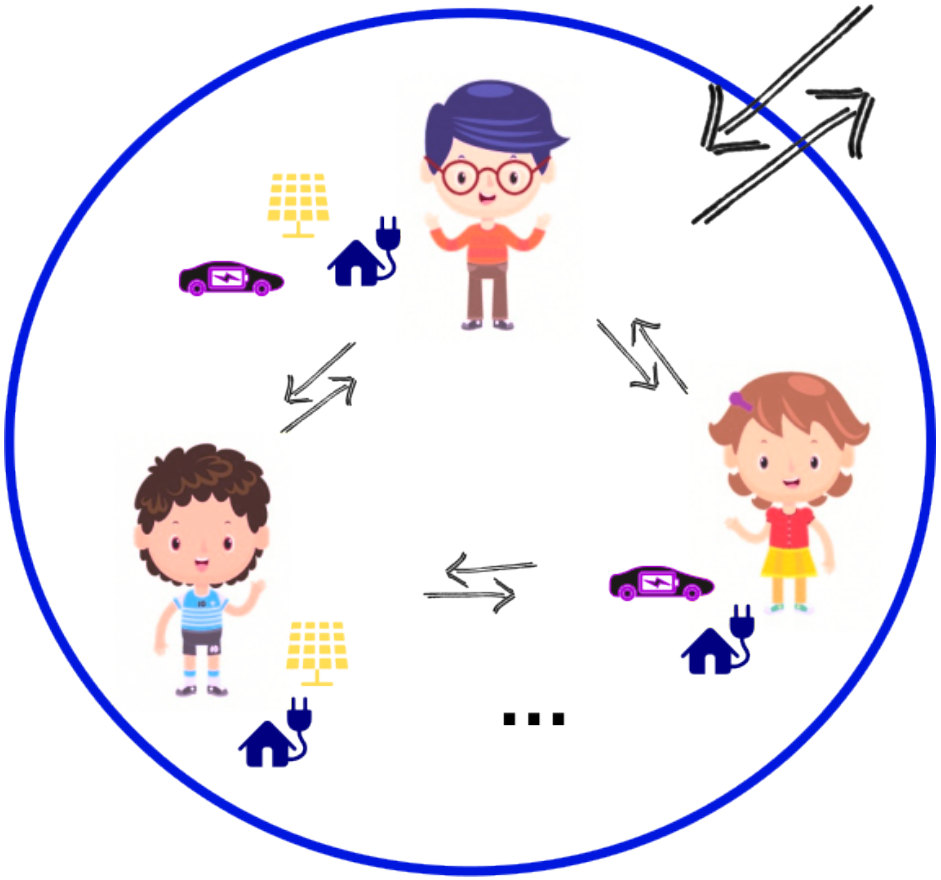
For real in Denmark

[*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]

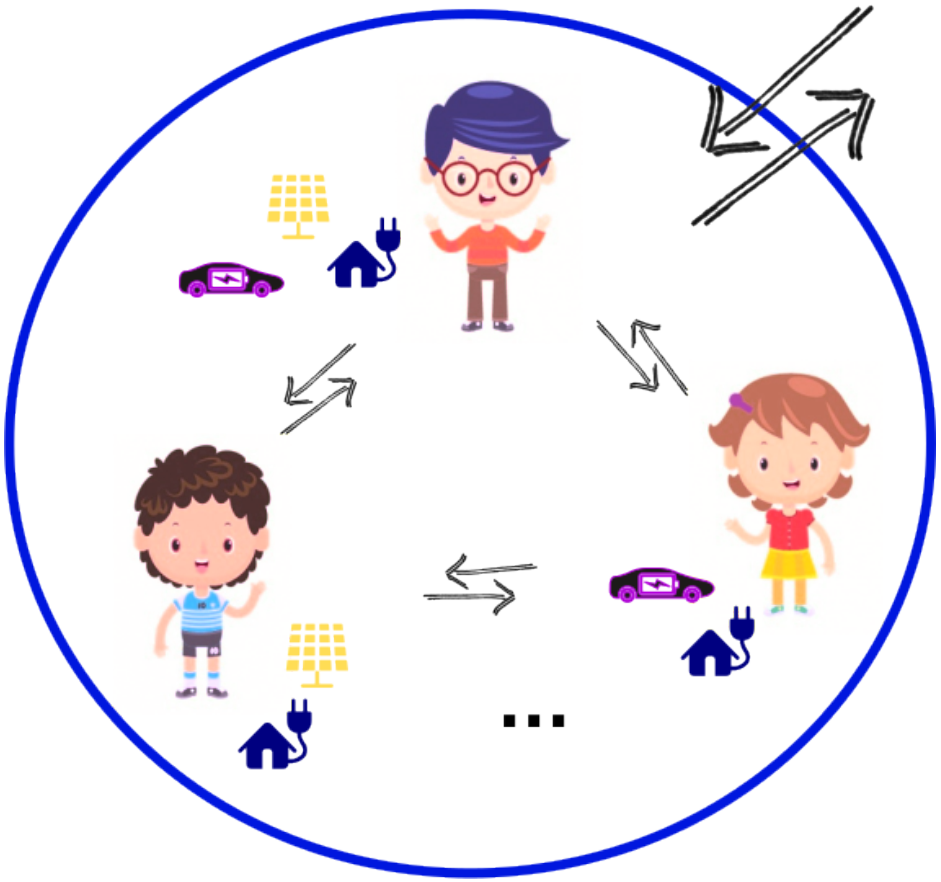
Introducing 'Energy Collectives'



[Characters designed by freepik.com]

- 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

On the fun side...



[Characters designed by 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 pratice, 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!

Prospects for 'Energy Collectives'

- 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!

Thanks for your attention!