AALBORG UNIVERSITY
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Flexibility Models and Flexibility Markets for DSOs and DHOs

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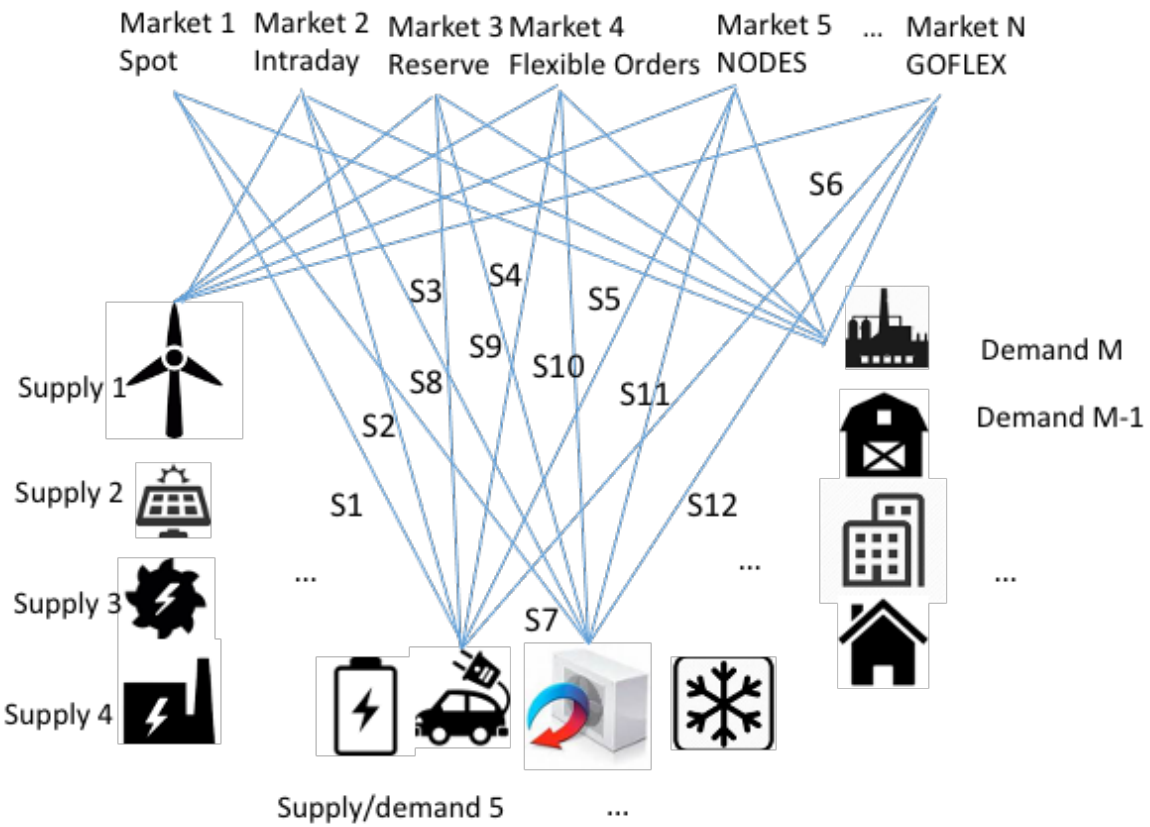
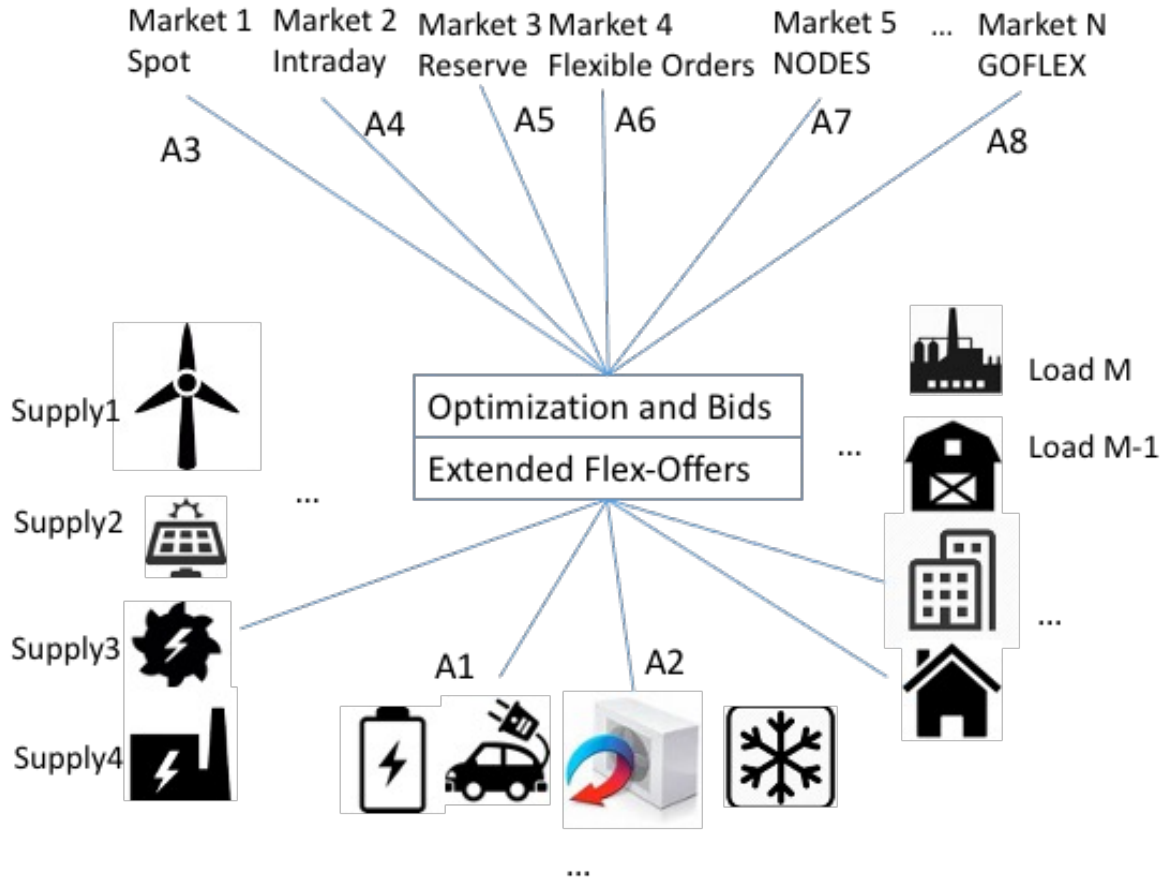
Why is a joint energy flexibility model needed?



Traditional approach: M*N
(100*10=1000) systems needed!



FlexOffer approach: only M+N
(100+10=110) connectors needed!

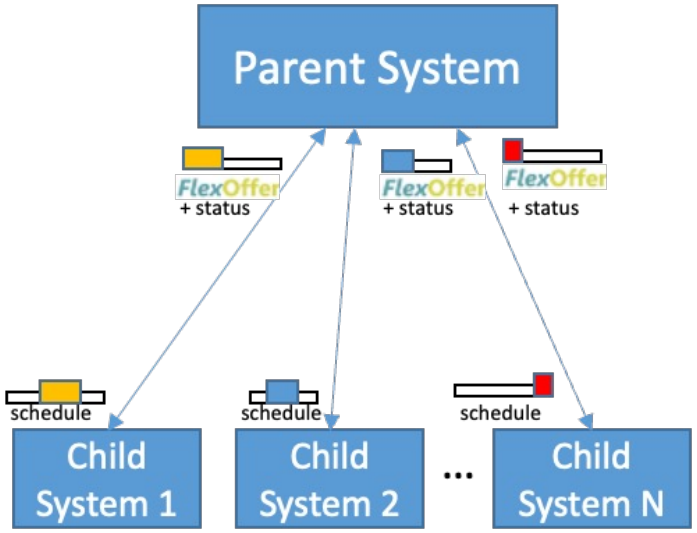
Flexibility Model Requirements

- A good flexibility model should be:
- **Explicit**
  - Flexibility traditionally modeled *implicitly* (price response)
  - Explicit models allow capturing more of the true flexibility
- **Capturing all/most loads**
  - Loads with state dependencies, production, storage, …
- **(Dis)aggregatable**
  - Allow small loads to be aggregated (kWh to mWh) and back
- **Scalable**
  - Allow (dis)aggregation of 1000s/millons of loads
  - Accurate models do not scale, (good) approximate models needed
- **Supporting multiple energy vectors**
  - Electricity, heat, hydrogen,..

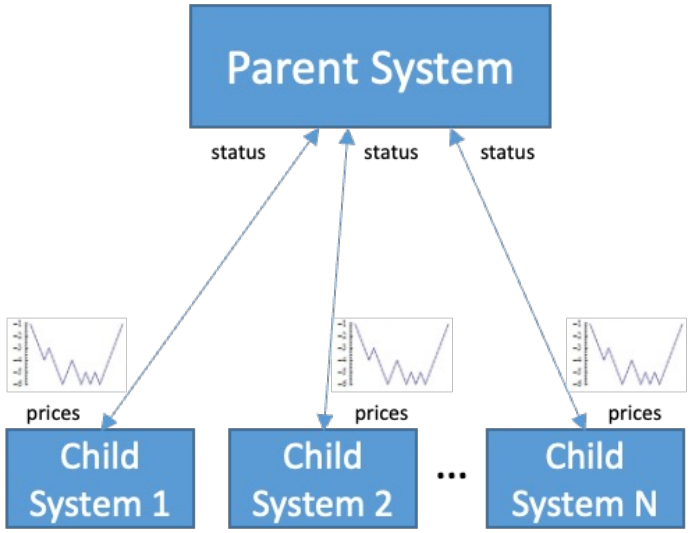
Key Flexibility Models

FlexOffer-based Mechanism

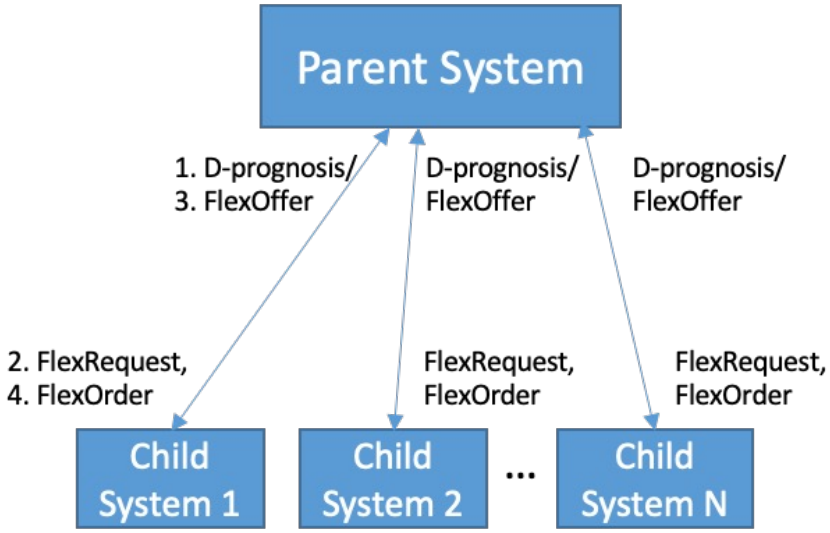
FlexOffer "Dark-grey models"



Price-based Mechanism



USEF Mechanism

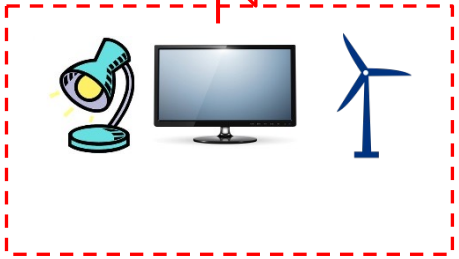


Comparison

	Pros	Cons
FlexOffer	• Explicit flexibility / insight • Standardized representations/tools • Robustness	• Modelling effort • Approximate model • Computational expensive • Better for higher energy system levels?
Price-based	• Simple approach • Privacy-preserving • Better for lower energy system level?	• Response difficult to predict • No up-to-date knowledge about available flexibility
USEF	• Simple negotiation-based approach • Exploration of responses	• Communication-intensive • No up-to-date knowledge about available flexibility

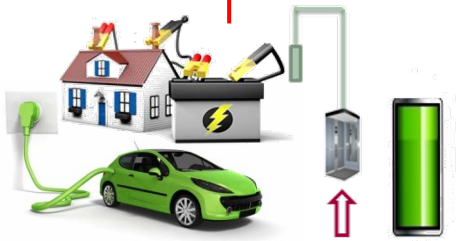
FlexOffers: a Joint Model for **All** Flexibilities

No or simple flexibility patterns → **Complex flexibility patterns**

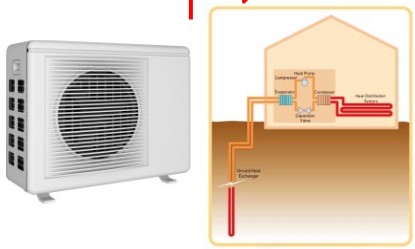


- No flexibility

- *Time-shift* flexibility



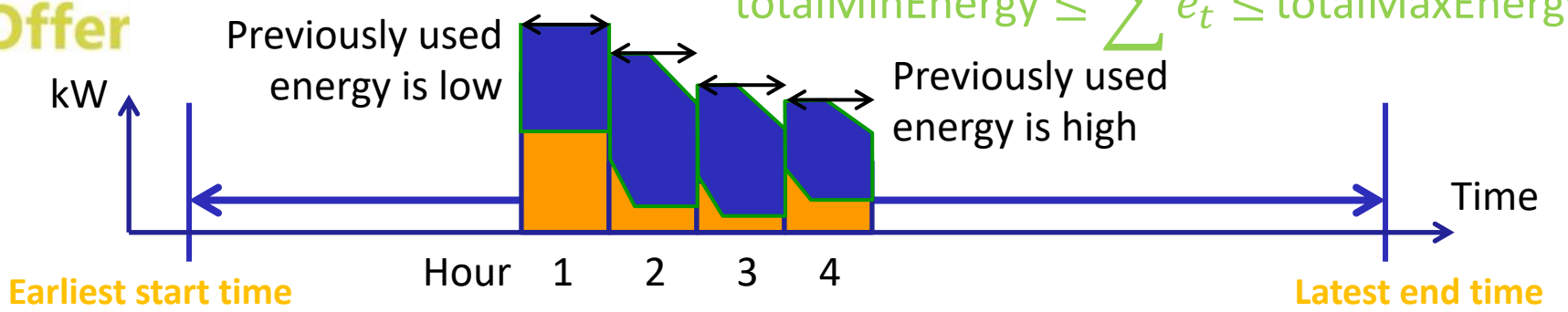
- *Time-shift* flexibility
- *Amount* flexibility
- [*Total Amount* requirement]



- Amount flexibility with intra-time unit dependencies

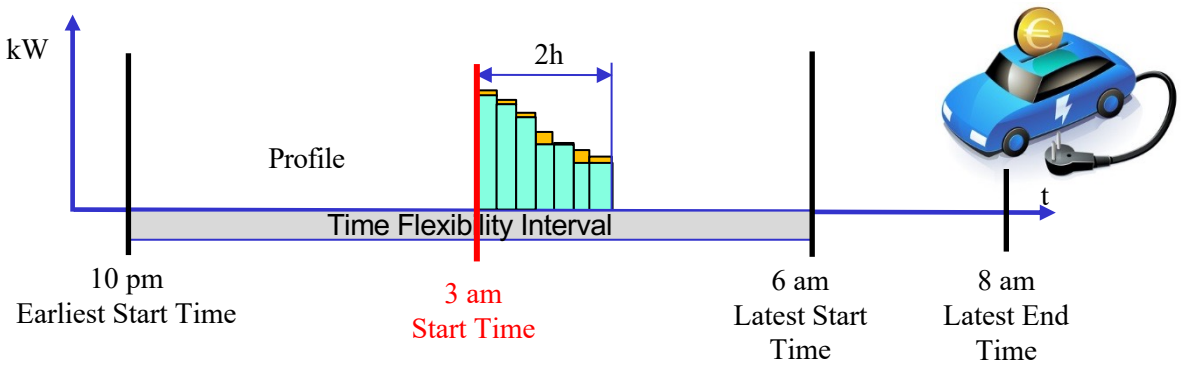
FlexOffer

$$\text{totalMinEnergy} \leq \sum e_t \leq \text{totalMaxEnergy}$$

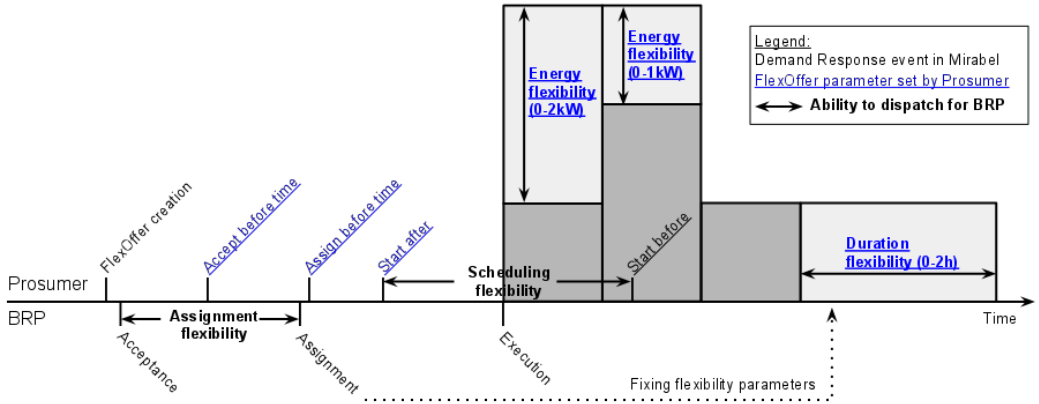


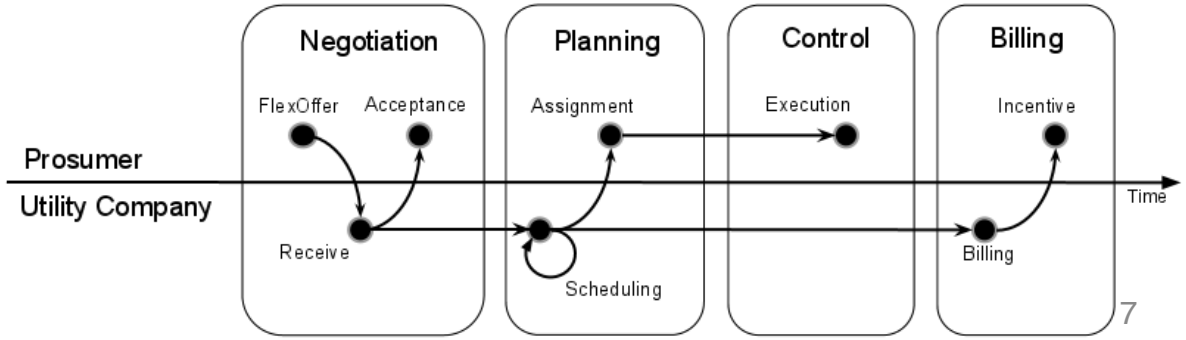
FlexOffer Example and Properties

1. Consumer arrives home at 10PM and wants to rechange EV battery at lowest possible priceor CO2 by 8AM next morning
2. Consumer‘s local EMS generates an FO:
3. A negotiation with the BRP/aggregator is started and energy is consumed:
4. The consumer is later rewarded for the offered flexibility

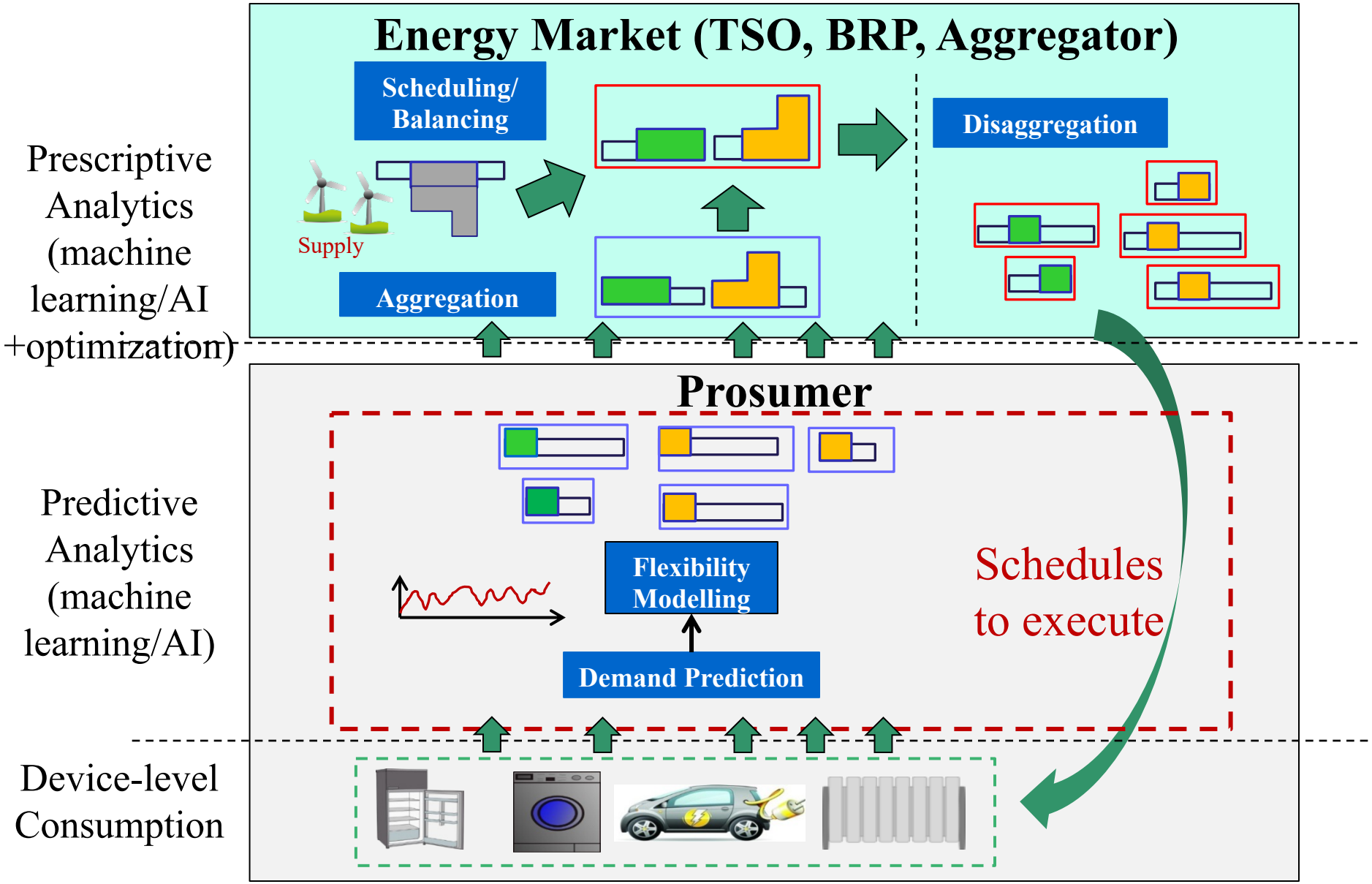


- **Exact location (meter, radial, transformer,…)!**
- **Aggregatable**
- **Options**: total energy, slice dependencies, **production/mixed**, grid capacity,…
- It is an **OFFER** from prosumer to flex purchaser
  - **No** force/**curtailment**
  - **Explicit offer** with commitment
  - Well-defined **specification** and **protocol**





FlexOffer Life Cycle: Hierarchical View



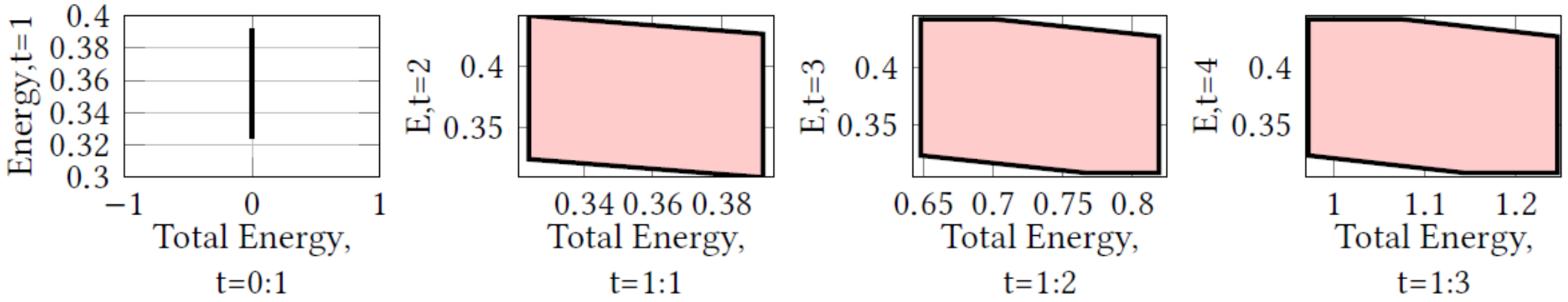
Multiple En. Vectors: *Heat FlexOffers (HFOs)*

- A Heat FlexOffer (HFO) is a FlexOffer capable of representing flexibility for devices that operate on heat, such as heat pumps.
- The energy vector represented by HFOs is heat, contrarily to previous FlexOffers (FOs) which represented electricity.
- The format in which energy constraints are represented is the same as Dependency FlexOffers (DFOs)

- HFOs can be converted from
  - Electricity to heat
  - …and back: heat to electricity
  - …allows us **to convert heat flexibility (storage) to electricity flexibility**
  - …and vice versa

HFO example

Example: a room 3m x 4m x 5m, with initial room temperature 22°C and outside temperature 2°C. If room temperature has to remain between 20°C and 24°C, the resulting HFO would look as follows:

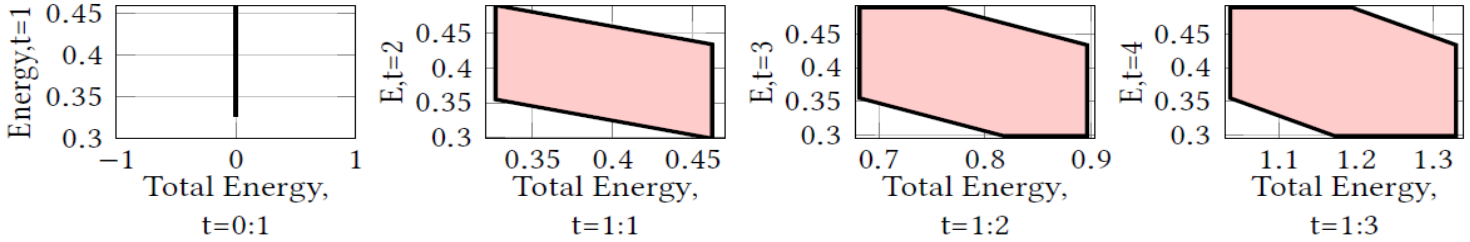


The x-axis describes the amount of energy used up to that point in time, the y-axis the amount of energy usable at that time.

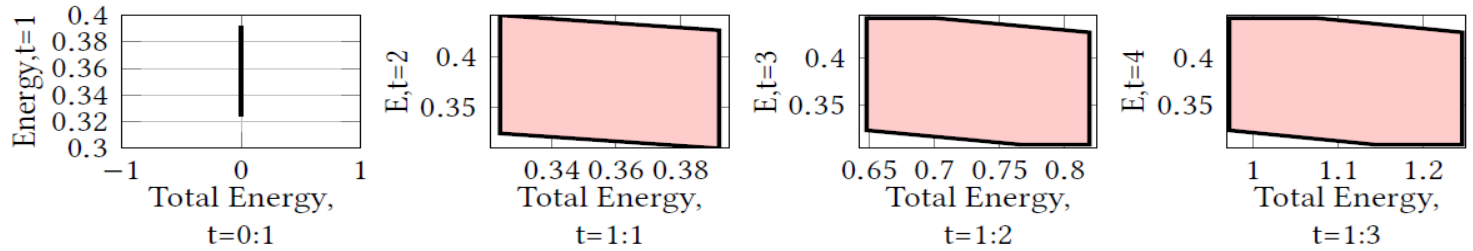
HFO generation for heat pumps

- HFOs are compliant with the Smart Grid-Ready standard for heat pumps. It allows four operating modes: *Off*, *Normal*, *Recommended On*, *Forced On*.
- HFOs are aware of the power curve: for example, one heat pump that always uses a fixed amount of power within a time slice and one who consumes the same amount of energy but alternating SG-Ready modes, will generate two different HFOs.

Fixed power



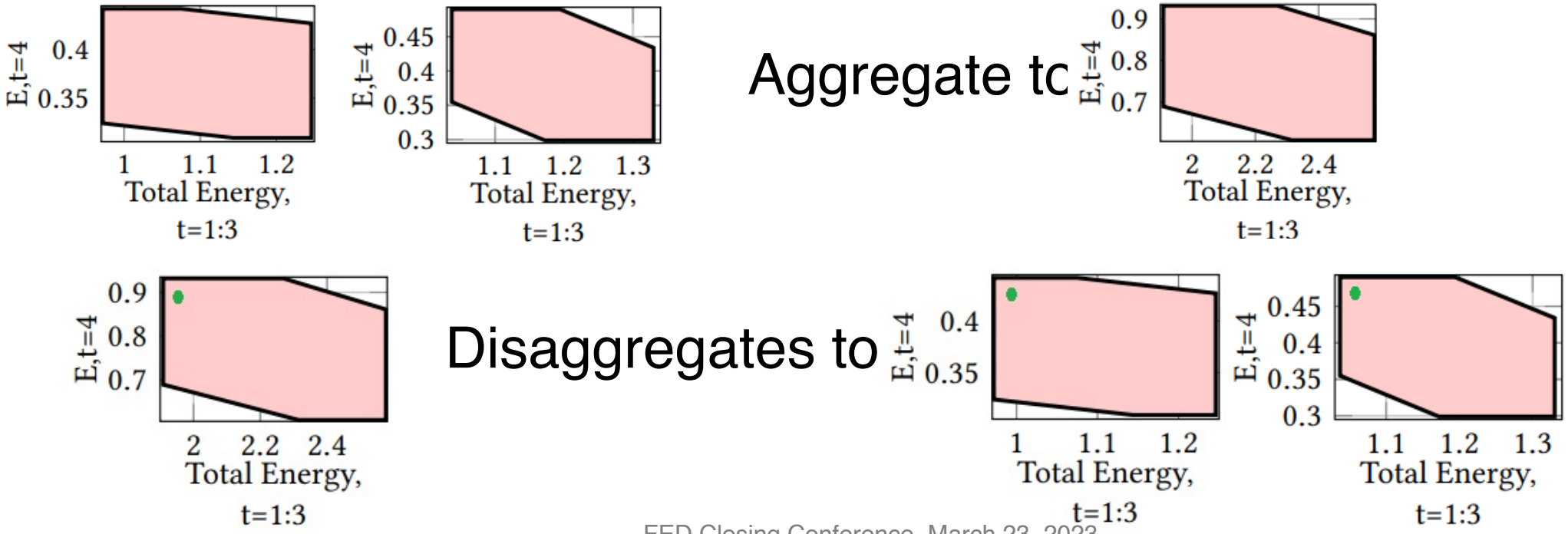
Alternating modes



HFO aggregation

Aggregation and disaggregation works exactly like for DFOs. Aggregation of HFOs will generate a single HFO which represents the combined flexibility of the aggregated HFOs. Disaggregation splits the schedule for one single HFO to schedules relative to the initial DFOs.

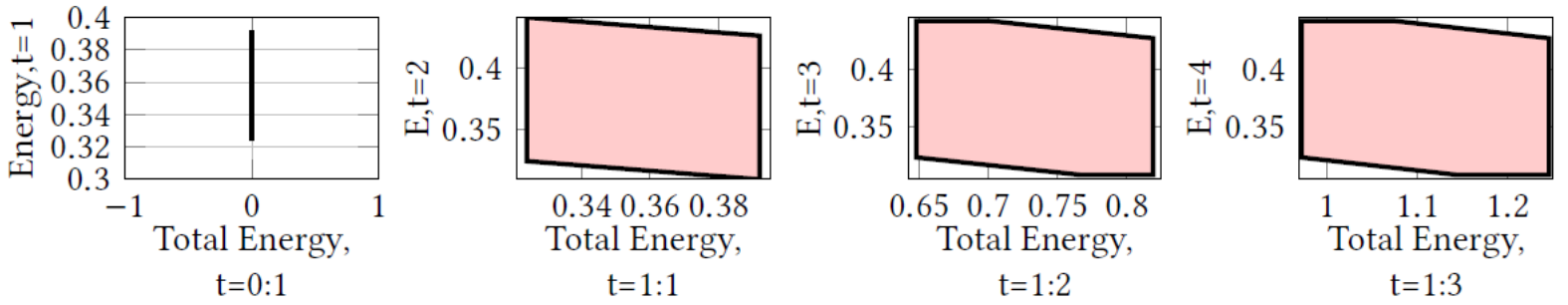
In our example case. at time 4:



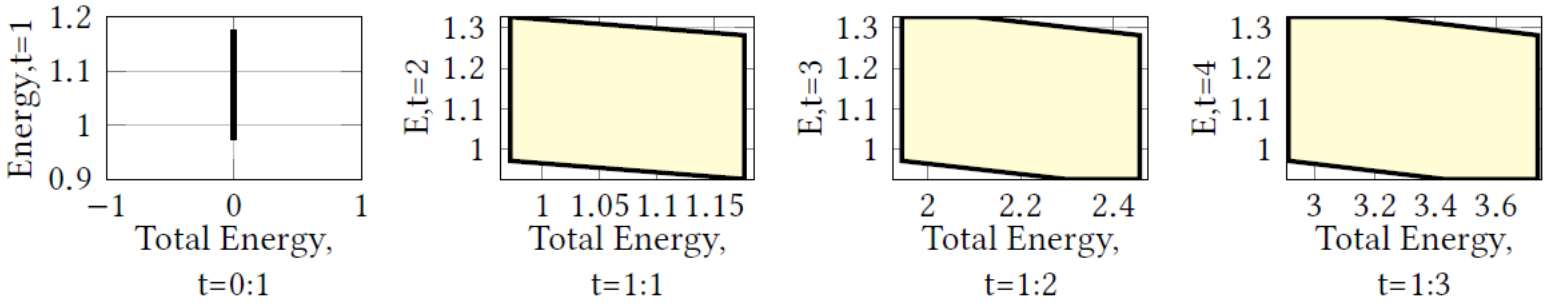
Heat-electricity conversion within HFOs

HFOs can be reversed: given an HFO representing heat for a heat pump, a DFO representing electricity consumed by the heat pump can be generated, and vice versa. Below, our example for a heat pump with coefficient of performance (COP) 3.

HFO (heat)

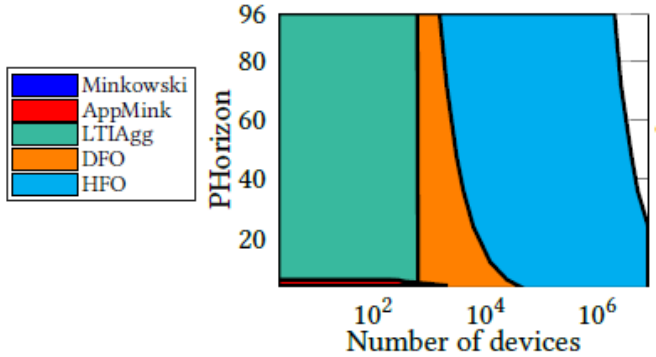


DFO (electricity)

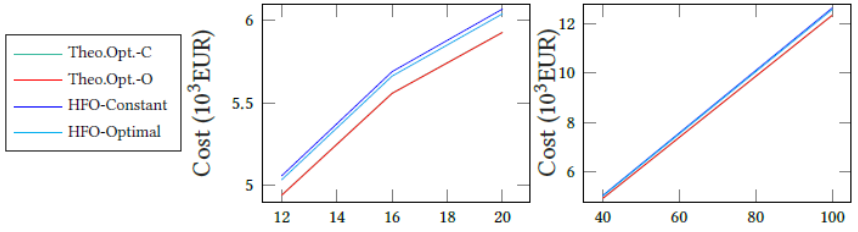


Experimental Results for HFOs

Feasibility: exact approaches can aggregate at most 500 loads for 24 hours, while DFOs can aggregate 1500. HFOs support a new approach for analytic aggregation, which allows to aggregate up to 2.000.000 loads.



Flexibility: HFOs are able to retain up to 97.7% of flexibility if designed on the constant power curve, and up to 98.1% of flexibility if designed on the optimal power curve.



DSO Flexibility Markets

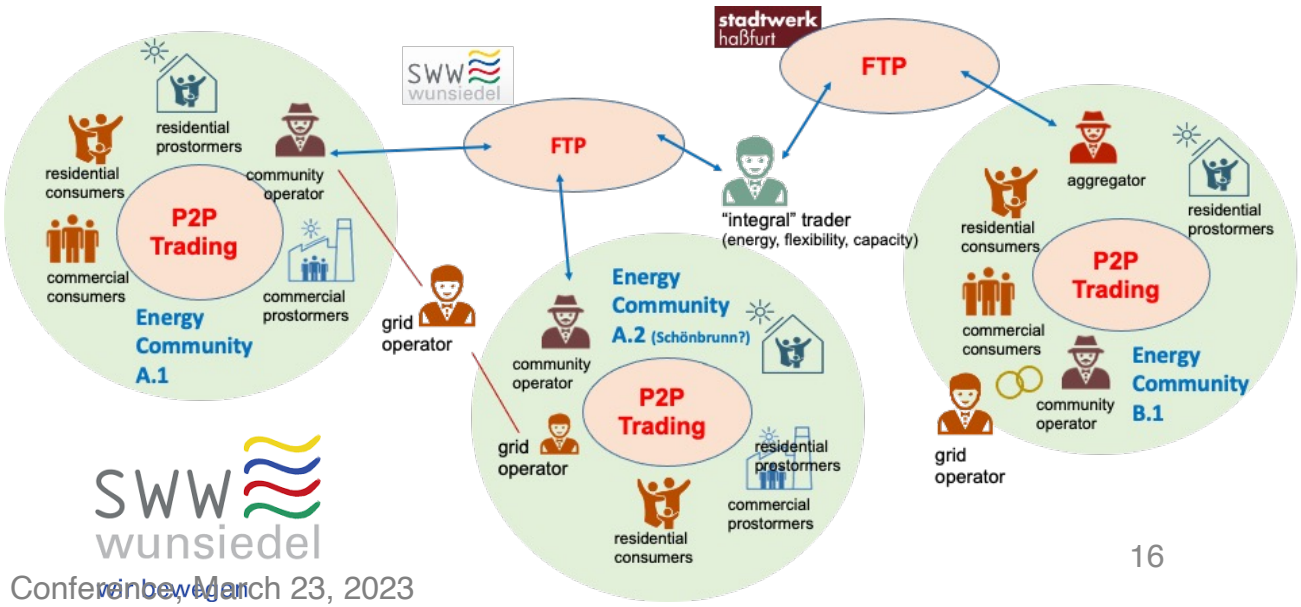
- **What** is traded?

- **Uniform** flexibility product
  - Like **commodities** (grain, oil,…)
  - **No** grid location -> need for (too) many markets, one per congestion point

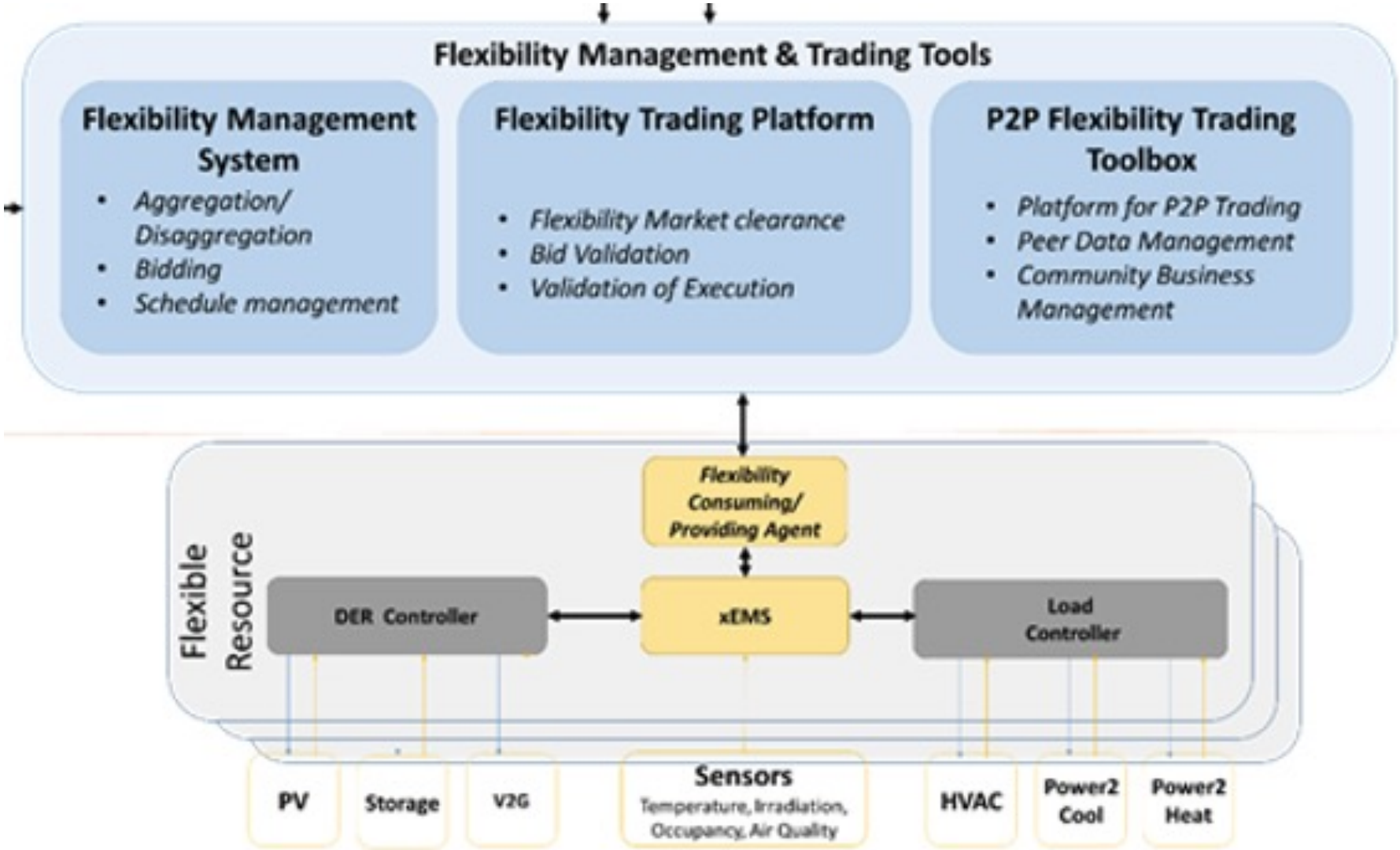
- **Tagged/parameterized** flexibility product
  - **Includes grid location tag**
  - Like **eBay (**many Iphone13s but different colors, memory,..)
  - Can be traded on a **single/few market(s)**
  - Use **hierarchical** location tags to search/aggregate flexibility **below** congestion point
  - NODES, Energinet.dk Lolland trial, FlexOffer markets

FlexOffer Trading in FEVER (SWW)

- SWW **Multi-utility**
  - DSO, electricity, heat, water, gas
  - Bavaria, Germany
  - 1000+ PV sites, big wind parks, big batteries
- **Vision:** local, green ”community of energy communities”
- **FlexOffer** platform
  - Flexibility aggregation, trading, and optimization for hundreds of users
- FEVER project
  - **P2P** blockchain trading in local village energy communities
  - **2nd-level trading** between ECs+DSOs
  - **Flexibility Bridge** with neighbor DSO StadtWerke Hassfurth (SWH)



FEVER Flexibility Architecture



FEVER User Stories: **all** trade **FlexOffers**

#	What is traded?	Who is trading?	Why is it traded?
US1	Amount of electricity for a specific appliance	EC member / buyer peer	Use locally produced electricity (save money, reduce CO_2, support EC)
		EC member / seller peer	Sell excess electricity (earn/save money, support EC)
US2	Amounts of excess PV-generated electricity	EC member / buyer peer	Use locally produced electricity (save money, reduce CO_2, support EC)
		EC member / seller peer	Sell excess electricity (earn/save money, support EC)
US3	Flexibility (up/down variations of energy/power)	EC peers	A number of reasons – see FMAR WP2 (D2.4).
US4	Flexibility (up/down variations of energy/power)	DSO	Stabilize the EC grid
		EC members	Reduce EC grid maintenance costs
US5	Flexibility (up/down variations of energy/power)	DSO	Stabilize the DSO grid
		EC-Operator	Bring value to EC (from DSO)
		EC members	Reduce costs

Flex-Coin: P2P Trading Pseudo-Currency

1 unit [FlexCoin] = XX unit [tangible asset]	**Household**	**Municipality**	**Industry**	**...**
1 Euro	1	1	1	...
1 kWh of locally produced electricity	0.8	1.2	1.4	…
1 ΔkWh/h of on-demand load reduction	0.1	0.2	0.2	…
1 bottle of local wine	0.2	(n/a)	(n/a)	...
1kg of local tomatoes	0.2	(n/a)	0.5	…
1m^2 of houses painted	2	0.5	5	...
...	...	...	...	...

Pilot starting May 2023…

DHO Flexibility Markets

- …do they even exist?
- varmelast.dk sends hourly price signals for centrally produced (transmission level) heat, to allow local heat producers to use this to optimize locally produced (distribution/DHO level) heat
  - But can that be called a market?
- Should not be separate
  - Electricity-heat **sector** coupling needed -> DSO-DHO **market** coupling needed
- How can that be done?
  - By having a **joint multi-energy vector flexibility model for trading**
- Example: Heat FlexOffers
  - Cheap and plentiful **heat flexibility converted** back to **electricity flexibility**
  - Can then be traded in **all** electricity flexibility markets, including DSO
- How to trade?
  - A topic for our next research project ☺

Links

- Flexoffer info page https://www.daisy.aau.dk/projects/flexoffers/
- FlexShape web page https://www.flexshape.dk
- Flexcommunity https://flex-community.eu
- GOFLEX project http://goflex-project.eu
  - Open GOFLEX community http://goflex-community.eu
  - SWW CEO Marco Krasser explains about the GOFLEX system (based on FlexShape AaaS V1) "...*we will find a powerful, scalable, transferable solution that revolutionizes the energy market in Germany, and in Europe, and takes it to a new level*!" https://www.youtube.com/watch?v=VbbAl8MV94s
- Video about the underlying FlexOffer technology
  - https://goflex-project.eu/PlayVideo.asp?Video=2737_BAUM_FLAT_D2001_DE_final_01.mp4
- FEVER Horizon 2020 project https://fever-h2020.eu
- Flexible Energy Denmark web page https://www.flexibleenergydenmark.dk

Key References

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- Laurynas Šikšnys, Torben Bach Pedersen, Muhammad Aftab, and Bijay Neupane, "Flexibility Modeling, Management, and Trading in Bottom-up Cellular Energy Systems," ACM e-Energy 2019
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- Fabio Liliu et al: Uncertain Flexoffers: Uncertain flexoffers, a scalable, uncertainty-aware model for energy flexibility, ACM e-Energy 2023

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