Limassol, Cyprus
ENERGYCON 2018
IEEE International Energy Conference

Utilizing Flexibility Resources in the Future Power System Operation: Alternative Approaches

G. De Zotti* A. Pourmousavi** H. Madsen* N.K. Poulsen*

* Technical University of Denmark
** The University of Queensland

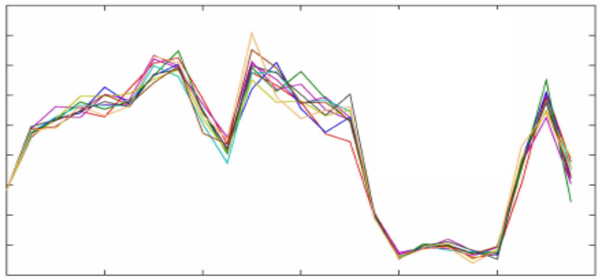
Outline

- Motivations
- Coordinating flexible resources
- Different approaches in literature: market versus control
- Proposed methodology: AS4.0
- Estimating the available flexibility
- Conclusions

The electricity supply service
Challenges introduced by RES

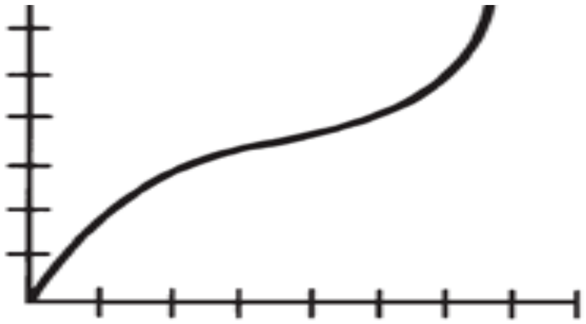
Adding RES to the generation portfolio affects the quality of service and power system operation because of:

Stochasticity



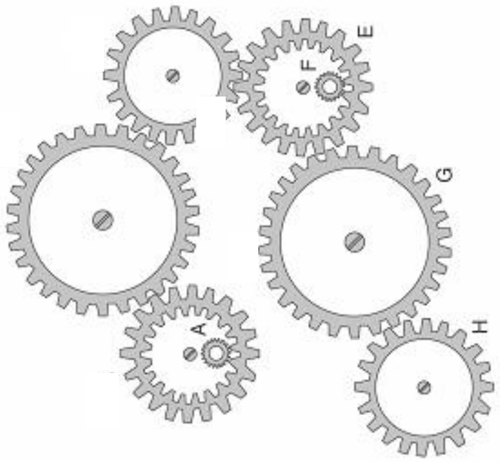
The generation from RES **cannot be planned** in the same way as conventional power plants.

Non-linearity



The generation can follow a **non-linear trend** in spite of the linear bidding and clearing process.

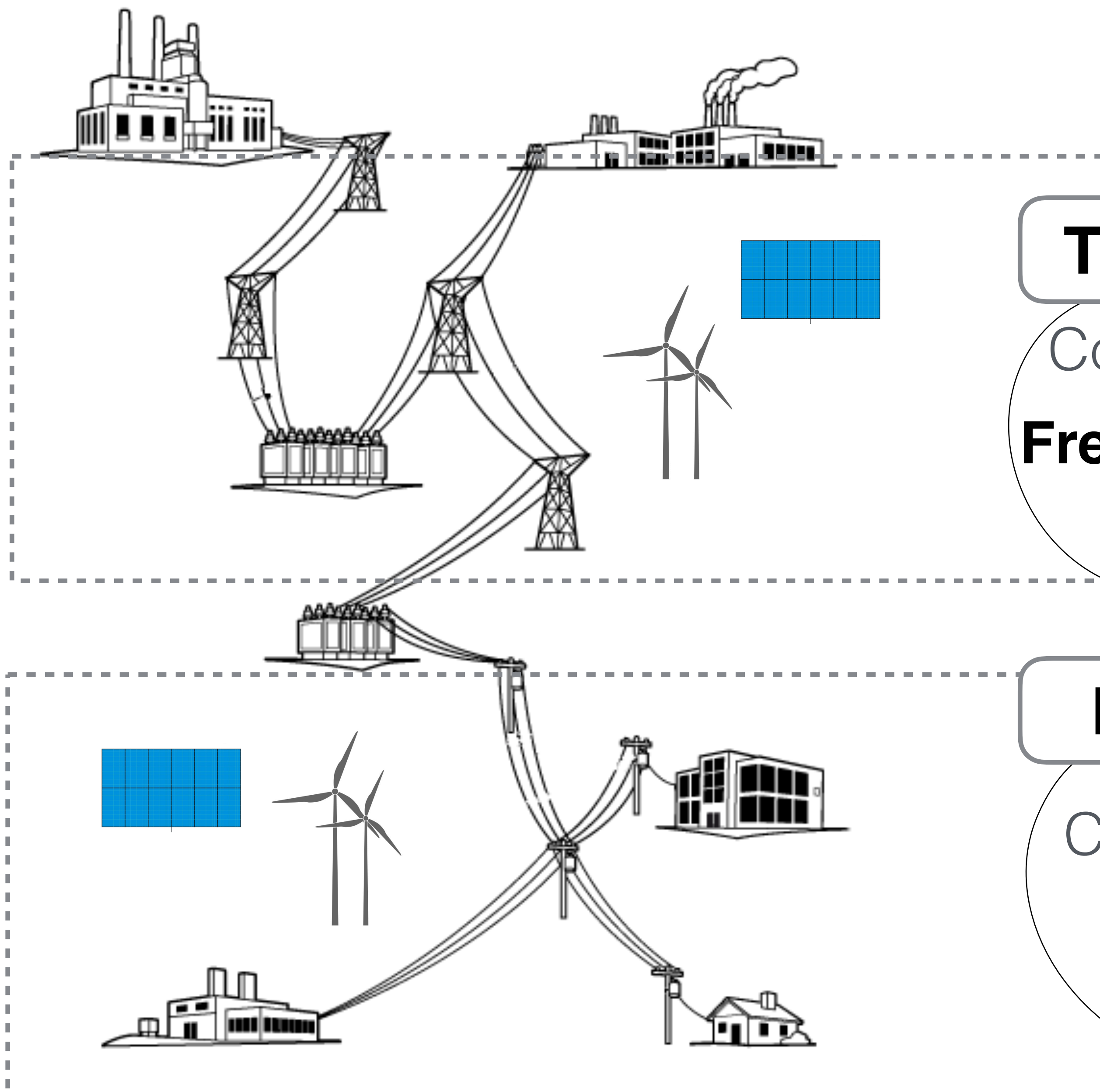
Dynamics



Voltage and **frequency** levels **fluctuate** due to the power imbalance.

The electricity supply service
Consequences for the AS

This is particularly affecting the provision of the ancillary services:



Transmission

Congestion management

Frequency management

Distribution

Congestion management

Voltage management

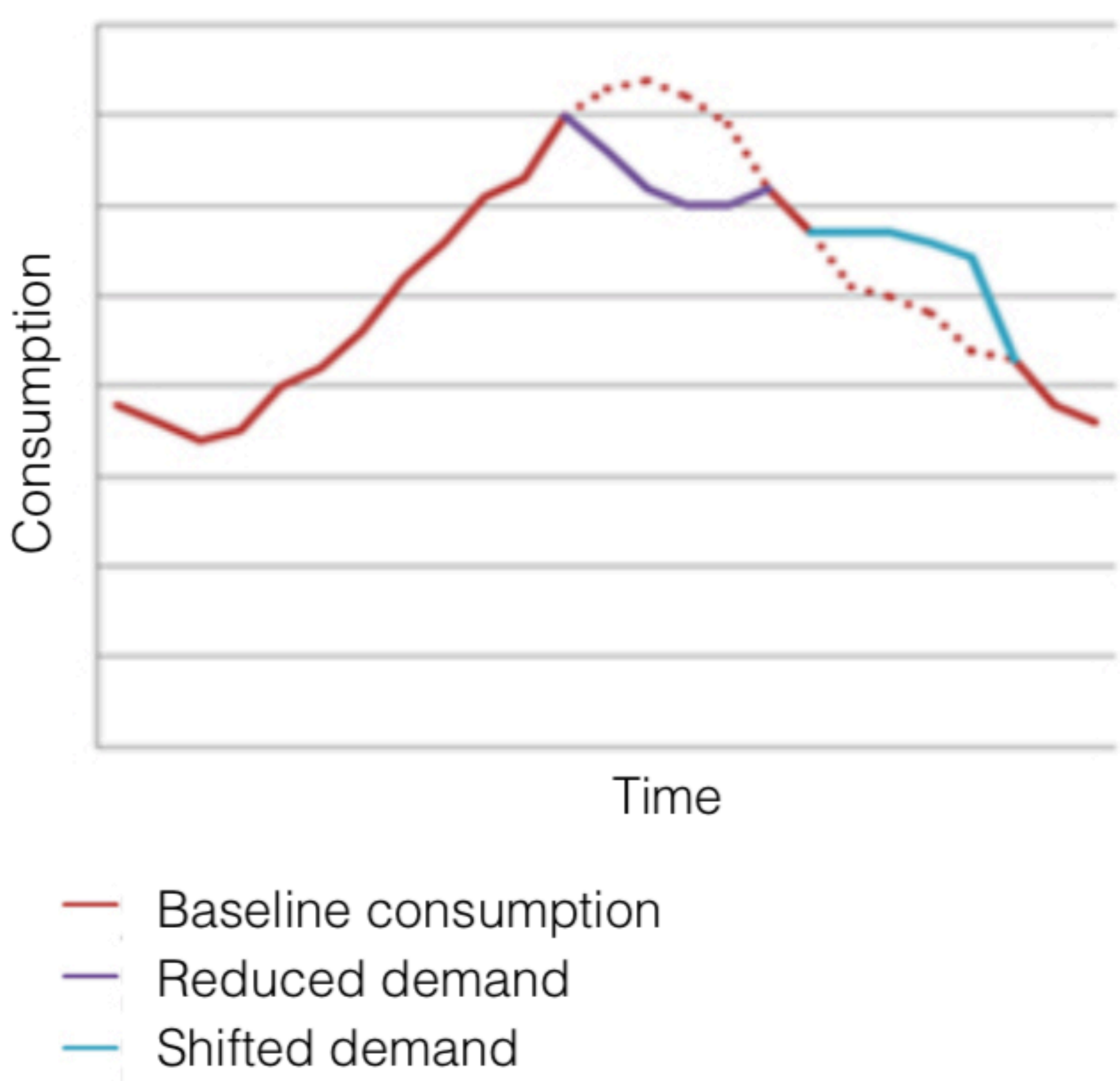
Balancing

The electricity supply service
Exploiting the energy flexibility

Flexible resources

Flexible loads, energy storage and generation are able to **adapt** their **behaviour** according to the **necessity** of the grid.

They need to be **coordinated** in a **fast** and **efficient** manner in order to be valuable.



Coordinating the energy flexibility AS provision operation

In order to coordinate the energy flexibility, it is important to develop an **approach** that satisfies all the different **requirements** of the smart grid era.

Literature considers various approaches:

Market-based approach	**Control-based approach**
Wholesale AS market	Direct control
P2P	**Indirect control**
Transactive energy	**AS4.0**

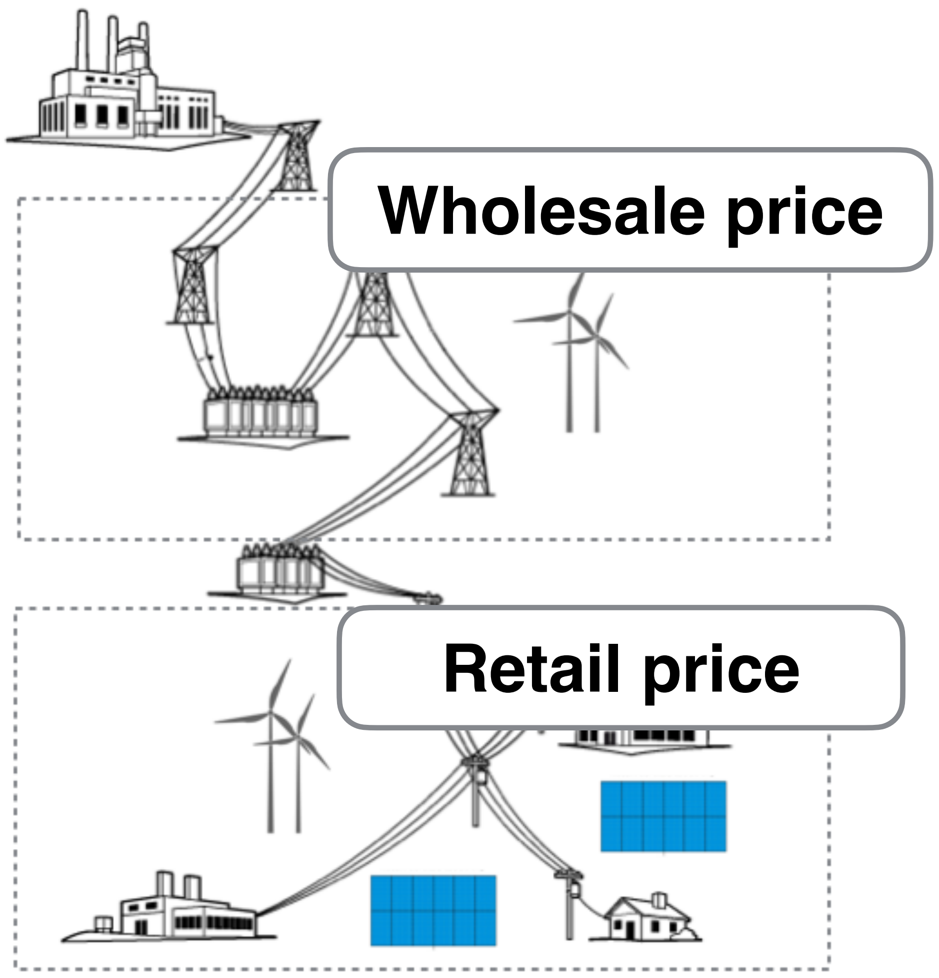
Requirements

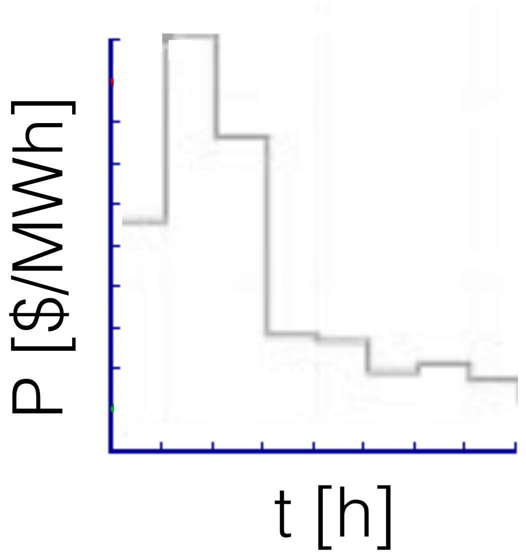
Stochasticity
Non-linearity
Dynamics
Certainty of the response
Energy system integration
DS management
TS management
Prosumer privacy

Scalable
Simple
Fast
Secure
Cheap

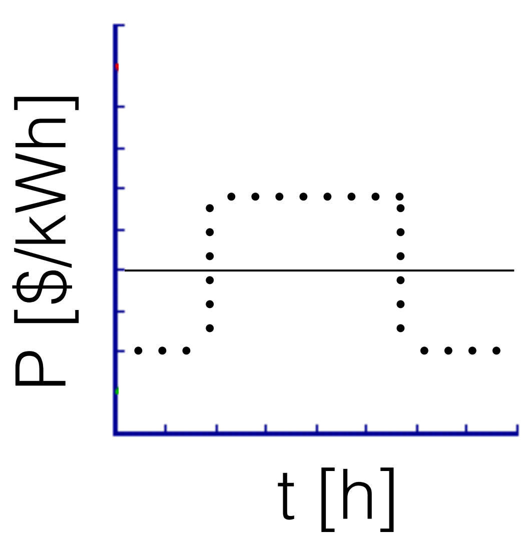
Coordinating the energy flexibility
The electricity price

The submission of **time-varying electricity prices** can support the exploitation of the **price responsiveness** for **flexible** energy resources.





Nowadays, the **wholesale** electricity price is **flexible** and **changes** sub- hourly through a market and clearing process.

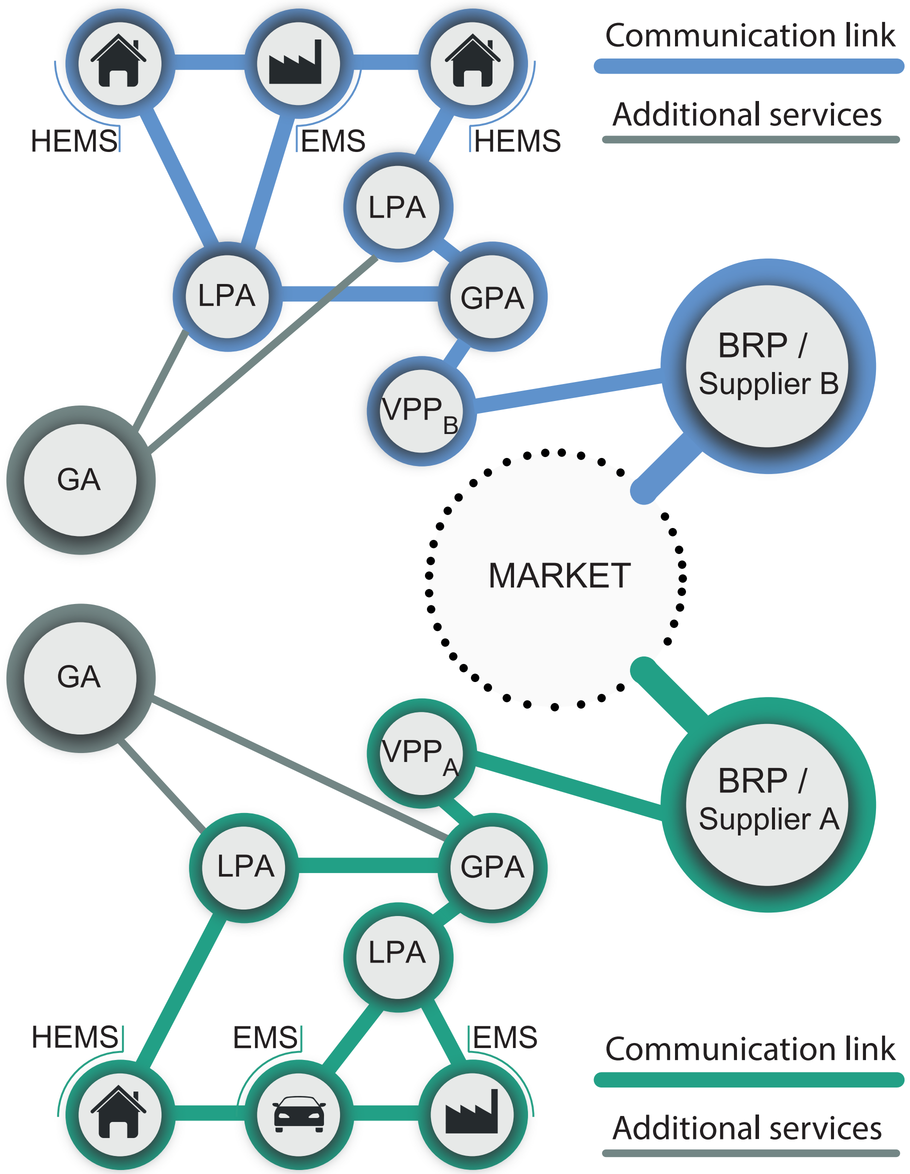


However, the **retail** electricity price is **fixed** by the **utility** and **does not change over time.**

Coordinating the energy flexibility

Market-based operation

Transactive energy



It involves an agent to **aggregate** DERs. It formulates bids from **feedback** signals communicated with the consumers.

Certain response

Distribution system management

Deterministic, linear and static

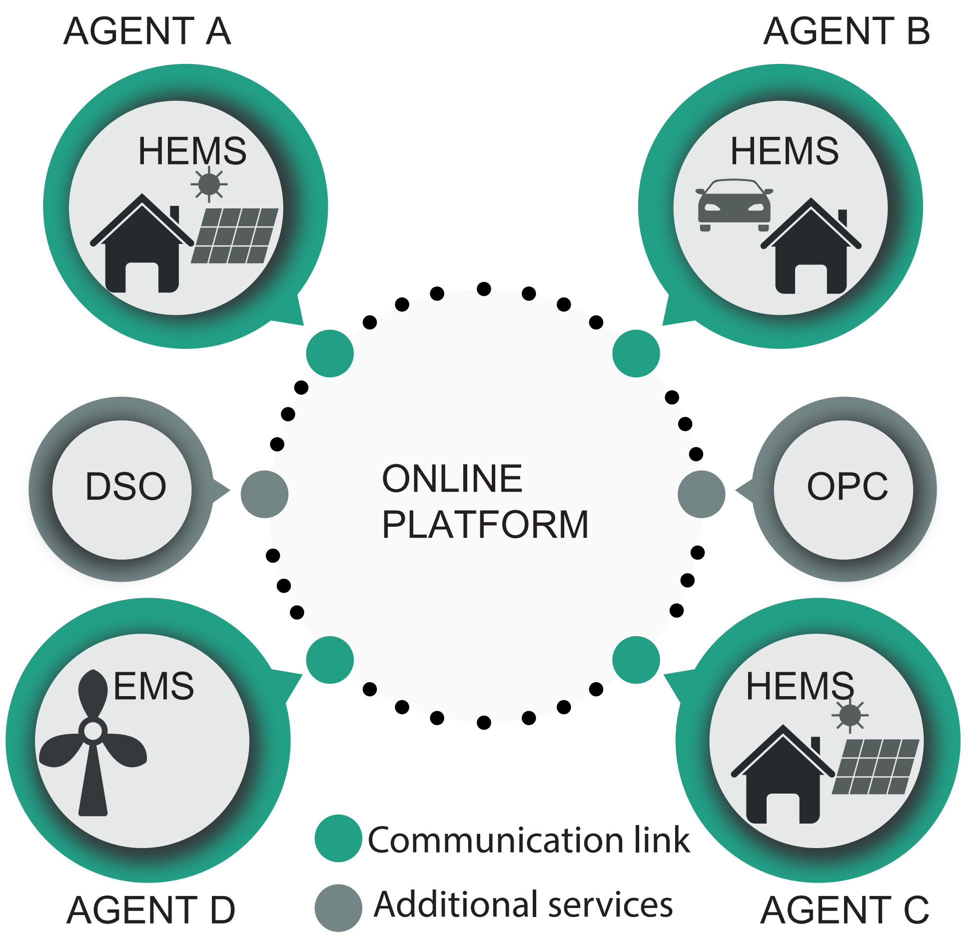
Two-way communication

Slow

Coordinating the energy flexibility

Market-based operation

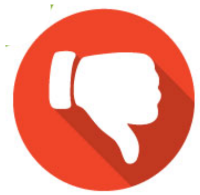
P2P



It is a coordinated multi-lateral trading framework which **avoids** the **interference** of the middle man.

Scalable

Stochastic, non-linear and dynamic

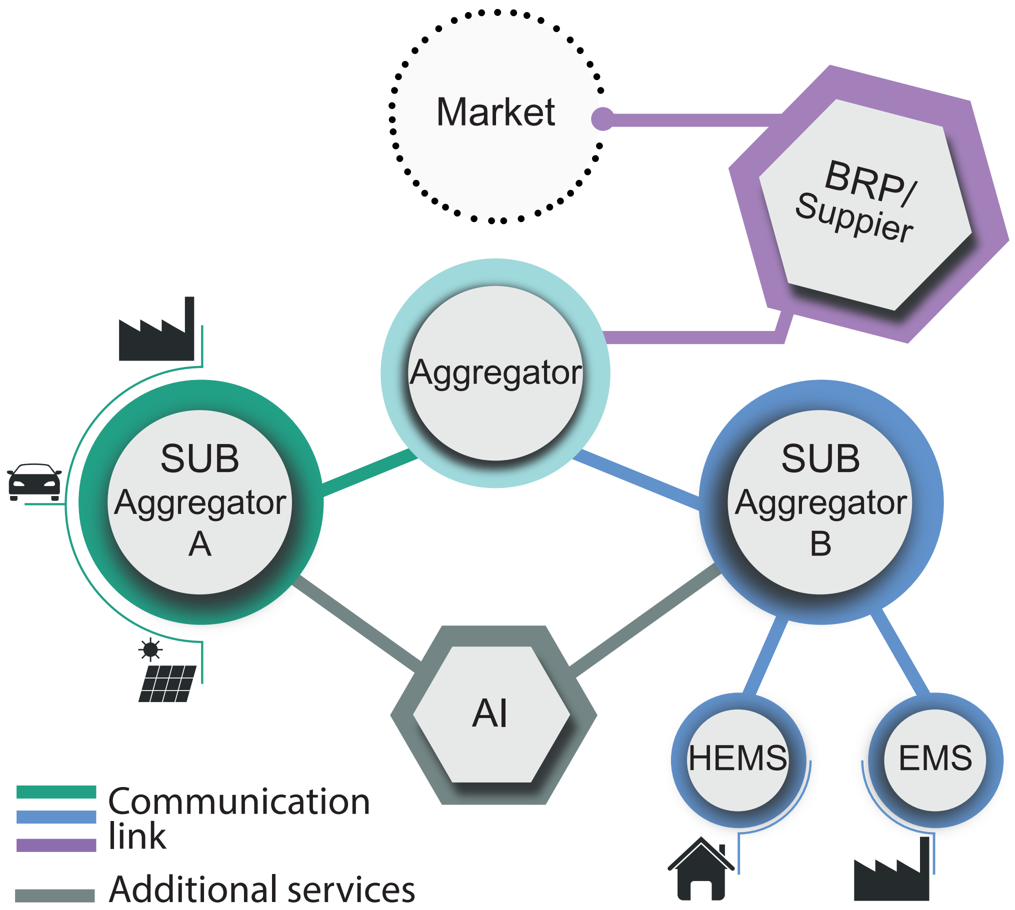


No transmission system management

Purely financial

Coordinating the energy flexibility
Control-based operation

Control-based approach



It adopts **controls** at the lowest level of the grid. Consumers are managed by **aggregators** through indirect and direct controls. Market is maintained at the highest level.

It can use one-way communication

Stochastic, non-linear and dynamic

Dependency on the market

No transmission system management

Coordinating flexible resources
AS4.0: Idea

What if system operators could formulate real-time varying prices according to the flexibility needed and exploit a one-way communication?

Coordinating flexible resources
AS4.0: Idea

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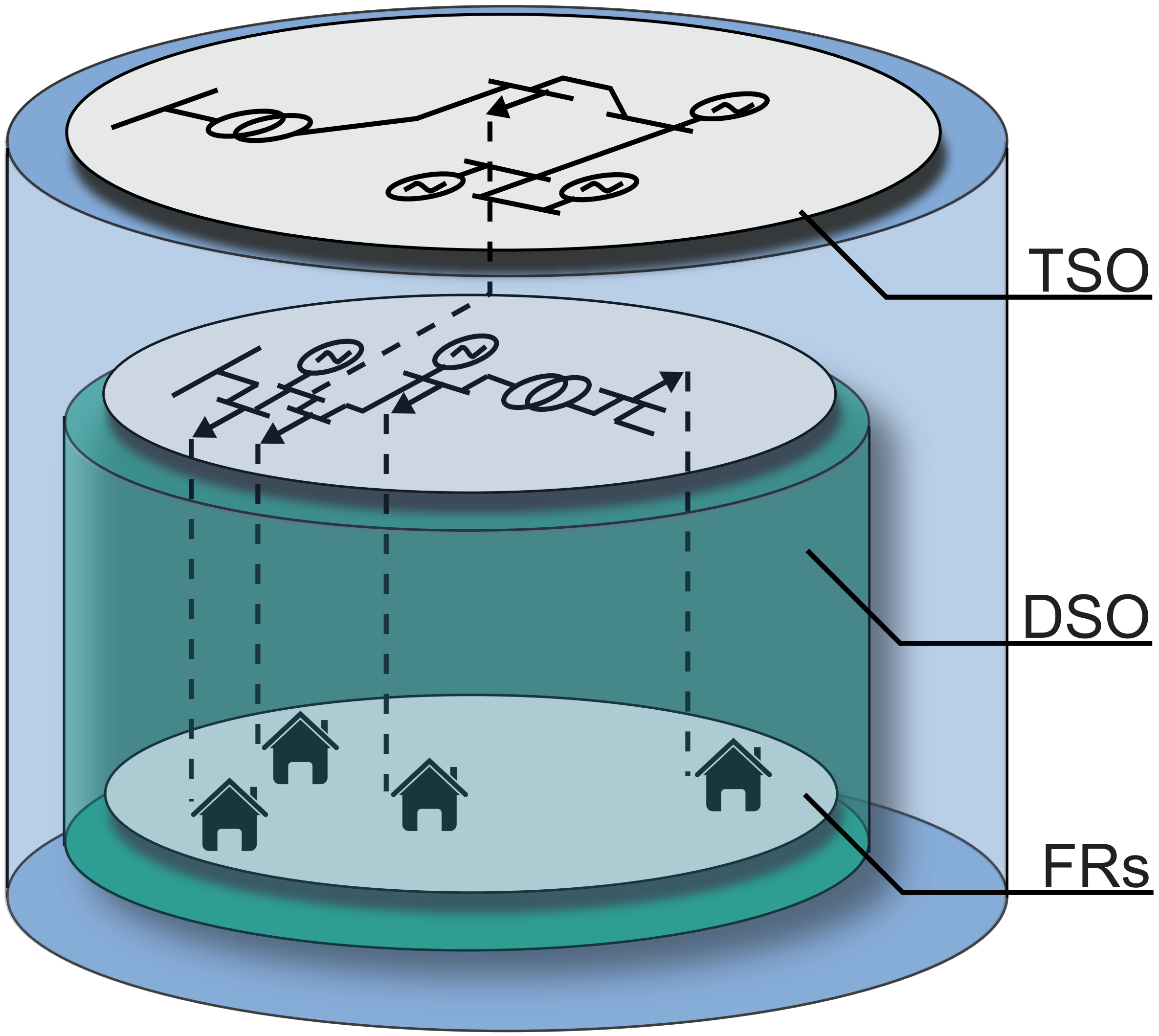
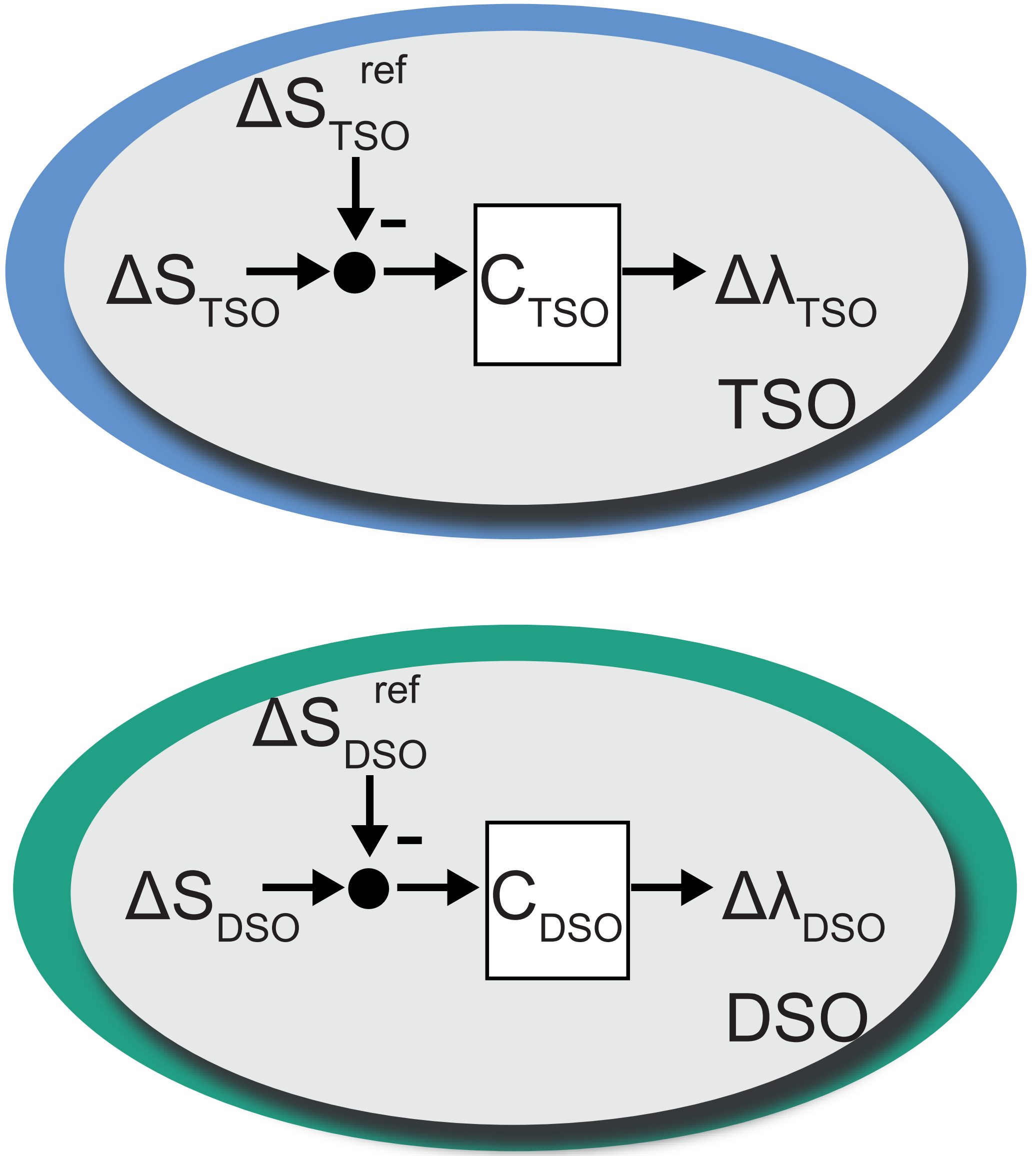
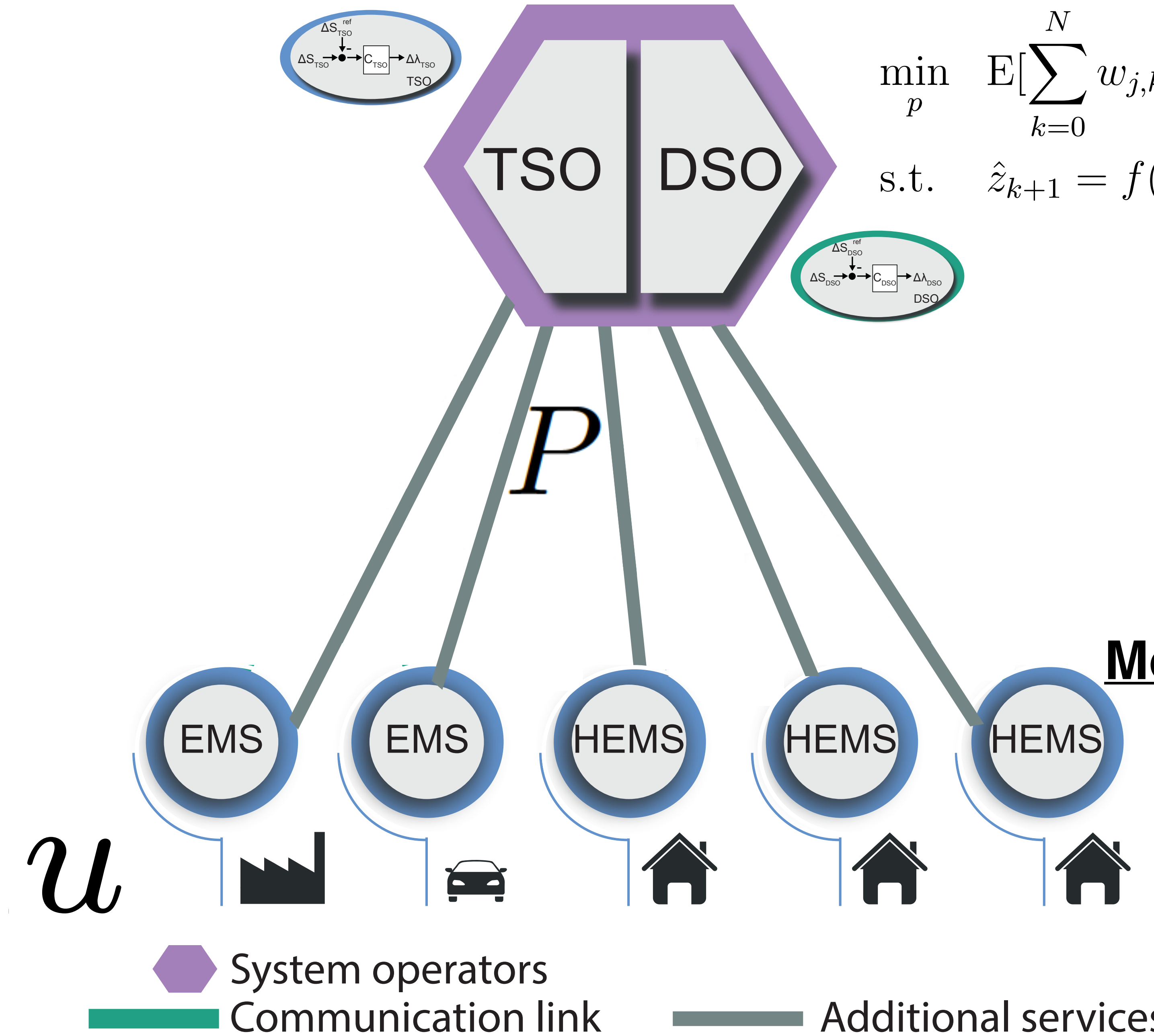




Coordinating flexible resources
AS4.0: Structure



Control-based approach

$$\min_{p} \quad \mathrm{E}\Big[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||\Big]$$

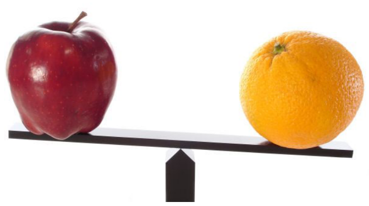
$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

Model predictive control

$$\min_{u} \quad \mathrm{E}\Big[\sum_{k=0}^{N}\sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)\Big]$$

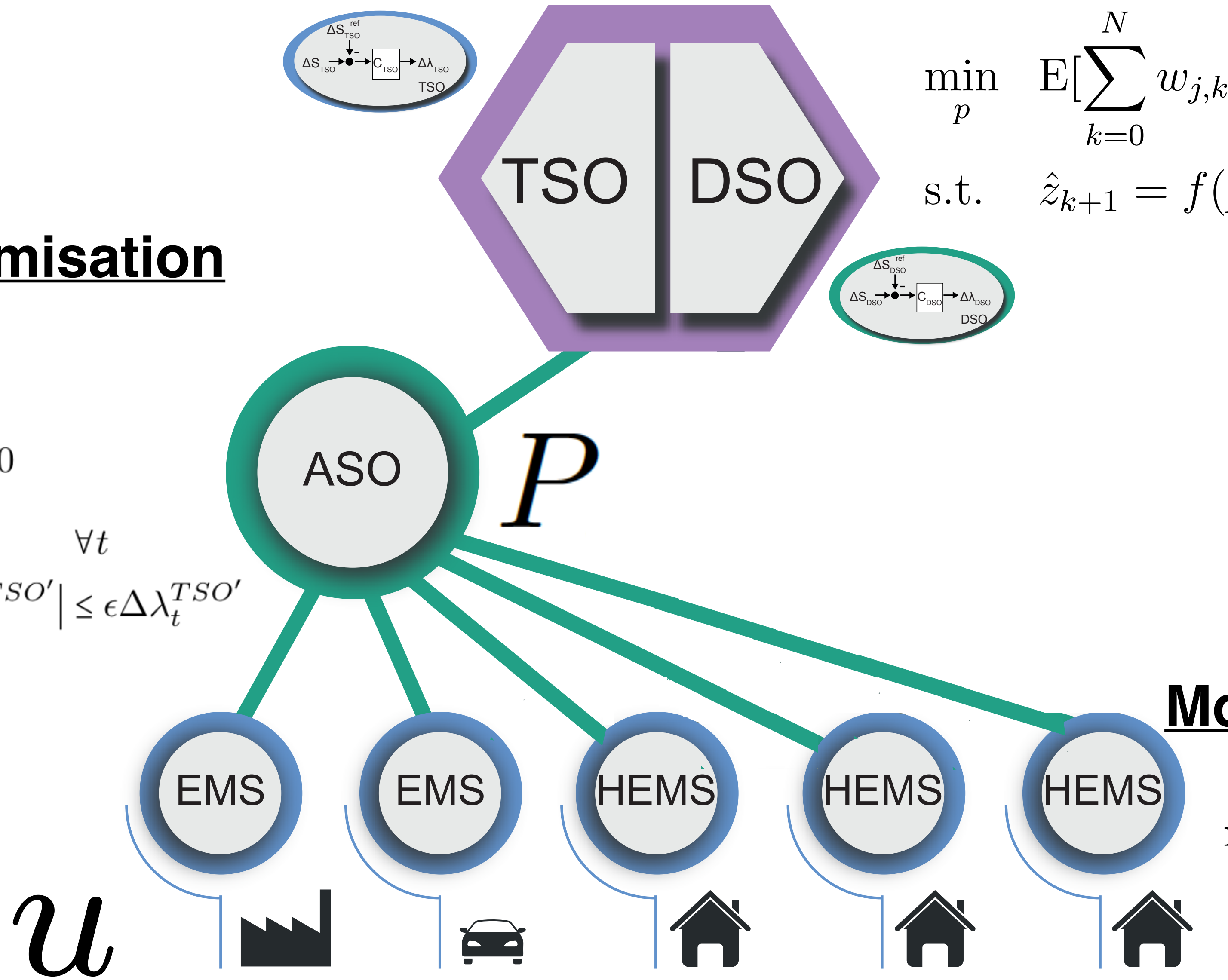
$$\begin{aligned} \text{s.t.} \quad x_{k+1} &= Ax_k + Bu_k + Ed_k, \\ y_k &= Cx_k, \\ y_k^{min} \leq y_k &\leq y_k^{max}, \\ u_k^{min} \leq u_k &\leq u_k^{max} \end{aligned}$$

Coordinating flexible resources
AS4.0: Structure



Deviation minimisation

$$
\begin{aligned}
\min_{\Delta\lambda_t^{TSO}} \quad & \sum_{t=1}^{T} U_t \\
\text{s.t.} \quad & \sum_{t=1}^{T} \Delta\lambda_t^{TSO} = 0 \\
& |\Delta\lambda_t^{TSO}| \leq U_t \qquad \forall t \\
& |\Delta\lambda_t^{TSO} - \Delta\lambda_t^{TSO'}| \leq \epsilon \Delta\lambda_t^{TSO'} \\
& U_t \geq 0 \qquad \forall t
\end{aligned}
$$



System operators
Communication link
Additional services

Control-based approach

$$
\begin{aligned}
\min_{p} \quad & \mathrm{E}[\sum_{k=0}^{N} w_{j,k}||\hat{z}_k - z_{ref,k}|| + \mu||p_k - p_{ref,k}||] \\
\text{s.t.} \quad & \hat{z}_{k+1} = f(p_k)
\end{aligned}
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Model predictive control

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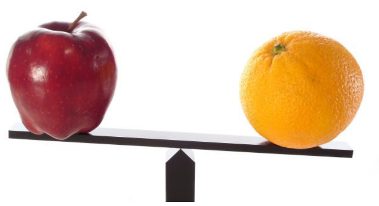
Coordinating flexible resources
AS4.0: Structure



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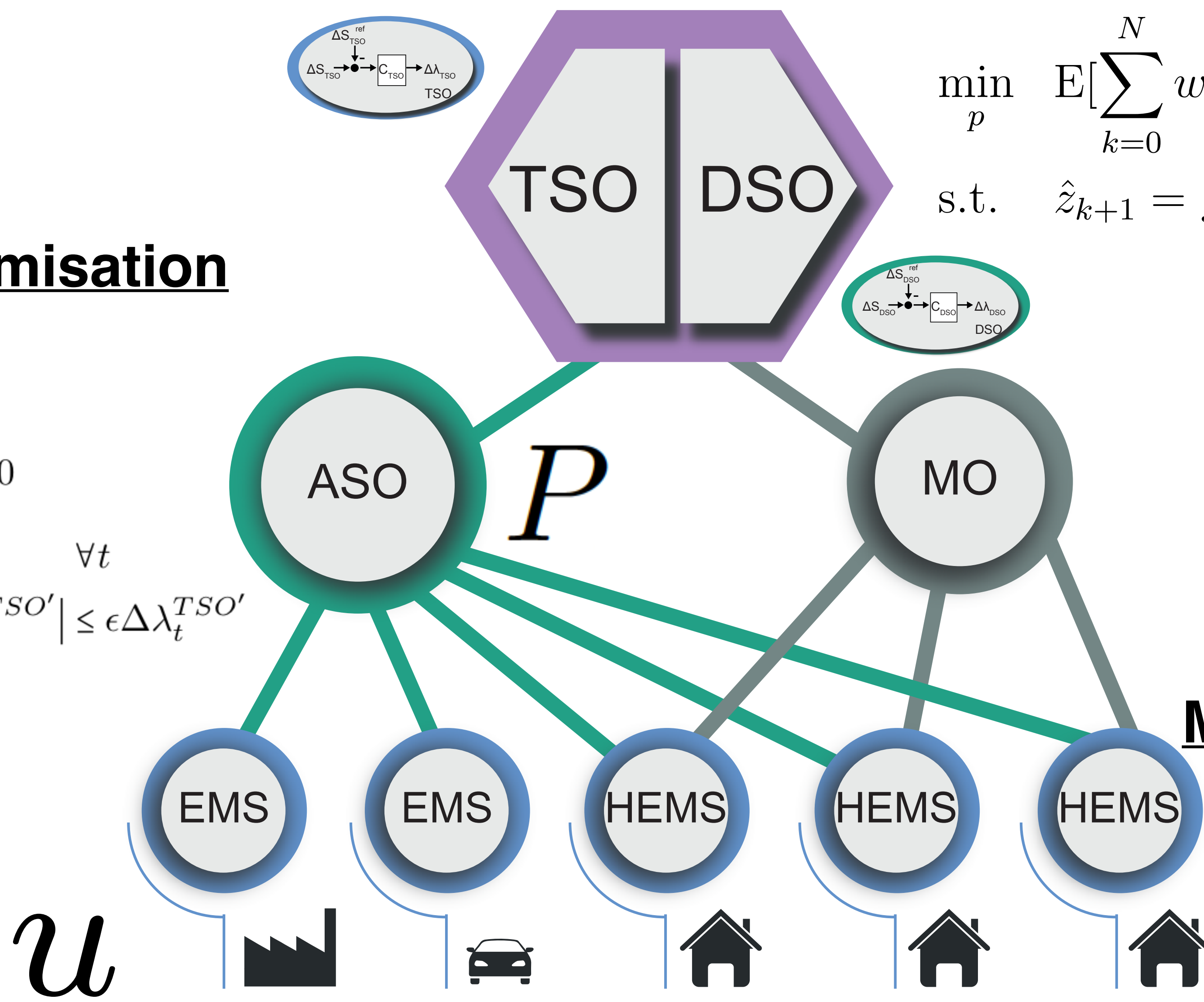

System operators
Communication link
Additional services

Control-based approach

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$$\text{s.t.} \quad \hat{z}_{k+1} = f(p_k)$$

Model predictive control

$$\min_{u} \quad \mathrm{E}[\sum_{k=0}^{N} \sum_{j=1}^{J} \phi_j(x_{j,k}, u_{j,k}, p_k)]$$

$$\text{s.t.} \quad x_{k+1} = Ax_k + Bu_k + Ed_k,$$

$$y_k = Cx_k,$$

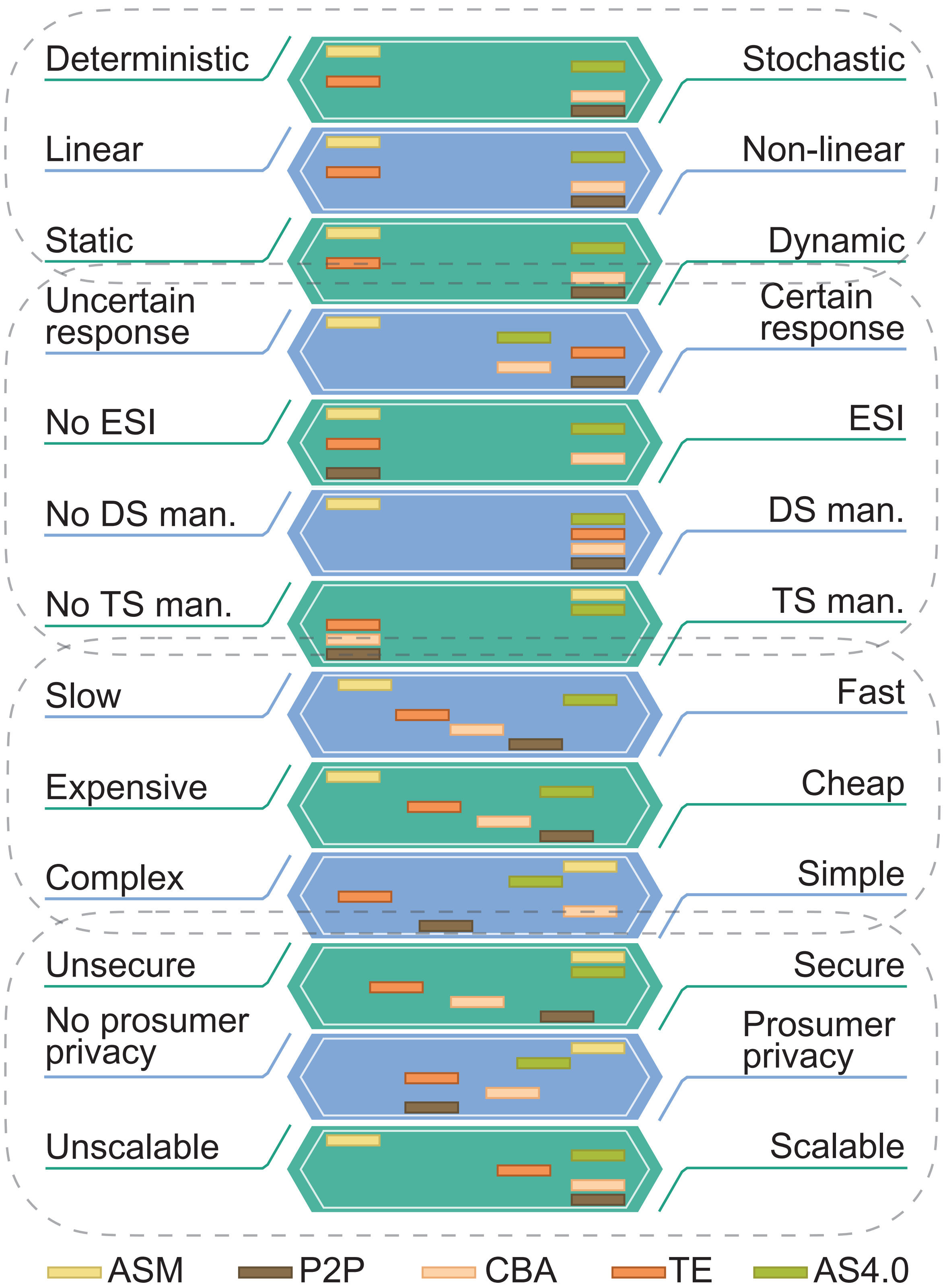
$$y_k^{min} \leq y_k \leq y_k^{max},$$

$$u_k^{min} \leq u_k \leq u_k^{max}$$

AS4.0: Summary

AS4.0 is able to solve all the problems in one set, taking into account **stochasticity**, **non linearity** and **dynamics**.

It exploits the **potential** of the flexible resources at the prosumers' level of **any size**. Also, being based on indirect controls, it is **fast** and fully **automated** at different levels.



Estimating the available flexibility
Aggregated price response

How can we estimate the consumers' behaviour at the TSO level?

Estimating the available flexibility
Aggregated price response

How can we estimate the consumers' behaviour at the TSO level?

We assume to deal with consumers that are equipped with **energy management systems**.

Their response is statistically modelled, knowing:

- The **composition** of the aggregated pool of consumers.
- The aggregated **measurements** for each **load category**.

We approach a **cost minimisation**, evaluating the perspective of the consumers.

$$\min_{L^{\alpha}_{t,j}} \quad \sum_{t=1}^{\tau} (\boldsymbol{\lambda}^{\text{base}} + \boldsymbol{\Delta\lambda}^{u}_{t} + \boldsymbol{\Delta\lambda}^{d}_{t}) \sum_{j=1}^{J} (\boldsymbol{L}^{\text{base}}_{t,j} + L^{d}_{t,j} - L^{u}_{t,j})$$

$$
\begin{aligned}
\text{s.t.} \quad & -\mathbf{r}^{\alpha}_{j} \le L^{\alpha}_{t,j+1} - L^{\alpha}_{t,j} \le \mathbf{r}^{\alpha}_{j} && \forall t, j \\
& 0 \le L^{d}_{t,j} \le u^{d}_{t,j}(\mathbf{L}^{\max}_{t,j} - \mathbf{L}^{\text{base}}_{t,j})\mathbf{a}^{d}_{t,j} && \forall t, j \\
& 0 \le L^{u}_{t,j} \le u^{u}_{t,j}(\mathbf{L}^{\text{base}}_{t,j} - \mathbf{L}^{\min}_{t,j})\mathbf{a}^{u}_{t,j} && \forall t, j \\
& \sum_{1}^{\tau} (L^{d}_{t,j} - L^{u}_{t,j}) = 0 && \forall j \\
& u^{d}_{t,j} + u^{u}_{t,j} \le 1 && \forall t, j \\
& y^{\alpha}_{t,j} - z^{\alpha}_{t,j} = u^{\alpha}_{t,j} - u^{\alpha}_{t,j-1} && \forall t, j \\
& y^{\alpha}_{t,j} + z^{\alpha}_{t,j} \le 1 && \forall t, j \\
& \sum_{t=1}^{\tau} y^{\alpha}_{t,j} \le \mathbf{n}^{\alpha}_{j} && \forall j \\
& \sum_{t=t'}^{t'+\underline{\mathbf{d}}^{\alpha}_{j}} u^{\alpha}_{t',j} \ge \underline{\mathbf{d}}^{\alpha}_{j} y^{\alpha}_{t',j} && \forall t' \in \Psi, j \\
& \sum_{t=t'}^{t'+\overline{\mathbf{d}}^{\alpha}_{j}} z^{\alpha}_{t,j'} \ge y^{\alpha}_{t',j} && \forall t' \in \Psi, j \\
& t' \in \Psi, t' : \left[(t + \overline{\mathbf{d}}^{d}_{j} < \tau) \cap (t + \overline{\mathbf{d}}^{u}_{j} < \tau)\right]
\end{aligned}
$$

Conclusions

We present **AS4.0**, a one-way communication approach which exploits controls to handle the ancillary services provision in smart grids. Such an approach is presented together with the existing **alternatives,** including **P2P, transactive energy and the control-based approach**.

This new method potentially satisfies the various **requirements** of the grid with high penetration of RES, handling stochasticity, non-linearity and dynamics in a fast and simple manner.

We also present an approach for the **estimation of the available flexibility** achievable from consumers at the transmission system level. This is possible by exploiting aggregated measurements for different categories of loads.

In the future, the higher penetration of **energy management systems** will facilitate to get a fast reaction from the consumers to different price signals.

Future work

- Modelling the interaction of DSO and TSO under the AS4.0 mechanism
- Handling the possible conflicts of interest
- Implementing a model to derive time-varying retail prices

Contacts

- Giulia De Zotti gizo@dtu.dk
- Seyyed Ali Pourmousavi Kani a.pour@uq.edu.au
- Henrik Madsen hmad@dtu.dk
- Niels Kjølstad Poulsen nkpo@dtu.dk

Thank you!