INVADE

*Smart system of renewable energy storage based on **IN**tegrated E**V**s and b**A**tteries to empower mobile, **D**istributed and centralised **E**nergy storage in the distribution grid*

Roberto Villafáfila Robles

roberto.villafafila@citcea.upc.edu

roberto.villafafila@upc.edu

CITCEA

UPC

Departament d'Enginyeria Elèctrica

UNIVERSITAT POLITÈCNICA DE CATALUNYA

Jornada Indústria 4.0 a l'ETSEIB

Barcelona, July 3rd 2019

*Smart system of renewable energy storage based on **IN**tegrated E**V**s and b**A**tteries to empower mobile, **D**istributed and centralised **E**nergy storage in the distribution grid*

This project has received funding from the *European Union's Horizon 2020 Research and Innovation programme* under Grant Agreement No 731148.

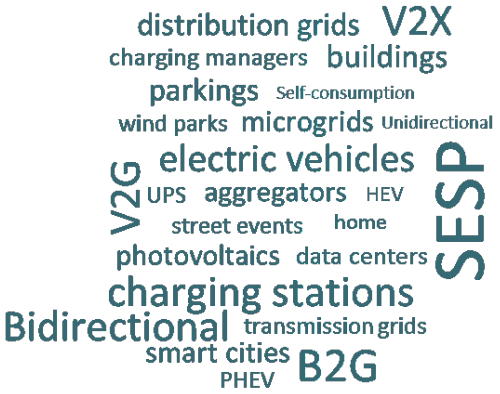
*local **E**lectricity retail **M**arkets for **P**rosumer smart grid p**OWER** services*

This project has received funding from the *European Union's Horizon 2020 Research and Innovation programme* under Grant Agreement No 646476.

Content

- Introduction
- System architecture
- Business model
- Conclusions

Introduction



Introduction

EMPOWER (2015-2017) (EU Horizon 2020 INNOVATION ACTION)

INVADE(2017-2019) (EU Horizon 2020 INNOVATION ACTION)

TARGETS

Develop a complete **new business models** and **local energy markets** at distribution network where**:**

- **consumers** are the **center**
- consumers can buy and sell **"neighborhood energy"** which is produced locally by solar panels, wind turbines and other **decentralized energy production**
- use of **electrical vehicles** energy and **batteries** to facilitate mobile, distributed and centralized **energy storage**
- will be **tested** in pilots sites: EMPOWER (3) , INVADE (5)

Introduction

EMPOWER (2015-2017) (EU Horizon 2020 INNOVATION ACTION)

Partners:

- Smart Innovation Østfold AS (NO)
- Schneider Electric Norge AS (NO)
- eSmart Systems AS (NO)
- Fredrikstad Energi Nett AS (NO)
- CITCEA-UPC (ES)
- University of St. Gallen (CH)
- Malta Intelligent Energy Management Agency (MT)
- NewEn Projects GmbH (DE)

Introduction

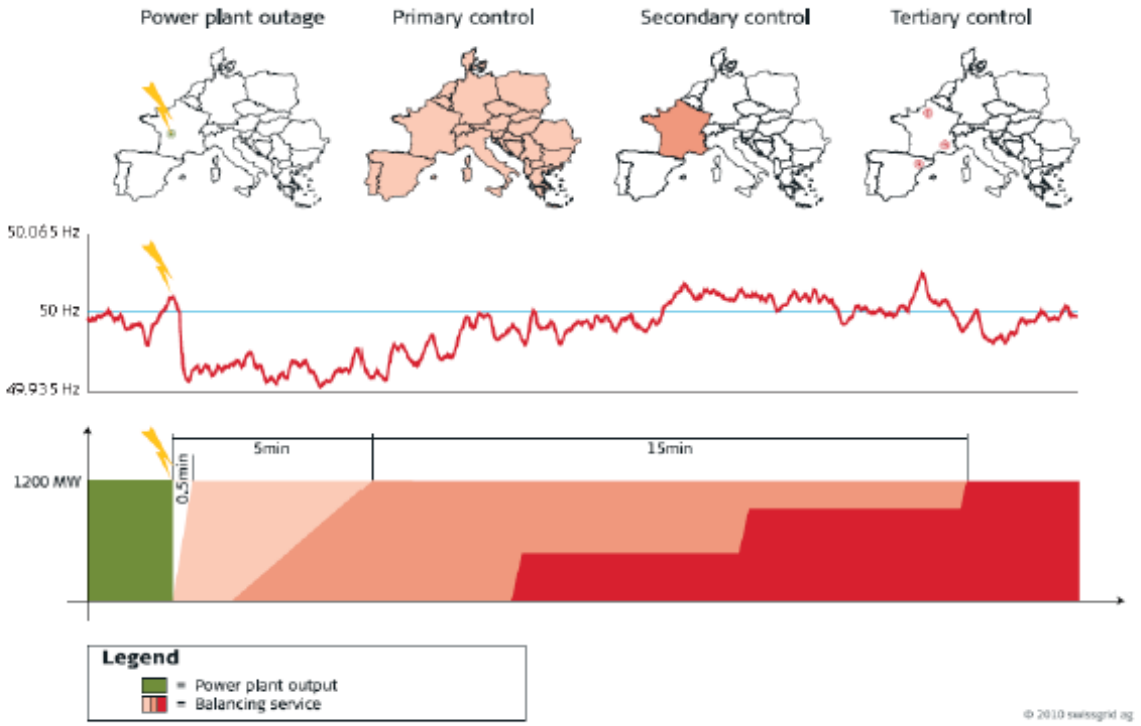
INVADE(2017-2019) (EU Horizon 2020 INNOVATION ACTION)

Partners:

- Smart Innovation Østfold AS (NO)
- Schneider Electric Norge AS (NO)
- eSmart Systems AS (NO)
- Lyse (NO)
- NTNU (NO)
- CITCEA – UPC (ES)
- EPESA (ES)
- Elaad (HO)
- Greenflux (HO)
- NewEn Projects GmbH (DE)
- VTT (FI)
- Albena (BU)

Background: generation=demand

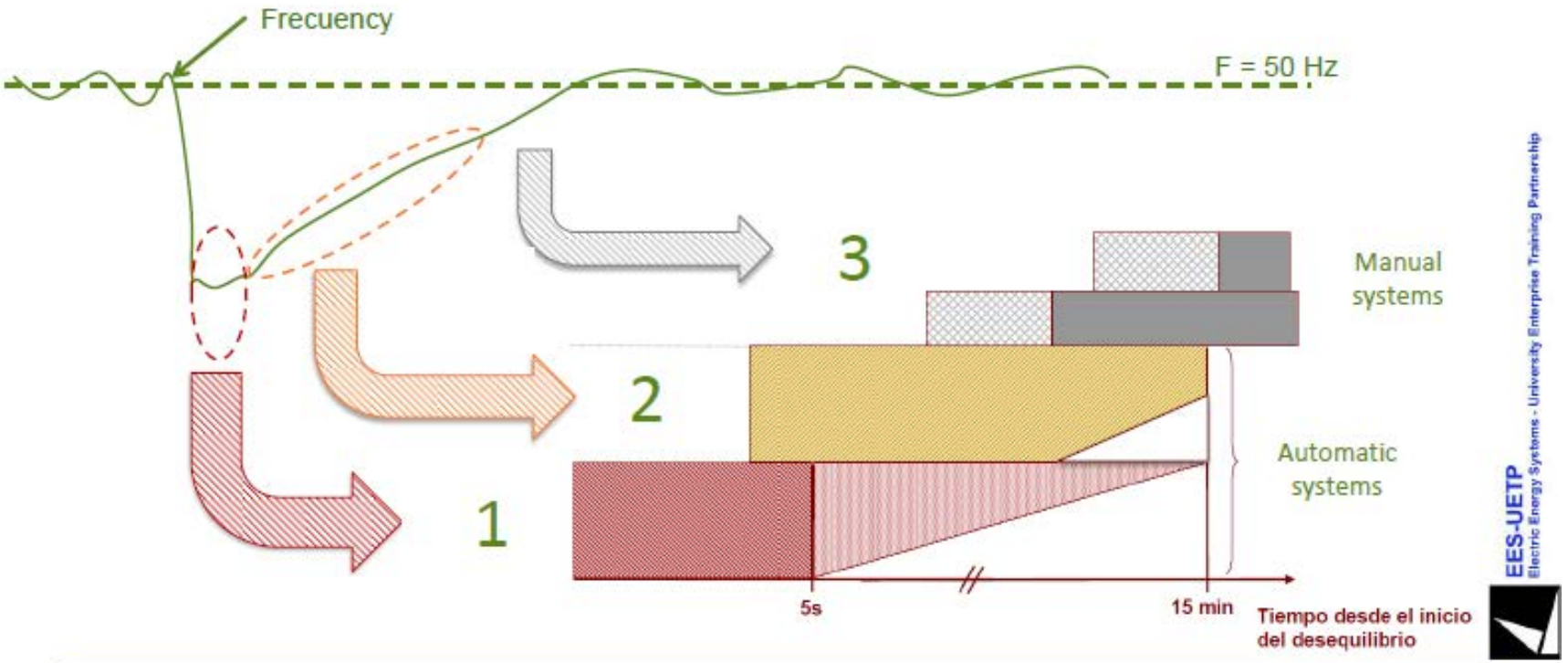
Long term: adequacy
Mid/short term: guarantee of supply, firmness
Real-time: security of supply



Introduction

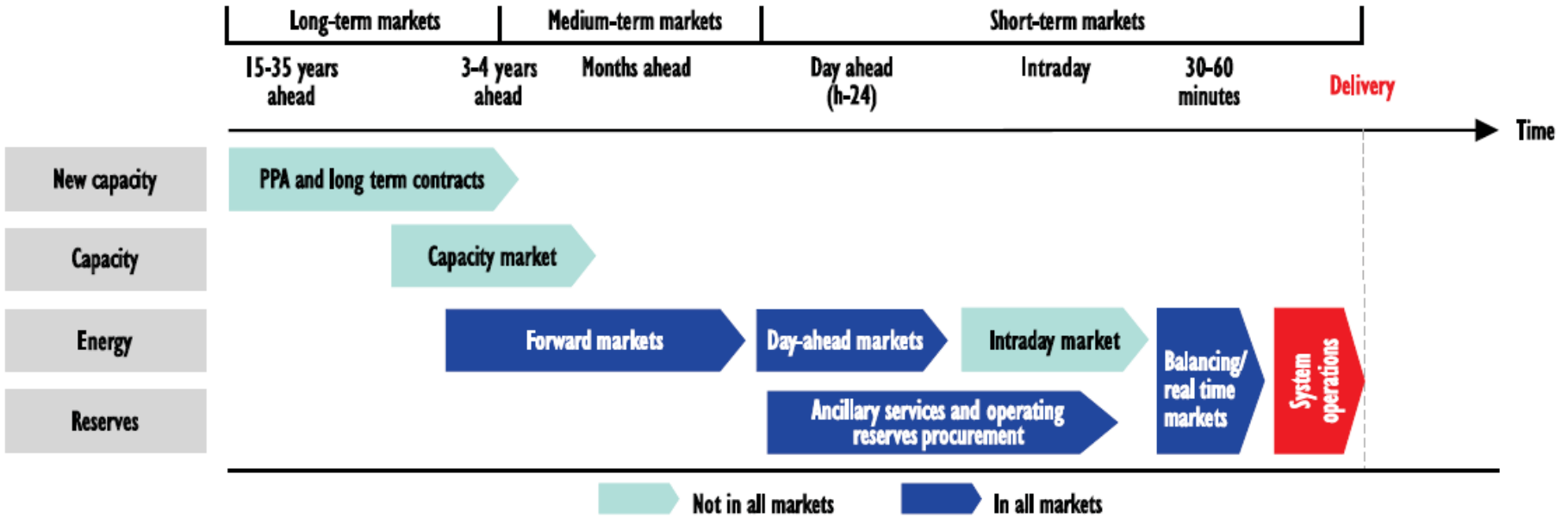
Balancing Services.

The System Operator uses different tools to ensure the technical functioning of the system. One of the most common tools is based on controlling the frequency of the system.



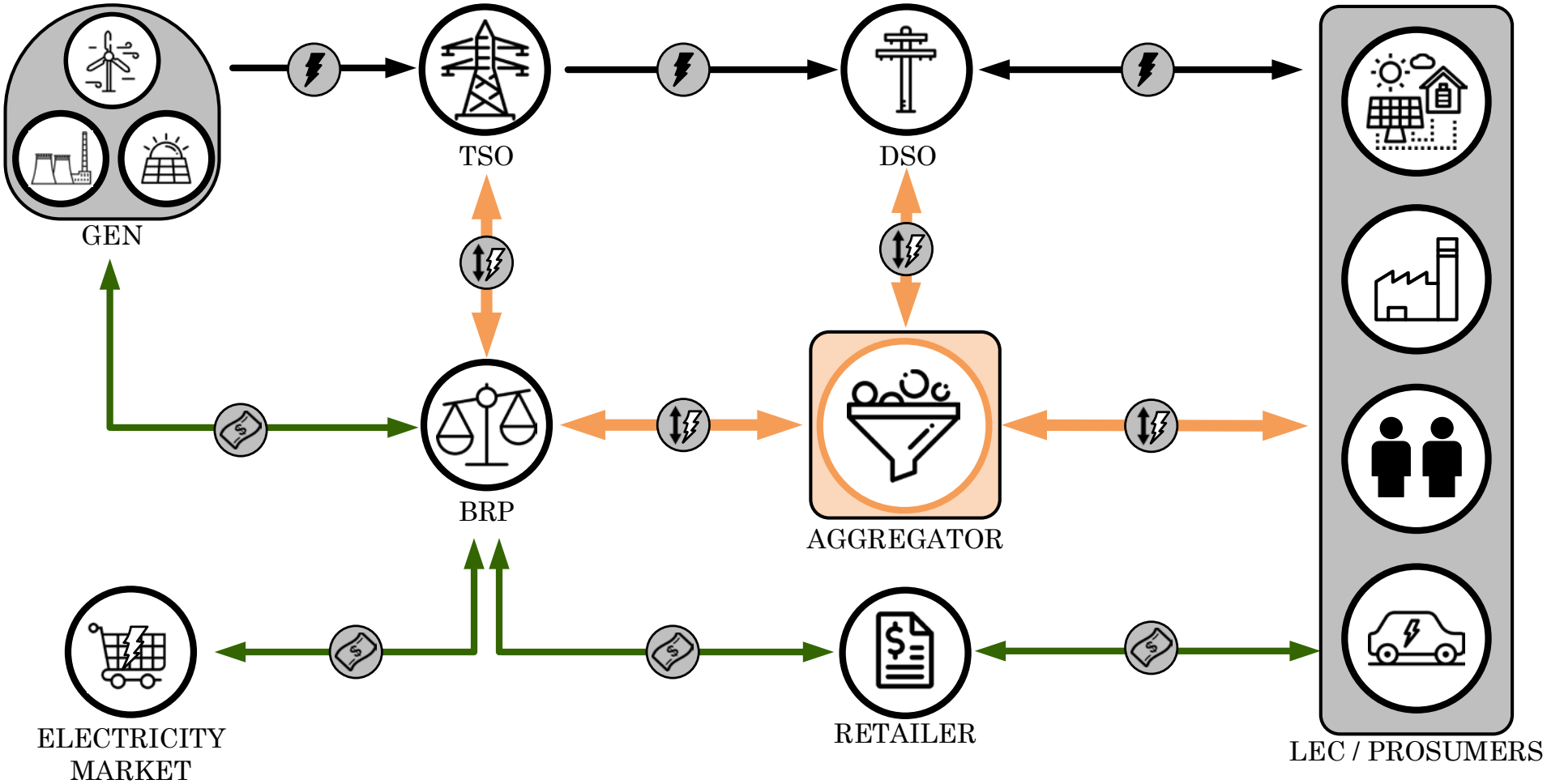
Introduction

Figure 1.8 • Overview of different building blocks of electricity markets



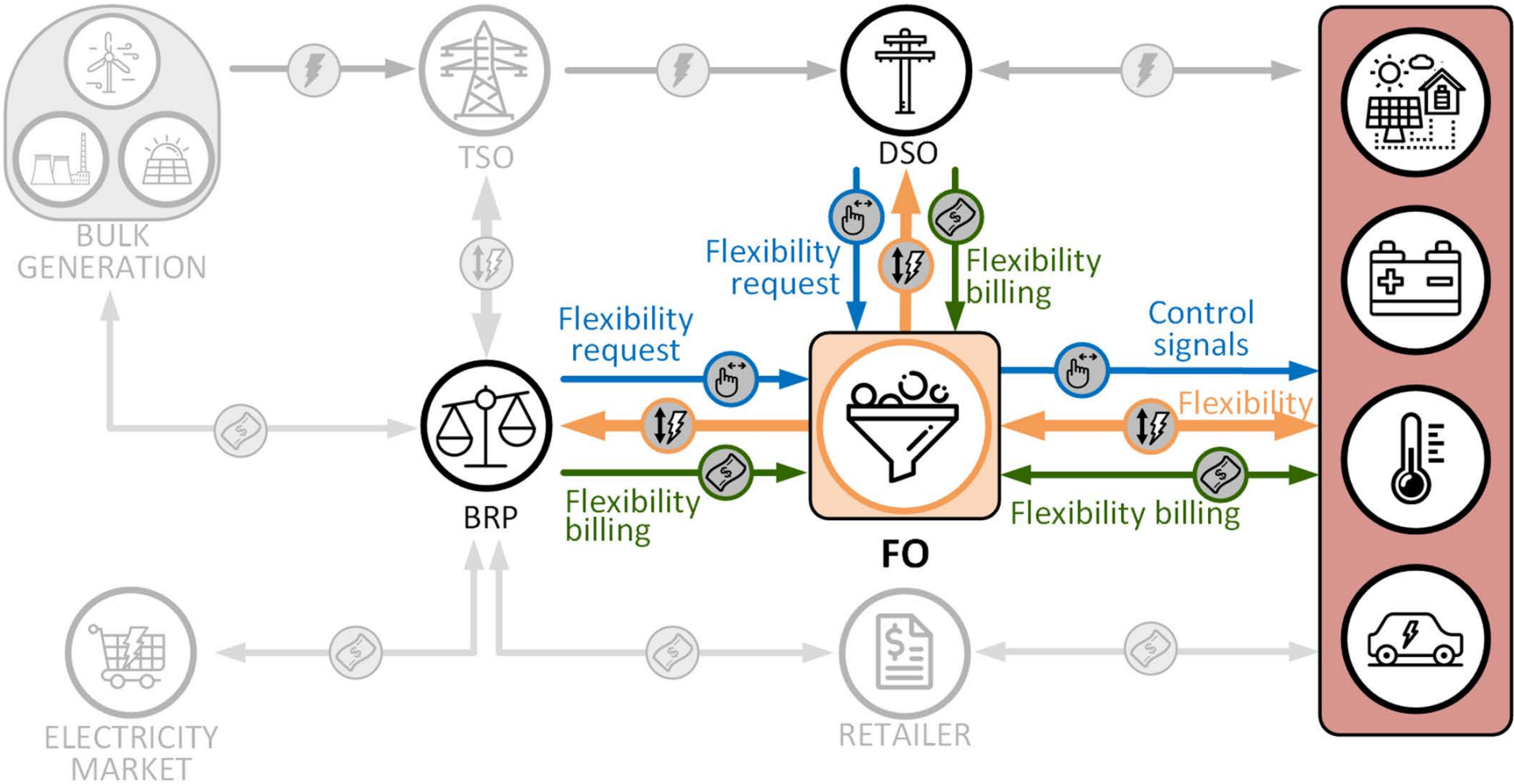
Key point: A suite of interrelated markets is used to match generation and load in the short, medium and long term.

Introduction



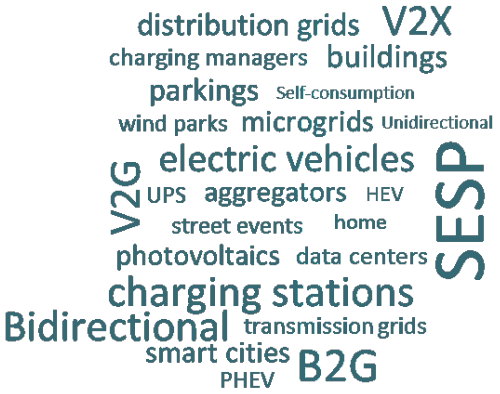
Source: Olivella-Rosell, P., Lloret-Gallego, P., Munné-Collado, Í., Villafafila-Robles, R., Sumper, A., Ottessen, S., Rajasekharan, J., Bremdal, B.; "Local Flexibility Market Design for Aggregators Providing Multiple Flexibility Services at Distribution Network Level", V 11, N 4, P 822, Energies 1996-1073, doi:10.3390/en11040822, https://www.mdpi.com/1996-1073/11/4/822

Introduction



Source: Olivella-Rosell, P., Lloret-Gallego, P., Munné-Collado, Í., Villafafila-Robles, R., Sumper, A., Ottessen, S., Rajasekharan, J., Bremdal, B.; "Local Flexibility Market Design for Aggregators Providing Multiple Flexibility Services at Distribution Network Level", V 11, N 4, P 822, Energies 1996-1073, doi:10.3390/en11040822, https://www.mdpi.com/1996-1073/11/4/822

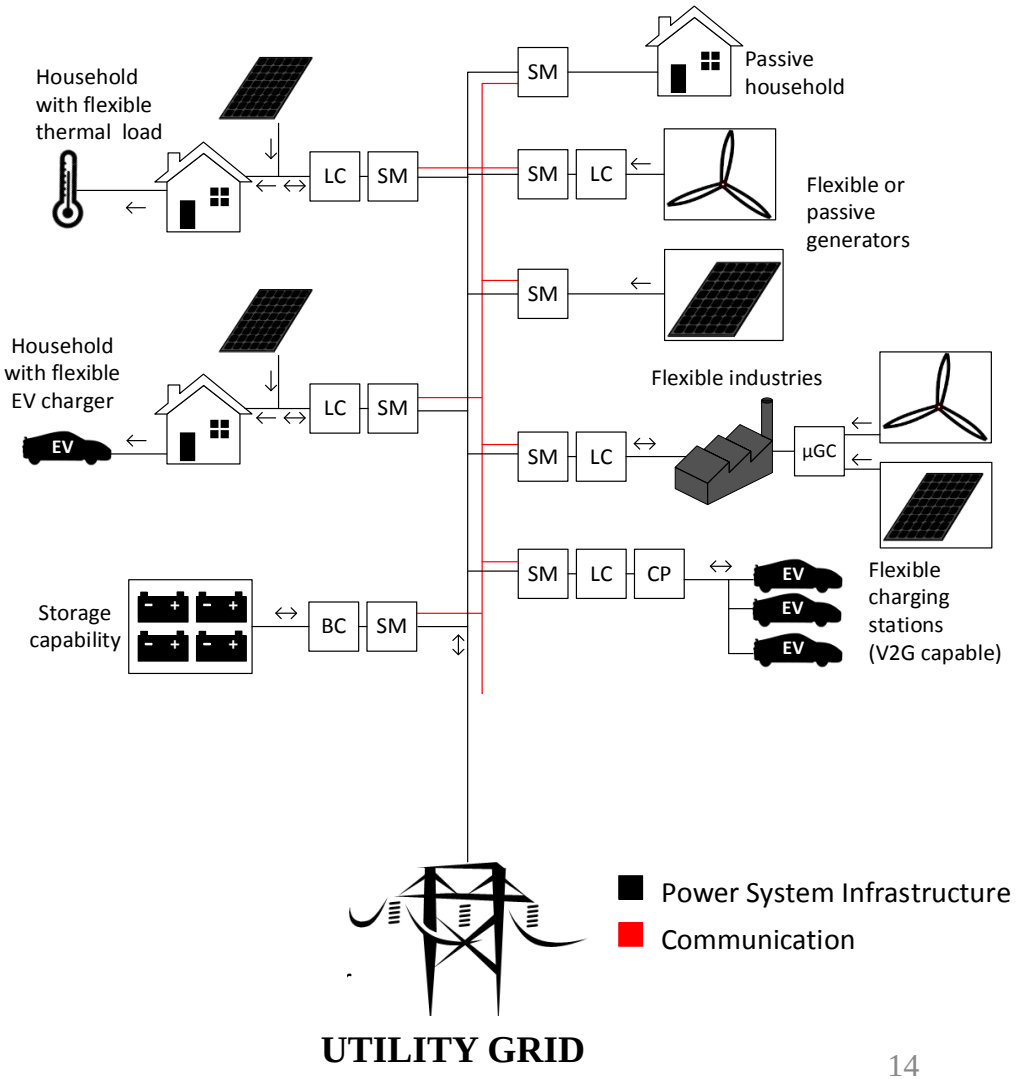
System architecture



System architecture

Why?

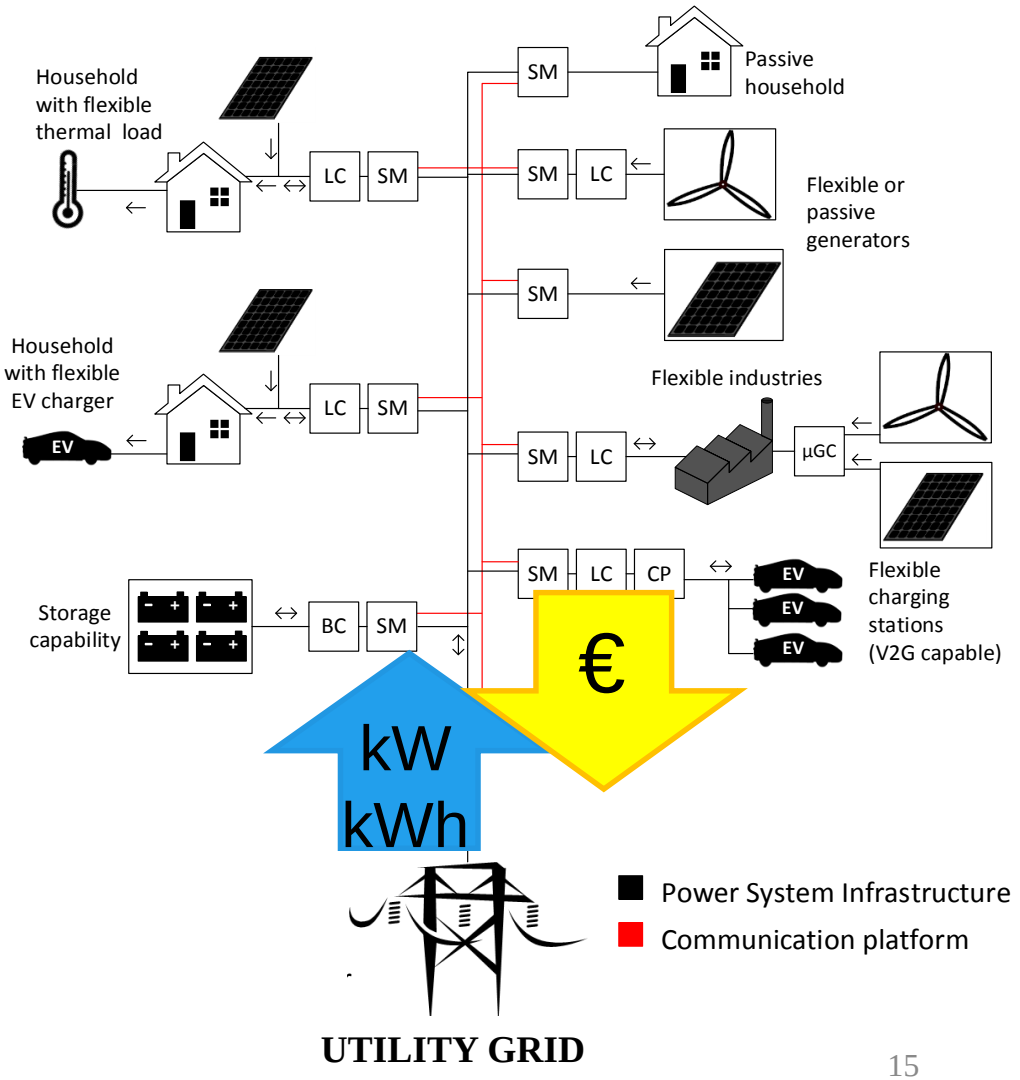
- Traditional business:
  - Centralized and hierarchical
  - Large power plants
  - Passive consumers



System architecture

Why?

- Traditional business:
  - Centralized and hierarchical
  - Large power plants
  - Passive consumers



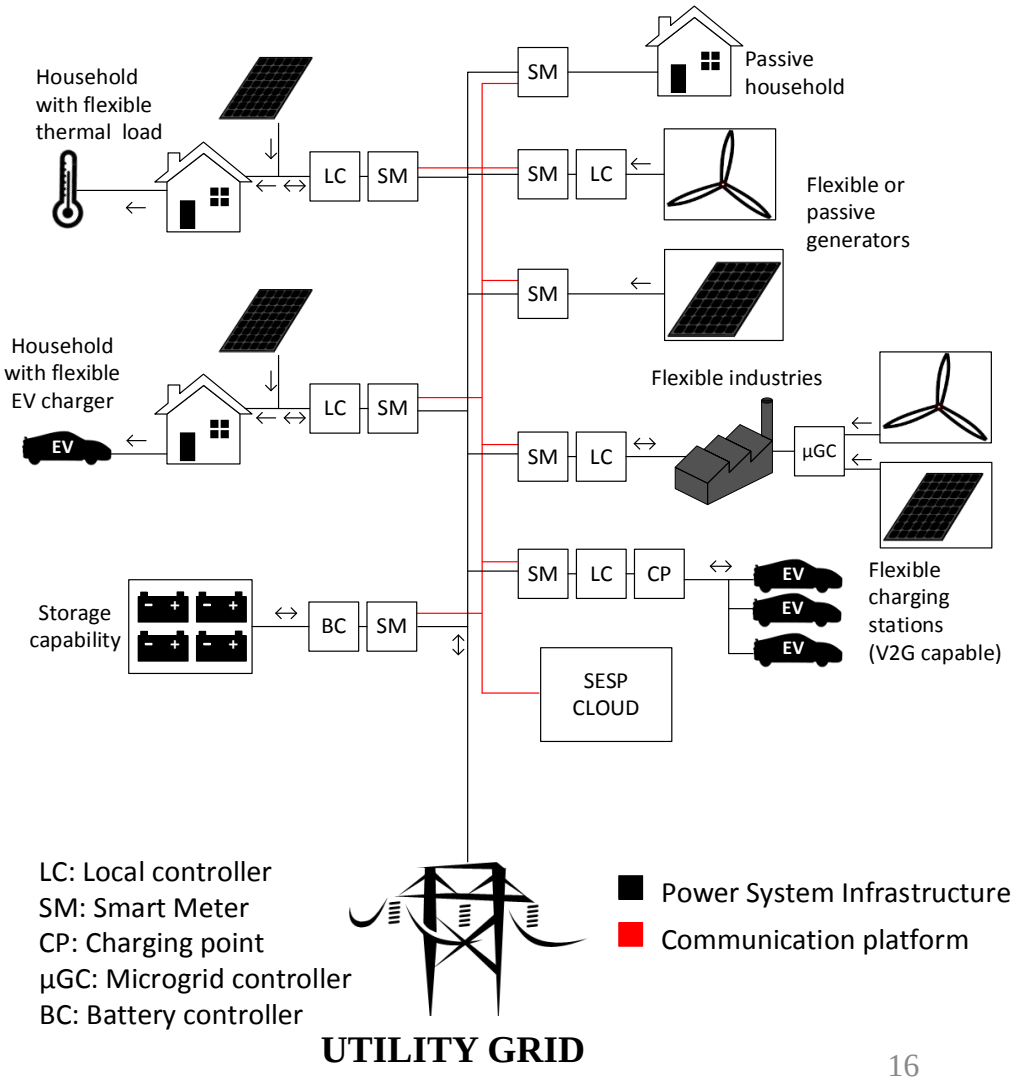
System architecture

Why?

- Smart grid elements are already developed and deployed:

DISTRIBUTED ENERGY RESOURCES (DERs)

- local renewable generation (PV, WP)
- EV (V2G)
- Storage systems
- Demand response
- ITCs
- Power electronics
- Microgrids



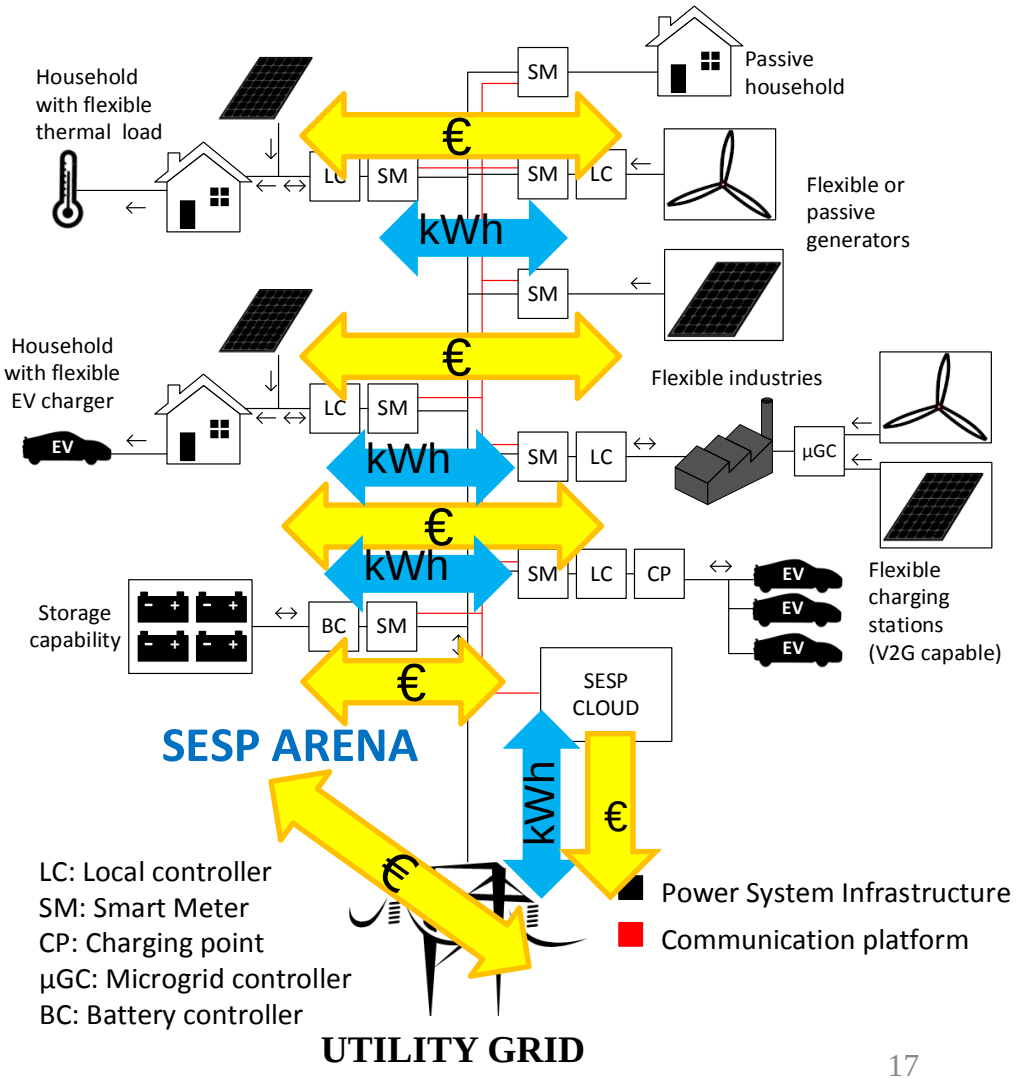
System architecture

Why?

- Smart grid elements are already developed and deployed:

DISTRIBUTED ENERGY RESOURCES (DERs)

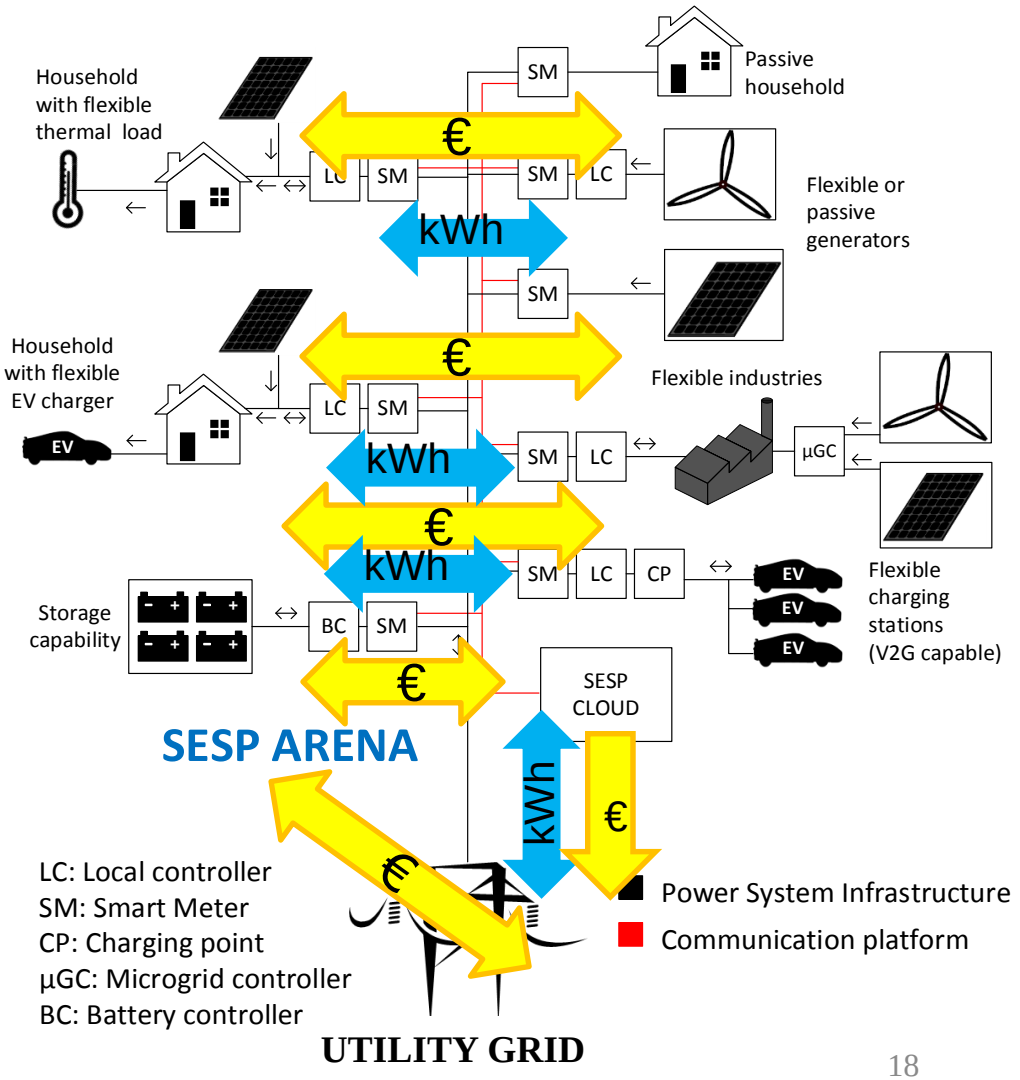
- local renewable generation (PV, WP)
- EV (V2G)
- Storage systems
- Demand response
- ITCs
- Power electronics
- Microgrids



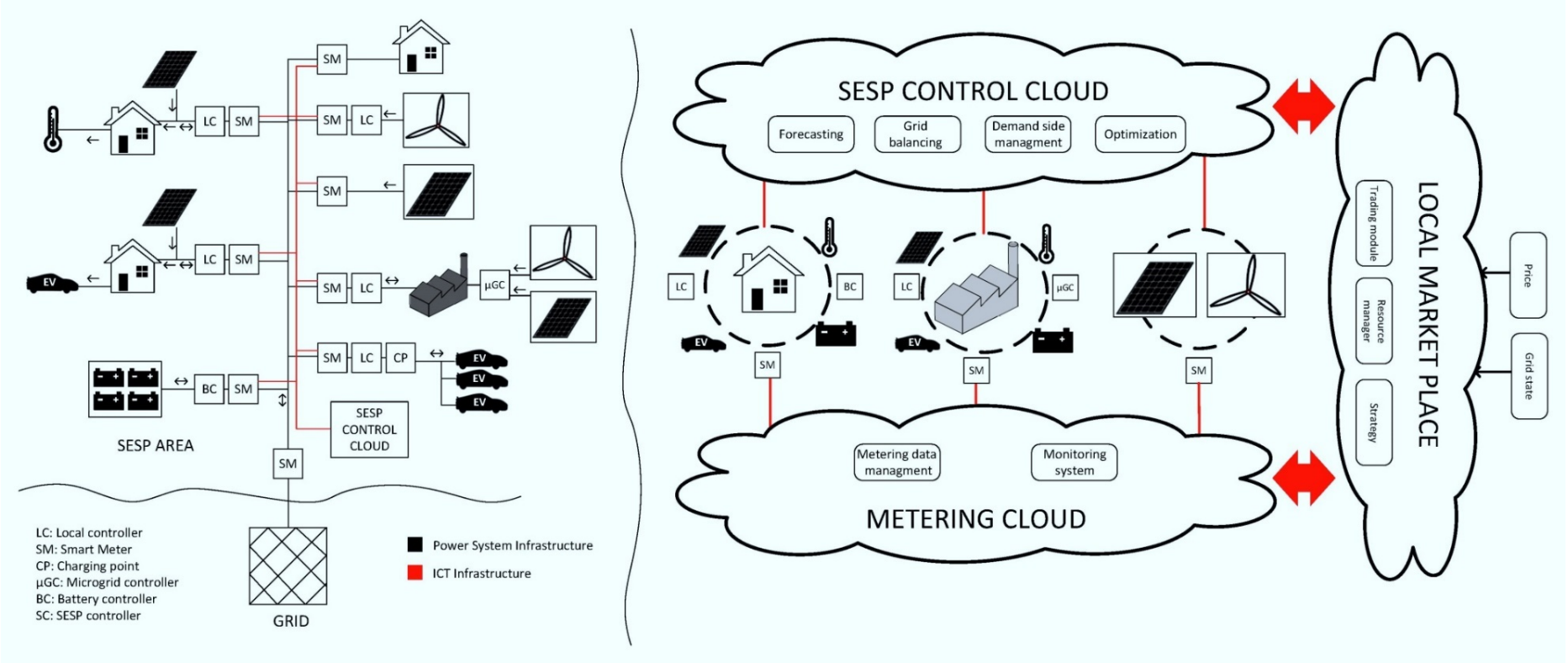
System architecture

Why?

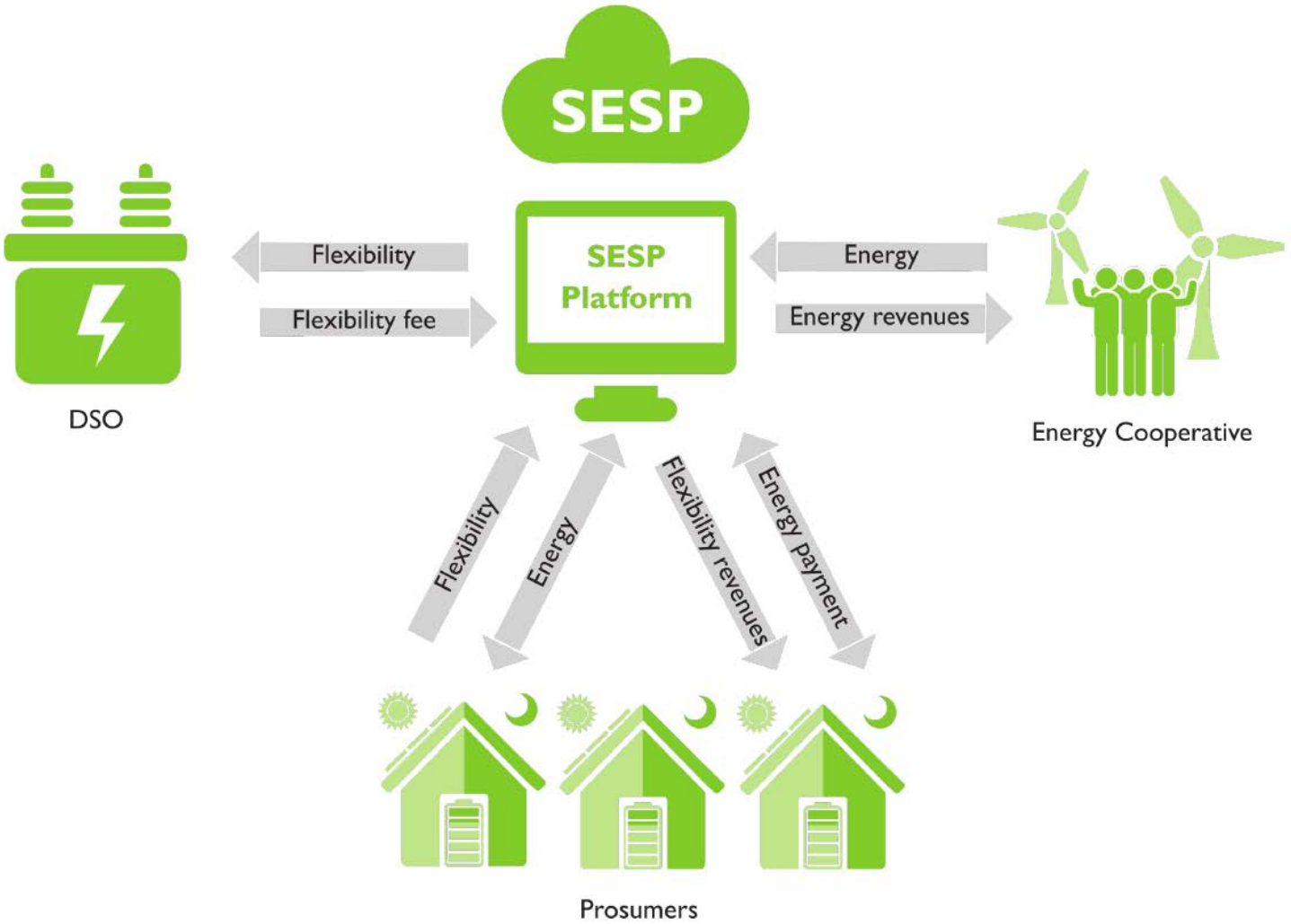
- Interaction of participants: consumers, producers, prosumers, community storage units, distribution system operators (DSO).
- Allowing deployment of a platform for negotiation and trading of energy and flexibility in a community
  - ***Smart Energy Service Provider*** (**SESP**) EMPOWER
  - ***Flexibility Operator*** (**FO**) INVADE



EMPOWER: New local market model



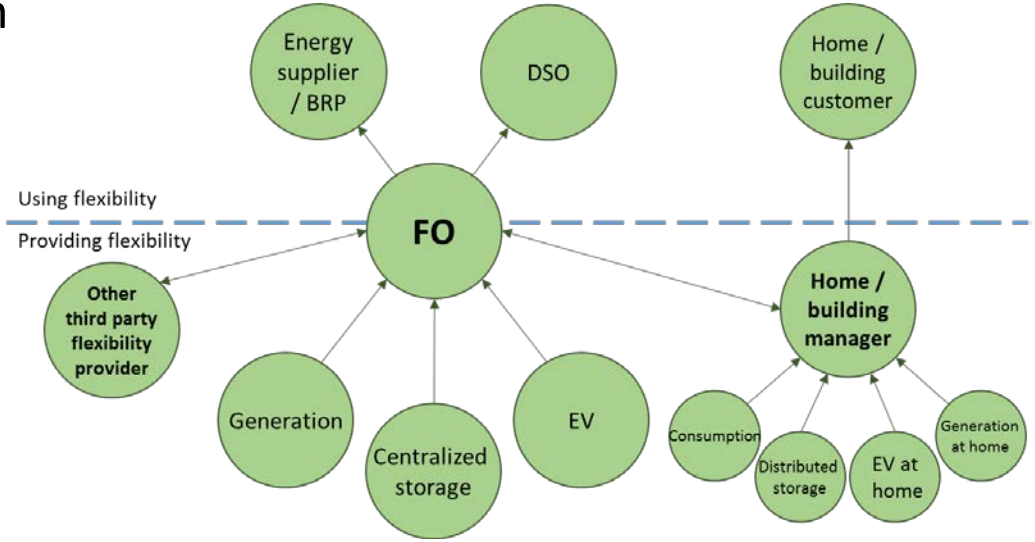
EMPOWER: New local energy business model

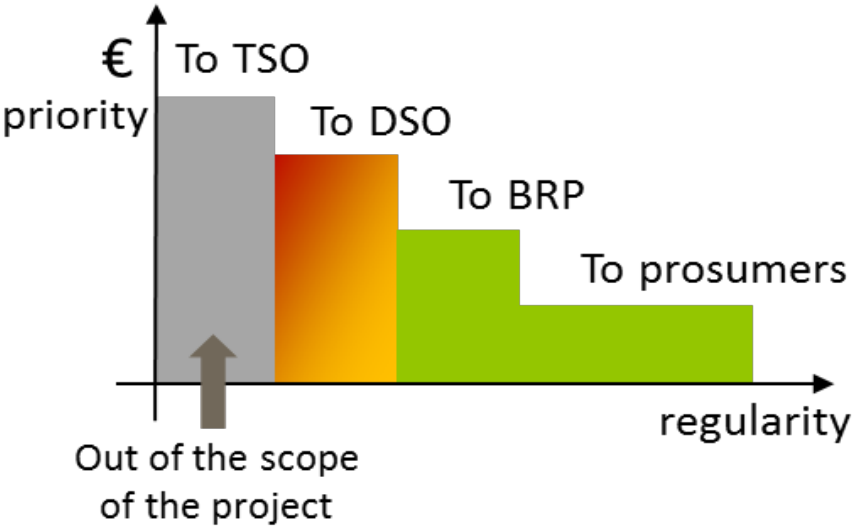


Source: P. Olivella-Rosell, E. Bullich-Massagué, M. Aragüés-Peñalba, A. Sumper, S. Ottesen, J.A. Vidal-Clos, R. Villafáfila-Robles; "Optimization problem for meeting distribution system operator requests in local flexibility markets with distributed energy resources", Applied Energy, Volume 210, 2018, Pages 881-895, ISSN 0306-2619, https://doi.org/10.1016/j.apenergy.2017.08.136.

INVADE: New flexibility operator

- The system is a peer-to platform based on direct control of demand and supply. The flexibility operator (FO) takes decisions based on flexibility contracts. Third party platforms can be integrated.
- Flexibility resources to be controlled are:
  - Batteries
  - Electric vehicles
  - Photovoltaic panels
  - Water heaters
  - Heat pumps
- Flexibility services for:
  - End-users/prosumers reducing the electricity bill
  - BRP to reduce imbalance penalties
  - DSO to control grid congestions

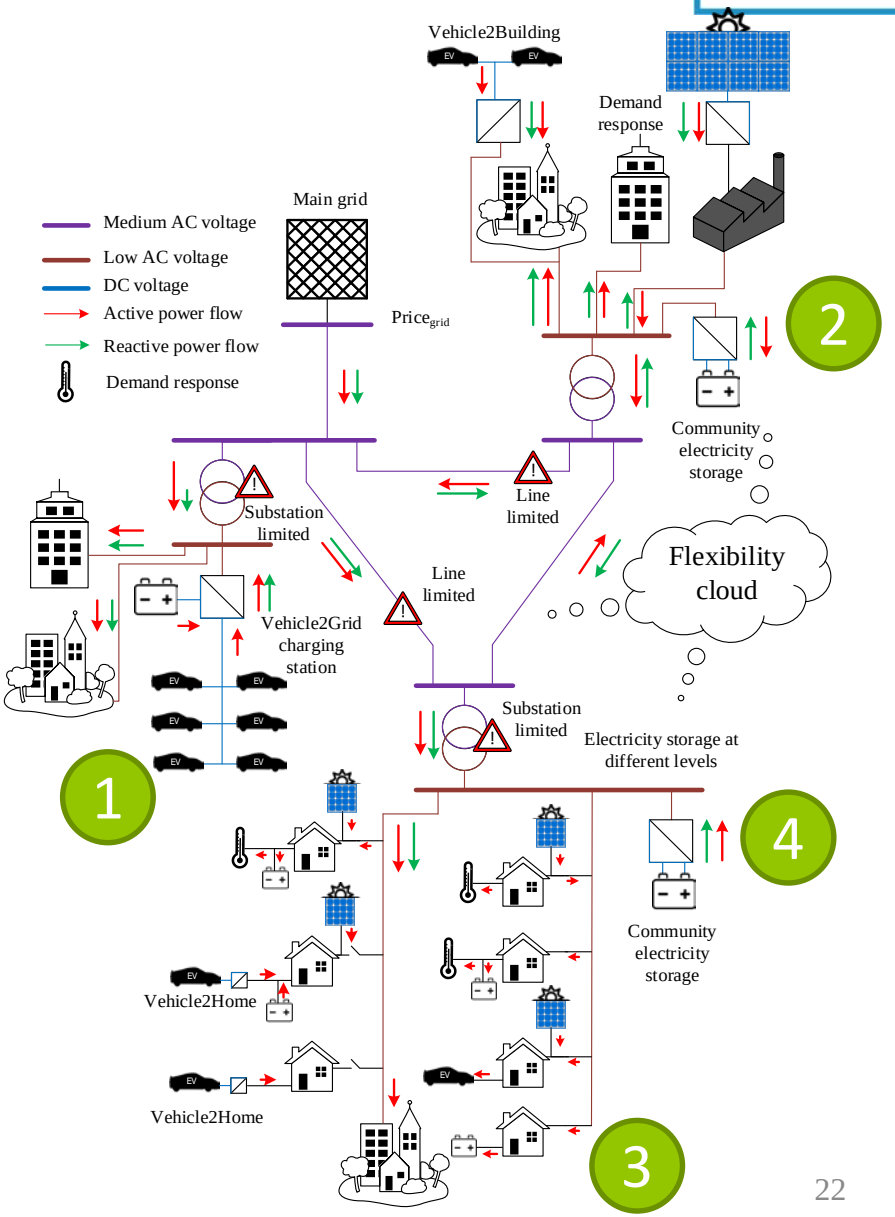




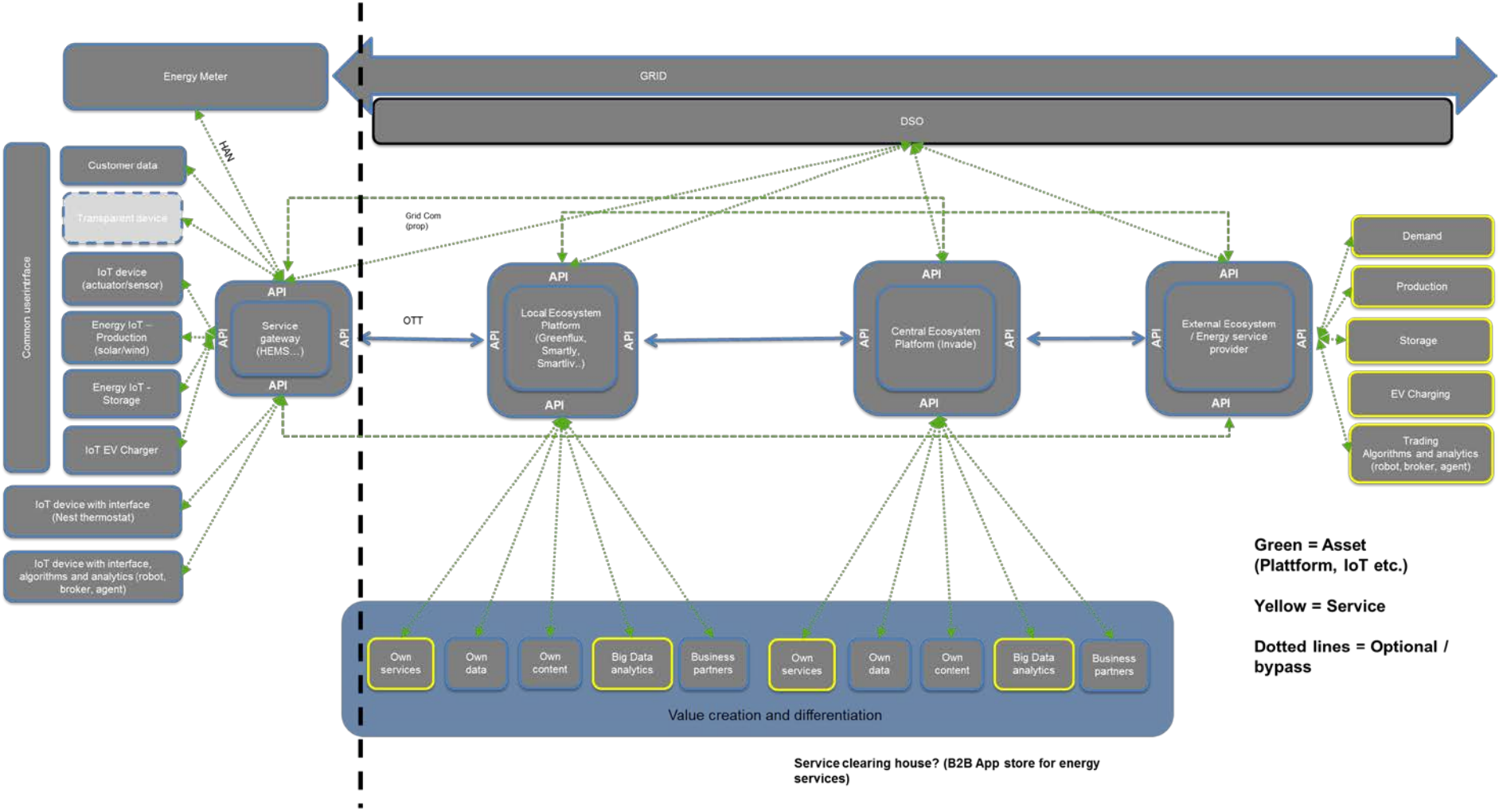
INVADE: Use cases

- Use cases (UC):

1. Mobile energy storage using EVs for V2G, V2B and V2H operations
2. Centralized energy storage using an array of batteries at the sub-station or street level
3. Distributed energy storage using individual batteries at the household level
4. Hybrid level energy storage solutions addressing a combination of use cases 2 and 3



INVADE: New ecosystem based business model combining energy and ICT



System architecture

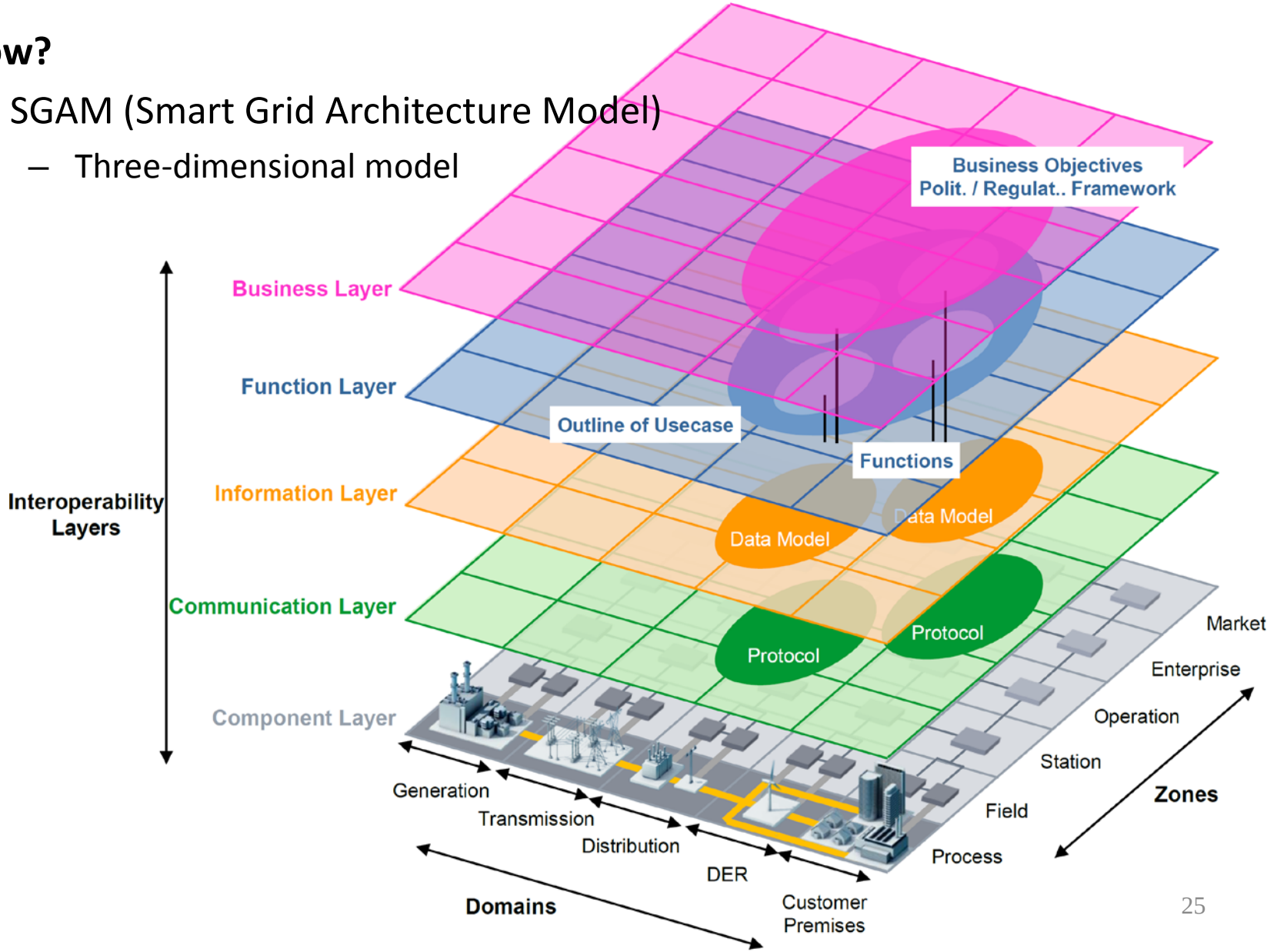
- Local Smart Grids Architecture aims to define **relationships** between the different agents:
  - **Mapping technically** business models and local market.
  - Design of **communication and physical connections** of the prosumers to the control and market cloud
  - Design of **software architecture of the control and market clouds**

- **How**
  - **to define the relationships between the different participants?**
  - **to specify the control, the market and the communications interactions?**

System architecture

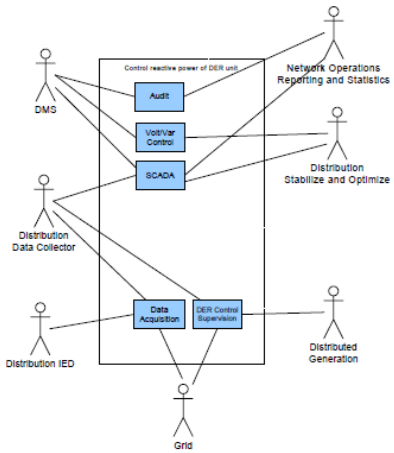
How?

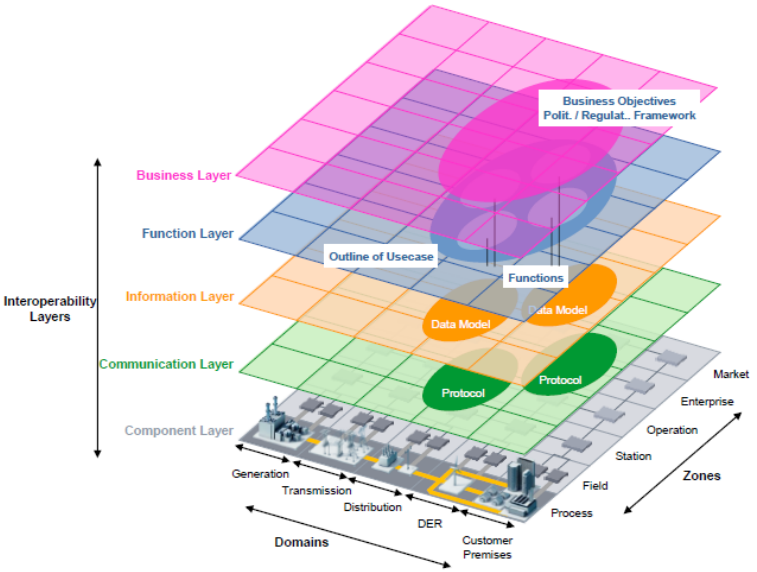
- SGAM (Smart Grid Architecture Model)
  - Three-dimensional model



System architecture

Application of SGAM to EMPOWER





Use Case Description → Business Layer Analysis → Function Layer Analysis → Component Layer Analysis → Information Layer Analysis → Communication Layer Analysis

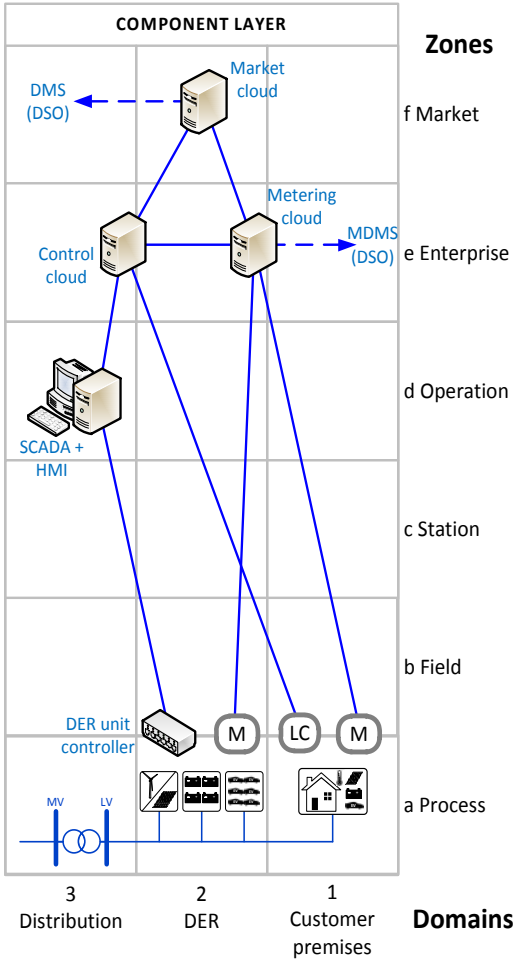
Communications system

Market cloud technical architecture

Control cloud technical architecture

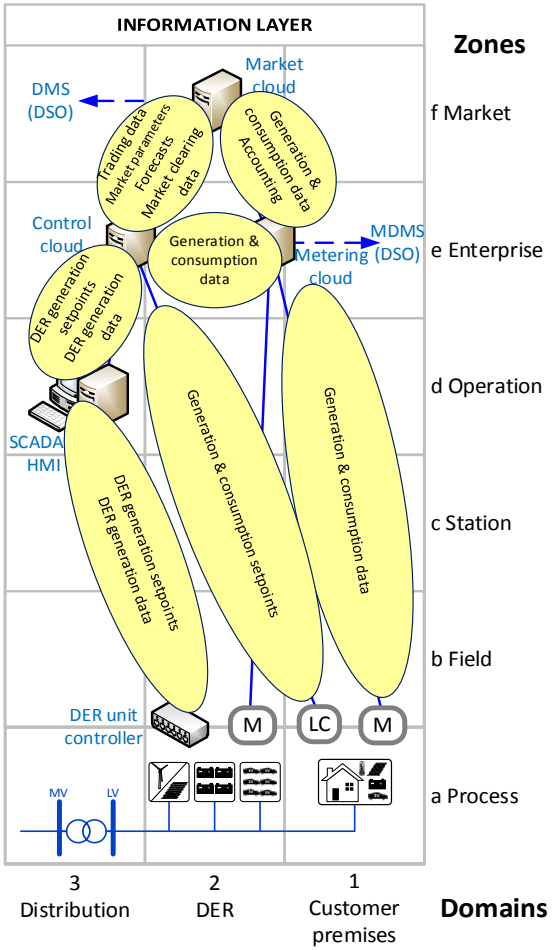
Communication and physical connections

SGAM component layer

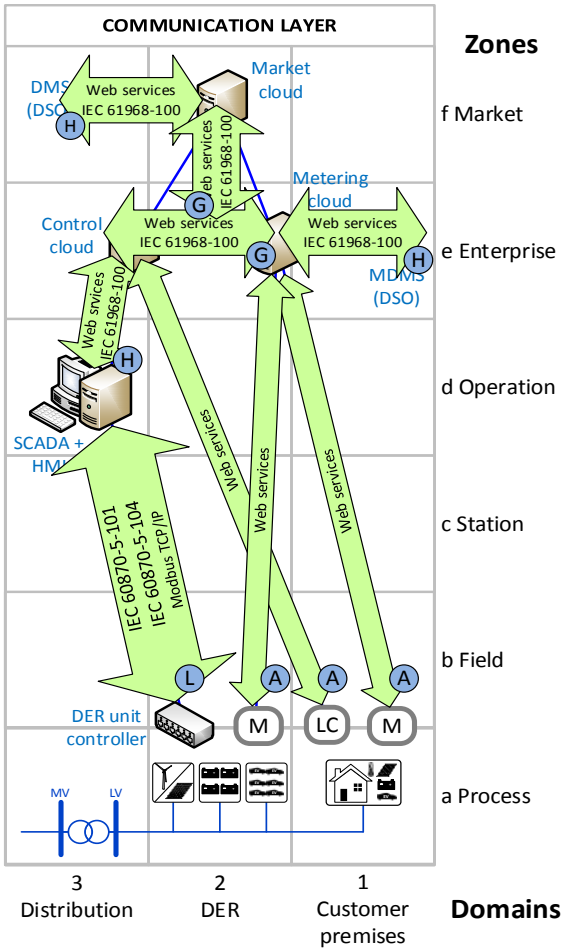


No cooperation with DSO

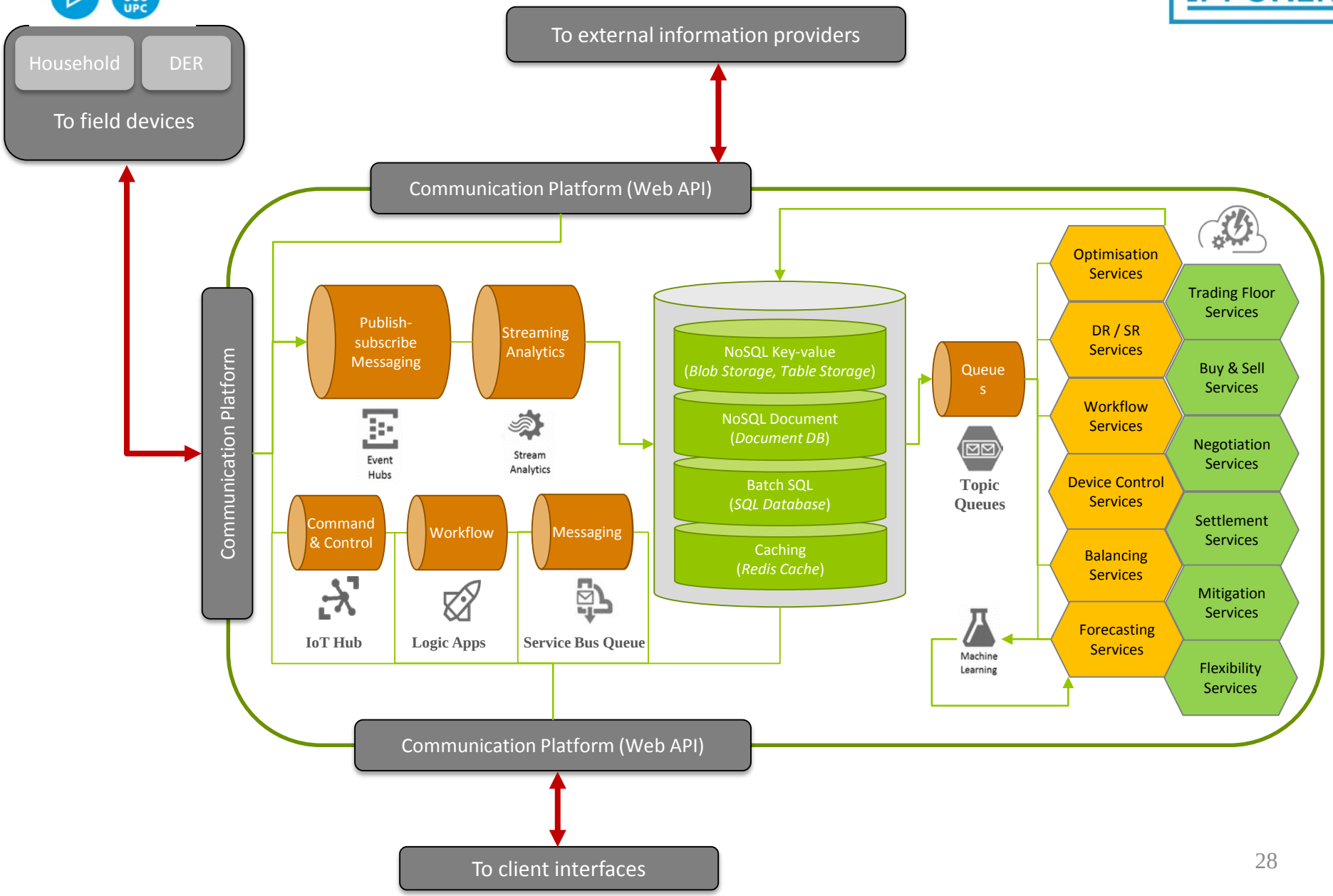
SGAM generic information layer



SGAM generic communication layer

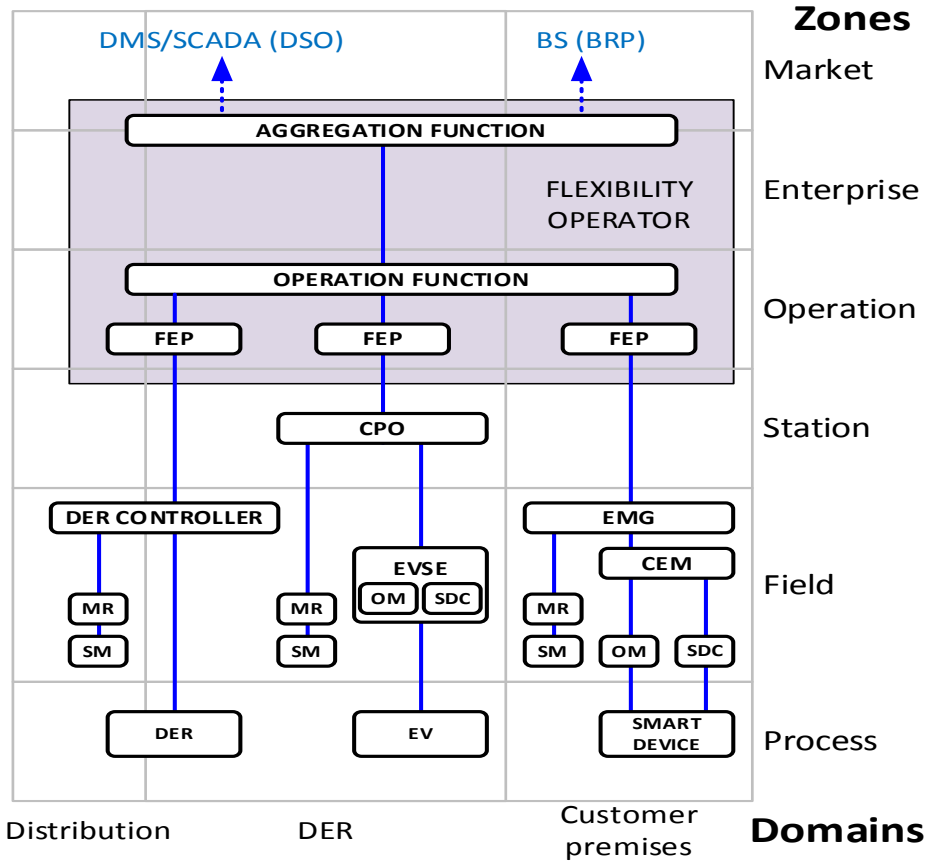


EMPOWER ICTs system

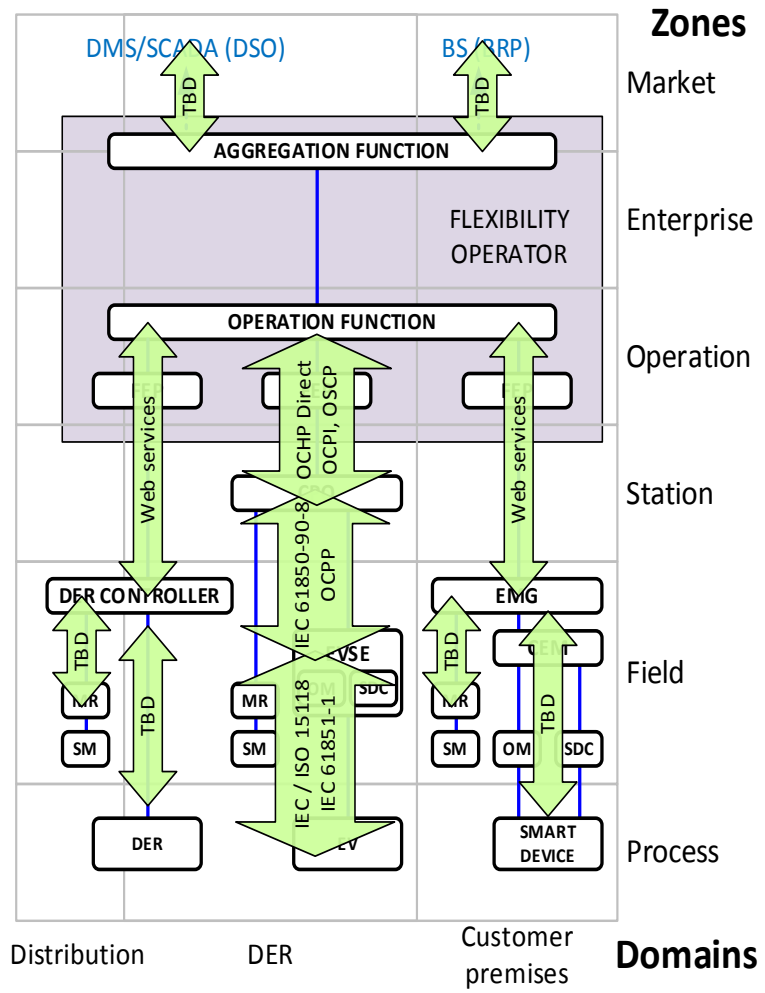


INVADE generic SGAM layers

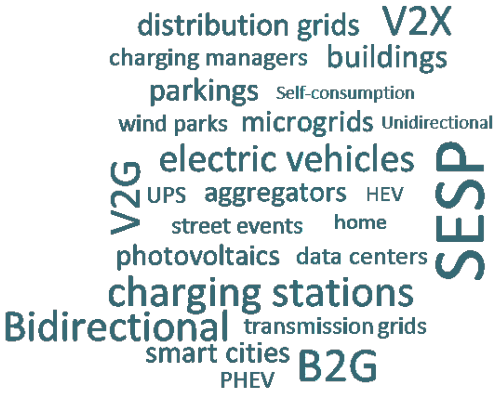
Generic component SGAM layer



Generic communication SGAM layer



Business model

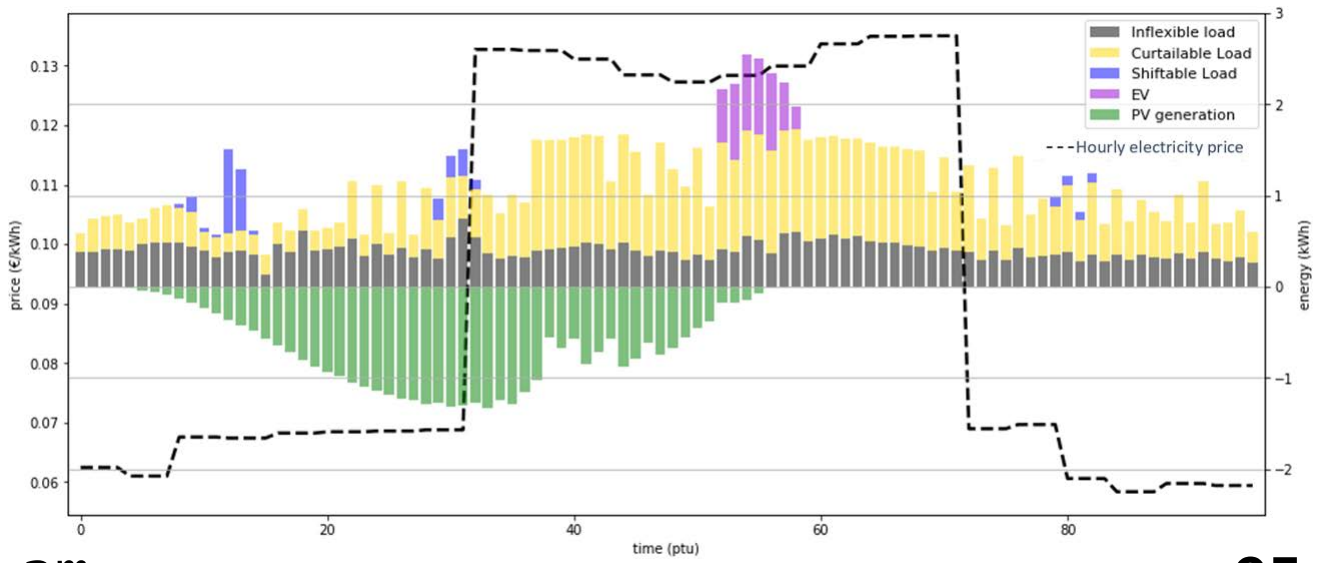


Flexibility services

Flexibility customer	Flexibility services INVADE	Description (Flexibility usage)
DSO	Congestion management	Avoiding the thermal overload of system components by reducing peak loads where failure due to overloading may occur.
	Voltage / Reactive power control	Using load flexibility by increasing the load or decreasing generation is an option to avoid exceeding the voltage limits. Voltage control is typically requested when solar PV systems generate significant amounts of electricity.
	Controlled islanding	Preventing supply interruption in a given grid section when a fault occurs in a section of the grid feeding into it
BRP	Day–ahead portfolio optimization	Shifting loads from a high-price time interval to a low-price time interval before the day-ahead market closure. It enables the BRP to reduce its overall electricity purchase costs
	Intraday portfolio optimization	Enabling value creation on intraday market, equivalent to the day-ahead market
	Self-balancing portfolio optimization	Reducing imbalance by the BRP within its portfolio to avoid imbalance charges. The BRP does not actively bid on the imbalance market using its load flexibility, but uses it within its own portfolio.
Prosumer	ToU optimization	Flexibility from high-price intervals to low-price intervals or even complete load shedding during periods with high prices.
	Maximum power control	Reducing the maximum load (peak shaving) that the Prosumer consumes within a predefined duration (e.g., month, year), either through load shifting or shedding.
	Self-balancing	Value is created through the difference in the prices of buying, generating, and selling electricity (including taxation if applicable).
	Controlled islanding	Preventing supply interruption in a household/building during grid outages.

Flexibility management for prosumers

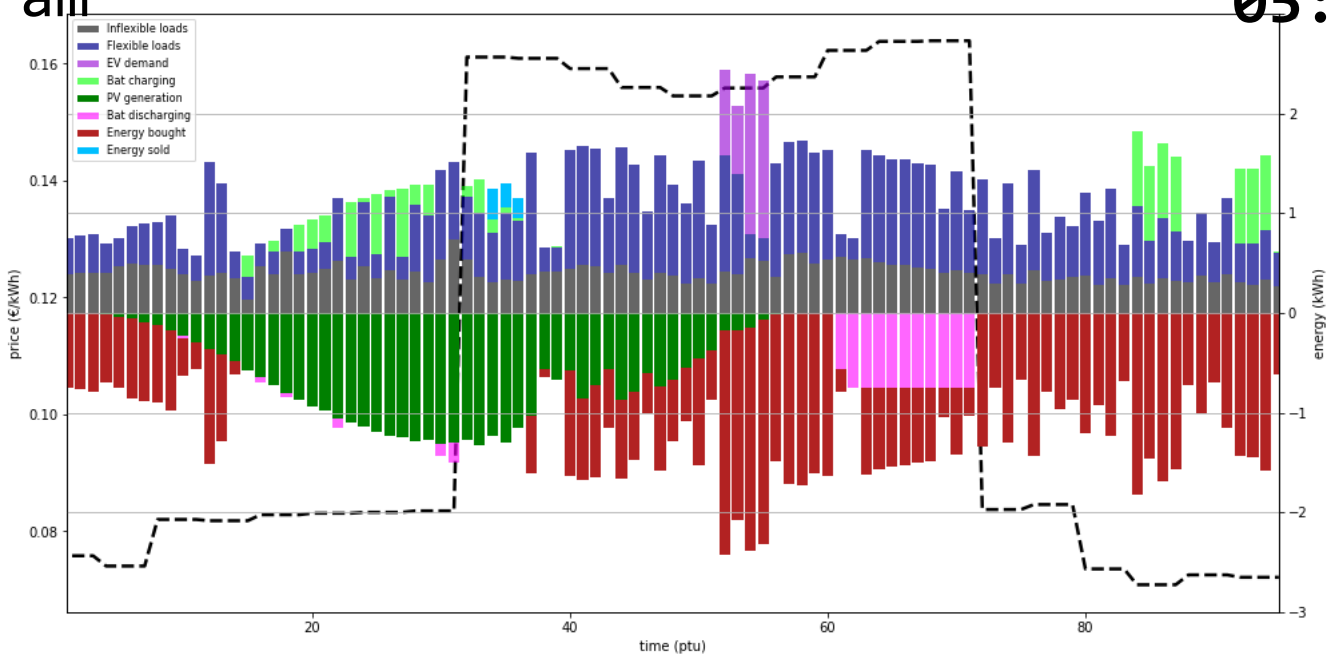
Base line



06:00 am

05:59 am

HEMS



Flexibility management for prosumers

OBJECTIVE FUNCTION: **minimizing** the prosumer **electricity bill**, having into account his comfort level and maximizing self-consumption as well.

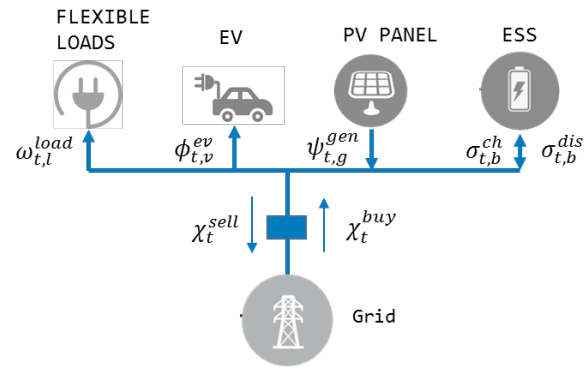
Prosumer BUYS/SELLS electricity from/to the grid

$$\min o.f. = \sum_{t\epsilon T}\left(P_t^{retail,buy}\cdot\chi_t^{buy}\right)P^{taxes} - \sum_{t\epsilon T}\left(P^{retail,sell}\cdot\chi_t^{sell}\right) + flexibility\ penalization$$

Param Var Param — Cost of electricity bought to the grid (PVPC tariff)

Param Var — Revenues for selling electricity back to the grid

Flexibility (discomfort) penalization



$$flexibility\ penalization = \zeta^{battery,ch} + \zeta^{ev} + \zeta^{gen,d} + \zeta^{gen,r} + \zeta^{load,d} + \zeta^{load,r} + \zeta^{load,p} + \zeta^{load,v}$$

Battery

$$\zeta^{battery,ch} = \sum_{t\epsilon T}\sum_{b\epsilon B} P_b^{b,ch}\cdot\sigma_{t,b}^{ch}$$

PV Generation

$$\zeta^{gen,d} = \sum_{t\epsilon T}\sum_{g\epsilon G^d} P_g^{gen,d}\cdot\left(W_{t,g}^{gen,d} - \psi_{t,g}^{gen,d}\right)$$

$$\zeta^{gen,r} = \sum_{t\epsilon T}\sum_{g\epsilon G^r} P_g^{gen,r}\cdot\left(W_{t,g}^{gen,r} - \psi_{t,g}^{gen,r}\right)$$

EV charging point

$$\zeta^{ev} = \sum_{i\epsilon I^{ev}}\sum_{v\epsilon V} P_v^{ev}\cdot\rho_{i,v}^{ev}$$

Loads

$$\zeta^{load,d} = \sum_{t\epsilon T}\sum_{l\epsilon L^d} P_l^{load,d}\cdot\left(\delta_{t,l}^{start,d} + \delta_{t,l}^{run,d}\right)$$

$$\zeta^{load,r} = \sum_{t\epsilon T}\sum_{l\epsilon L^r} P_l^{load,r}\cdot\left(\delta_{t,l}^{start,r} + \delta_{t,l}^{run,r}\right)$$

$$\zeta^{load,p} = \sum_{i\epsilon I^p}\sum_{l\epsilon L^p} P_l^{load,p}\cdot\sum_{n=0}^{T_{i,l}^{end,p}-V_{i,l}^{end,p}}\gamma_{i,l,n}\cdot n$$

$$\zeta^{load,v} = \sum_{i\epsilon I^v}\sum_{l\epsilon L^v} P_v^{load,v}\cdot\rho_{i,l}^{load}$$

CONSTRAINTS: Restrictions of the Prosumer model.

- Energy balance: generation = consumption

$$\sum_{g\epsilon G^d}\psi_{t,g}^{gen,d} + \sum_{g\epsilon G^r}\psi_{t,g}^{gen,r} + \sum_{b\epsilon B}\sigma_{t,b}^{dis} + \chi_t^{buy} =$$

$$= \chi_t^{sell} + \sum_{b\epsilon B}\sigma_{t,b}^{ch} + \sum_{v\epsilon V}\phi_{t,v}^{ch} + \sum_{l\epsilon L^d}\omega_{t,l}^{load,d} + \sum_{l\epsilon L^p}\omega_{t,l}^{load,p} + \sum_{l\epsilon L^r}\omega_{t,l}^{load,r} + \sum_{l\epsilon L^v}\omega_{t,l}^{load,v}$$

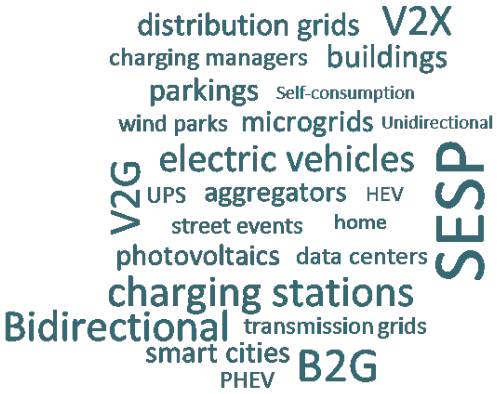
- Maximum energy imported/exported from/to the grid

$$\chi_t^{buy} \le X^{max,import}/N$$

$$\chi_t^{sell} \le X^{max,export}/N$$

Source: Barja, S.; Olivella, P.; Lloret-Gallego, P.; R. Villafafila-Robles; "Intelligent flexibility management for prosumers: development of algorithms for the energy management of electric vehicles, loads, generators and batteries ", Proceedings, pp 166-190, I Ibero-American Congress of Smart Cities (ICSC-CITIES 2018), 26-28/9/2018, Soria, Spain.

Conclusions



Conclusions

- Developing a completely new market system for trading energy and flexibility locally
  - Most of the energy consumers use will be produced where it is used
  - Power electronics and automation facilitates flexibility
- Increased feed-in of decentralized renewable energy
  - Central power supply will only be used as a reserve
  - Power electronics facilitates proper operation of the system
- Based on Big Data, Cloud Computing and Artificial Intelligence
  - ICTs allow new roles in the energy market (prosumers, aggregators, SESP, ESCOs, …) & many new business models.
  - Power electronics facilitates link between cloud and physical electricity delivery

http://empowerh2020.eu/

https://twitter.com/EmpowerH2020

https://www.linkedin.com/groups/8342696

https://www.facebook.com/pg/Empower-H2020-project-1702049186677133/about/?tab=page_info

https://www.youtube.com/channel/UCsTRAP13mzIkOiGJIpjUFfA

This project has received funding from the *European Union's Horizon 2020 Research and Innovation programme* under Grant Agreement No 646476.

http://h2020invade.eu/

https://twitter.com/INVADEH2020

https://www.linkedin.com/company/18070383/

https://www.facebook.com/invadeh2020

https://www.youtube.com/channel/UCMXP8Re01KixtAT4F8ZPtzA

This project has received funding from the *European Union's Horizon 2020 Research and Innovation programme* under Grant Agreement No 731148.