# Urban Electrical Energy Systems

Projekt „Leonardo“

Interdisziplinäre Lehre:
Meeting Global Challenges

Ein Projekt der RWTH

Prof. Ferdinanda Ponci, Ph.D.
Monitoring and distributed control for power systems

ACS | Automation of Complex Power Systems

E.ON Energy Research Center

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# The impact of urban energy systems

- EU urban areas
  - host ~ 75% of EU population
  - cause 60-80% of global energy consumption and $CO_2$ emissions
- Climate change ←→ cities
- Other challenges: housing, pollution, mobility, health, aging, social segregation, … ←→ energy systems
- Directions
  - More renewables
  - More resilience
  - More efficiency
  - Less emissions
  - Sustainability
  - Circularity

The Future of Cities, JRC Report
EUR 29752 EN

Go to **www.menti.com** and use the code **3801 6252**

# The complex world of urban energy systems



- Energy used in many forms
  - Electricity
  - Heat, Gas, Oil..
- … and for many uses, in
  - Residential and commercial buildings
  - Industry
  - Mobility
  - Communication
- Infrastructures are coupled:
  - Electricity&gas
  - Electricity&mobility
  - Electricity&water

  And also of:
  - Waste management, recycling,..

https://setis.ec.europa.eu/system/files/citizens_summary.pdf



and above all coupled with **society and people**



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# The context – Power System transformation



| Before | Fundamental Changes | Atfer |
|---|---|---|

**Before**

- Generation highly concentrated
- Generation has the inertia or large rotating masses
- System is quasi-static
- Generation is “totally” under control
- Loads are statistically predictable
- Flow of energy from transmission to distribution is unidirectional
- Distribution system  is passive
- AC
- Clear roles of power system operators

**Atfer**

- Generation distributed, all voltage levels and interfaced with power converters
- The system has low inertia (faster dynamics) and sudden changes (e.g. wind puffs)
- Renewable sources and (new) loads are not fully predictable nor controllable
- Power injection occurs also at distribution level, power flows “backward”
- The distribution system is active, automated
- AC, DC, hybrid
- New actors and modes of operation: Demand-Response, Aggregators, Third Parties providing technical services

# The electrical levers and their potential



- Renewable generation
- E-mobility
- Energy storage
- Automation
- Digitalization
- Citizen-driven innovation

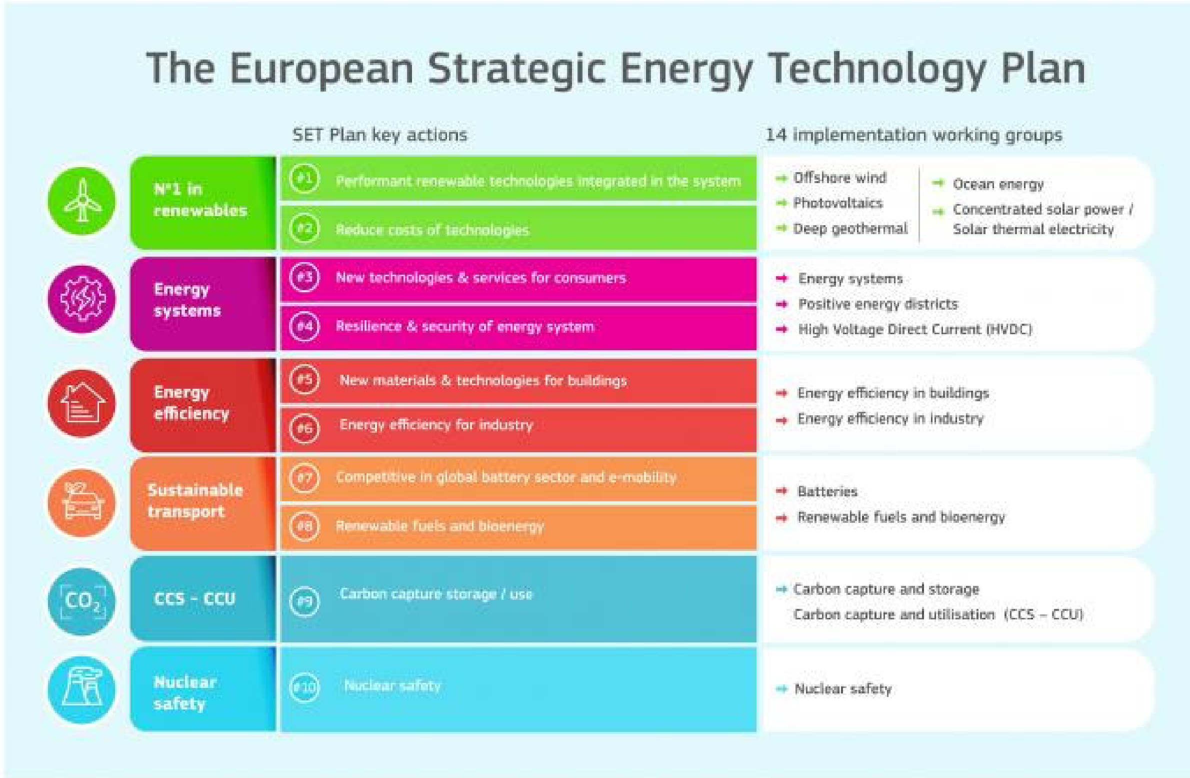

- Flexibility
- Maximum self-consumption
- Less losses
- Energy positive buildings and districts
- Ramp up of deployment of new solutions

The Future of Cities, JRC Report EUR 29752 EN

# The means and tools

- Planning
  - Optimization across sectors
- Technology
  - Automation, control
  - IoT, AI
  - Sensors, materials
  - Data sharing and protection
  - Open source digitalization
  - Cyber-security
- Operation
  - Monitoring and control
  - Self-healing
- Policy, legislation and regulation
- Energy trading
  - P2P, aggregation, Energy Union

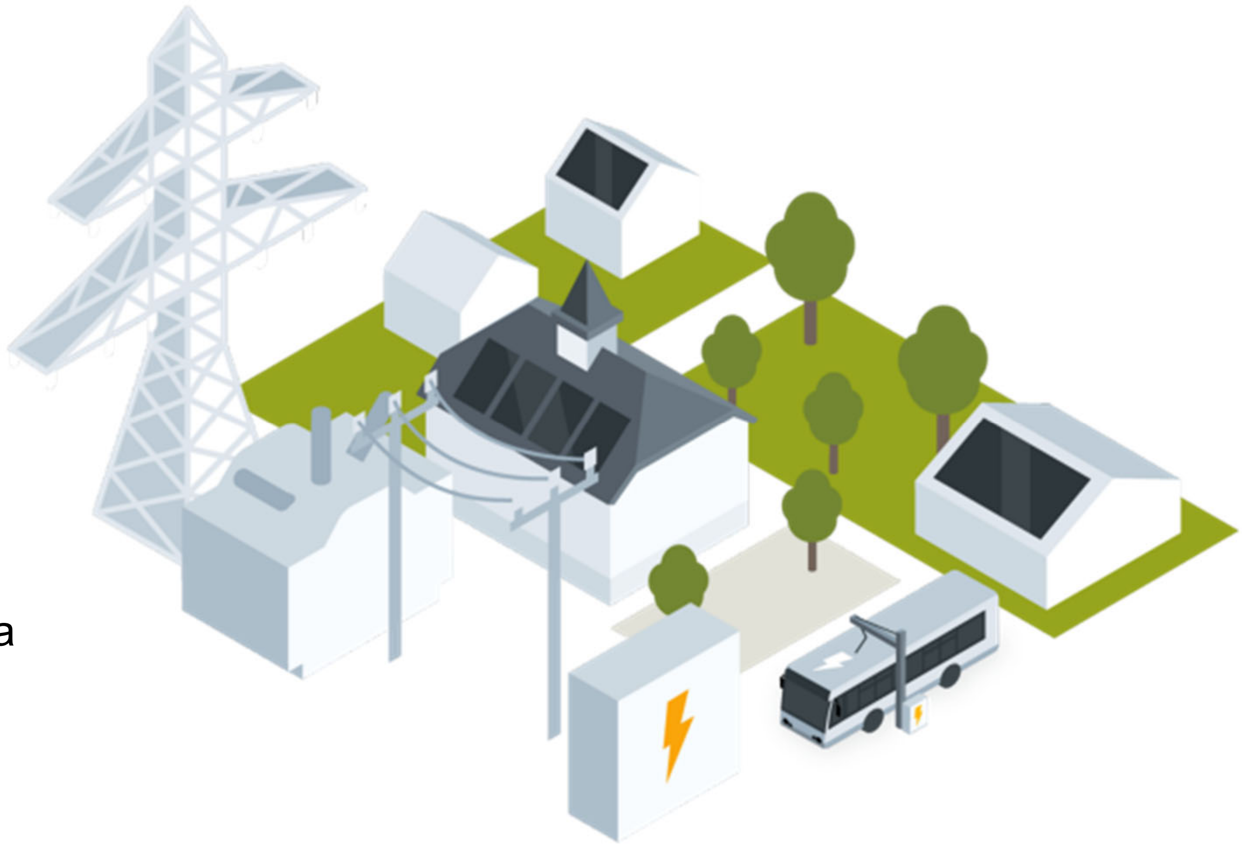
- Engagement & Education
  - Citizens
  - Administrations
  - Urban governance




https://setis.ec.europa.eu

# Energy transition – the grid edge

- Grid Edge, where the consumers, the prosumers and the communities are
- Pushing intelligence and action to the customer
  - Changes the business models, mobilizes investments
  - Requires management and grid interaction solutions
- Edge Technologies for the customer
  - Optimization, analytics, data platforms,…
  - peer-to-peer trading, e.g. blockchain
- Technologies for the grid
  - Monitoring, control, data platforms



https://new.siemens.com/global/en/company/topic-areas/smart-infrastructure/grid-edge.html

# Energy Communities

- Energy communities are groups of individual actors who voluntarily accept certain rules for the purposes of a common objectives (only or also) relating to energy;

that is:

  - Purchasing energy as collective groups

and/or

  - Managing energy demand and supply

and/or

  - Generating energy,

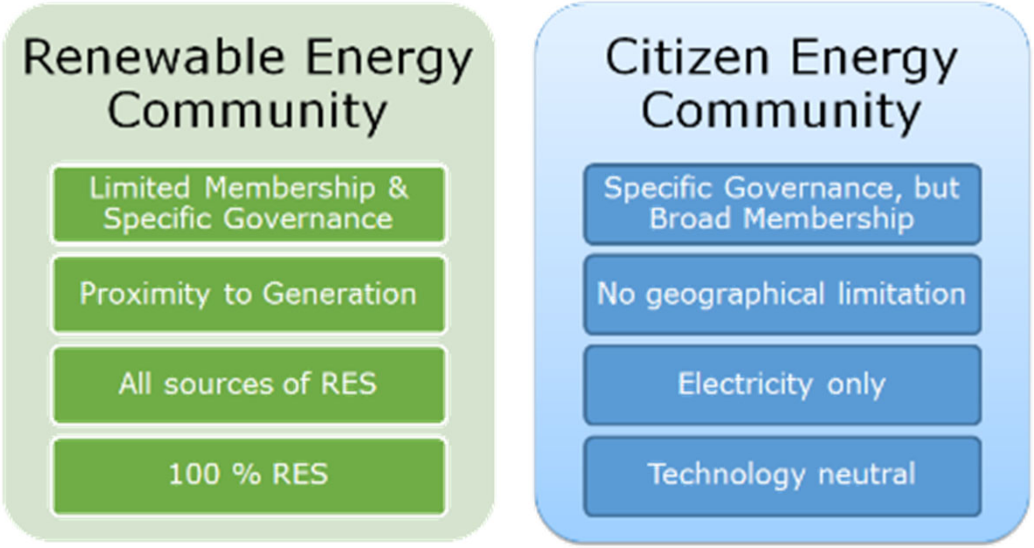
and/or

  - Providing energy-related services

Artists in residence: Dan Edelstyn and Hilary Powell with some of their Lynmouth Road neighbours. Photograph: Charlie Clift/The Observer – The Guardian 18.12.2022

# Energy Communities - types

- Institutionalised Energy Communities as a part of EC‘s Clean Energy Package




Art. 22 of the Directive on the promotion of the use of energy from renewable sources on “Renewable Energy Communities” (RED), National transposition by June 30, 2021

Art. 16 of the Directive on the Internal Market for Electricity Directive on “Citizen Energy Communities” (EMD), National transposition by December 31, 2020

https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001&from=fr

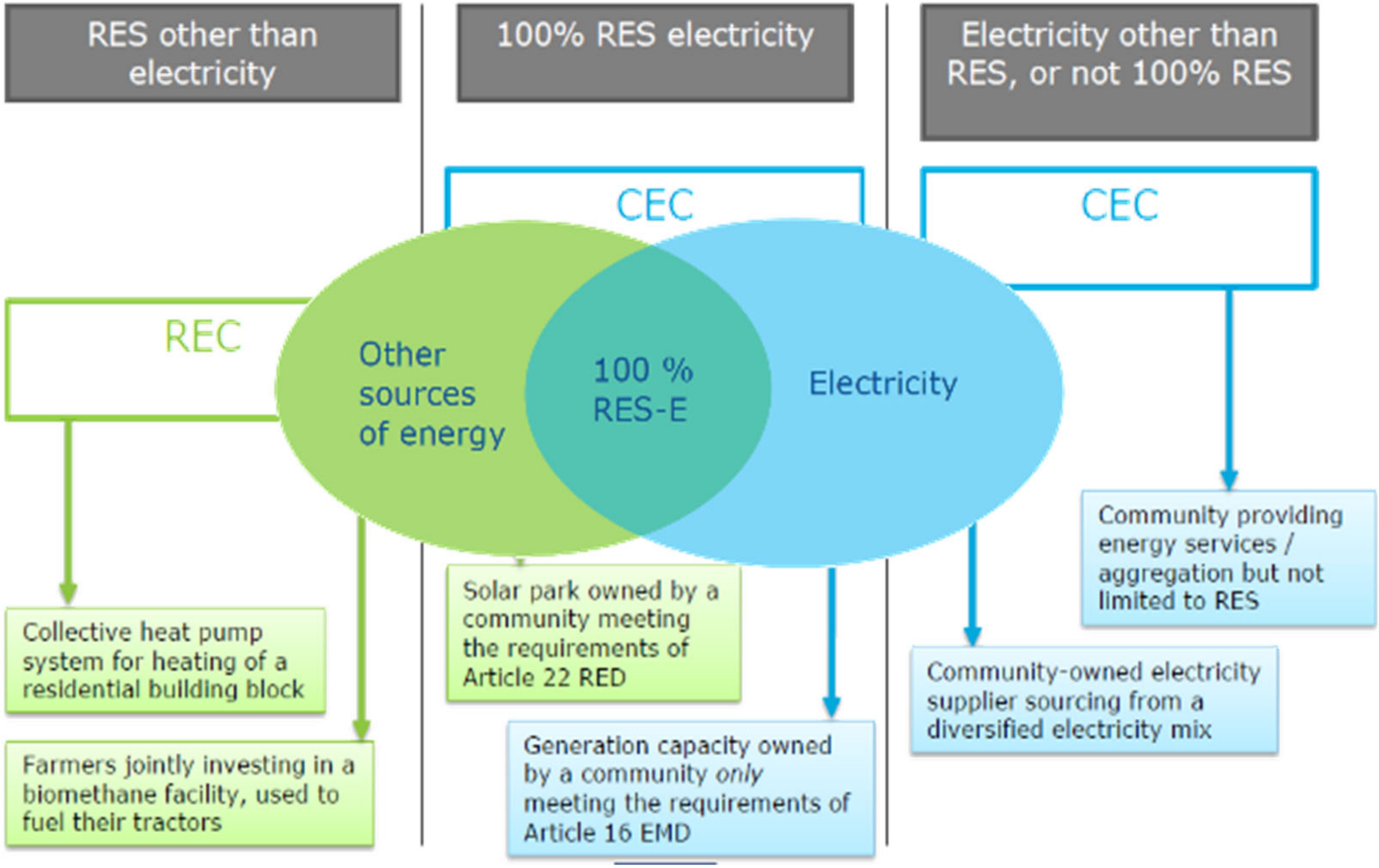
# Energy Communities - objectives

- Objectives of Renewable (REC) and Citizen (CEC) Energy Communities
  - Provide environmental, economic or social community benefits for members or the local area by …
  - Empowering citizens
    - Tool to increase public acceptance of new projects
    - Tool to mobilise private capital for energy transition
    - A tool to increase flexibility in the market
  - RECs:
    - Favorable conditions and promotion for renewables
  - CECs:
    - Recognition of new market actors
    - Level playing field and non-discrimination

*Source*: Energy Communities and SWW Approach, L. Karg and G. Meindl

# Energy Communities - relations

- Relation of REC and CEC




*Source*: Energy Communities and SWW Approach, L. Karg and G. Meindl

# Energy Communities – key characteristics

## Key characteristics of REC and CEC

**REC**

| | |
|---|---|
| Participation and Governance | only non-professional actors, control remains with members located in proximity |
| Active policy | Promote and facilitate the development of RECs<br>Elimination of barriers |
| Role in support schemes | Member States to take specificities of RECs into account when designing support schemes |

**CEC**

| | |
|---|---|
| Participation and Governance | open to all kinds of entities, but control remains with non-professional actors |
| Charges, taxes and fees | Respect for the Member States' autonomy |
| DSO status | Member States may allow the DSO status, possibility of "closed DSO" status |

*Source*: Energy Communities and SWW Approach, L. Karg and G. Meindl

# How can we practically try to create an energy community



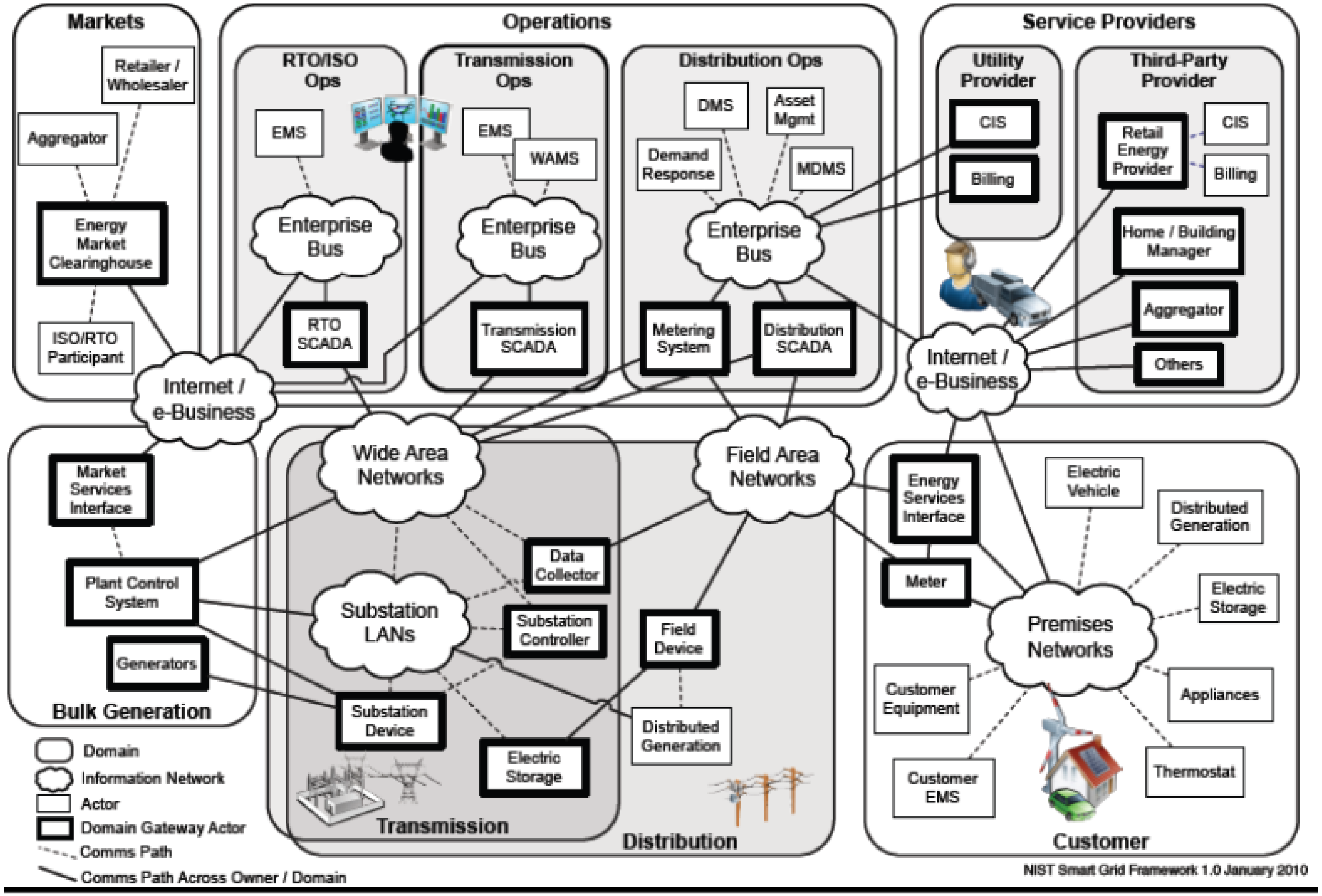
- All people in the neighborhood install rooftop PV and hope for the best?
  - Challenges: buy, rent or rent space? Injected energy is paid to you ~6c per kWh (so little it is not worth it), vs the 40-60c you pay, return on investment 30 years? Does not cover your consumption, and not at the right time. No synergy.
- Add battery storage?
  - Buy, rent? Many DC loads, so impossible to charge them DC cannot cover all consumption
- Agree to share with neighbor?
  - What combination: e.g. share battery? Share all? But how to connect: what is legally possible? What terminals are accessible (usually none)? Is DC point connection possible (not quite)?
- Agree to share with more neighbors?
  - Challenges as above but on larger scale; plus what legal guarantees? What safety guarantees? What quality? And without „copper-connecting“ (like Powerpeers Vattenfall)?
- Shared investment in a larger collective plant?
  - This is a REC

# Steps to create a PV REC

- **Feasibility study**. Verify the essential conditions for activating a REC. Permanent consultation with stakeholders, evaluation of sites, drafting of business plan, mapping of the territory and its stakeholders, and context analysis (needs of the territory to which a REC can respond).
- **Territory involvement**. Information campaign to communicate the project to possible beneficiaries, collect pre-adhesions with actual consumption data, calibrate the business model.
- **Activation of the legal entity of the REC**. Design, implementation, testing and commissioning of one or more PV systems. Coordination and supervision with public admin.
- **Photovoltaic plant realization**. the REC is activated from a legal point of view, energy flow monitoring, metering and shared energy allocation are initiated.
- **REC activation**. PV system is built and connected, ERC registration and incentive application done. Energy flow monitoring, shared energy accounting, and economic benefit sharing initiated. Training courses for local staff to manage the ERC once it is fully operational.

# Conceptual model of smart grid – v1.0, 2010

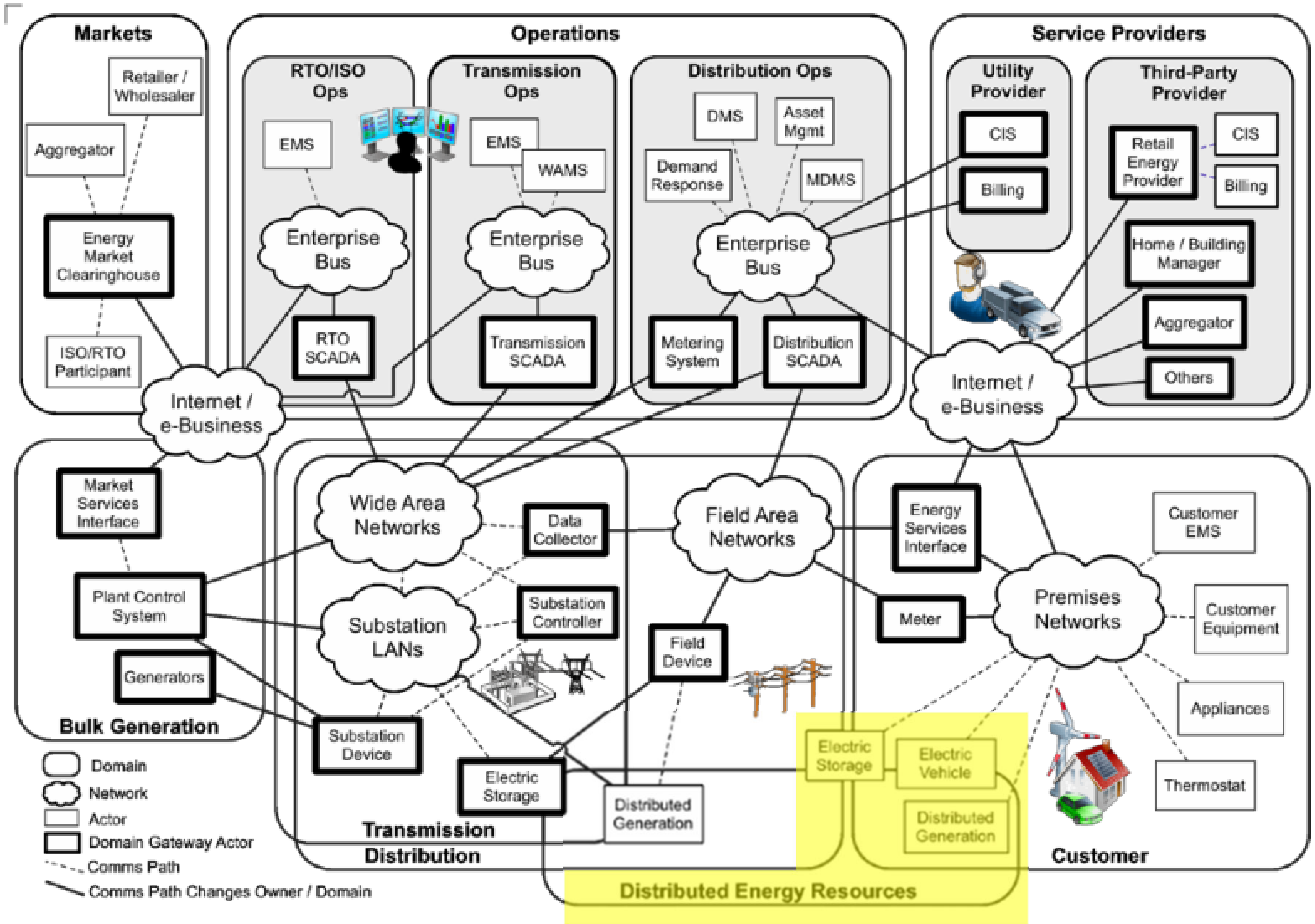





https://www.nist.gov/system/files/documents/public_affairs/releases/smartgrid_interoperability_final.pdf

# Conceptual model of smart grid – v2.0, 2012

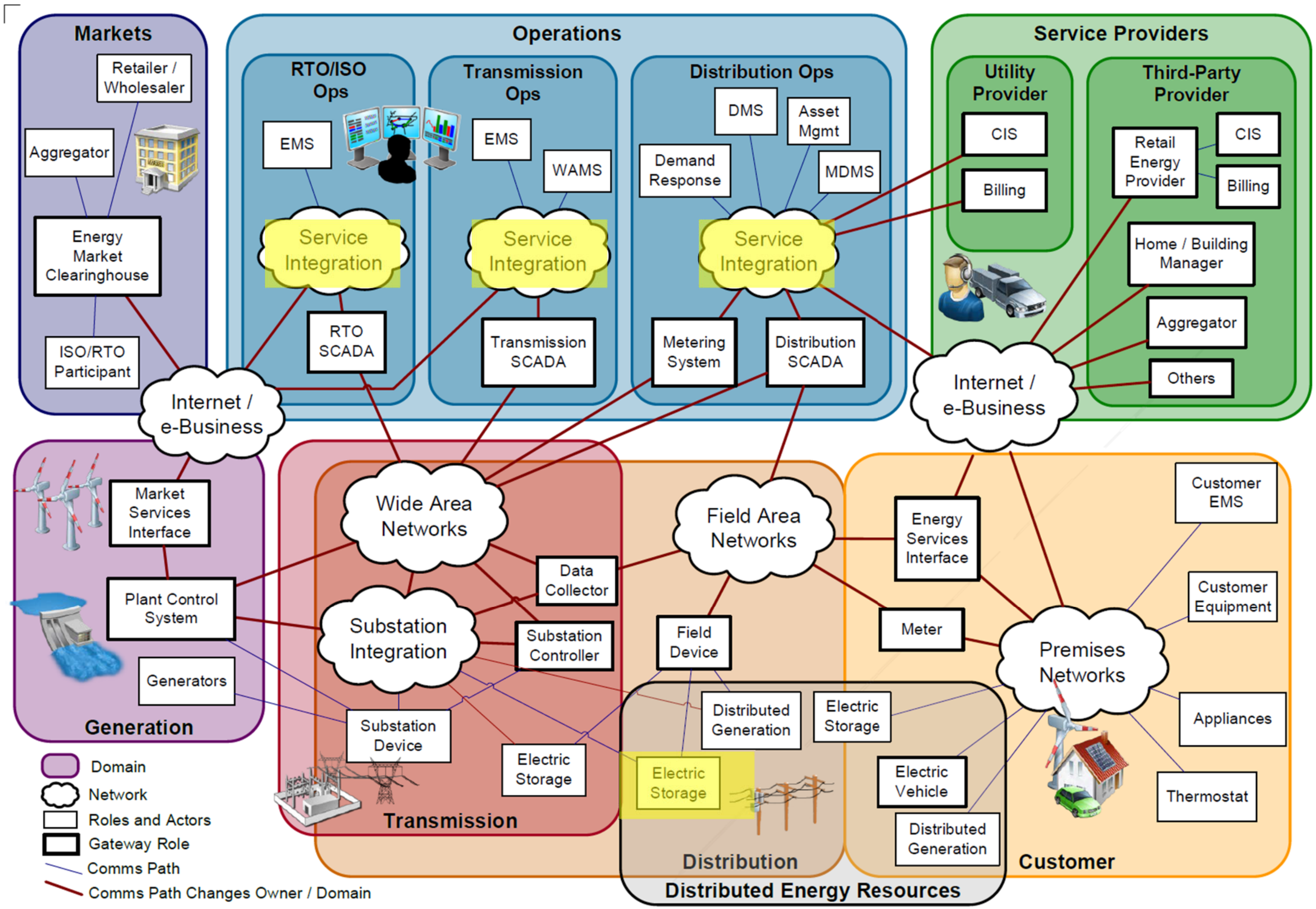





https://www.nist.gov/system/files/documents/smartgrid/NIST_Framework_Release_2-0_corr.pdf

# Conceptual model of smart grid – v3.0, 2014

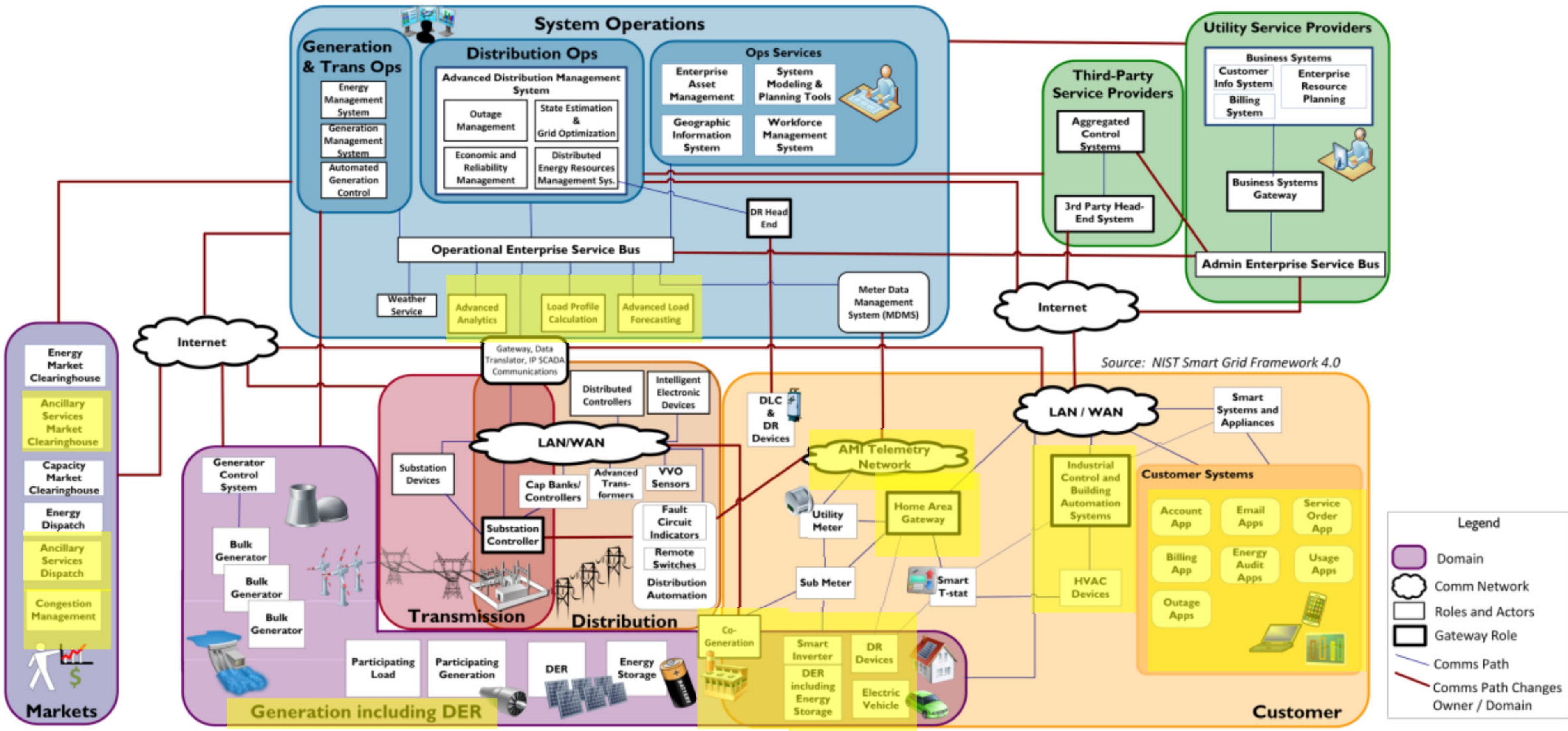





https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1108r3.pdf

# Conceptual model of smart grid – v4.0, 2021






NIST Framework and Roadmap for  Smart Grid Interoperability Standards, Release 4.0, Feb. 2021
https://nvlpubs.nist.gov/nistpubs/SpecialPublications/NIST.SP.1108r4.pdf

# of our very own Some projects advancing energy systems

Urban energy system and electrical systems | Grid edge, and energy communities | Examples: multi-energy management, EVs | Technical development for grids, monitoring, testing

For research trends check out ongoing projects:

https://www.acs.eonerc.rwth-aachen.de/

int:net
Interoperability Network for the Energy Transition
European Commission

ONENET
one network for Europe

FLOW
Flexible energy systems Leveraging the Optimal integration of EVs deployment Wave
European Commission

Platone
PLATFORM FOR OPERATION OF DISTRIBUTION NETWORKS
European Commission

IDEAL
Ideal Grid for All

SHAR-Q: Storage capacity over virtual neighbourhoods of energy ecosystems

SMEP
Energy Platform

RESERVE – Future grids: fast, safe, sustainable

FINESCE
FIWARE
Open APIs for Open Minds
Future Internet Smart Utility Services

IDE4L – Advanced Distribution Management System

FLEXMETER - Flexible smart metering with active prosumers

SOGNO
SOGNO – Service oriented grid for the network of the future

Elsa
ELSA – Energy Local Storage Advanced Systems

Supported by:
Federal Ministry for Economic Affairs and Climate Action
on the basis of a decision by the German Bundestag

TransUrban .NRW

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EUROPÄISCHE UNION Investition in unsere Zukunft Europäischer Fonds für regionale Entwicklung
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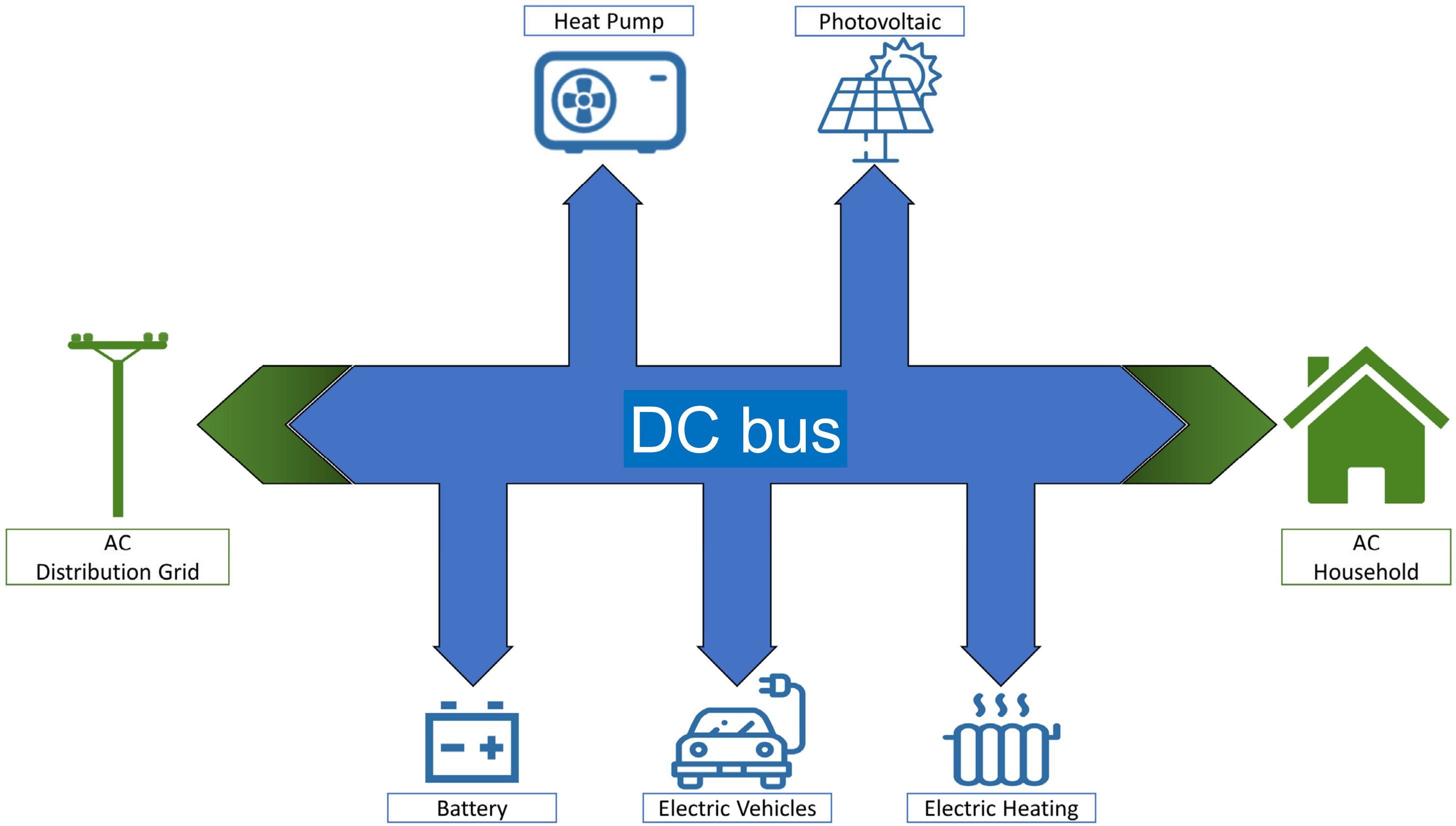
# House, building, district communities AC, DC, hybrid

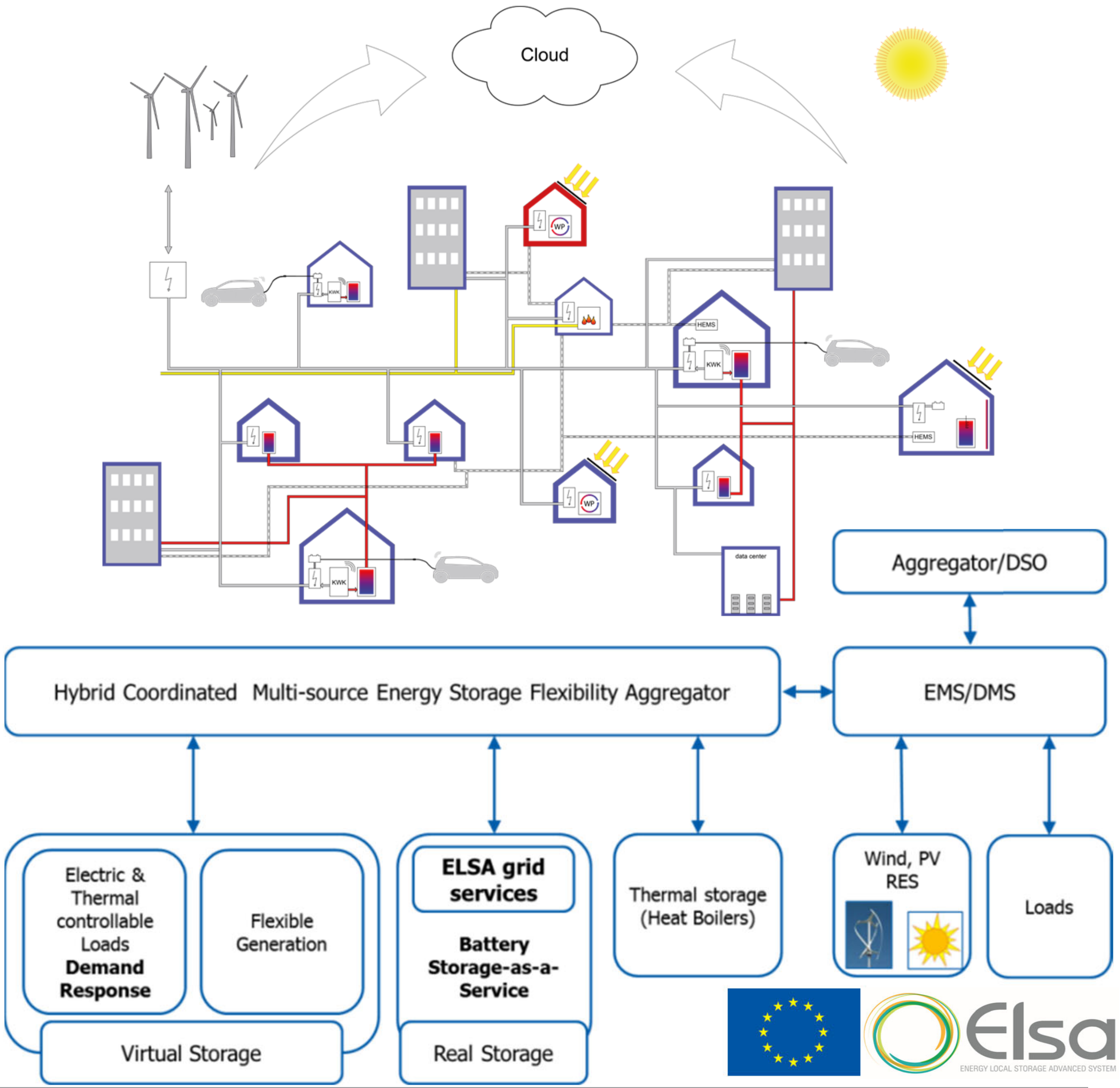




# District energy management system Example



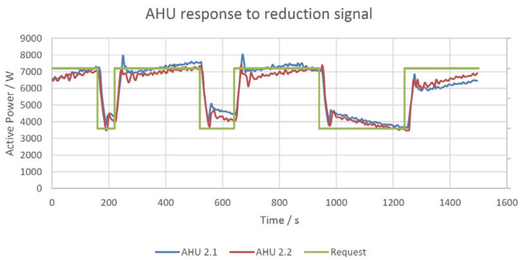
- Potential: self-consumption, peak-shaving, load-shifting, support to grid operators, integration of renewable generation.
- Among the tech objectives
  - Use second life batteries
  - Multi-physics, multi-energy carrier (thermal-electrical)
  - ICT energy management for storage-building-grid (cloud implementation, open source platform)
  - Local services for optimization and demand response

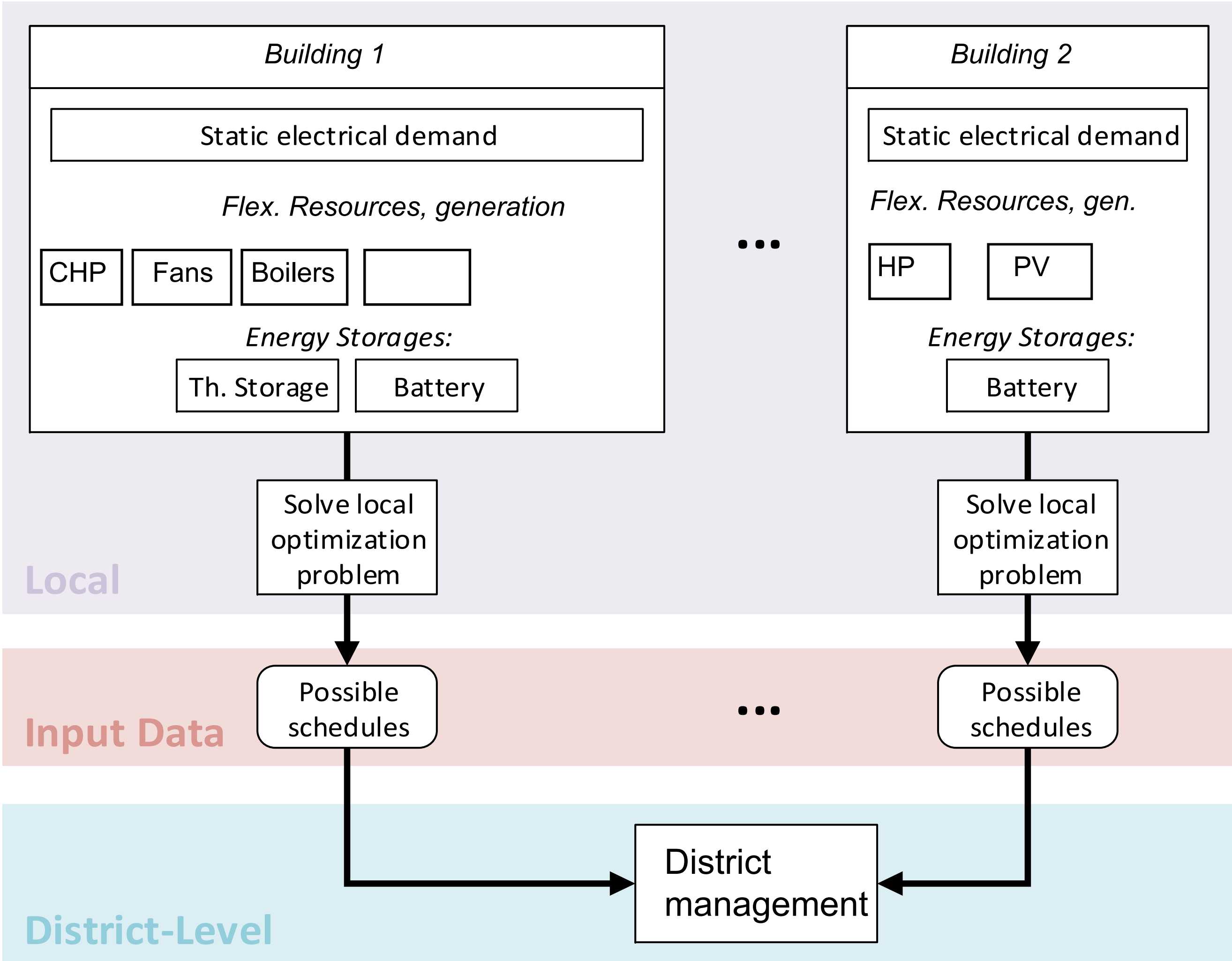


# District energy management system – a closer look



- Each building has its own energy system, goals, local optimum, acceptable schedules
- Shared battery storage, plus own other storage



# Local Energy Systems/communities as Microgrids

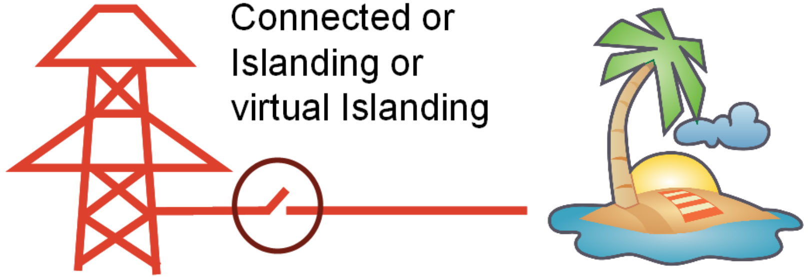


**Benefits**

- Local usage of energy resources
- Feasible size for optimal control
- Isolation possible in failure scenario

**Challenges**

- Active control with additional intelligence
- Many uncertain parameters
- Interaction with higher control levels




Exemplary strategies

**Case (a)**
**Economic value**

- Minimize operational cost
- Maximize revenue from services

**Case (b)**
**Local use of Energy**

- Minimize Power Exchange with the main grid
- Minimize energy import

**Case (c)**
**Max Potential Islanding Time**

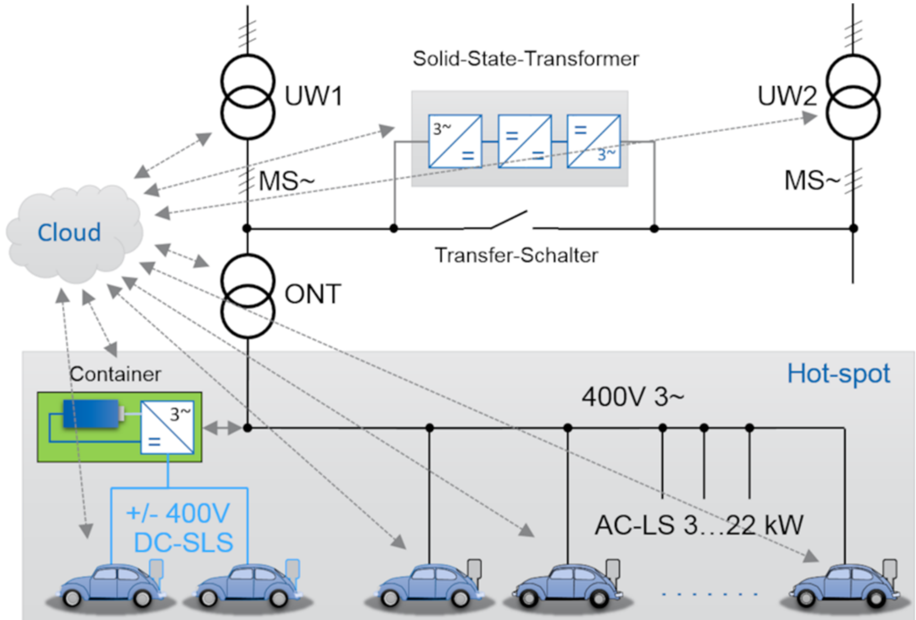
- Maximize potential islanding time
- Minimize cost

# E-mobility, plug-in e-vehicles

Transport: 25% of EU's greenhouse gas emissions; European Green Deal target: 90 % reduction of emissions by 2050

How

- Coupling traffic – electricity - smart city
- Boosting home/building self-consumption
- Enabling EV-to-grid (V2G) services




ALigN: Ausbau von Ladeinfrastruktur durch gezielte Netzunterstützung

And how

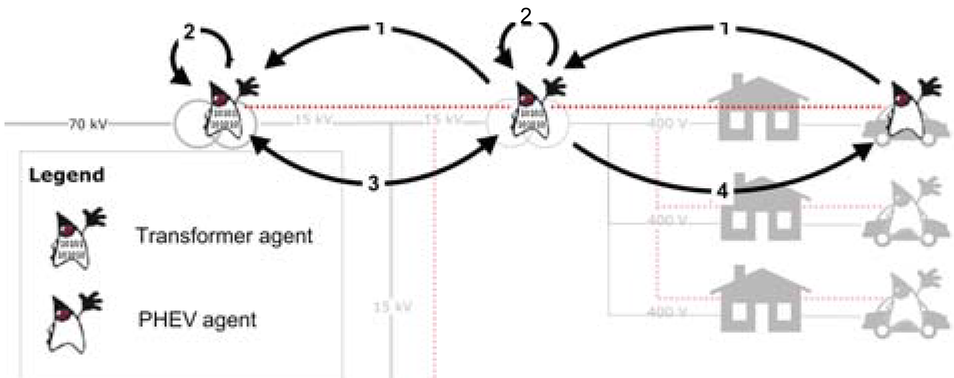
- Grid security against potential grid stress
- Large recharging infrastructures
  - Architecture
  - location
- Optimal energy management
- Standards for power, data, service

eCitaro for ASEAG
https://www.urban-transport-magazine.com/

# EVs – Demand side management

Agents with interdependent goals:
- PHEV agent – goal: charge of battery charging
- Transformer agent – goal: flatten the load and prevent overloading

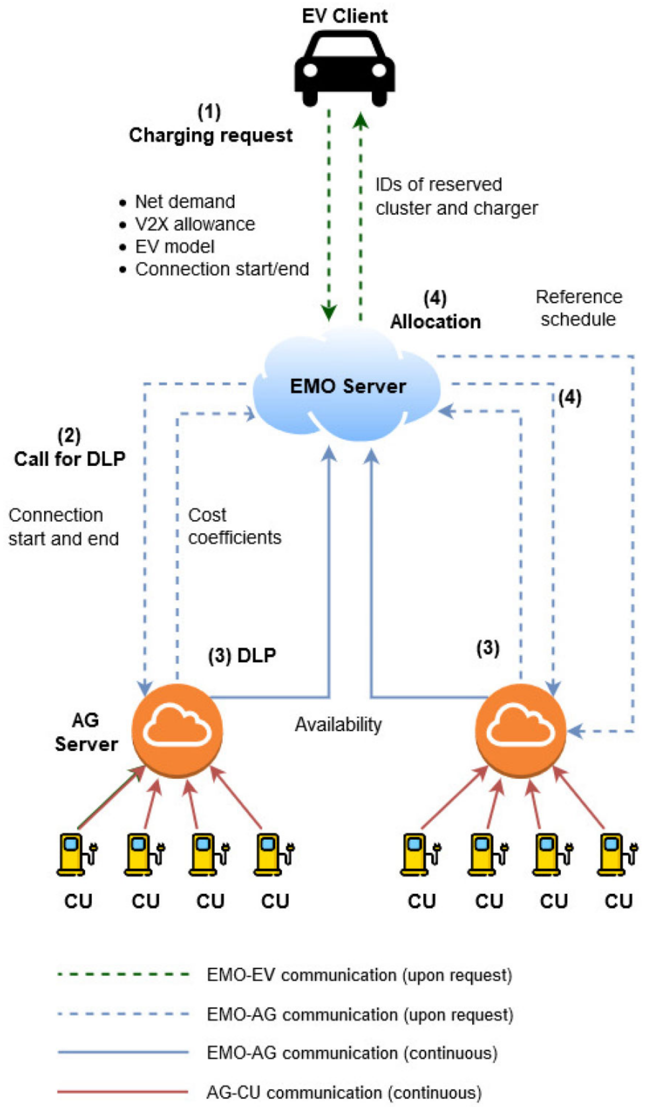
Coordination:
1. PHEV agent requests charging permission to connecting Transformer Agent
   - All PHEV agents send requests (and updates) for intentions (asynchronously)
2. Transformer agents determine charge power that flattens own load
3. Transformer agents negotiate for flattening load of both
4. LV Transformer agent announces agreement to PHEV agent




Stijn Vandael, Nelis Boucké, Tom Holvoet, Geert Deconinck, "Decentralized demand side management of plug-in hybrid vehicles in a Smart Grid", ATES 2010, Toronto, 11 May 2010

# EVs – routing for best price and infrastructure use






**Simulator**

Code repository
https://github.com/erdemgumrukcu/datafev

https://datafev.fein-aachen.org

## Documentation

Python package datafev is a framework for the development, testing, and assessment of managemant algorithms for EV charging scenarios. The framework allows to develop scenario-oriented management strategies. It includes a portfolio of optimization- and rule-based algorithms to coordinate charging and routing operations in clustered charging systems. Furthermore, it provides statistical scenario generation tool to create EV fleet demand profiles. Its target users are researchers in the field of smart grid applications and the deployment of operational flexibility for local energy systems.

### Contents:

- datafev
  - Packages
- Tutorials
  - Packages

## Indices and tables

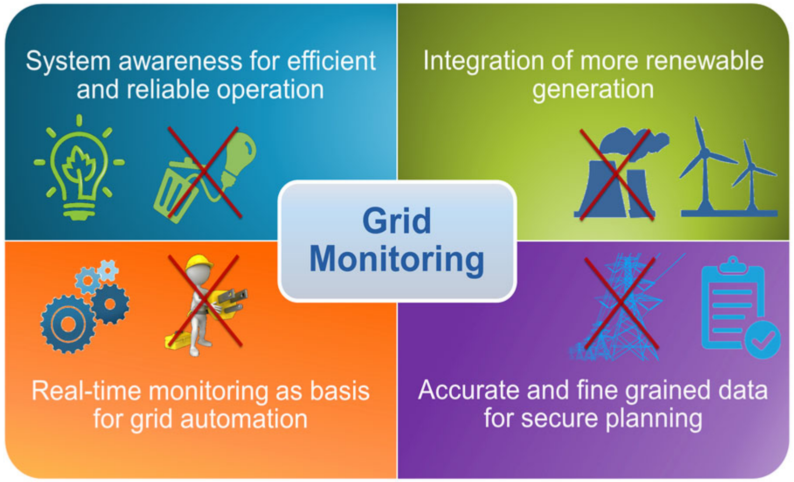
- Index
- Module Index

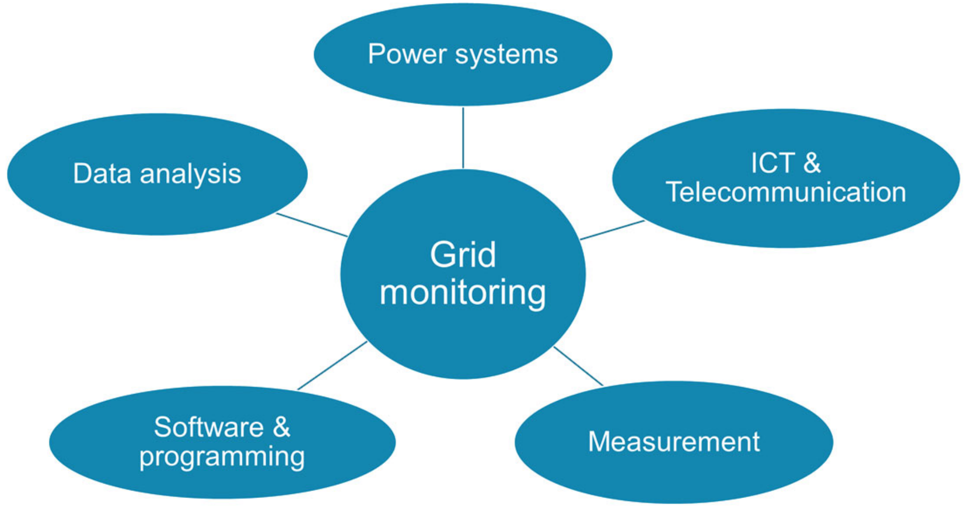
# Electrical distribution system evolution

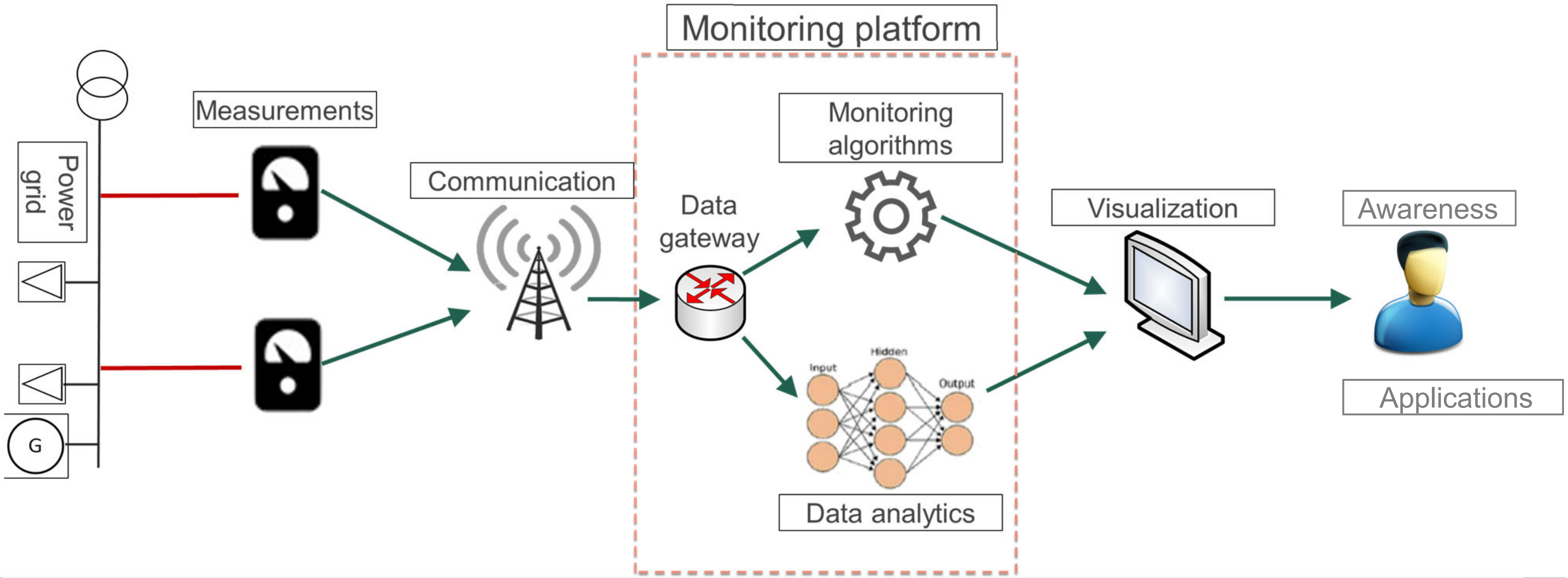
- Devices
  - Low cost devices (new instruments, substation automation units, sensors, multi-domain meters, virtual instruments)
- Architecture
  - Distributed functions
  - Cloud-based infrastructure, centralized and edge could
  - Cyber-security
- Services and applications
  - to customers
  - to infrastructure operators
- Testing of HW, SW, architectures, services
- Education and training


Unareti secondary substation in Brescia implementing the IDE4L substation automation unit

# Monitoring as an example – the monitoring chain





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# Testing, verification and validation of solutions for urban energy systems



Offline numerical simulation

Hardware-In-the-Loop (**HIL**), e.g. control boards for simulated power converters
Power Hardware-In-the-Loop (**PHIL**), e.g. real power converters connected to simulated power systems
Software-In-the-Loop (**SIL**), e.g. state estimation algorithms with measurements from the simulation

Dynamic phasor and time domain
Multi-physics simulation, co-simulation
Cyberphysical system simulation
Interoperability testing

Lab demonstrations
Field pilots
Large scale demonstrations

Performance
Replicability
Scalability

RTDS installation at the ACS Realtime Lab

Flexible Power System Simulator (FlePS) for PHIL experiments at RWTH ACS Lab.

# Education and Training for the Energy Transition



- Blueprint Strategy and European Sectorial Skills Alliance to **match demand of skills for the digitalization of the Energy sector**
- improved/new vocational training and beyond
- framework for education providers to define and update educational programs responding to industry changes
- Pilot

- Attract, engage, create innovative programmes for educating
  - training actors
  - students, newly hired employees, citizens;
  - companies in the energy sector;
  - policy makers, authorities, public administrations and market regulators;
- Tools for fast and easy creation of learning material

EDucation for DIgitalisation of Energy

European Commission

European Commission

A holistic and Scalable Solution for research, innovation and Education in Energy Transition

Go to **www.menti.com** and use the code **3801 6252**


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