L E M U R
ELECTRICAL ENERGY RESEARCH

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Universidá d'Uviéu
University of Oviedo

Is the Electrical Distribution Ready for a Revolution?

Pablo Arboleya (arboleyapablo@uniovi.es)

CÁTEDRA MILLA DEL CONOCIMIENTO
GIJÓN SMART CITIES

¿Why change somethig that works?

1. The forecasts indicate a very significant **increase in load** on the network in the short/medium term as a result of an unstoppable **electrification** process that not only includes technologies related to **electric mobility** but also includes **other technologies** such as heat pumps or other air conditioning equipment.

2. An **increase** in the installation of **distributed resources**, mainly solar photovoltaic energy in many cases combined with accumulation systems, is expected.

3. The **uncoordinated** use of the above resources may cause **congestion** in the network in the short/medium term.

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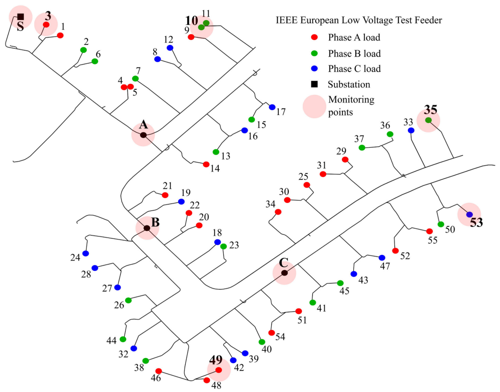
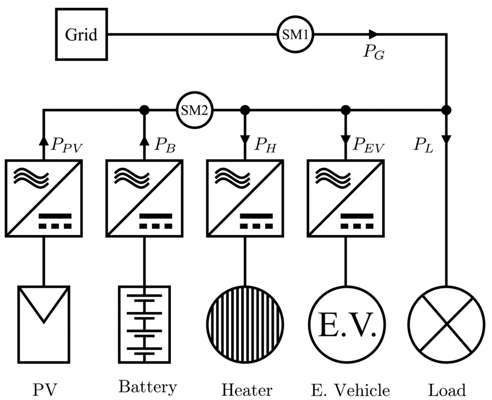
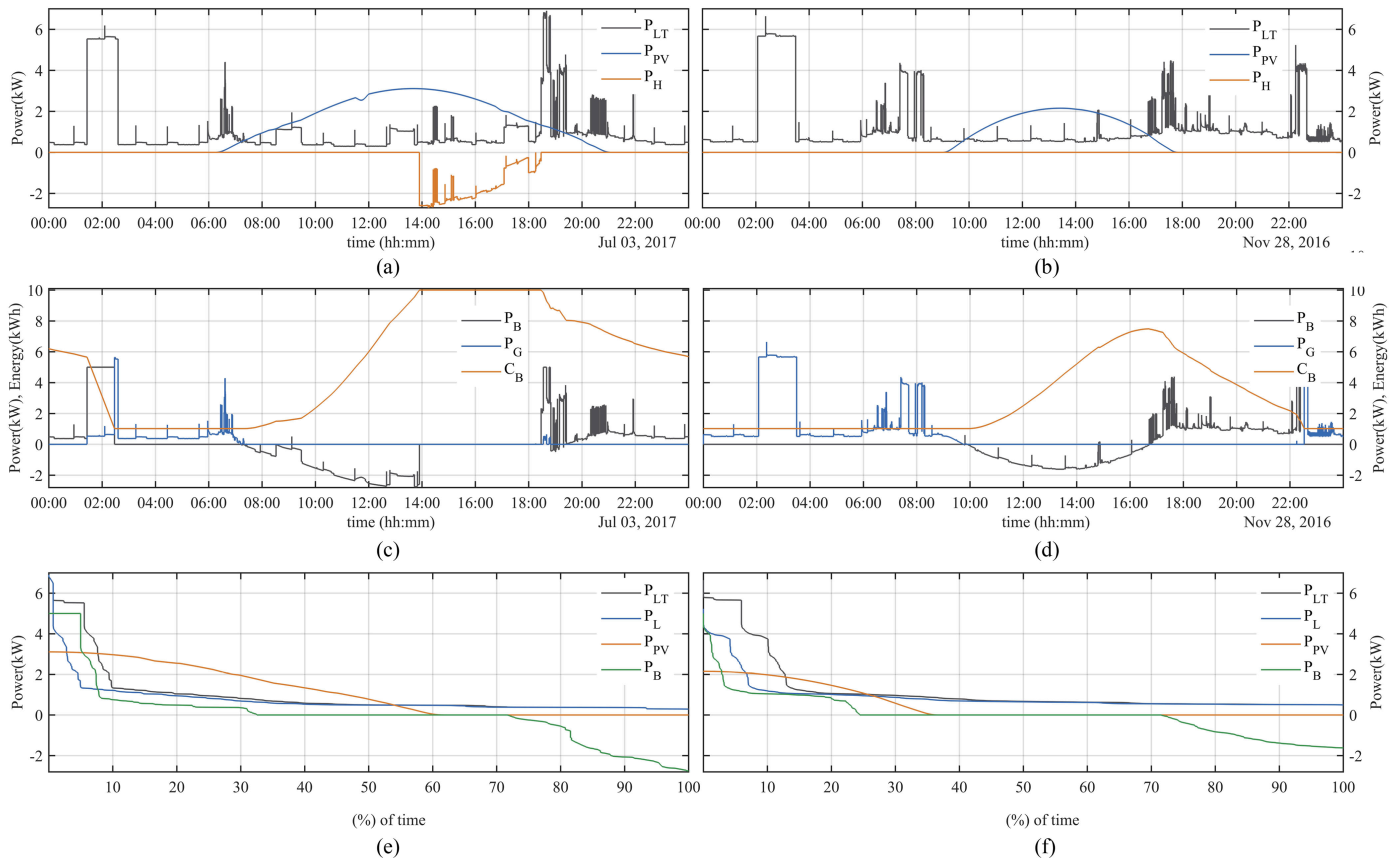
Case of Study (Self-consumption without surplus):







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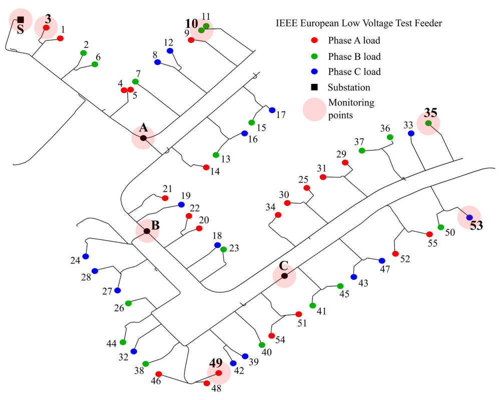
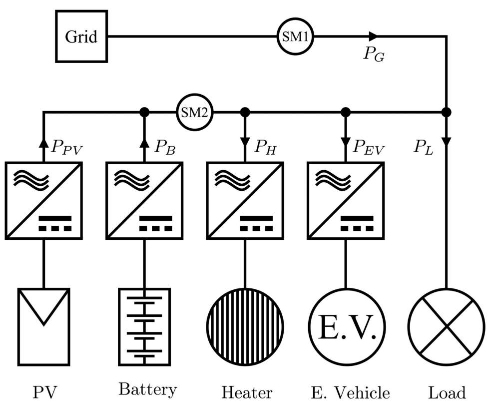
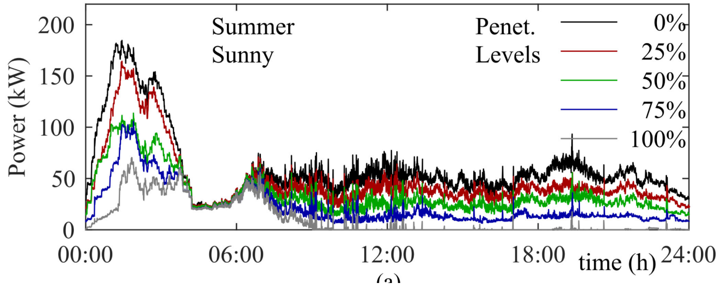
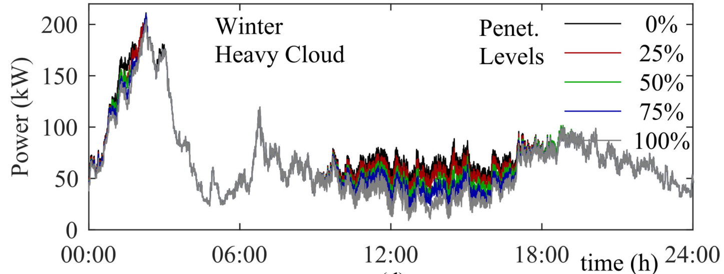








(d)

	Summer	Winter
P_{LT} (Average) (W)	737.8	897.4
P_{LT} (Max) (W)	6902.7	5230.8
P_L (Average) (W)	987.9	1203.7
P_L (Max) (W)	6902.7	6638.1
P_G (Average) (W)	158.6	698.1
P_G (Max) (W)	5640.8	6638.1
P_{PV} (Average) (W)	1118.2	505.5
P_{PV} (Max) (W)	3107.6	2150.2
P_B when ($P_B > 0$ (Average) (W)	442.4	229.7
P_B when ($P_B < 0$ (Average) (W)	-418.6	-229.7
E_{LT} (kWh)	23.7	28.9
E_L (kWh)	17.7	21.5
E_G (kWh)	3.8	16.7
E_{PV} (kWh)	26.8	12.1
E_B when ($P_B > 0$) (kWh)	10.6	7.2
E_B when ($P_B < 0$) (kWh)	-10.1	-7.2
E_H (kWh)	7.5	0

Season	Summer				Winter				House
Weather Scenario	Load	Sunny Load+Sys	Cloudy Load+Sys	Heavy Cl. Load+Sys	Load	Sunny Load+Sys	Cloudy Load+Sys	Heavy Cl. Load+Sys	
Net Energy (kWh)	27,2	5,4	6,8	11,9	26,1	10,9	14,0	17,7	Node 3
Maximum Power (kW)	8,5	4,0	8,5	6,1	6,8	6,8	8,3	6,7	
Average power (kW)	1,1	0,2	0,3	0,5	1,1	0,5	0,6	0,7	
Net Energy (kWh)	19,4	2,5	5,0	9,0	66,3	51,5	56,9	56,3	Node 10
Maximum Power (kW)	6,6	6,1	6,1	6,1	11,3	11,3	10,8	11,3	
Average power (kW)	0,8	0,1	0,2	0,4	2,8	2,1	2,4	2,3	

Why change something that works?

4. The **problem** of **congestion** in the distribution network can be avoided by **investments** in the distribution network (basically increasing the power of transformers and increasing the section of conductors).

5. On the other hand, **regulators** are **reducing** the **remuneration** of distribution operators, which generates a **low return** on network **investments**.

Changes in regulation, a few examples:

European Commission Energy Efficiency Directive 2012/27/EU (Art. 15. 4) requires Member States to: "Ensure the **removal** of those **incentives** in transmission and **distribution tariffs** that are **detrimental** to the overall **efficiency** (including energy efficiency) of the generation, transmission, distribution and supply of electricity or those that might hamper **participation** of **Demand Response**, in **balancing markets** and **ancillary services** procurement".

"Ensure that network operators are incentivized to **improve efficiency** in infrastructure design and operation, and, within the framework of Directive 2009/72/EC, that tariffs allow retailers to **improve consumer participation** in system efficiency, including **Demand Response**, depending on national circumstances".

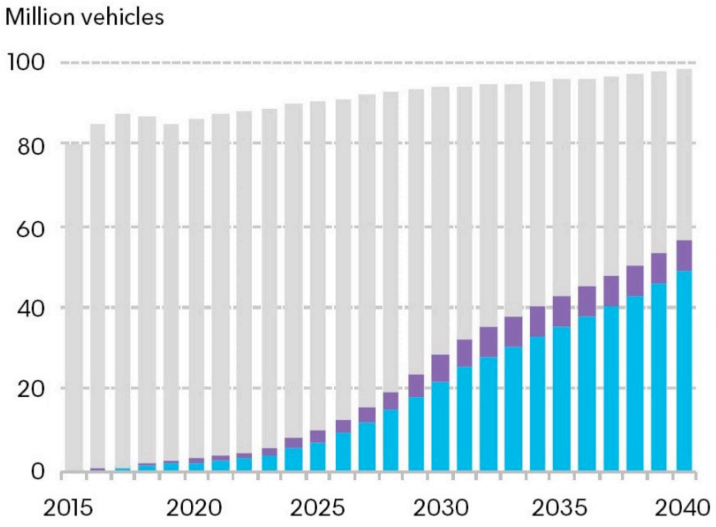
Why change something that works?

6. The only way to **manage** a **massive penetration** of electric vehicles and other resources distributed in the network is through their **coordinated installation**, which makes it possible to **limit investment** in **infrastructure** and to **manage distributed resources** and increase overall efficiency through their active participation.

¡¡¡ FLEXIBILITY !!!

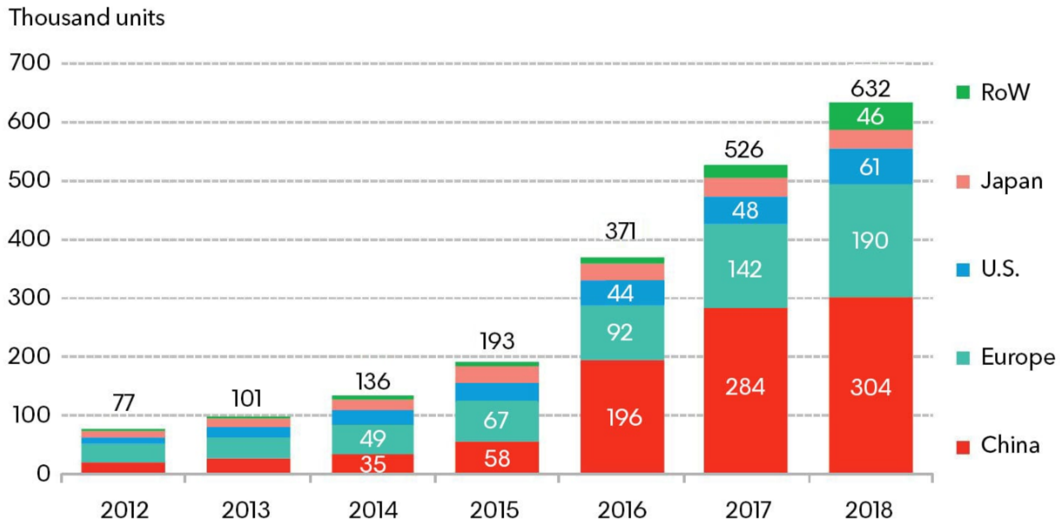
Electrical Vehicles

Global long-term passenger vehicle sales by drivetrain



Source: BloombergNEF

Public charging outlets installed globally

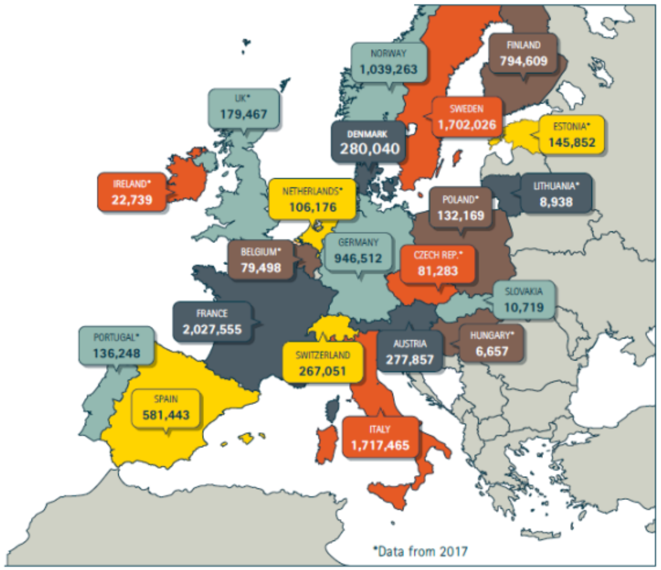


Source: BloombergNEF. Note: Data current as of January 1, 2019. Data will be updated on the BNEF data hub at the end of 1H 2019.

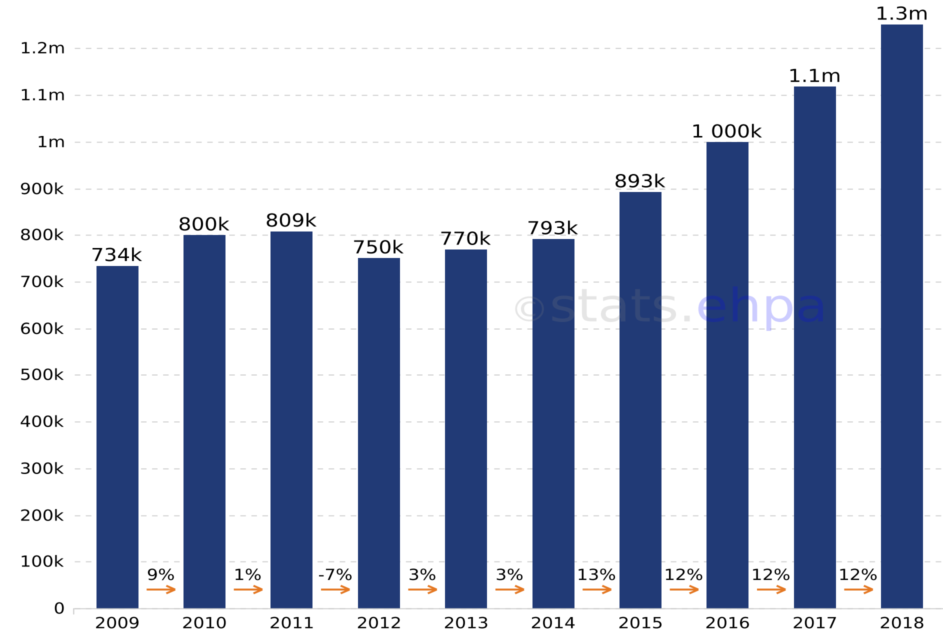
- Electric vehicles in Spain (63,000) less than half are cars.
- Average daily travel is 45km
- Average consumption of an EV is 15kWh/100km
- Average daily consumption of a car 6.75kWh/day -> 2.5MWh per year
- For 100,000 electric vehicles the consumption would be 250GWh, (1% of the global energy consumption).
- Average consumption of a Spanish home (3.5MWh per year) -> EV would increase consumption by 70%

Climate control heat pumps and air conditioning

Figure 28 **HEAT PUMPS INSTALLED IN EHPA MEMBER COUNTRIES IN 2018**



Source: EHPA.

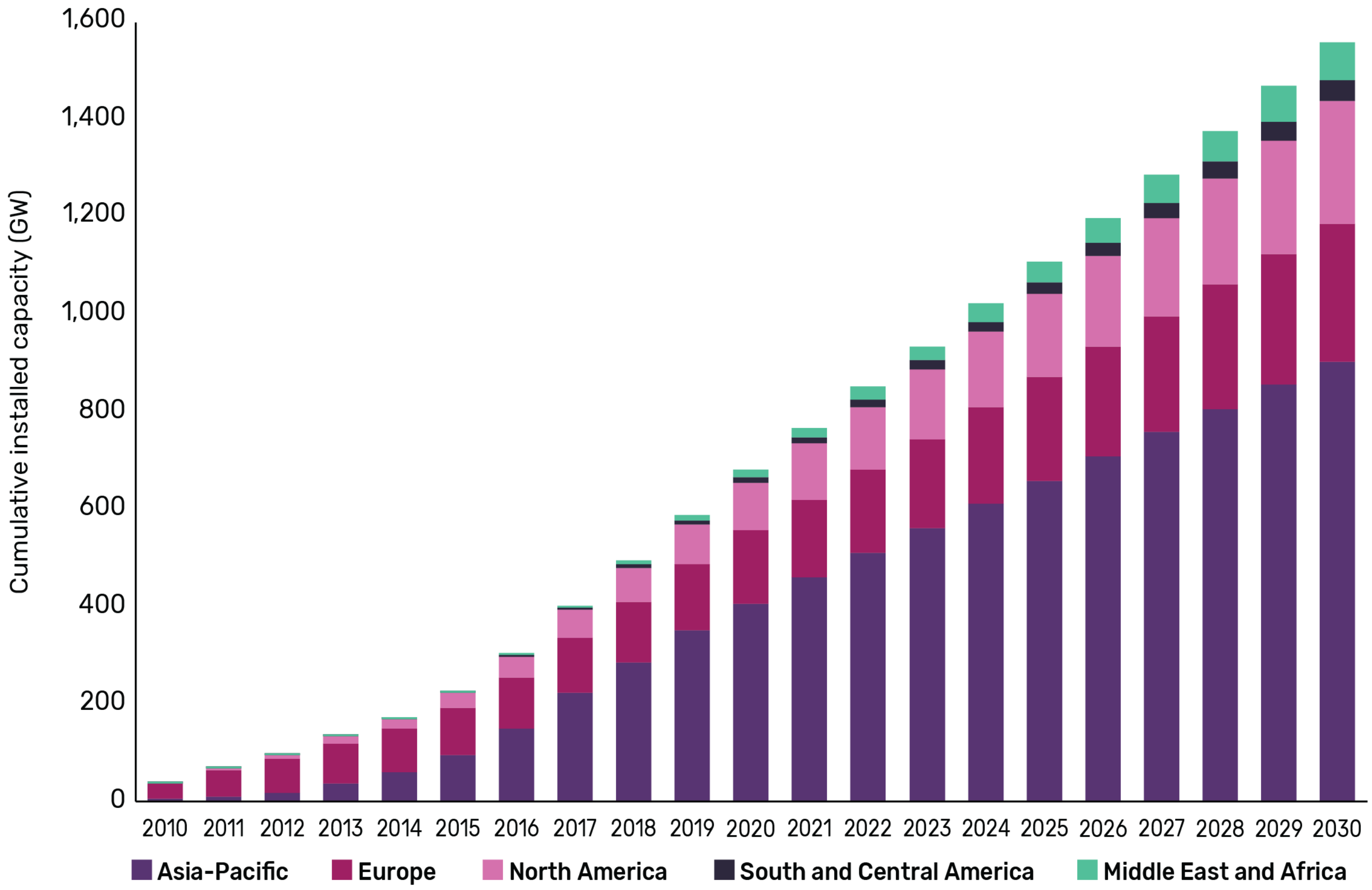


Webinar: EHPA market report and statistics outlook 2019 | Thomas Nowak | 24.06.2019

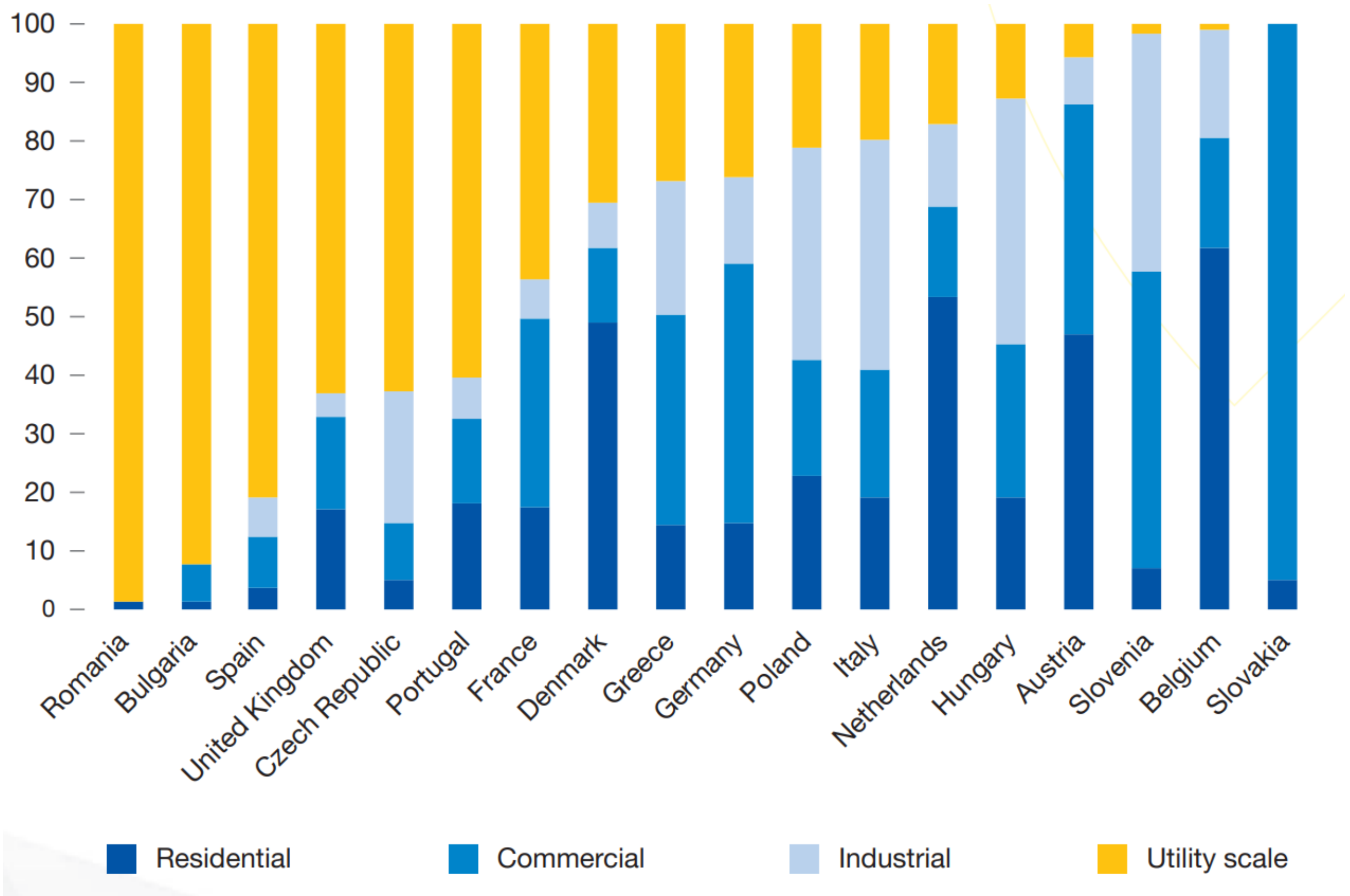
Case of Study:

- **100m^2 house with Energy Label E in Climate Zone D**
- Energy demand data:
  - Heating: 102 kWh/m^2 year -> 10.200kWh/year (thermal consumption)
  - Refrigeration: 14.53 kWh/m^2 year -> 1453kWh/year (thermal consumption)
- Seasonal yields for heating and cooling
  - SCOP aerothermal energy A+: 6.2 -> 10200kWh/6.2 = 1645.16kWh heating (electricity consumption)
  - SEER cooling A+: 5.7 -> 1453kWh/5.7= 254.91kWh cooling (electricity consumption)
- Total electricity consumption for climate control = 1900.07kWh -> 1.9MWh
- Annual electricity consumption of the average Spanish home 3.5MWh
- Annual energy consumption of the average Spanish home (gas + electricity) 10MWh per year
- Electrification would bring this consumption down to 1.9+3.5 = 5.4MWh (down 46%).
- Consumption of heat pumps installed in Spain (1100GWh -> 0.5% of total).
- Without distributed generation, congestion in the distribution network would increase by 54% due to heat pumps alone.

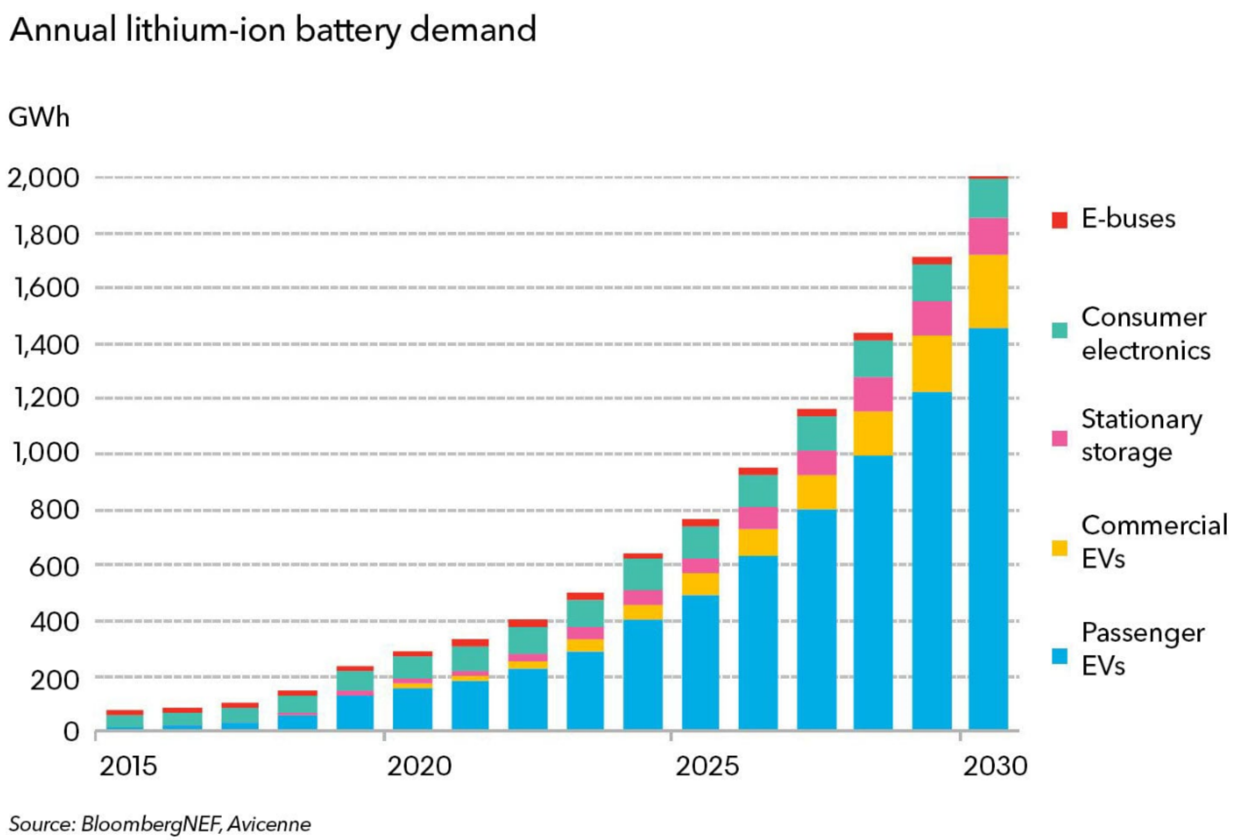
PV Generation



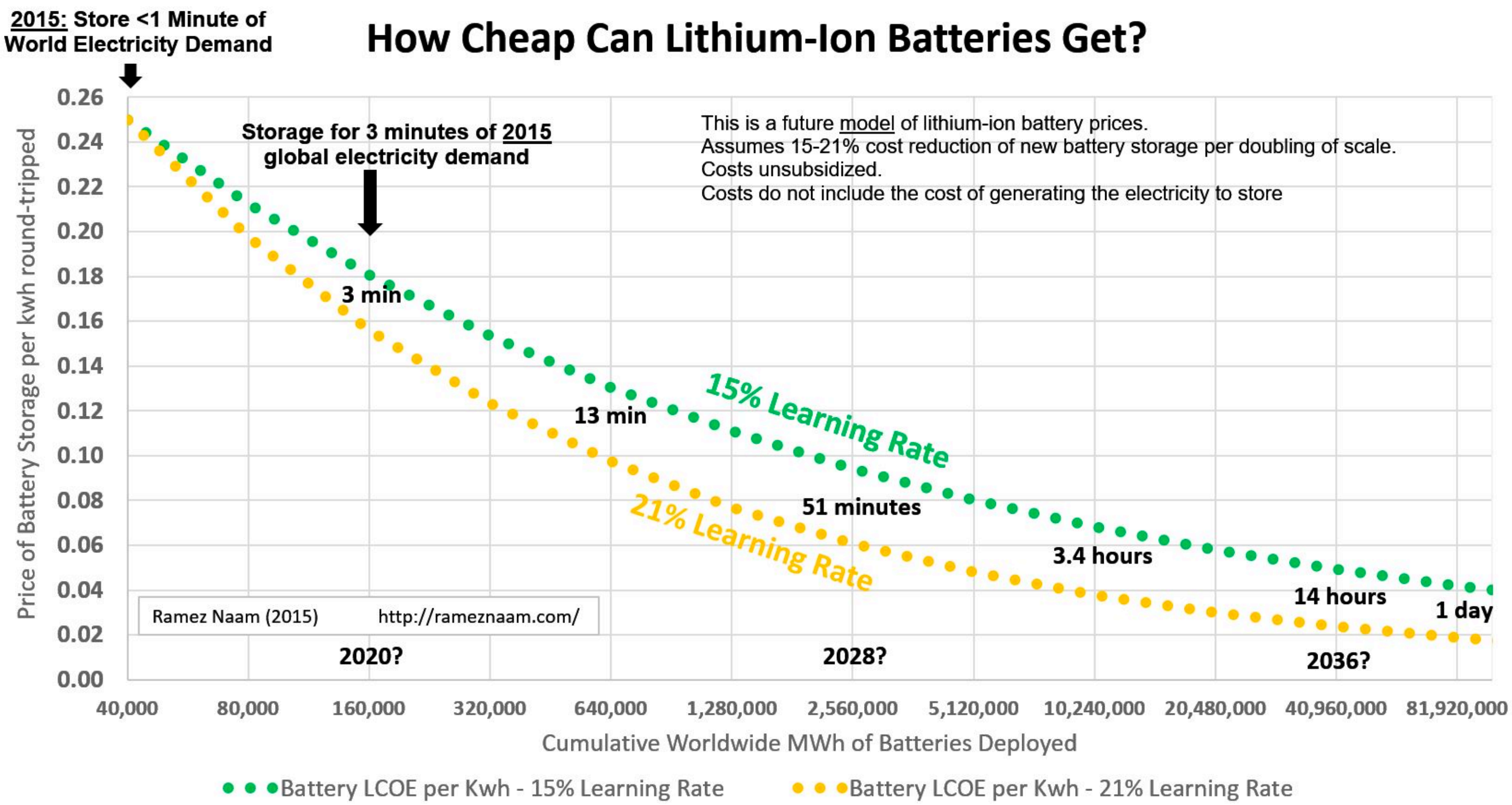
PV Generation



Energy Storage:



Energy Storage:



What we researchers have done over the last 20 years?

- **Microgrid**: Solution for the coordination of different distributed resources in a portion of the network connected through a coupling point.

- **SmartGrids**: Relaxation of topological restrictions and automatic or semi-automatic network management that allows the implementation of **Demand Response** systems or **flexibility** management.

- **Transactive Energy**: Application of economic techniques in conjunction with conventional network management techniques, giving rise to new roles or business models such as the **Aggregator**.

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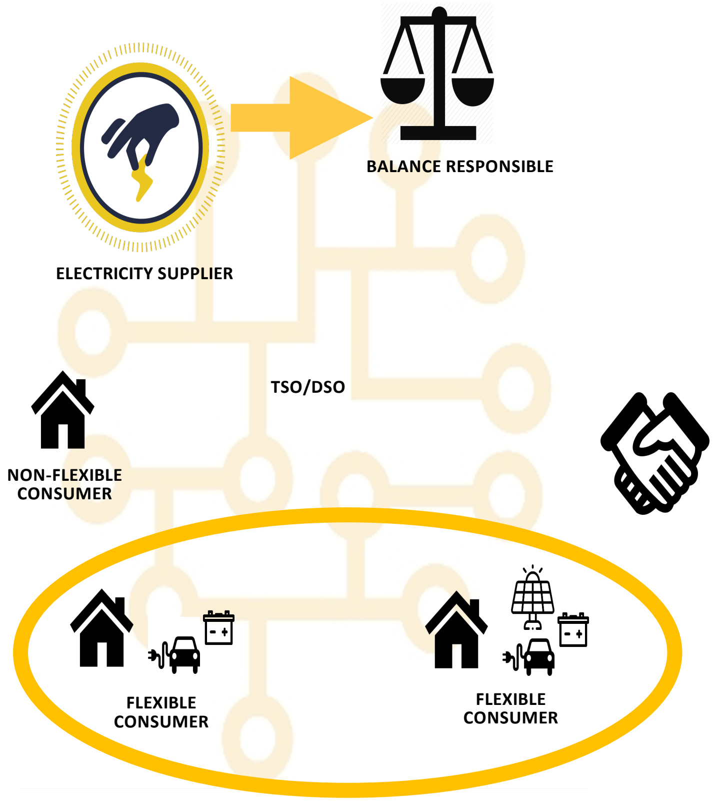
Which Aggregator models do we have? Are they "deployable"?

- There is a vast catalogue of aggregation models that depend mainly on the following factors:
  - Regulation
  - Available technology
  - Regulation
- In this presentation we will see two models that represent the two "extremes" but there are many proposals and solutions in between.
- Model 1:
  - Consume and generate energy in a coordinated way.
  - One more agent in the system
  - No responsibility for the energy supply to the customer



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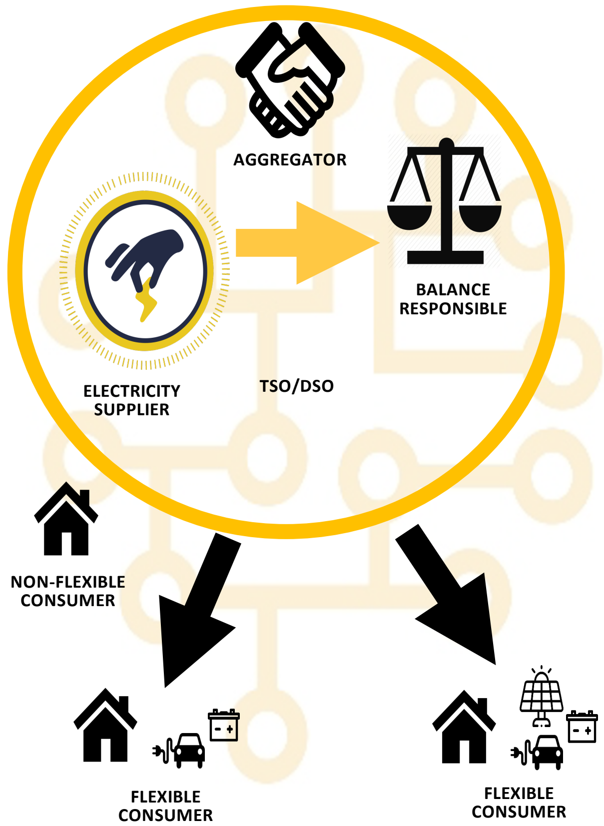
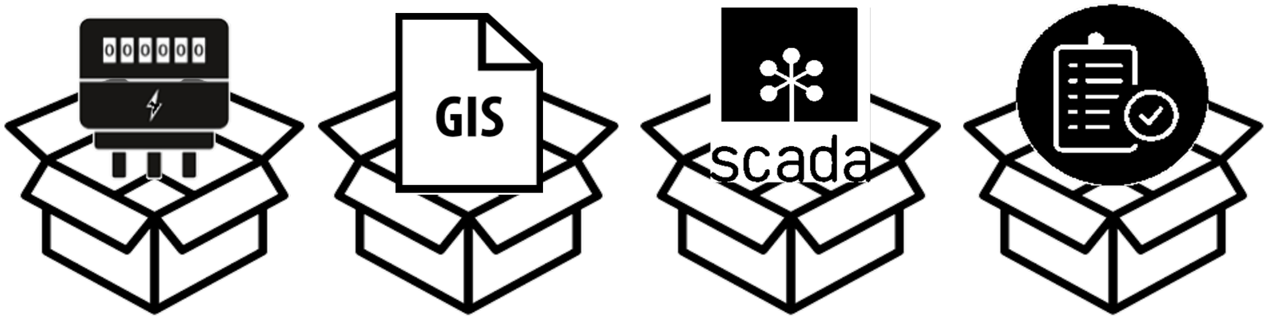
- Model 4:
  - Integrated management with the TSO, DSO or energy supplier.
  - It optimises the management of resources to the maximum and increases efficiency.
  - It can be a role within an agent or an agent itself



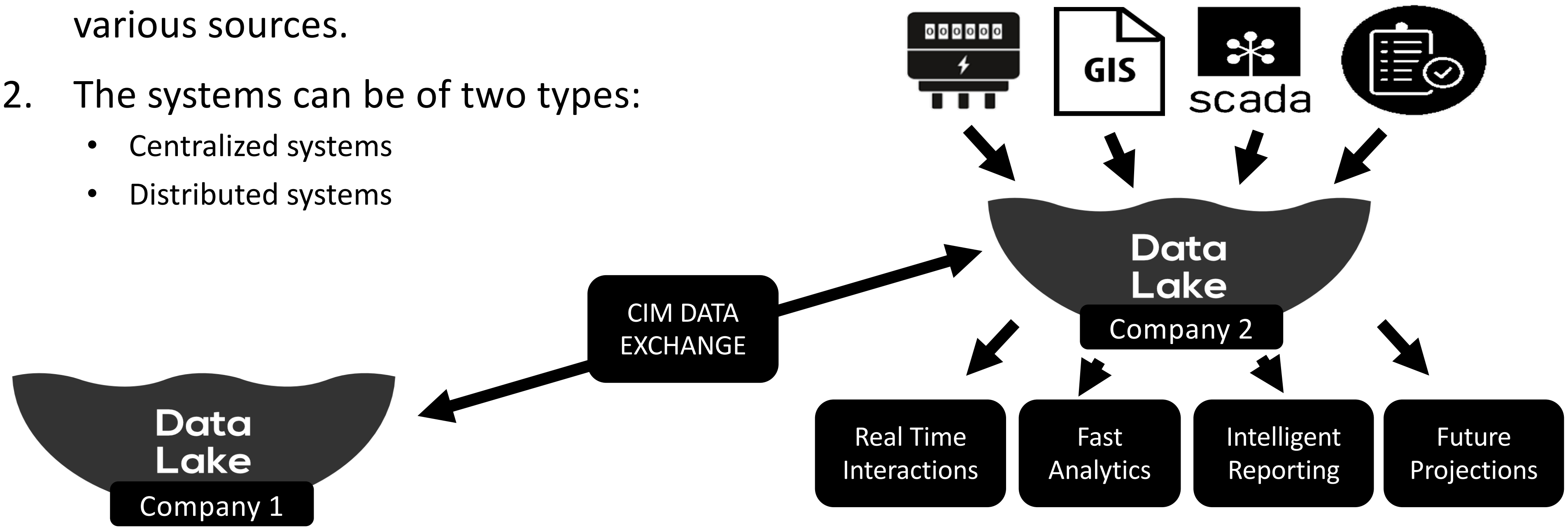
What is the reality in utilities?



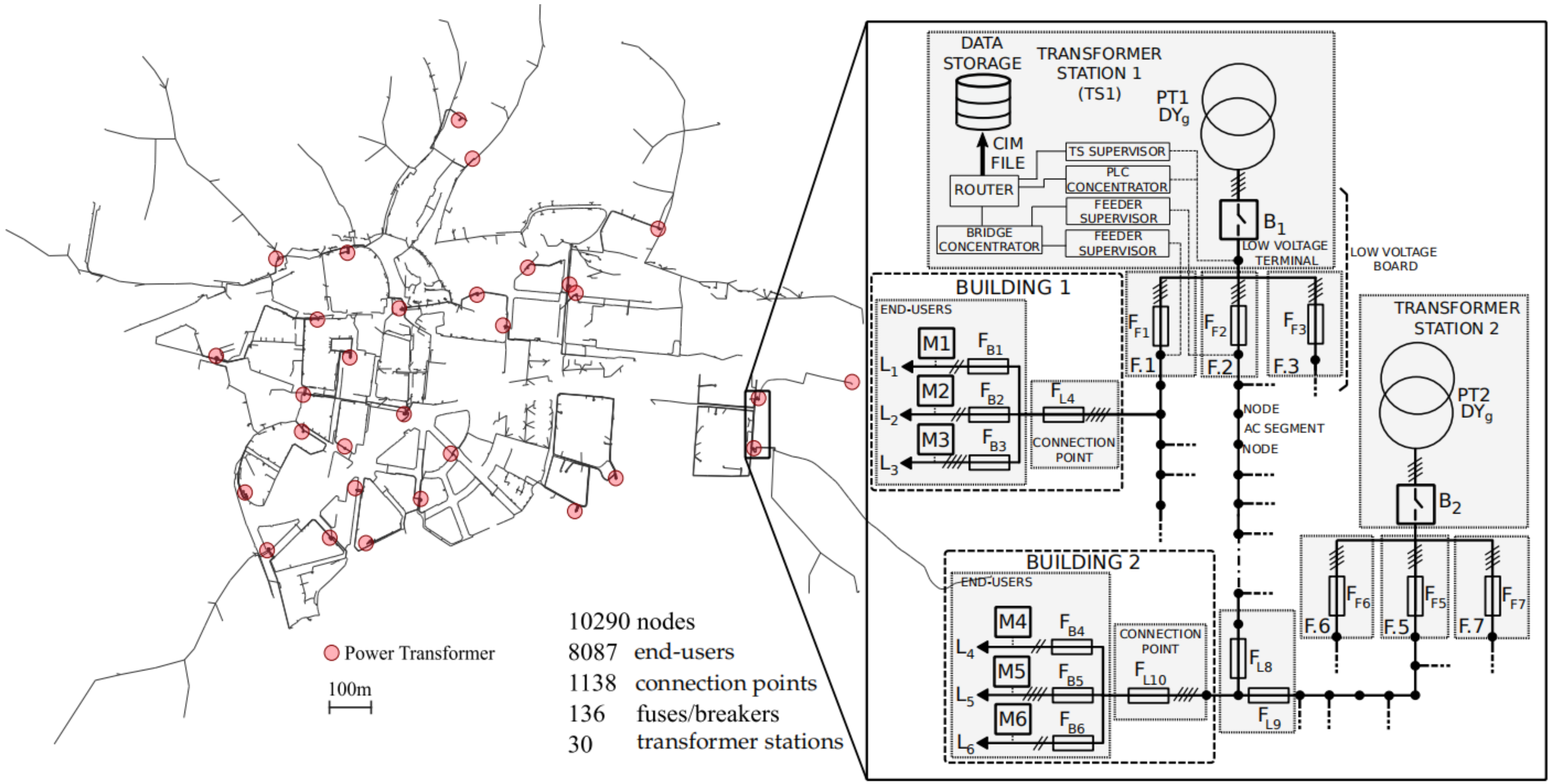
1. The **utilities** have made a tremendous effort in **digitalization** generating an immense **volume** of **invaluable data**.
2. **Data** is the oil of the 21st century, but data collection and storage **does not directly means** the generation of **knowledge**.
3. In many cases, **data** is in **separate, non-intercommunicating** systems, making it **difficult** to manipulate and **extract knowledge** from it.

Which is the path we must follow?

1. Create data storage and management systems that enable ultra-fast, highly complex queries with cross data from various sources.
2. The systems can be of two types:
   - Centralized systems
   - Distributed systems

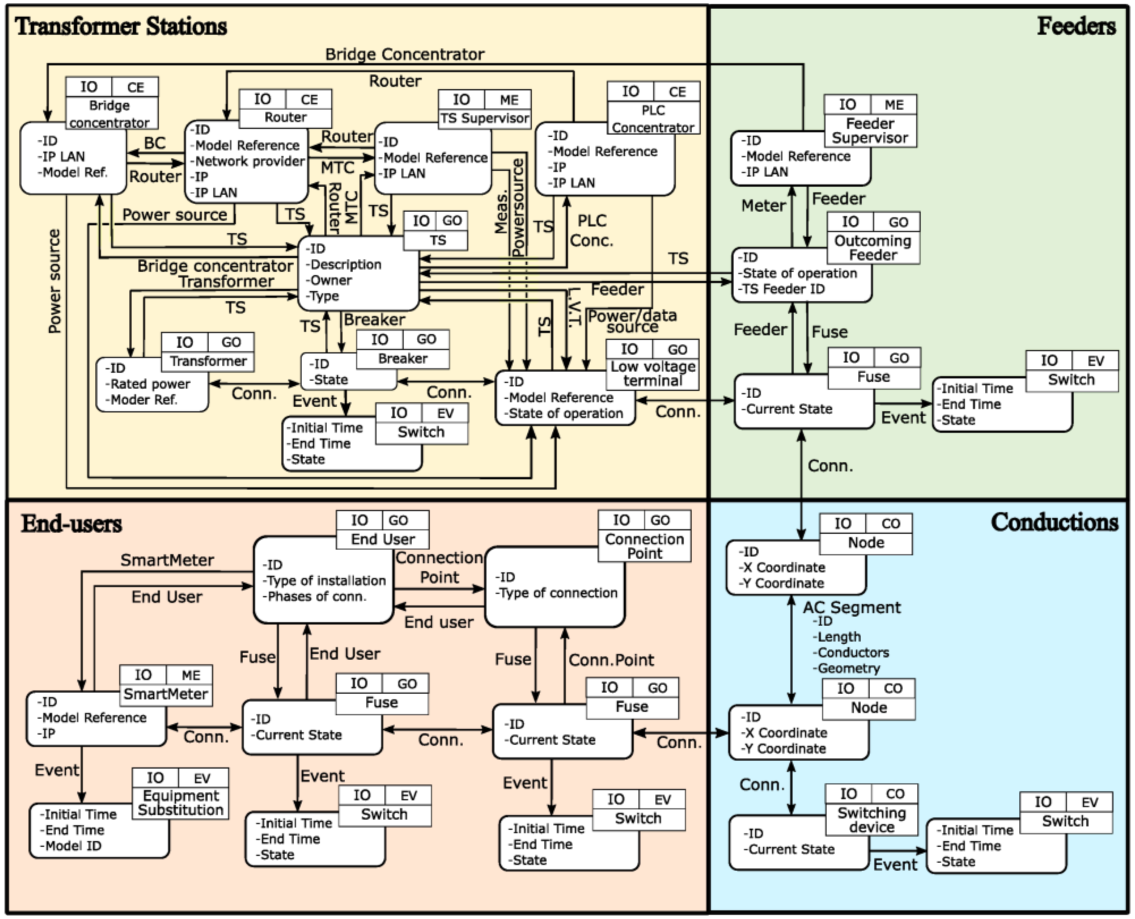


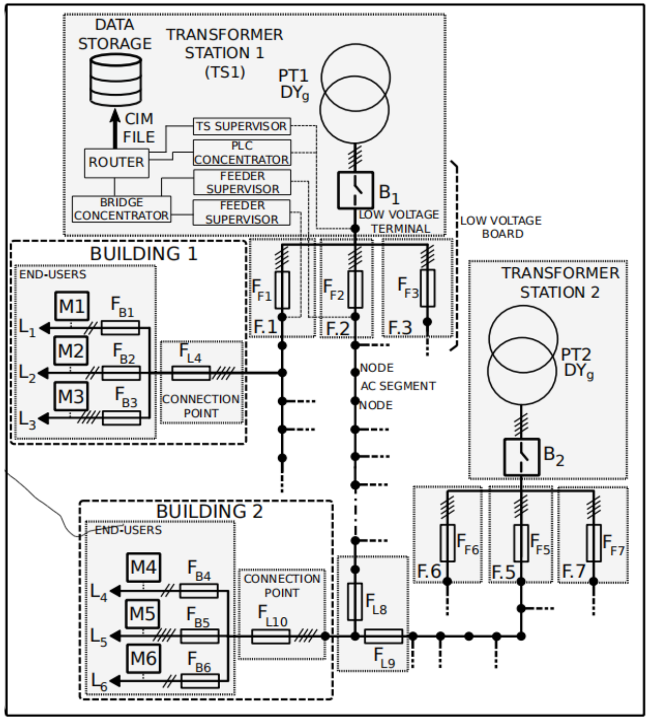
Development of data models is a critical task



Arpan Koirala, Lucía Suárez-Ramón, Bassam Mohamed, Pablo Arboleya, “*Non-synthetic European low voltage test system*”, International Journal of Electrical Power & Energy Systems, Volume 118, 2020.

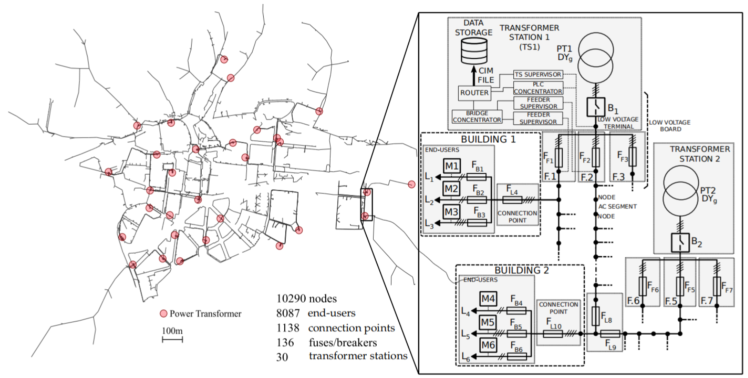
Development of data models is a critical task

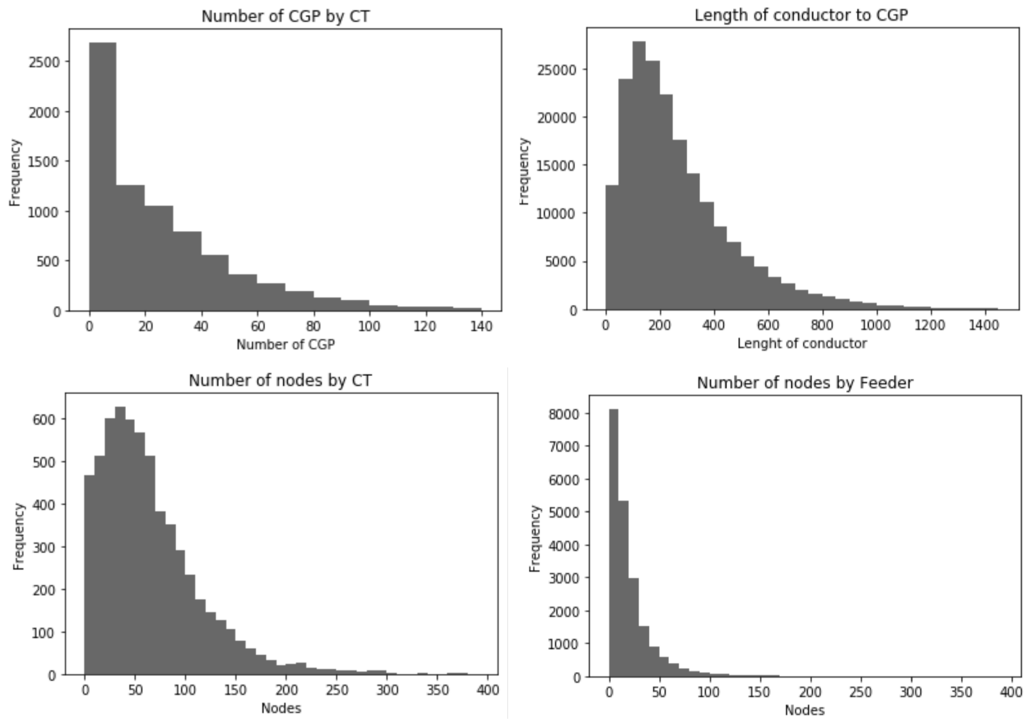




A Specific data model for each case of application

The parallelization of data processing systems





	Case	Min	Percentile 5	Average	Percentile 95	Max
0	Nodes by CT	2	6.0	67.303422	163.0	590
1	Nodes by Feeder	2	2.0	19.958337	63.0	258
2	CGP by CT	0	0.0	25.797784	82.0	465
3	Length to CGP	0	41.0	269.575146	683.0	3027

In distribution, it is essential to break down the problem.

A natural grouping element is the power transformer station.

Knowing the dimensions of the problem to optimize the algorithms is fundamental.

Case of study, complex query

The real-time calculation of the network impedance map involves the generation of real-time networks that That allow to reach from each point to its corresponding transformer.

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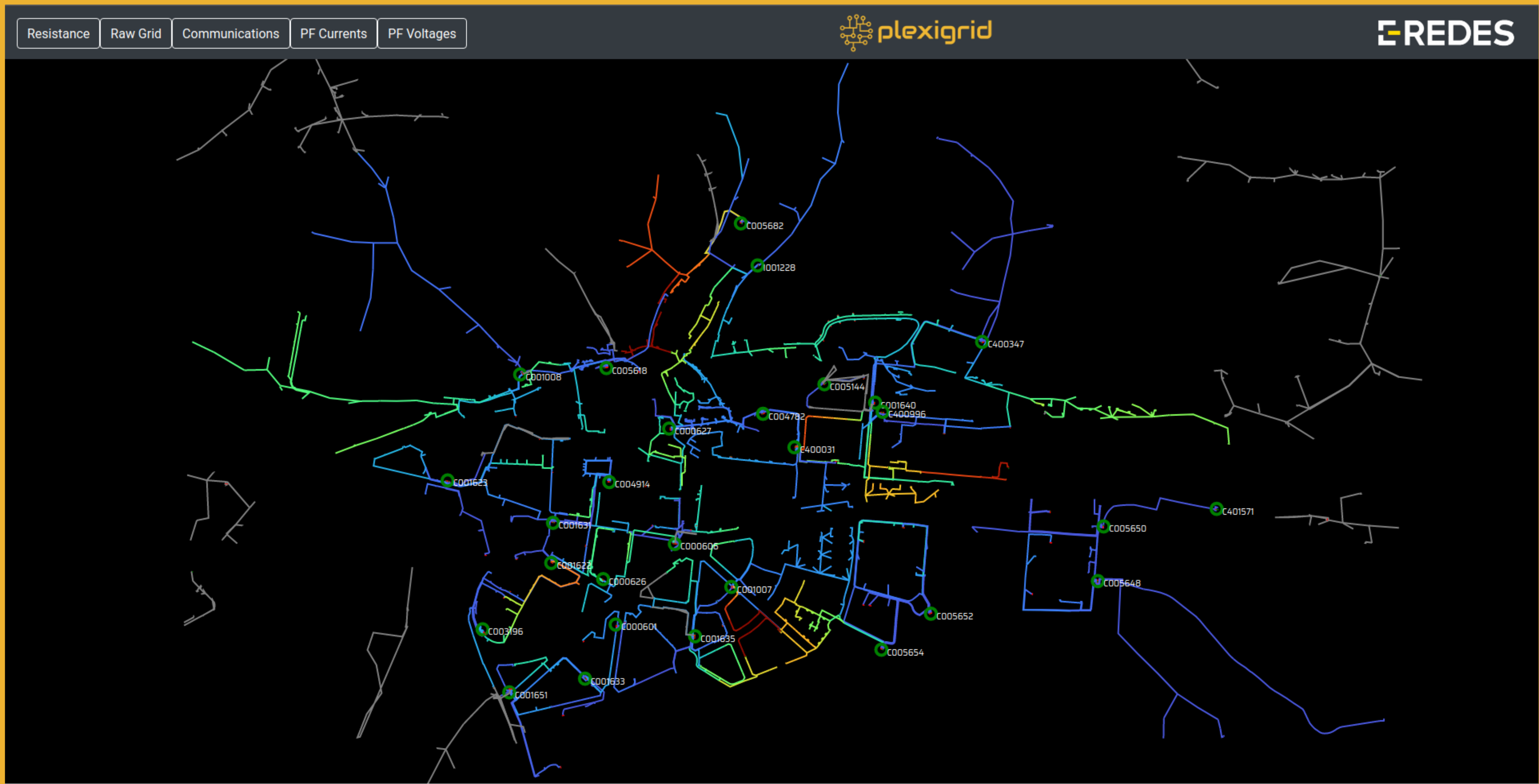
Case of study, complex query

Impedance map

Case of study, complex query



Voltages map

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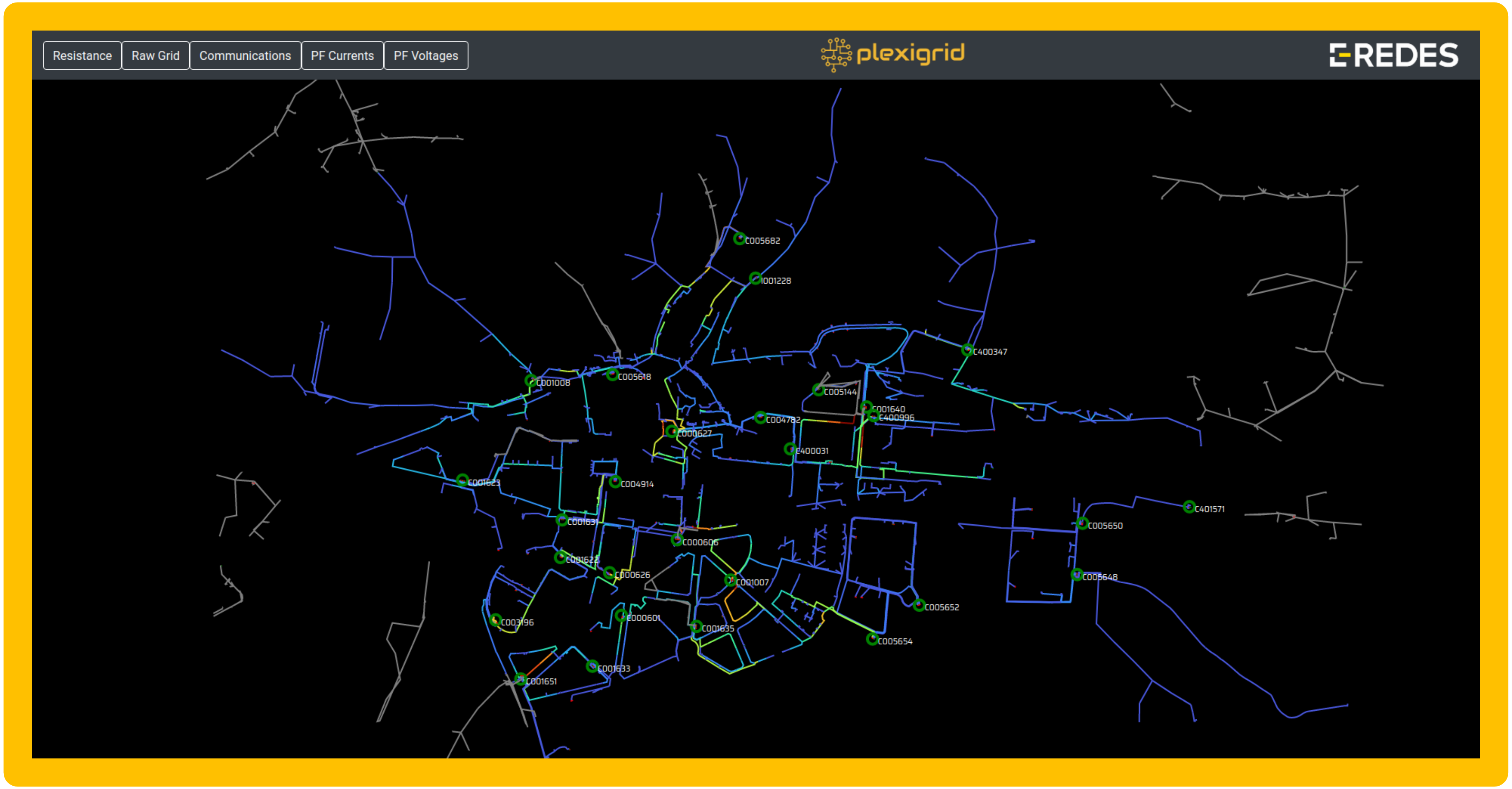
Case of study, complex query



Currents map

Is it posible to run a real-time state estimation?

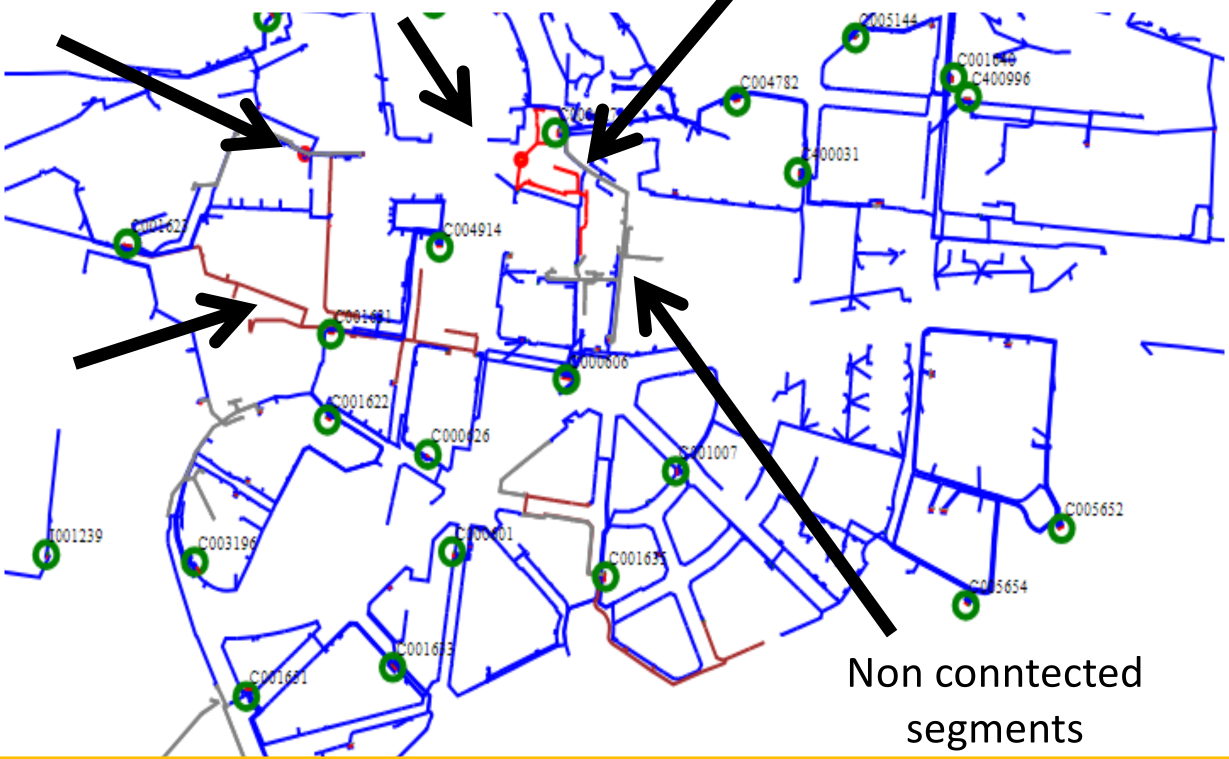
- Again the key is in data acquisition and management and parallelization of operations.
- The technology used in Spanish smartmeters is PLC technology.
- As the main advantage of PLC technology we could indicate the elimination of the dependence on third party communication networks.
- PLC technology allows us to obtain a lot of topological information and the configuration of network resources.
- The bandwidth is very limited.

Is it posible to run a real-time state estimation?

Switch of non coherent meter

Non coherent meter

Non coherent line



Segments communicating with portable equipment

Non conntected segments

- Loop detections
- Fraud detections
- Grid inconsistencies
- Phase detection

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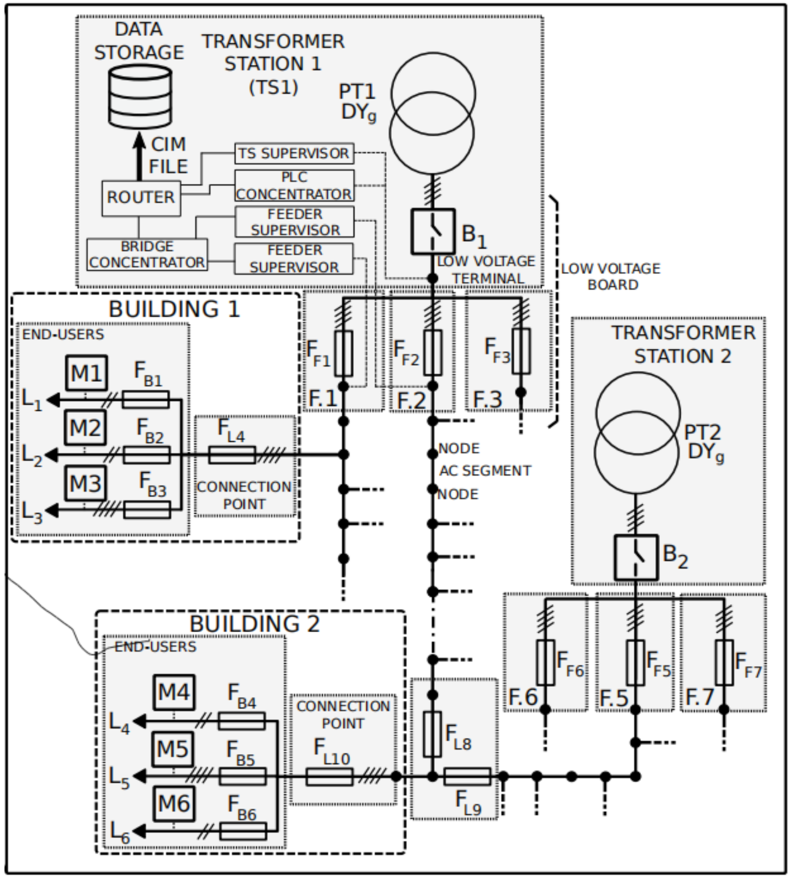
Is it posible to run a real-time state estimation?

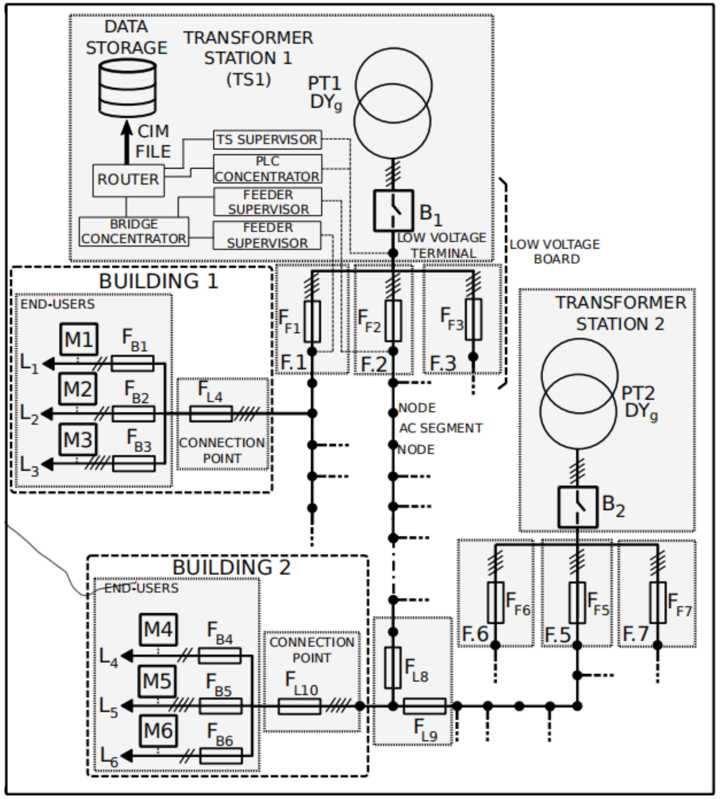
- The **state estimation** algorithms in four-wire systems are **developed**.
- Once the problem of topological estimation is solved, everything depends on the **acquisition** of **measurements** that allow the **observability** of the system.
- The **advanced measurement infrastructure** consisting of smartmeters, line supervisors and advanced supervisors at the transformer station level is capable of **providing sufficient information**.
- It is **essential** to **understand the sampling** process and the delays generated by it in obtaining the information.



Is it posible to run a real-time state estimation?

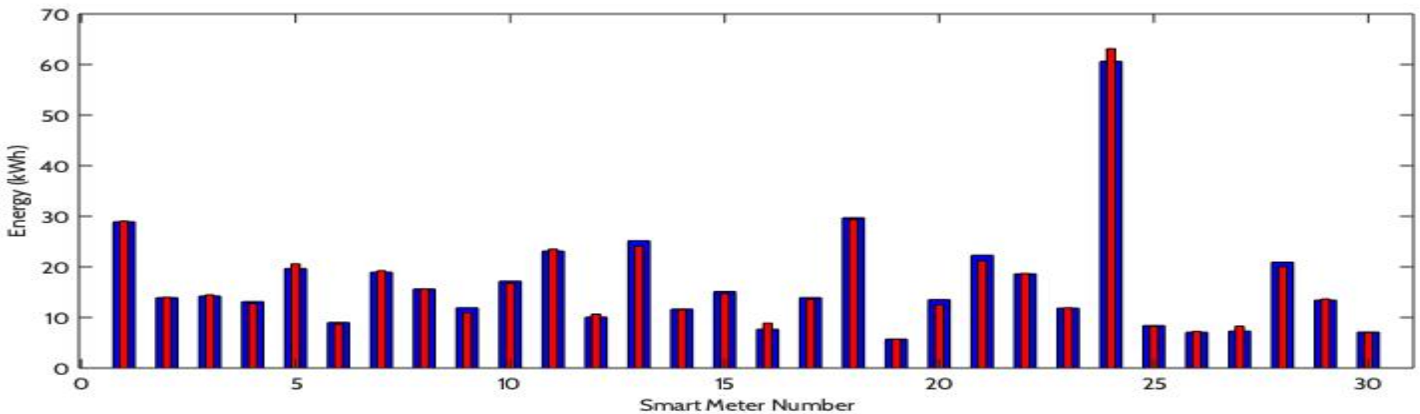
- What is the delay in requesting data from a SmartMeter?
  - Injection phase
  - Distance to the concentrator
  - Network saturation
  - Electromagnetic interference

- Example request active power to smartmeter:
  - Request time: 30-Nov-2019 17:27:36
  - Answer received: 30-Nov-2019 17:28:10
  - Value (active power W): 599.9
  - Value timestamp: 30-Nov-2019 17:27:57
  - Total delay: 34 seconds



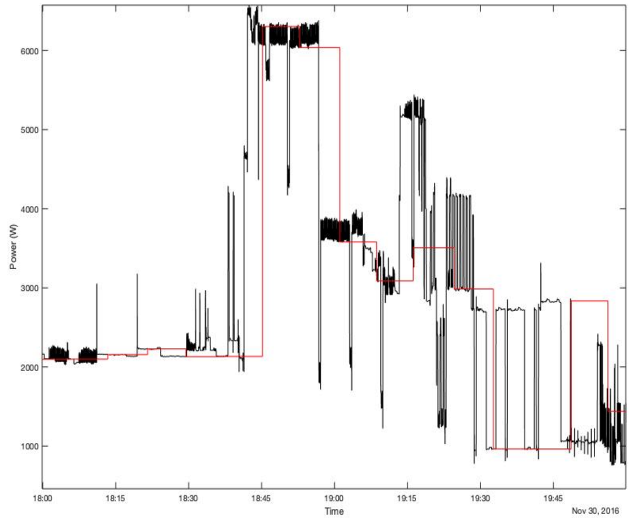
Is it posible to run a real-time state estimation?

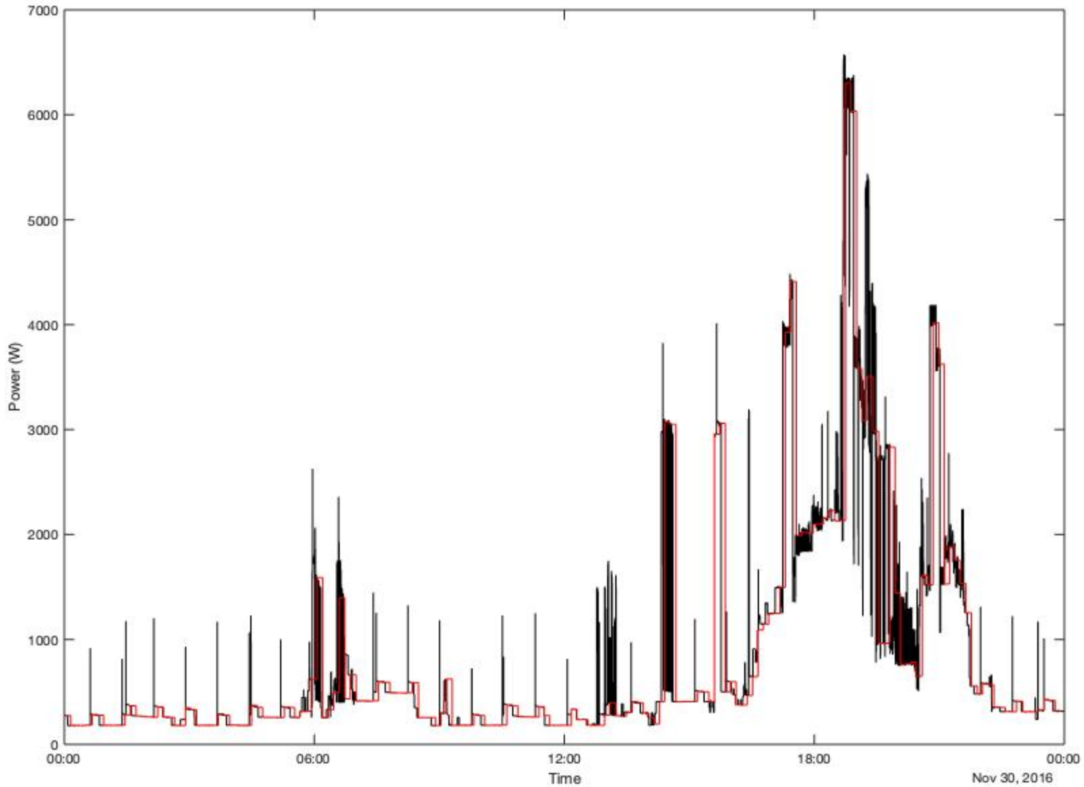
- Data obtained with a sampling emulator in a system of 30 dwellings divided into 5 connections located in the same feeder and distributed in 3 phases.
- Distance of the connections in meters [25 37 52 91 103].
- Initial curves obtained with recorders and sampled with a frequency of 1 second.
- The average delay in the slowest smartmeter was 19.73 seconds, in the fastest one 7.81 seconds. The number of records obtained by each meter was 181, in this case only active power was sampled. This implies that a data could be obtained from each smartmeter every 7 minutes and 57 seconds.



Is it posible to run a real-time state estimation?

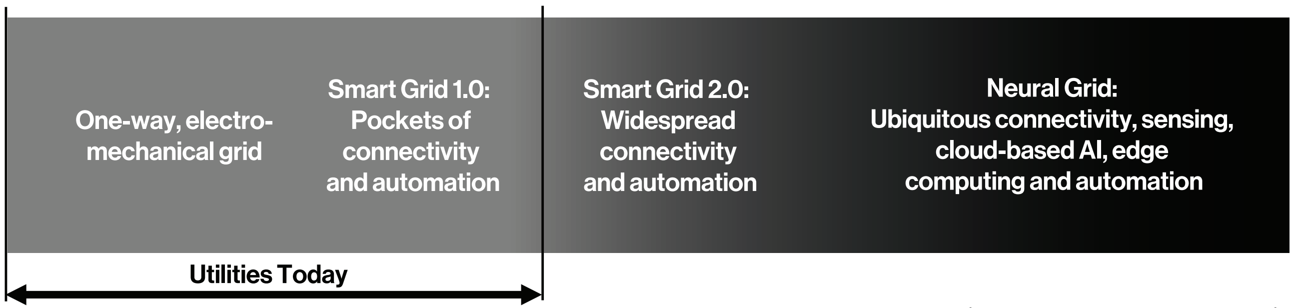
- Difference between real signal and sampled signal on smartmeter number 7
- The definition of the sampling strategy is fundamental.
- The measurements have to be used together with prediction techniques and AI algorithms.





The path towards the **Neural-Grid**

- From Smart Grid to Neural Grid – Industry Transformation and the Top Five Technologies Poised to Bring the Cloud – Guidehouse Consulting White Paper (2018).
- Enabling technologies:
  - In addition to the already mentioned distributed resources.
  - Connectivity: Fiber, Low Power Wide Area Communications or other solutions such as 4G, 5G...
  - Low-cost sensors combined with advanced measurement infrastructure
  - Cloud and Edge computing, centralized/distributed hybrid solutions will be imposed
  - Artificial Intelligence, will be the nuclear technology of the "brain" of the neural grid.
  - Cybersecurity, a critical point to be addressed since holistic connectivity carries an intrinsic risk of cyberattacks.
  - Drones and robotics, the basics for advanced monitoring, maintenance and repair.



(Source: Navigant Research*)

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