Combined cooling, heating, and power (CCHP) microgrids in nearly Zero-Energy Building with critical loads under high Power Quality and Reliability requirements, a position paper

Antonio Moreno-Munoz
Industrial Electronics and Instrumentation R&D,
University of Cordoba, Spain

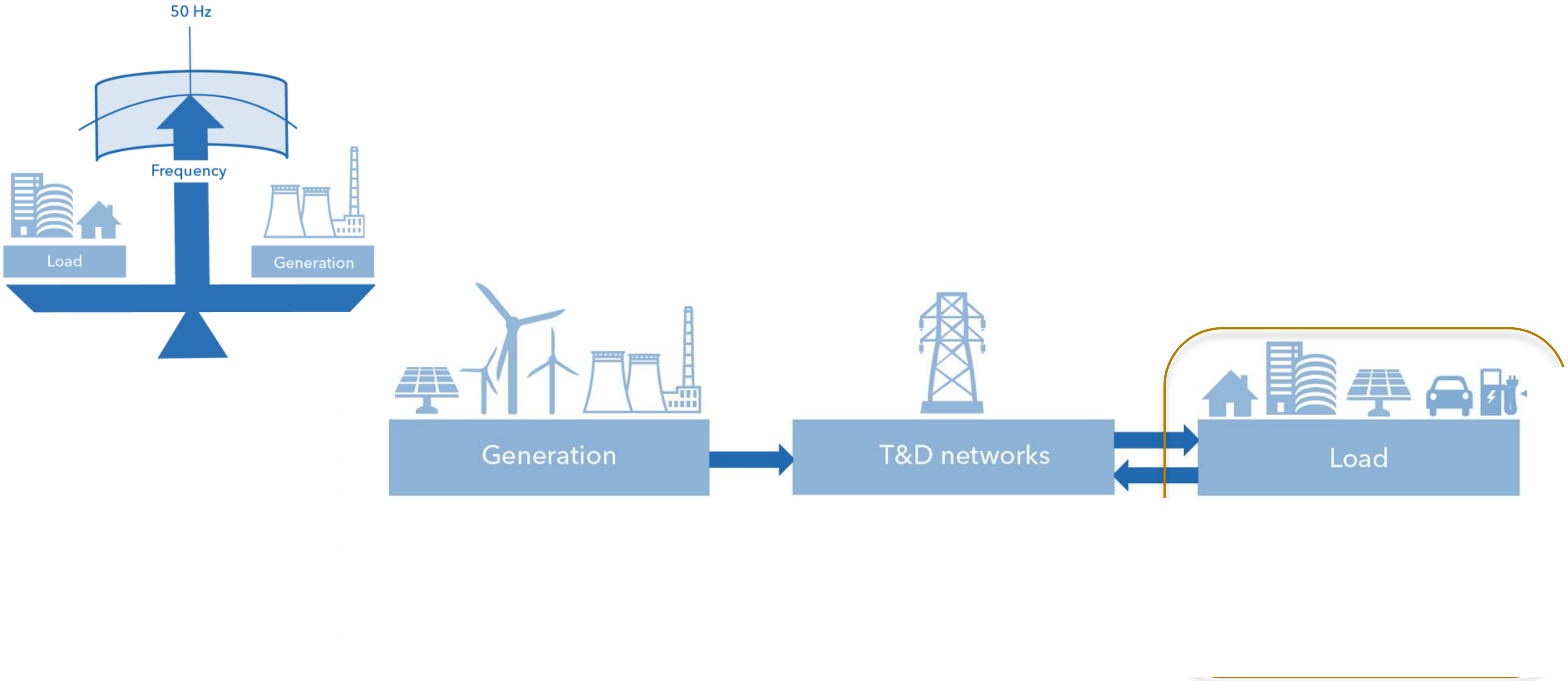
Universidad de Córdoba (UCO) location

UNIVERSIDAD DE CÓRDOBA

Agenda

- Demand Side Management/Demand Response
- Grid-Interactive Efficient Buildings (GEB) and Energy Smart Appliance
- Relevance of Submetering
- Interreg Sudoe IMPROVEMENT
- Conclusions

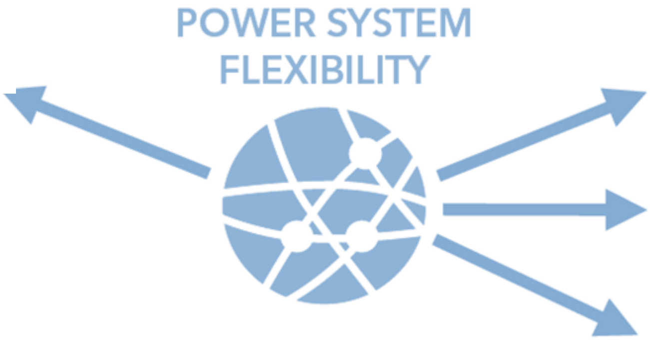
Variability and flexibility in power system



- Variability in generation is increasingly present due to the large-scale integration of RES like solar or wind.
- Flexibility services can be provided not only on the supply side, but also by improving power transmission and on the demand side…

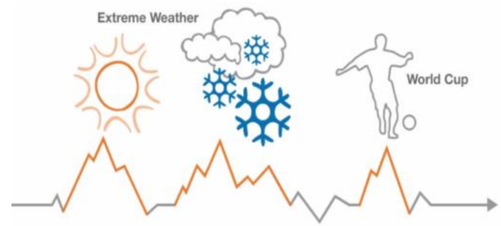
Flexibility options in the power system

- The current state of technologies and advances that allow for more active and dynamic consumer behavior can also provide flexibility to the system trough…
  - **Demand-Side Management/Demand Response**

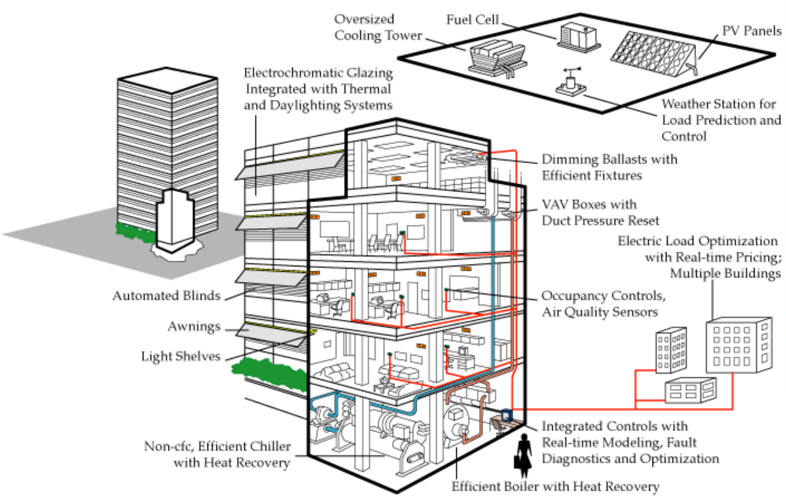


Demand Side Management

- **Demand-Side Management (DSM)** comprises a portfolio of measures to improve the energy system at the side of consumption*.



Commercial Building with Integrated System Design and Operations



Air handling
- Air conditioning and circulation, variable speed drive fans
- Short term change to temperature set point doesn’t affect comfort and can reduce a building’s consumption by 20%

Building Management Systems
- Existing management systems can be used to intelligently and automatically control systems

Lighting
- Common area, floor and feature lighting
- Shutting off or dimming certain lights for a short time can cut consumption by 15%

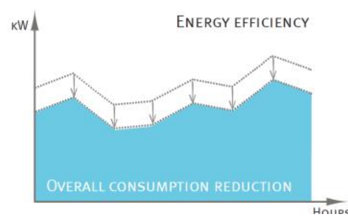
* Palensky, P., & Dietrich, D. (2011). Demand side management: Demand response, intelligent energy systems, and smart loads. *IEEE transactions on industrial informatics*, *7*(3), 381-388.

Demand Response

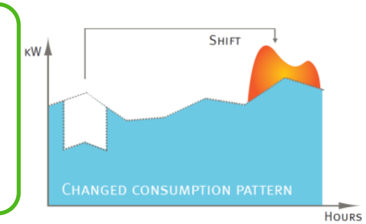
Demand response (DR) can be defined[1] as **changes in electric usage by end-use customers from their normal consumption patterns** in response to changes in the price of electricity over time, or to incentive payments designed to induce lower electricity use at time of high wholesale market prices or when system reliability is jeopardized

Demand-Side Management

Energy Eficiency



Demand Response



High Efficiency Equipment

Energy Conservation (behavior)

EE-DR Convergence

(1) U.S Department of Energy (DOE)
Source: Harry Vreuls, Experts meeting Task 21 April 29/30 March 2010

Demand Response Programs

DR services are normally classified in two groups attending to mechanism used to promote the response

	Explicit Demand Response	Implicit Demand Response
Definition	This is committed, dispatchable DR action traded on the energy market. Usually provided by an independent **aggregator** or a supplier. Consumers receive an incentive to change their consumption when required: grid congestion, balance problems, etc. This is referred to as "***incentive driven***" DR.	Consumers choose to be exposed to hourly or shorter-term tariffs in which the price of electricity varies depending on production costs. Adapting their demand (through automation or personal choices) to save on energy expenses. This is referred to as "***price-based***" DR.
Products	▪ Direct Load Control (DLC) ▪ Interruptible/curtailable rates (I/C) ▪ Demand bidding/Buy-back programs (DB) ▪ Emergency Demand Response Programs (EDRP) ▪ Capacity Programs (CAP) ▪ Ancillary Services markets program (A/S)	▪ Time-of-use (TOU) ▪ Critical peak pricing (CPP) ▪ Real-time pricing (RTP)

The role of the Aggregator

Explicit Demand Response

- An Aggregator explores, contracts, operates, aggregates and valorizes the flexibility of Prosumers
- A Balance Responsible Party (BRP) is responsible for actively balancing supply and demand for its portfolio of Producers, Suppliers, Aggregators, and Prosumers.

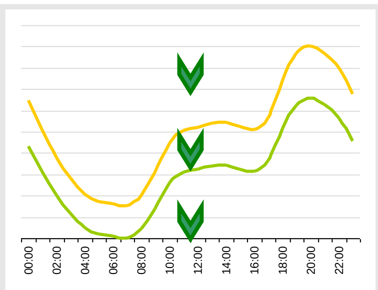
- **EU Clean Energy Package**: "Consumers and communities will be empowered to actively participate in the electricity market and generate their own electricity, consume it or sell it back to the market while taking into account the costs and benefits for the system as a whole"."Every consumer will be able to offer demand response and to receive remuneration, directly or through aggregators" https://ec.europa.eu/energy/en/topics/energy-strategy-and-energy-union/clean-energy-all-europeans
- **Real Decreto-ley 15/2018, de 5 de octubre**. El autoconsumo no será principalmente para el uso de viviendas aisladas, sino de amplias comunidades que, además, podrán asociar el autoconsumo a servicios energéticos que permitan una gestión de la demanda compartida, la acumulación compartida, la agregación compartida.

Demand Response results

Demand response measures and other technology options in the framework of Demand-side management

1

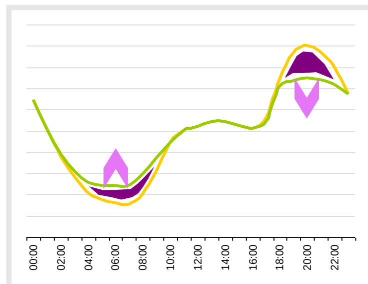
An Overall Demand reduction



- Improvements in the energy efficiency of appliances and processes
- Increasing user awareness of energy efficiency

2

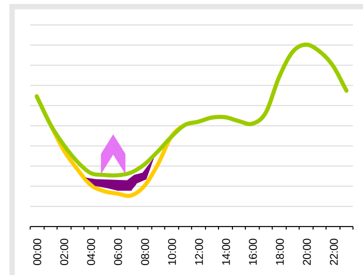
A movement of demand from peak to off-peak



- Time of use tariff
- Demand participation in electricity markets

3

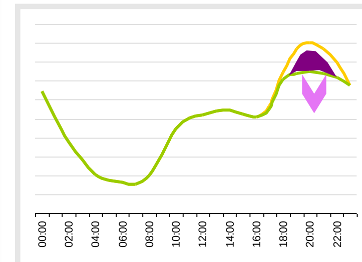
A high demand on off-peak



- Pumping
- Onsite energy storage
- Electric vehicles

4

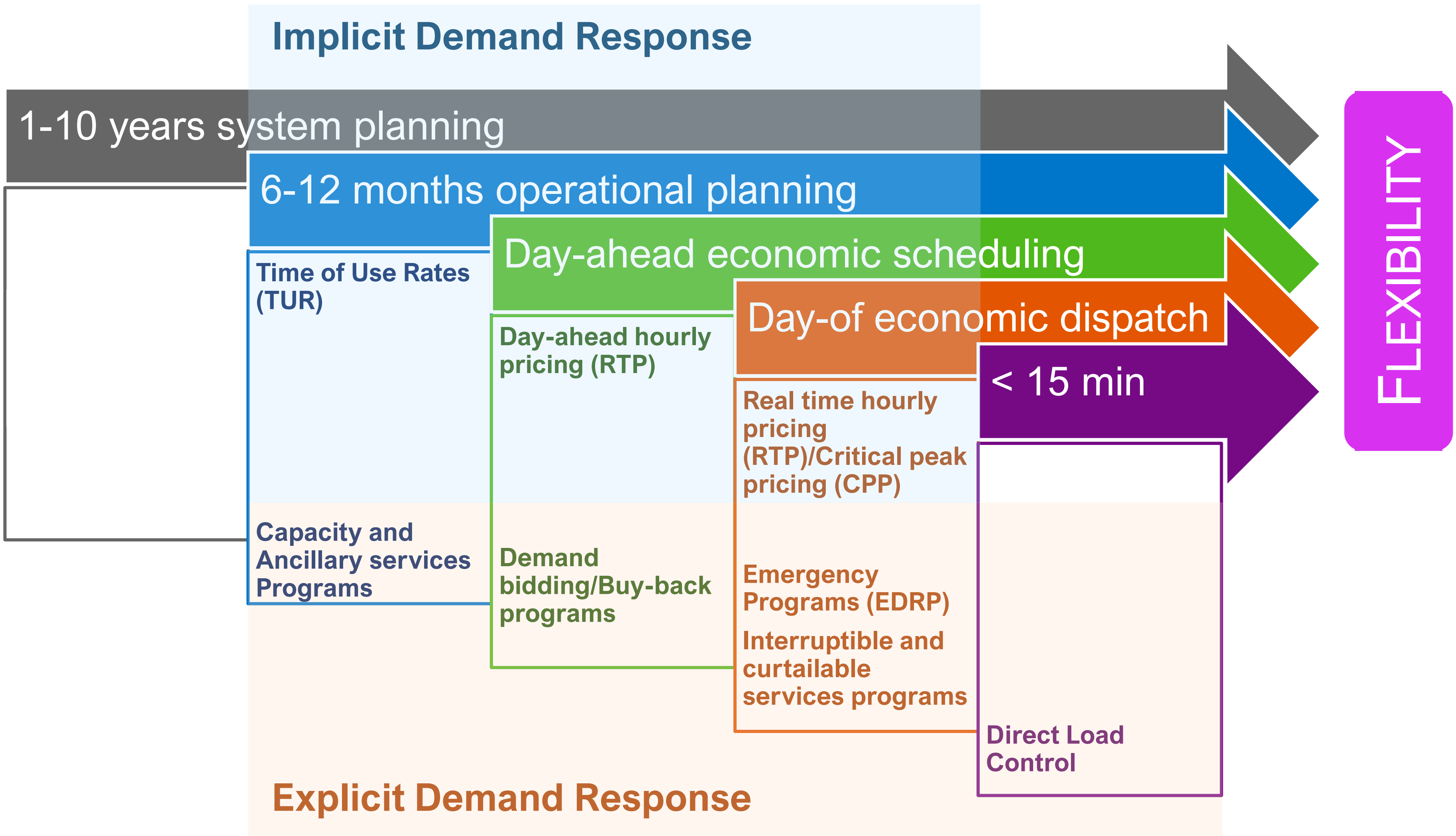
A demand reduction on peak hours



- Industrial DR: Interruptibility service
- Direct Load Control (DLC) programs

The final goal of demand response products is to influence customers to reduce energy consumption in response to conditions within the electricity system

Demand Response programs timescale



Demand Flexibility potential assets

Mining & Quarries

- Bitumen tank heating
- Crushers
- Grinders
- Conveyer belts
- Variable speed drives
- Building management systems

Foundries & Metal processing

- Electric induction furnaces
- Ovens
- Pumps & melting pots
- Variable speed drives
- Building management systems

IT & Telecoms

- Computer air conditioning units
- Chillers
- DRUPS
- UPS
- Batteries

Commercial property

- Chillers
- AHU's
- Pumps
- Fans
- UPS
- Building management systems

Airport & Hospitals

- Onsite generation
- UPS
- Combined heat & power system

Manufacturing

- Electric hot water boilers
- Pumps
- Variable speed drives
- Fans
- Building management systems

Commercial refrigeration

- Supermarket refrigeration
- Cold storage
- Compressors
- Refrigerator packs
- UPS
- Variable speed drives

Universities

- Chillers
- Electric heating
- Standby diesel generation
- AHU's
- Laundry rooms

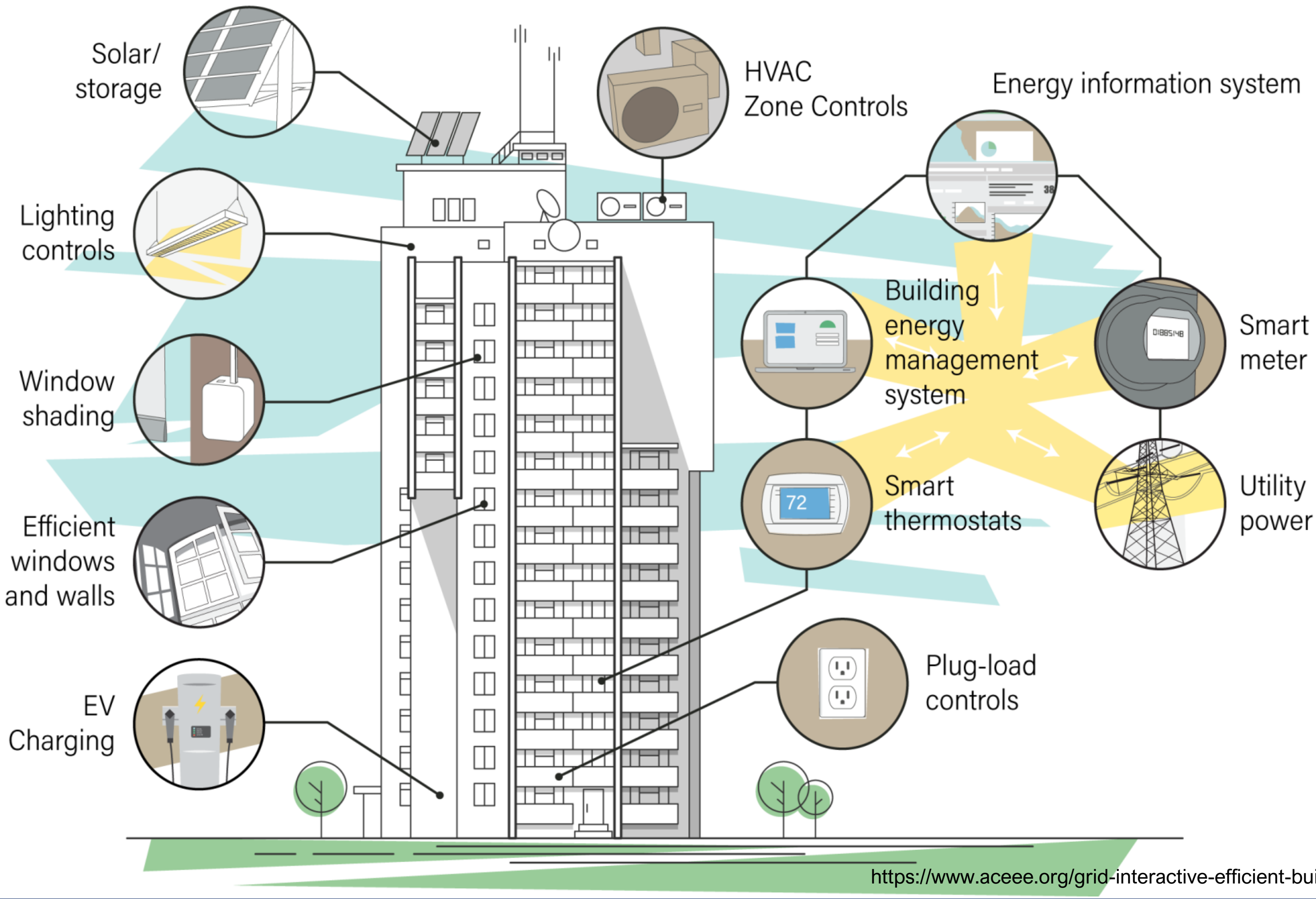
Water treatment & processing

- Variable speed drive pumps
- Blowers
- Aerators
- Motors & industrial plant
- BMS/PMS

DR products are oriented to change energy pattern, either promoting active participation or allowing an aggregator to manage energy consumption

Grid-Interactive Efficient Buildings (GEB)

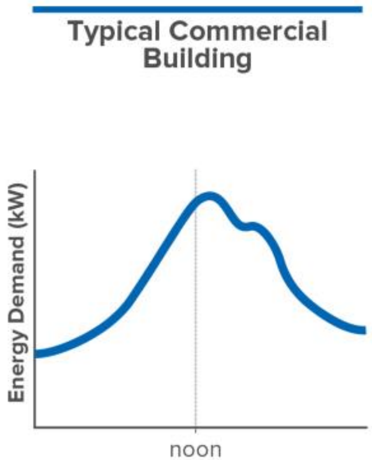
GEB have a holistically optimized blend of energy efficiency, energy storage, renewable energy, and load flexibility technologies enabled through smart controls.



https://www.aceee.org/grid-interactive-efficient-buildings-gebs

Typical GEB load profile

This results in a lower, “flatter,” more flexible energy load profile, which in turn delivers a more resilient and productive building.



At the campus or community scale, additional strategies such as microgrids and district energy systems may be included.

Matt Jungclaus, Cara Carmichael, and Phil Keuhn, Value Potential for Grid-Interactive Efficient Buildings in the GSA Portfolio: A CostBenefit Analysis, Rocky Mountain Institute, 2019. http://www.rmi.org/GEBs_report

Energy Smart Appliance (ESA)[1]

- Popularly, Smart Appliances (SA) are recognized for having some electronic processing capability and wireless connectivity.
- **In the energy field**, within the framework of Smart Grids, the term **"smart"** refers to those capable of **modulating their electricity demand** in response to **signal request** from the electrical system.
- Thus, incorporating different Demand Response (DR) strategies:
  - ✓ This would materialize into **load-shifting strategies**, which shift their operating period from peak to off-peak hours,
  - ✓ Or **load-modulation strategies**, which directly reduce or avoid energy use during peak hours.
- ➢ The ESAs covered include cold and wet appliances; heating, ventilation and air conditioning units; battery storage; and smart EV chargepoints.

Critical issues for effective DR implementation through ESAs:

- **Cybersecurity**: the prevention of unauthorized access to ESAs by third-parties.
- **Data privacy**: the secure storage of personal data on the device or on any controlling part.
- **Interoperability**: the ability of ESAs to work seamlessly across any DR service operated by any system player.
- **Power quality**: the prevention of grid disturbances caused by the incorrect or simultaneous operation of ESAs.

[1] https://www.bsigroup.com/en-GB/about-bsi/uk-national-standards-body/about-standards/Innovation/energy-smart-appliances-programme/

Suitability of appliances in load shifting

Appliance		WM	TD	DW	OS	RF	FR	AC	WH	EH	CP
Energy consumption and average load											
Annual energy consumption	[kWh/yr]	120	190	190	180	320	330	680	1.500	12.400	370
Average load over the year	[W]	13	22	22	20	37	38	78	170	1.410	42
Typical times of operations		day	day	day	day	day & night	day & night	day	night	night	day

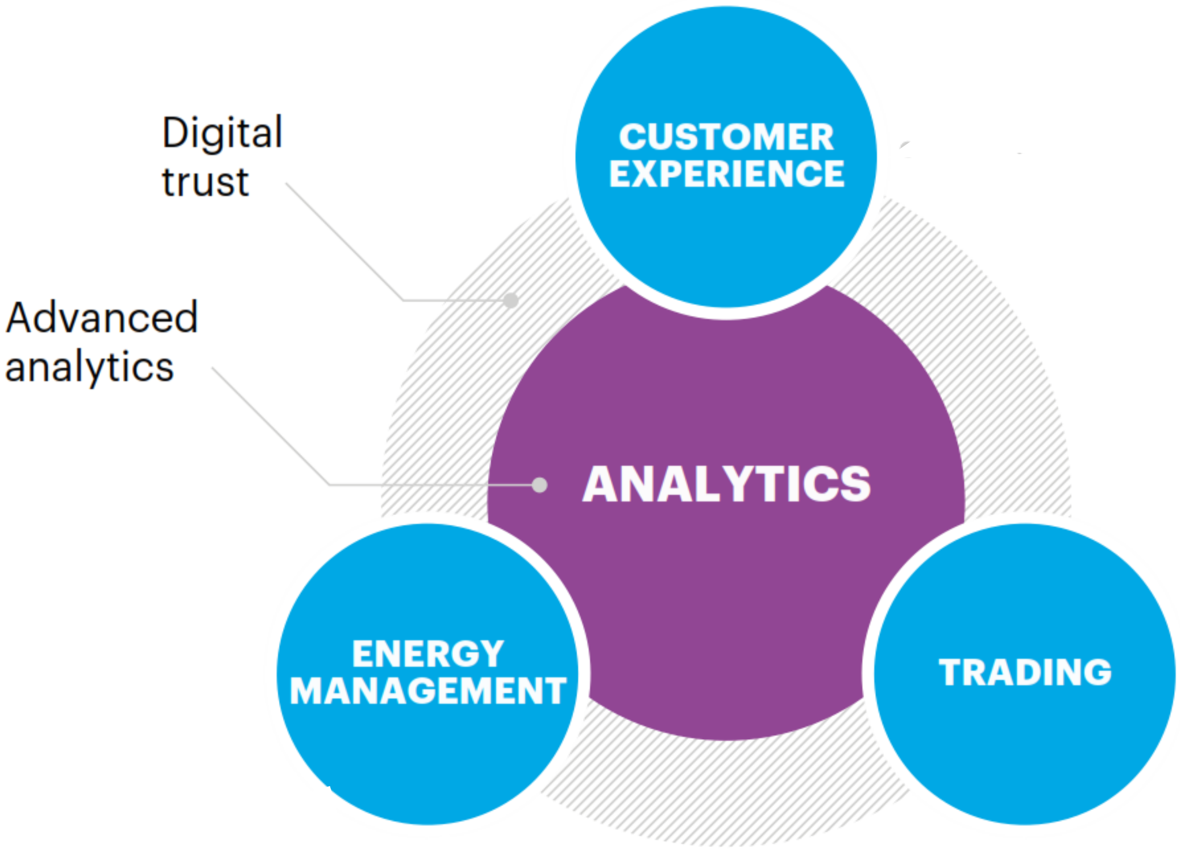
	WM	TD	DW	OS	RF	FR	AC	WH	EH	CP
Specific load during operation	high	high	high	high	low	low	mod.	high	v. high	low
Availability	low	low	low	low	high	high	low	mod.	mod.	mod.
Shifting flexibility	mod.	mod.	high	low	low	low	low	mod.	high	mod.
Convenience for consumers	low	low	mod.	low	high	high	low	mod.	high	mod.

AC Air Conditioner
CP Heating Circulation Pump
DW Dishwasher
EH Electric Storage Heating
FR Freezer
OS Oven & Stove
RF Refrigerator
TD Tumble Dryer
WH Electric Water Heater
WM Washing Machine

Timpe, C. (2009). Smart domestic appliances supporting the system integration of renewable energy. *Bericht der Ergebnisse aus dem Projekt, Smart Domestic Appliances in Sustainable Energy Systems (Smart-A)*.

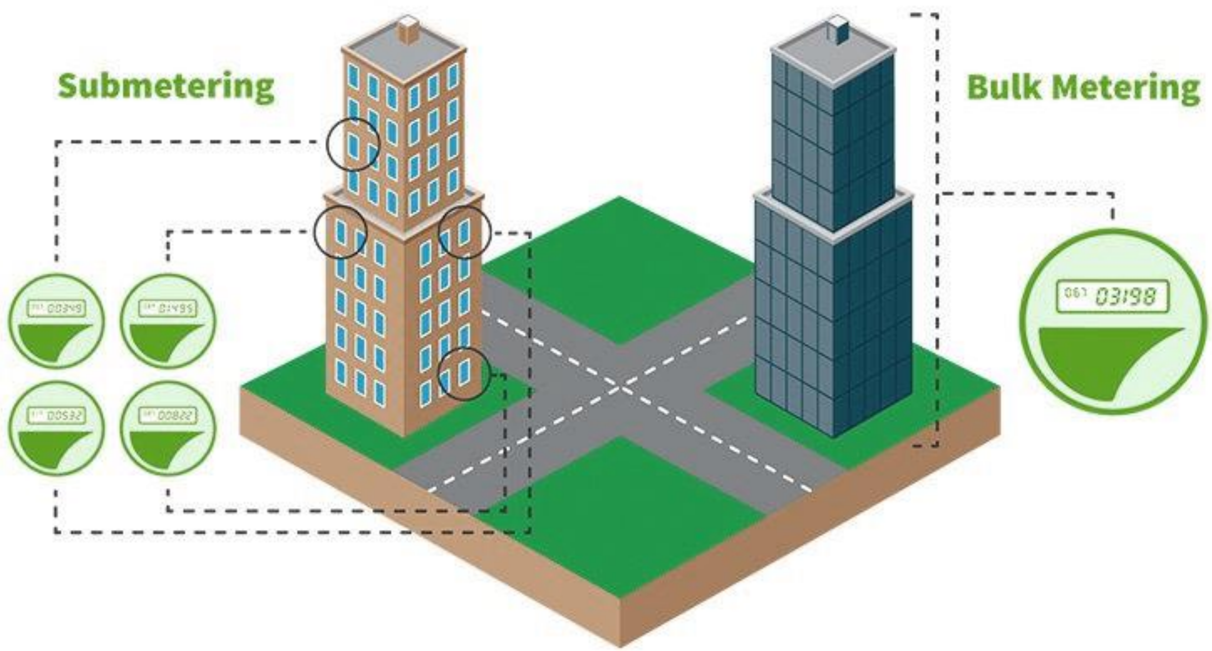
Keys to Successful Demand Flexibility

Successful propositions for demand flexibility require very different capabilities than needed for traditional energy supply business.



What is Submetering?

- Submetering, as opposed to bulk-metering, implies measuring power consumption for **individual units or appliances** in a building complex[1].
  - ✓ Submeters provide crucial information for more granular measurement of energy consumption data.



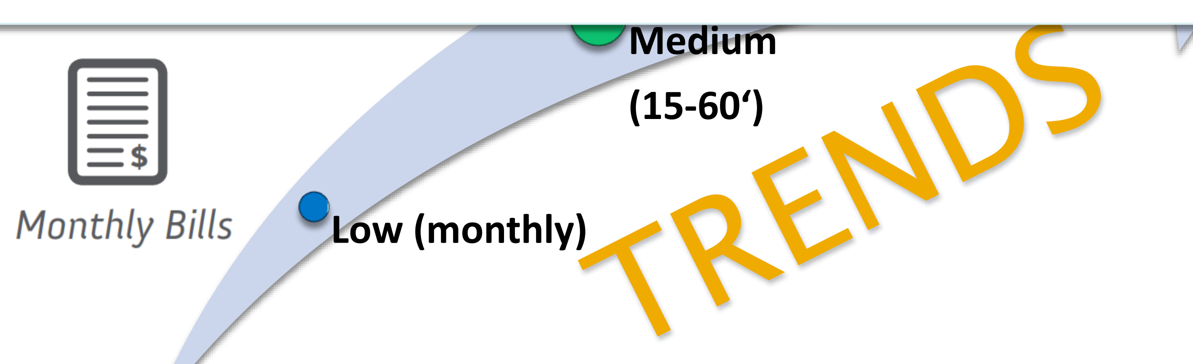
[1]Alonso-Rosa, M., Gil-de-Castro, A., Medina-Gracia, R., Moreno-Munoz, A., & Cañete-Carmona, E. (2018). Novel Internet of Things Platform for In-Building Power Quality Submetering. *applied sciences*, *8*(8), 1320.

Submetering: the granularity effectiveness

- Each additional level of metering was correlated with deeper energy savings, so EMS should integrate system-level and equipment-level submetering[1].
- Unlocking hidden benefits such as:

✓ Accurate energy monitoring, detection of utility bill errors.
✓ Ability to **record actual electricity use**
✓ **Comparison of usage across similar appliances** over time
✓ Ability to **identify equipment running outside schedule**, to avoid wasted energy
✓ **Early access to equipment health and maintenance** issues
✓ Ultimately **better management of Demand Response requests.**

✓ Examples from US have achieved savings of up to 17%, with PB < 1 year[2].



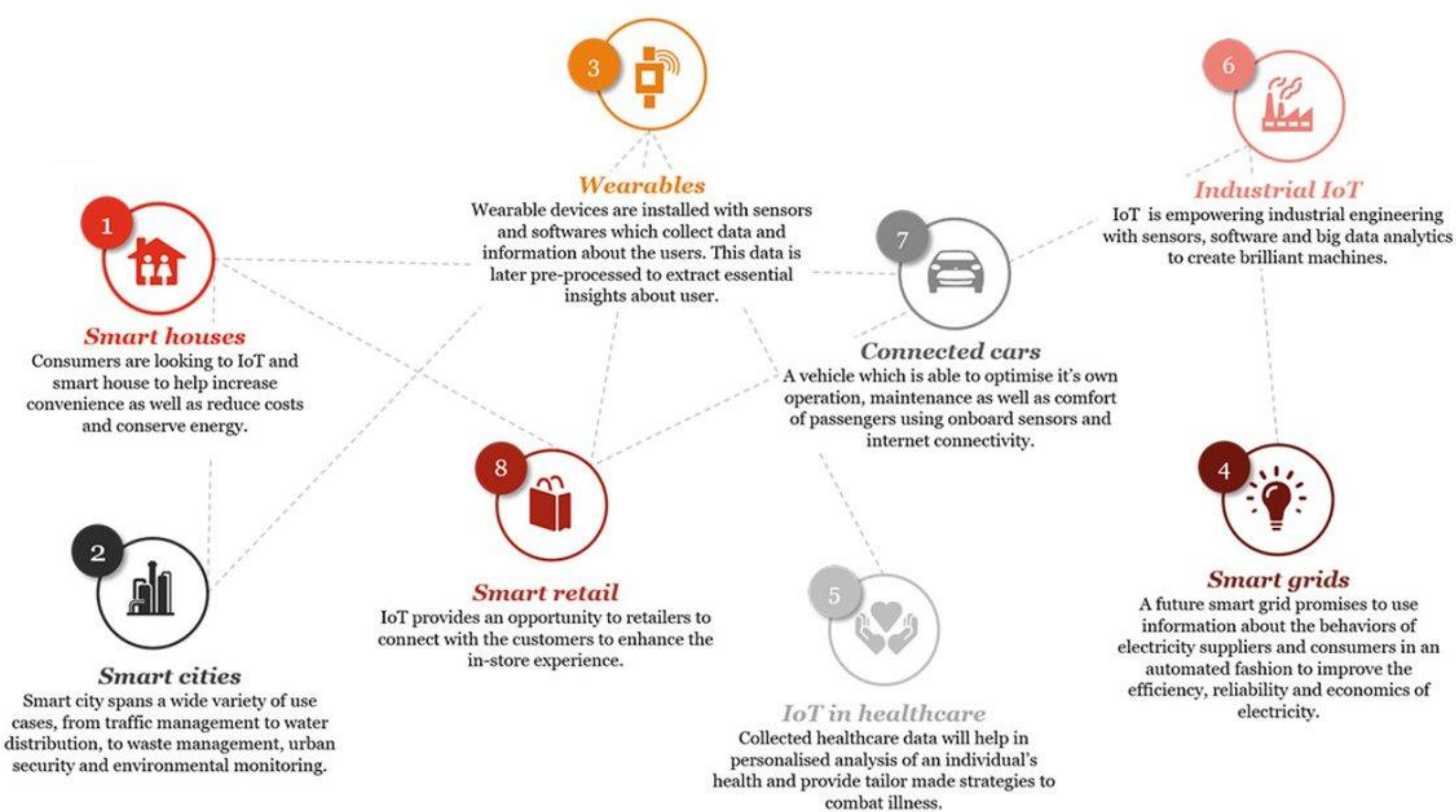
[1]Zhai, Z. J., & Salazar, A. (2020). Assessing the implications of submetering with energy analytics to building energy savings. *Energy and Built Environment*, *1*(1), 27-35.
[2]A smarter way to save energy: using digital technology to increase business energy efficiency (2020) https://www.green-alliance.org.uk/a_smarter_way_to_save_energy.php

Top IoT Trends in 2021 and beyond!

The **Internet of things** (**IoT**) describes the network of physical objects—"things"—that are embedded with sensors, software, and other technologies for the purpose of connecting and exchanging data with other devices and systems over the internet

https://en.wikipedia.org/wiki/Internet_of_things

Industries benefiting from IoT adoption



Impact of power quality on critical facilities.

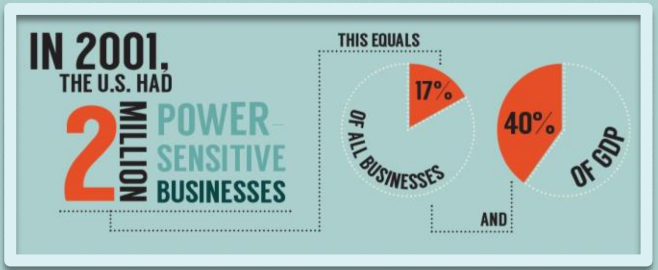
DIGITAL ECONOMY?

Digitalization and Industry 4.0

Major industries largely run on digital processes.

Digital industries rely on power-sensitive equipment that can be seriously disrupted by extremely brief

Outages or Power Quality disturbances

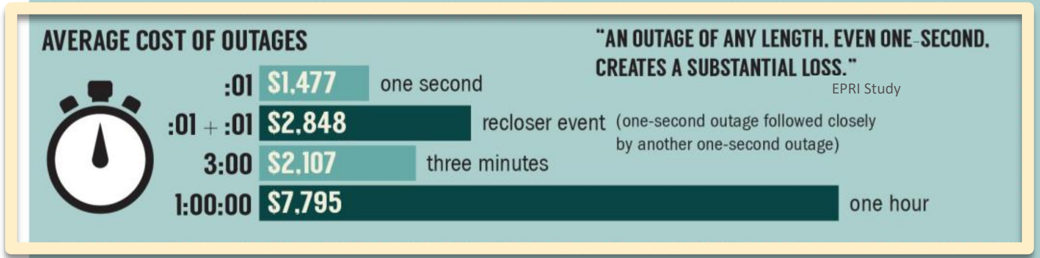


SENSITIVE SECTORS

- telecom and data storage
- biotech
- financial industry
- electronics manufacturing
- continuous process manufacturing (paper, chemicals, petroleum, rubber, metals)
- fabrication
- essential services (transportation, water treatment, gas and pipelines)

DIGITAL AND INDUSTRIAL FIRMS ARE LOSING $45.7 BILLION TO OUTAGES AND ANOTHER $6.7 BILLION TO POWER QUALITY DISTURBANCES PER YEAR

EPRI Study

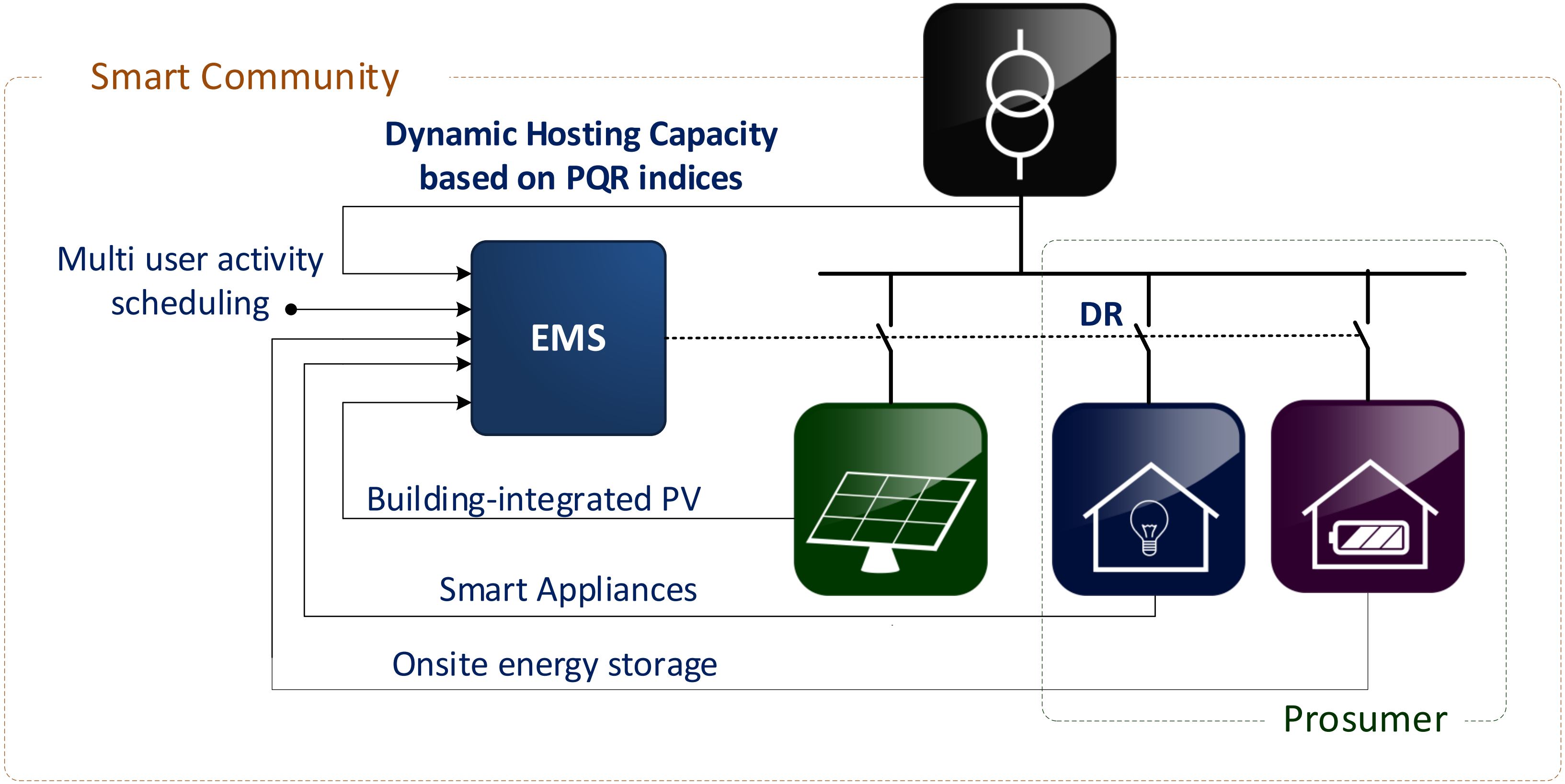


Power quality disturbances include minor voltage sags and surges, typically evidenced by flickerling lights, excessive equipment heating and failure rates, and computer or controller malfunctions.

Average annnual losses of $3,406 for power quality

Dynamic Hosting Capacity

- The possible amount of DER penetration that can be safely handled by grids is known as **Hosting Capacity** (HC).
- **DR** can be employed to manage **Hosting Capacity,** under PQ constraints.



- Castelo de Oliveira, T.E.; Bollen, M.; Ribeiro, P.F.; de Carvalho, P.M.S.; Zambroni, A.C.; Bonatto, B.D. The Concept of Dynamic Hosting Capacity for Distributed Energy Resources: Analytics and Practical Considerations. *Energies* **2019**, *12*, 2576.
- Palacios-Garcia, E. J., Moreno-Muñoz, A., Santiago, I., Moreno-Garcia, I. M., & Milanés-Montero, M. I. (**2017**). PV hosting capacity analysis and enhancement using high resolution stochastic modeling. *Energies*, *10*(10), 1488.

The European Interreg SUDOE Program

Interreg Sudoe IMPROVEMENT

- **The Interreg Sudoe Program supports regional development in southwestern Europe** as part of the European territorial cooperation objective Interreg, financed by the European Regional Development Fund (ERDF).

- The Program **promotes transnational cooperation to solve common problems,** such as low investment in research and development, low competitiveness of small and medium-sized enterprises and exposure to environmental risks, **acting on five priority axes**

  - Research and innovation
  - Competitiveness of SMEs
  - Low-carbon economy
  - Combating climate change
  - Environment and resource efficiency

Why IMPROVEMENT?

- **There are few projects related to the problem of integrating distributed energy resources in environments where the so-called "critical loads" predominate**: data centers, railroad stations, airports, hospitals, etc.
- **Given their extreme sensitivity** to electrical disturbances, the quality and continuity of the power supply is essential for the performance of these buildings.
- **E.g., the emergency power in a hospital supports only critical functions** - operating rooms, intensive care and emergency rooms - **which account for 20% to 50% of services.** As the number and severity of extreme weather events increase, power availability is needed for 100% of hospital services.
- These types of buildings use a lot of steam, hot water and, in general, **in the SUDOE region, require a huge amount of energy for air conditioning.**
- **The use of technologies such as IoT and ML would lead to further energy savings**, as it will allow to know (in much more detail) and predict the energy consumption at the equipment level.

About the European Project IMPROVEMENT

IMPROVEMENT, “*Integration of combined cooling, heating and power microgrids in zero-energy public buildings under high power quality and continuity of service requirements*”

- **SPAIN: National Hydrogen Center. Leading partner (CNH2).**
- **SPAIN: University of Castilla la Mancha.**
- **FRANCE: National Higher School of Mechanics and Aerotechnics (ENSMA).**
- **PORTUGAL: Higher Technical Institute (IST).**
- **PORTUGAL: National Laboratory of Energy and Geology (LNEG).**
- **SPAIN: General Secretariat of Industry, Energy and Mines of the Junta de Andalucía**
- **SPAIN: University of Córdoba.**
- **SPAIN: Andalusian Energy Agency.**
- **FRANCE: University of Perpignan Via Domitia.**

General objective:

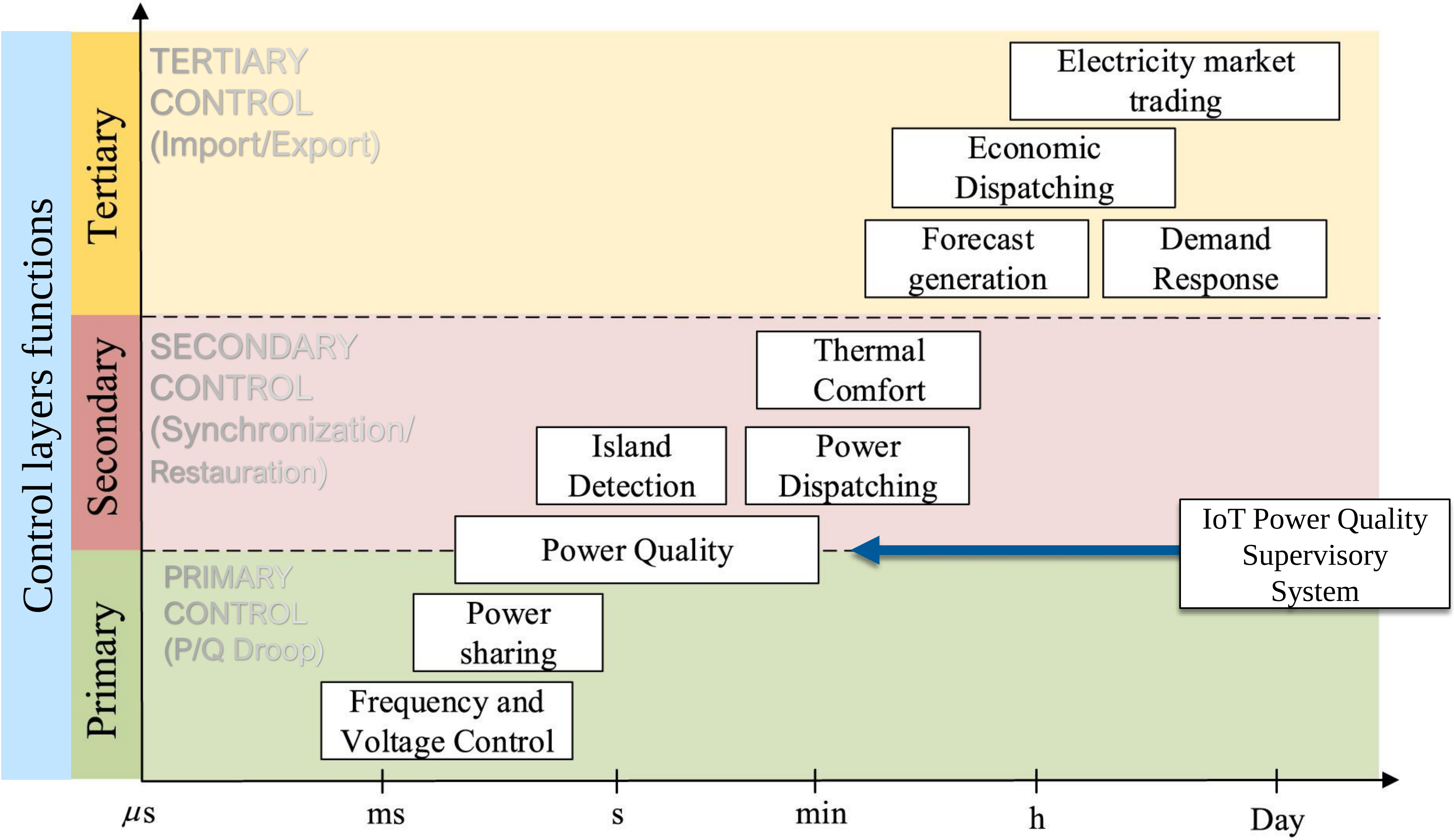
Transforming existing public buildings into Nearly Zero-Energy Buildings (NZEB) by integrating Renewable Energy Microgrid with Combined cooling, heat & power (CCHP), and Hybrid Energy Storage System (HESS).

Specific objectives:

Budget: 2.345.555 € (Funding Rate: 75%) Execution Period: 01/10/19 → 31/03/23

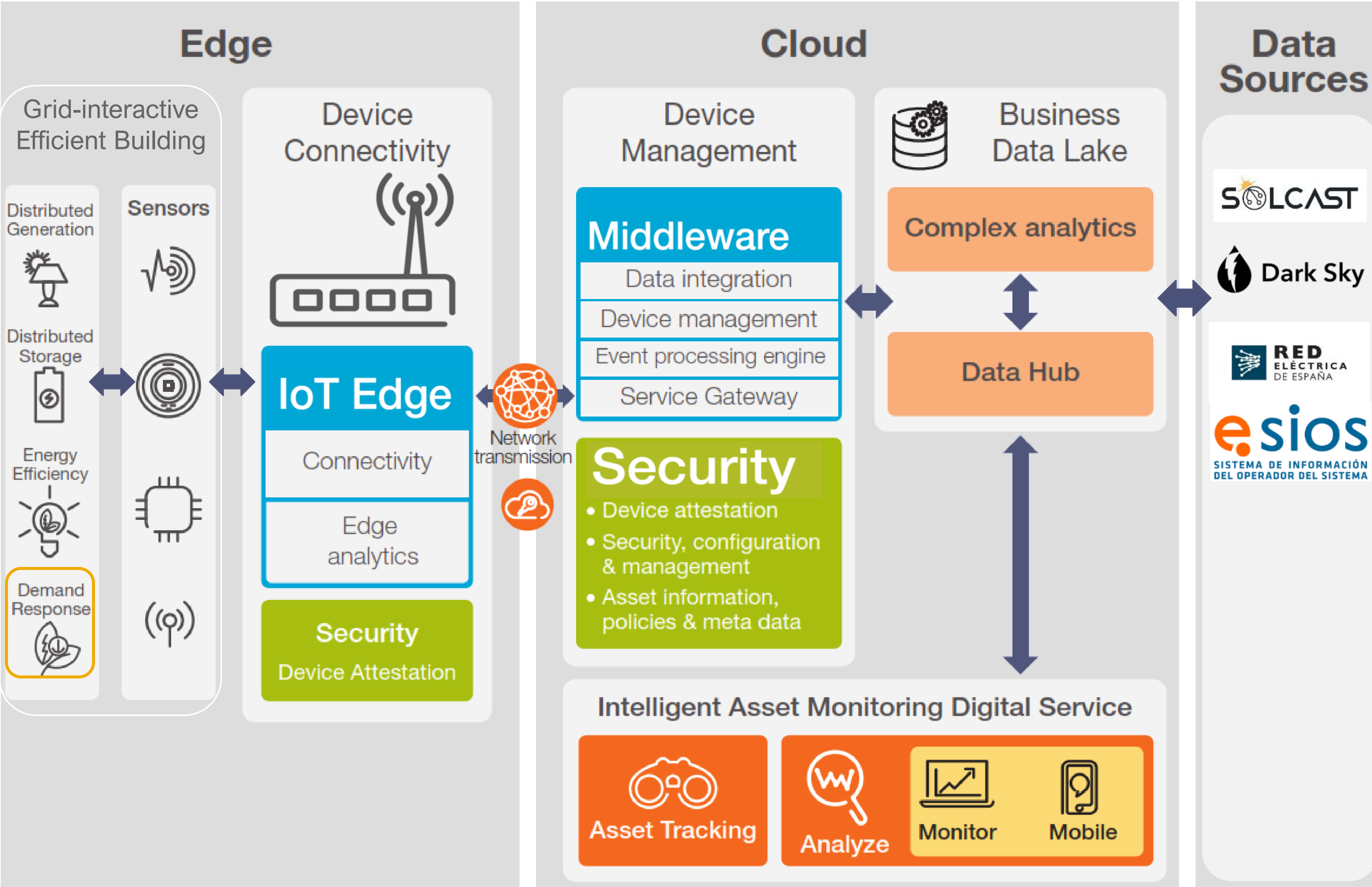
- ✓ Development of **Solar Heating & Cooling system**, with the incorporation of active and passive techniques for Nearly Zero-Energy Buildings (NZEB).
- ✓ Development of a **fault-tolerant power control system for microgrids** under **high Power Quality & Reliability** design criteria.
- ✓ Development of an **EMS** for renewable energy microgrids with Hybrid Energy Storage System (HESS) **under criteria of minimum degradation, maximum efficiency and priority in the use of renewable energies**.

IMPROVEMENT[1] Microgrid control layers

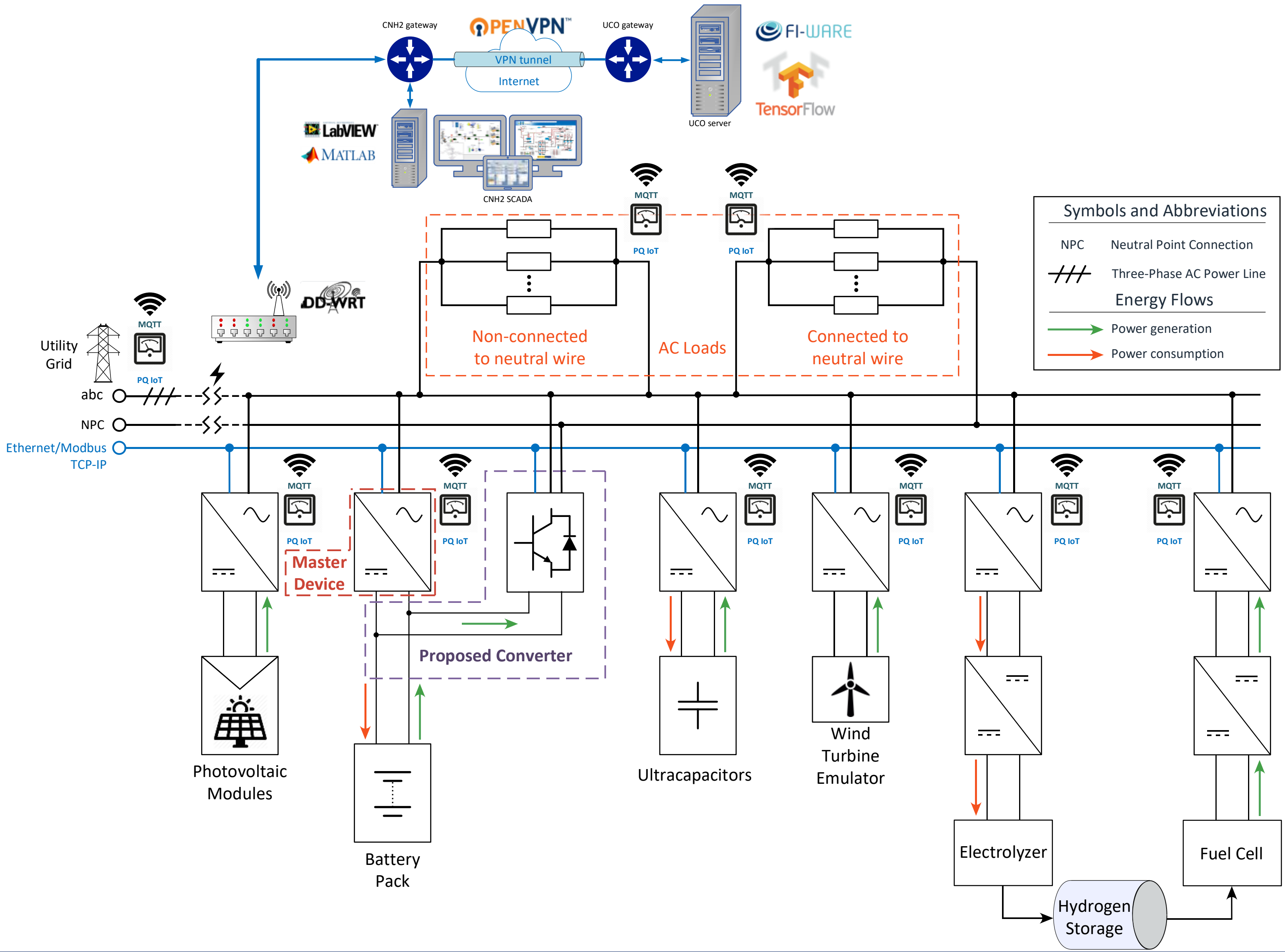


[1] Integration of combined cooling, heating and power microgrids in zero-energy public buildings under high power quality and continuity of service requirements **(IMPROVEMENT**), co-financed by the *Interreg SUDOE* Programme and the *European Regional Development Fund* (ERDF). Ref. SOE3/P3/E0901.

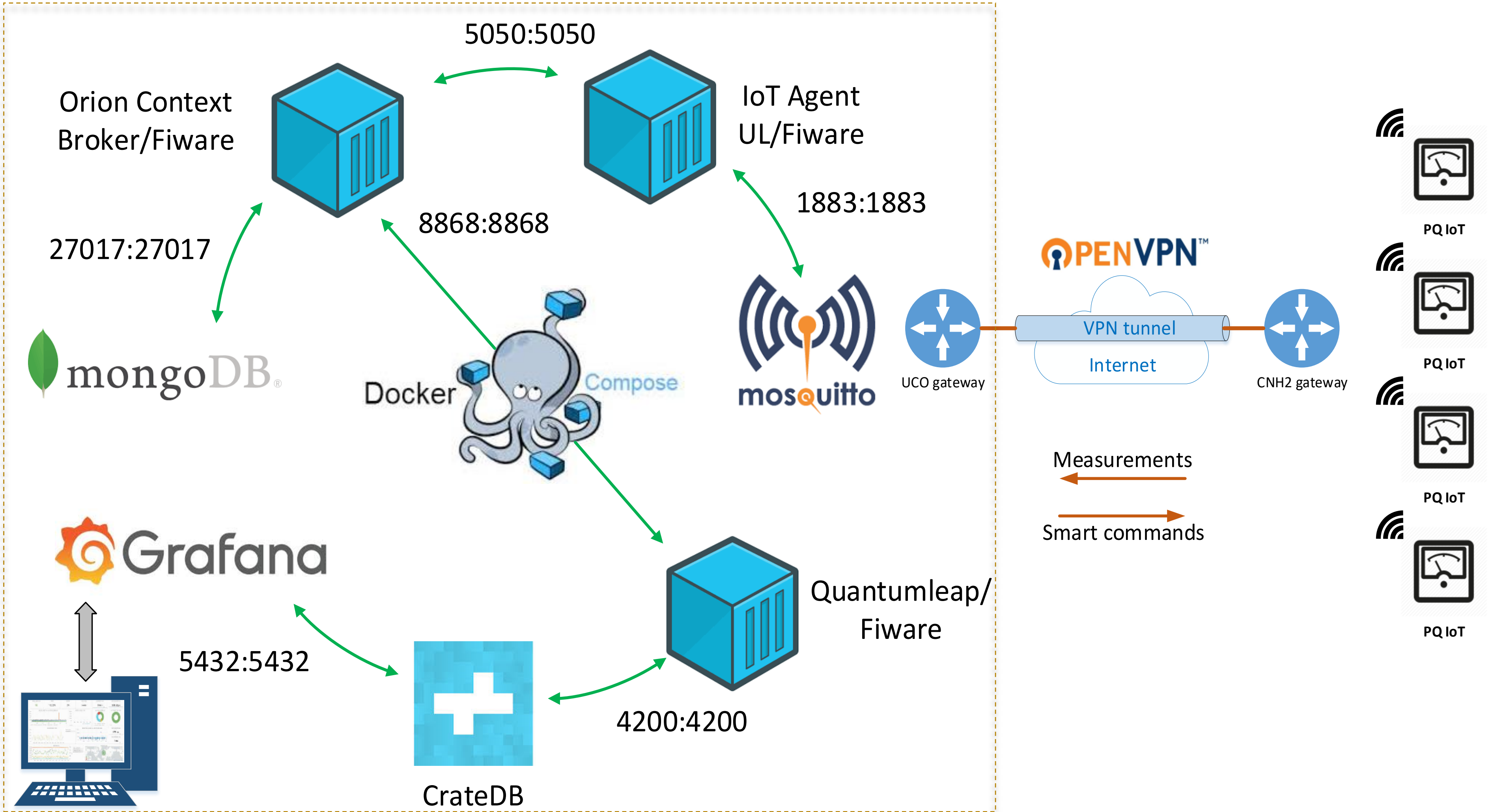
IoT architecture for energy applications



IMPROVEMENT Microgrid project scheme



FIWARE Ecosystem Architecture[1]



IoT cloud-based Power Quality extended functionality for Grid-Interactive Appliance Controllers

Publisher: IEEE

Cite This | PDF

Joaquin Garrido-Zafra ; Aurora del Rocio Gil de Castro ; Rafael Savariego Fernandez ; Matias Linan Reyes ; Felix Garcia ; Antonio Moreno-Munoz **All Authors**

J. Garrido-Zafra, A. d. R. Gil de Castro, R. Savariego Fernandez, M. Linan Reyes, F. Garcia and A. Moreno-Munoz, "IoT cloud-based Power Quality extended functionality for Grid-Interactive Appliance Controllers," in *IEEE Transactions on Industry Applications*, doi: 10.1109/TIA.2022.3160410

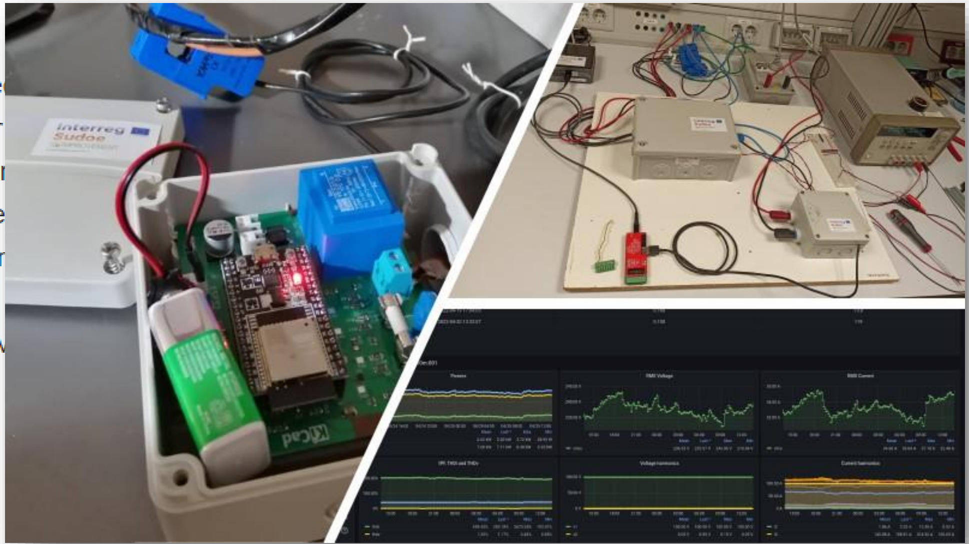
Abstract

Authors

Keywords

Metrics

Abstract:
Due to the myriad of loads that are collecte
4.0 paradigm, it is important to ensure their
monitoring approach, reaching a point wher
optimal. Otherwise, it can participate coope
work, we present cloud-based extended fur
autonomously or managed under the open
the main strength lies in its PQ monitoring v



Power quality data analytics

Power quality data analytics[1] is a discipline that specializes in collecting waveform-based power system data, extracting information from it, and applying the findings to solve a wide variety of power system problems beyond traditional power quality concerns, such as condition monitoring and fault diagnosis.

EDGE COMPUTING IN IOT PQ SENSOR

Monitoring and Data Log
- PQ Event Log
- PQ Steady-state Disturbances Log

Site PQ Reporting
- Event Classifications
- Apply temporal and spatial aggregation windows (IEC Std. 61000-4-30)
  - *10/12 cycles*
  - *150/180 cycles*
  - *10 min*
  - *2 h.*
- Statistical evaluation of the Compliance Limit (e.g. Std.EN-50160)

CLOUD COMPUTING

Visual Data Analytics
- Create Data Log Trends, Histograms, Profiles, Scatter Charts, and Statistical Summary Tables
- Generate ITIC, SEMI-F47, and Custom Voltage Sag Magnitude-Duration Charts

Diagnostic Models
- Site PQ&R global index
- Identify, Analyze, and Locate Faults
- Correlate PQ and Fault Events
- PQ event log correlation with *EMS* operation logs
- Continuously diagnose of low-voltage ride-through capability

Predictive Models
- Alarms (e.g. IEEE 1547)
- Trend forecasting
- Anticipated faults detection thanks to early-stage alerts.
- Identify and proactively manage reliability issues, establishing clearly whose responsibility it is, e.g. in insurance claims

Prescriptive Models
- Evaluate future predicted alternatives
- Recommend optimal scheduling focused on preventative maintenance

Time

Descriptive Analytics tells you what happened in the past

Diagnostic Analytics helps you understand why something happened in the past.

Predictive Analytics forecast what is most likely to happen in the future

Prescriptive Analytics recommend several different possible actions and guide them towards a solution.

[1] IEEE Working Group on Power Quality Data Analytics http://grouper.ieee.org/groups/td/pq/data/

Conclusions

- ✓ Submetering to capturing more granular in-deep energy data can be critical to properly accommodate **Demand Flexibility** resources
- ✓ Detailed **Power Quality** (PQ) data is also very important as the ongoing digitalization expand. And even more so when using **Dynamic Hosting Capacity**.
- ✓ An **IoT** PQ sensor to be embedded in **Energy Smart Appliances (ESA)** can be critical.
- ✓ This will be the cornerstone for the deployment of the **PQ data analytics** over an IoT platform, in the environment of a **Grid-Interactive Efficient Building**.
- ✓ This innovation can be the gateway to the incorporation of new self-diagnostic functionalities in ESA.

UNIVERSIDAD DE CÓRDOBA

Thanks for your attention!

uco.es

UNIVERSIDAD DE CÓRDOBA

Antonio Moreno-Munoz

Electronics and Computer Engineering Dep.

Leonardo da Vinci Building, Córdoba (Spain)

+34 957 218 373

amoreno@uco.es

http://www.uco.es/icei/en/