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Towards the Internet of Energy
A pathway to electric revolution

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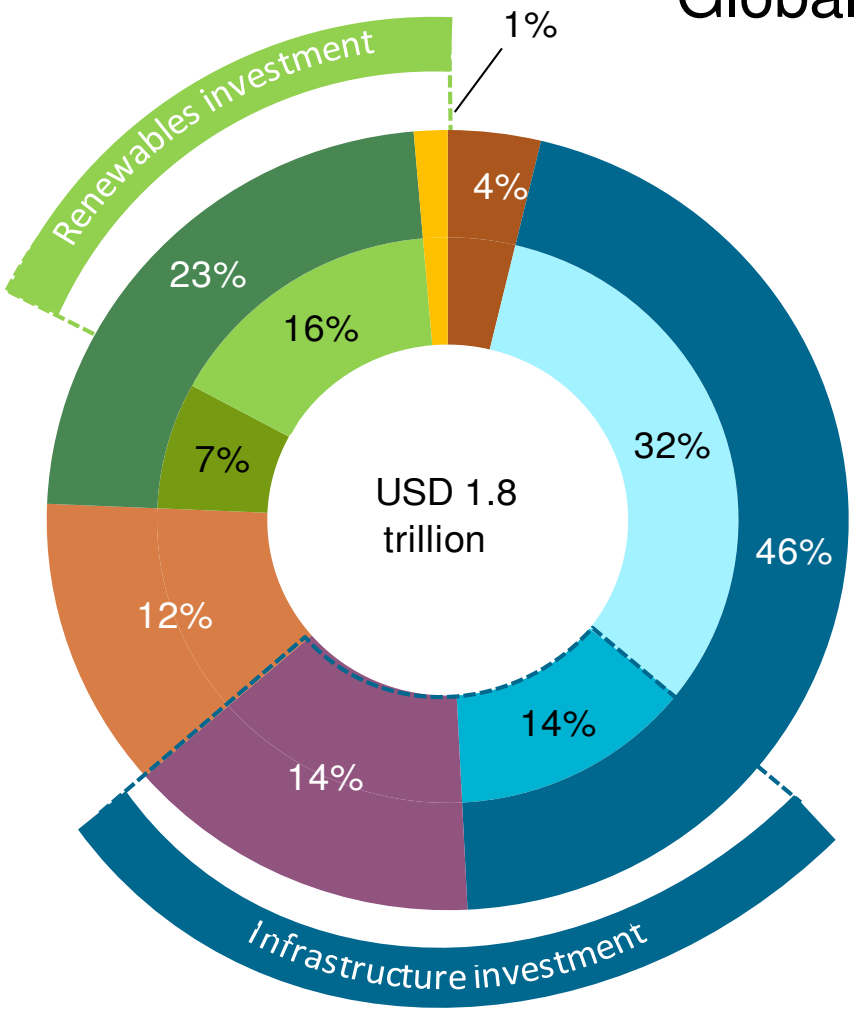
Outline

- Context
- Vision
- Local Area Energy Network (E-LAN)
- Internet of Energy (IoE)
- The E-LAN problem
- Conclusions

Context

International Energy Agency
2016 Report on World Energy Investments

Global energy investment in 2015



Coal

Oil & Gas
- Upstream
- Downstream and infrastructure

Electricity networks

Energy efficiency

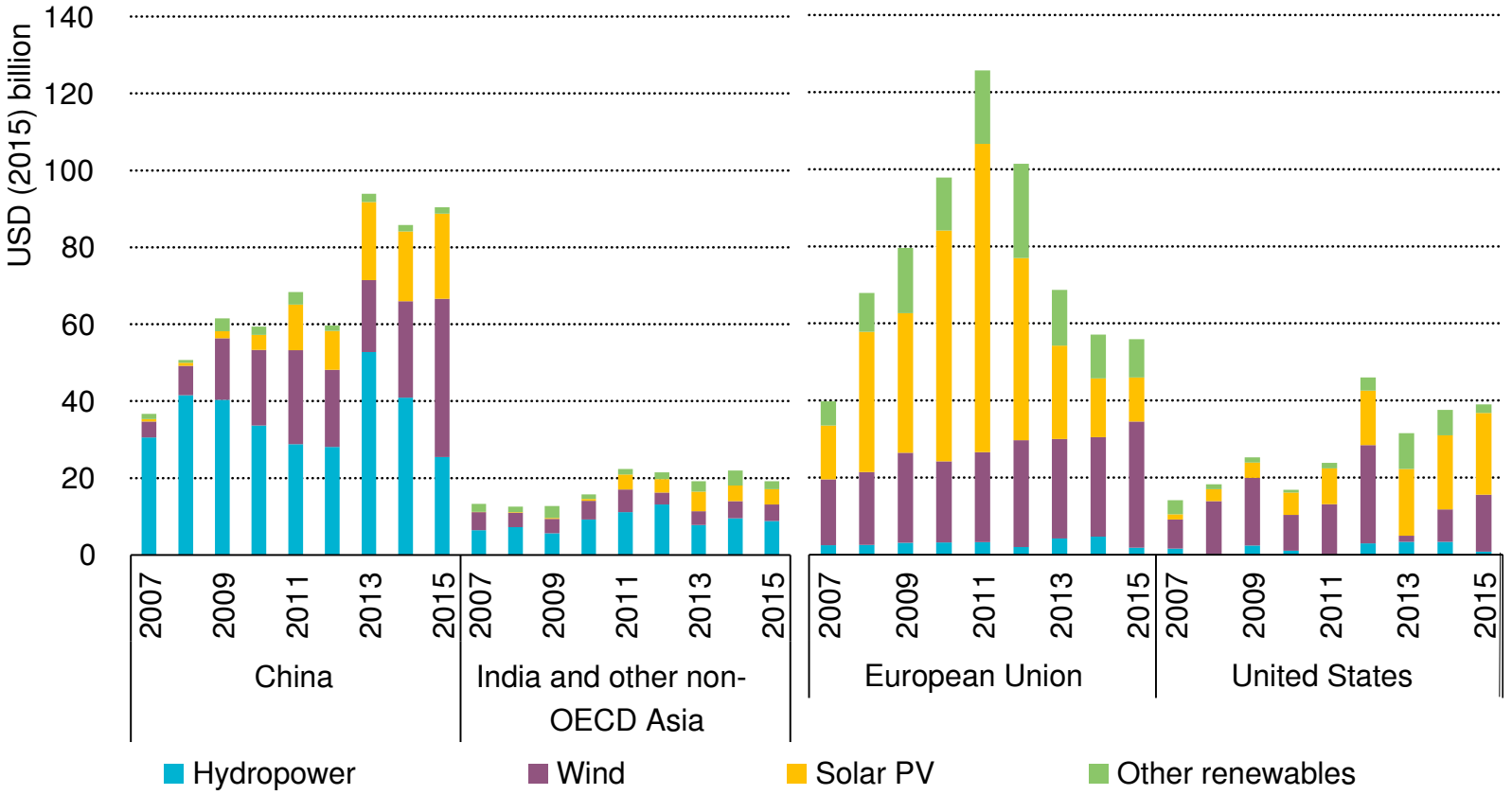
Power generation
- Conventional generation
- Renewables generation

Renewables transport and heat

Context

International Energy Agency
2016 Report on World Energy Investments

Investment in renewables-based power by technology in selected countries/regions



Context

International Energy Agency
2016 Report on World Energy Investments

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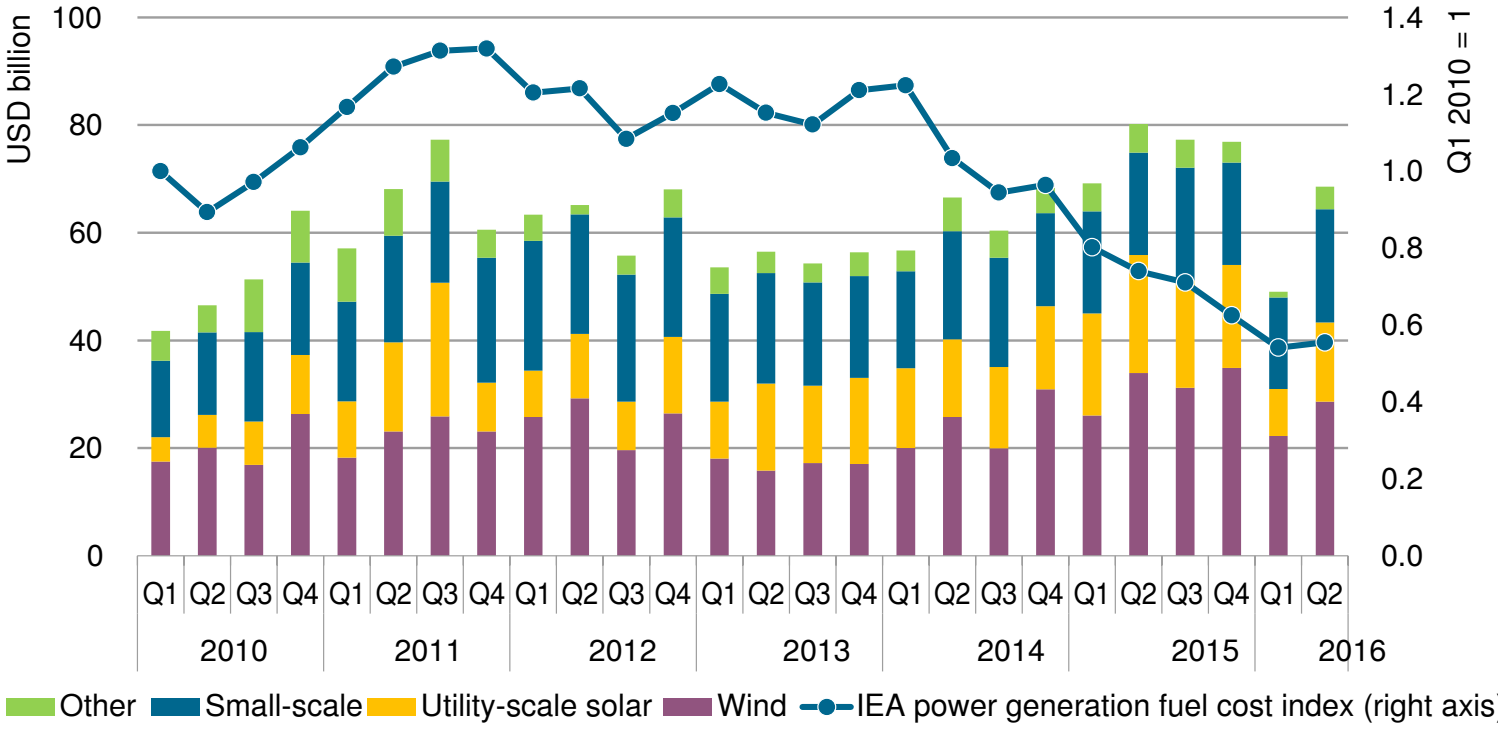
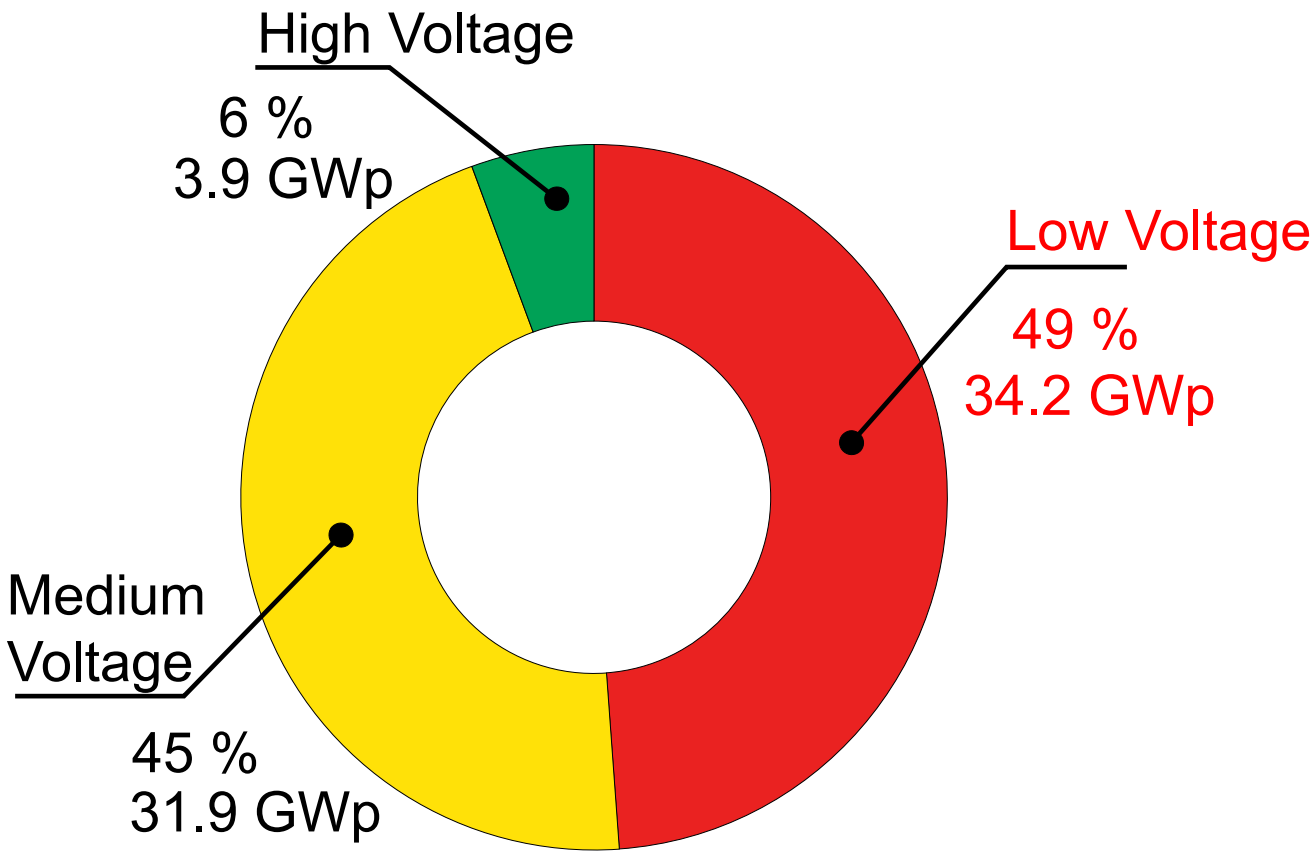


Context

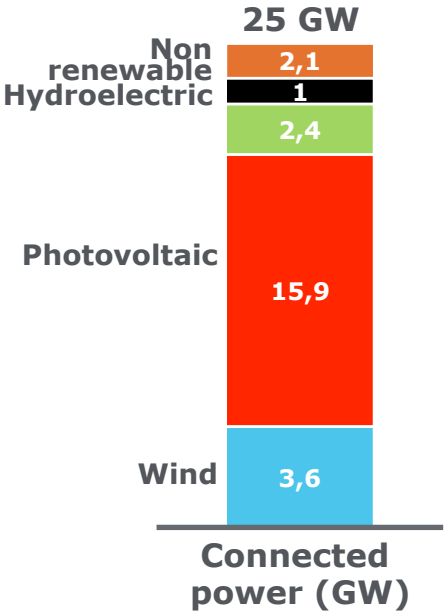
Renewable Energy Sources in Europe
Impact on distribution grids
(source: pvgrid.eu)



Context

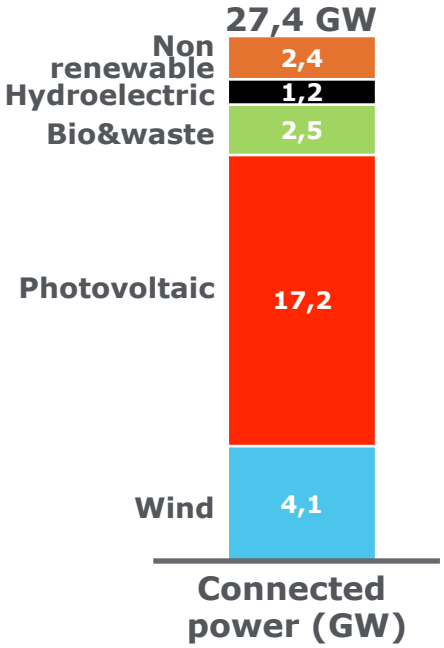
Renewable Energy Sources in Italy

2013



TOTAL
524128 connections
25059 MW

2016



TOTAL
666192 connections
27426 MW

NORTH
375014 connections
12592 MW

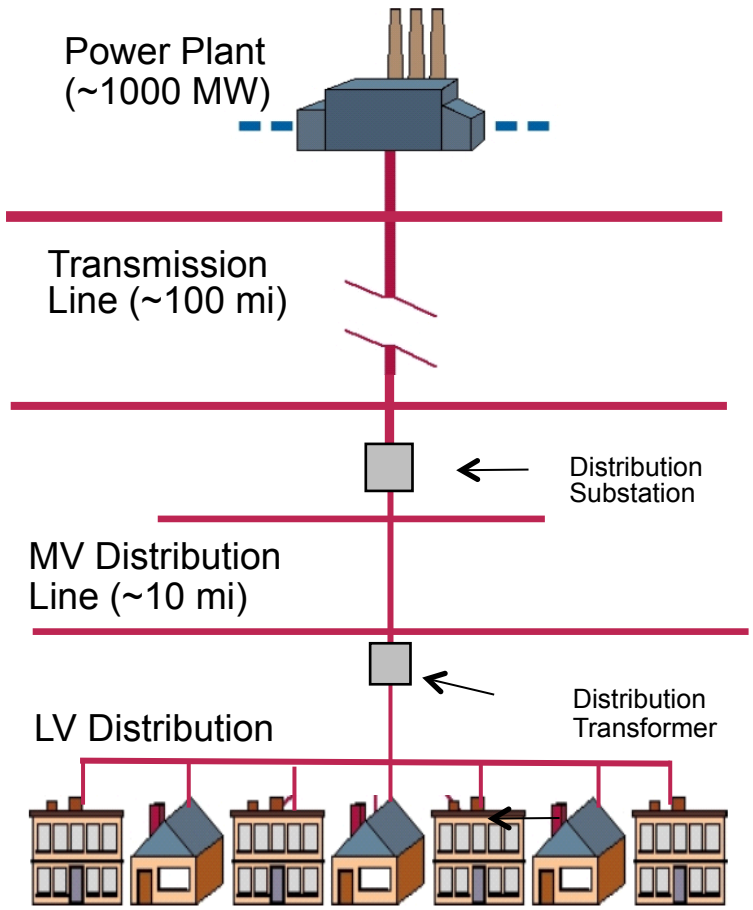
CENTER
169870 connections
6480 MW

SOUTH
121308 connections
8354 MW

550,000+ LV end-users invested ~ 25 B€
in residential PV plants

Vision – Conventional Grid

Conventional Grid



«For a variety of reasons, this legacy grid approach is proving to be nonviable for the present and the future.»

Steve E. Collier, "*The emerging Enernet*", IEEE Industry Applications Magazine, Mar/Apr 2017, pp.12-16.

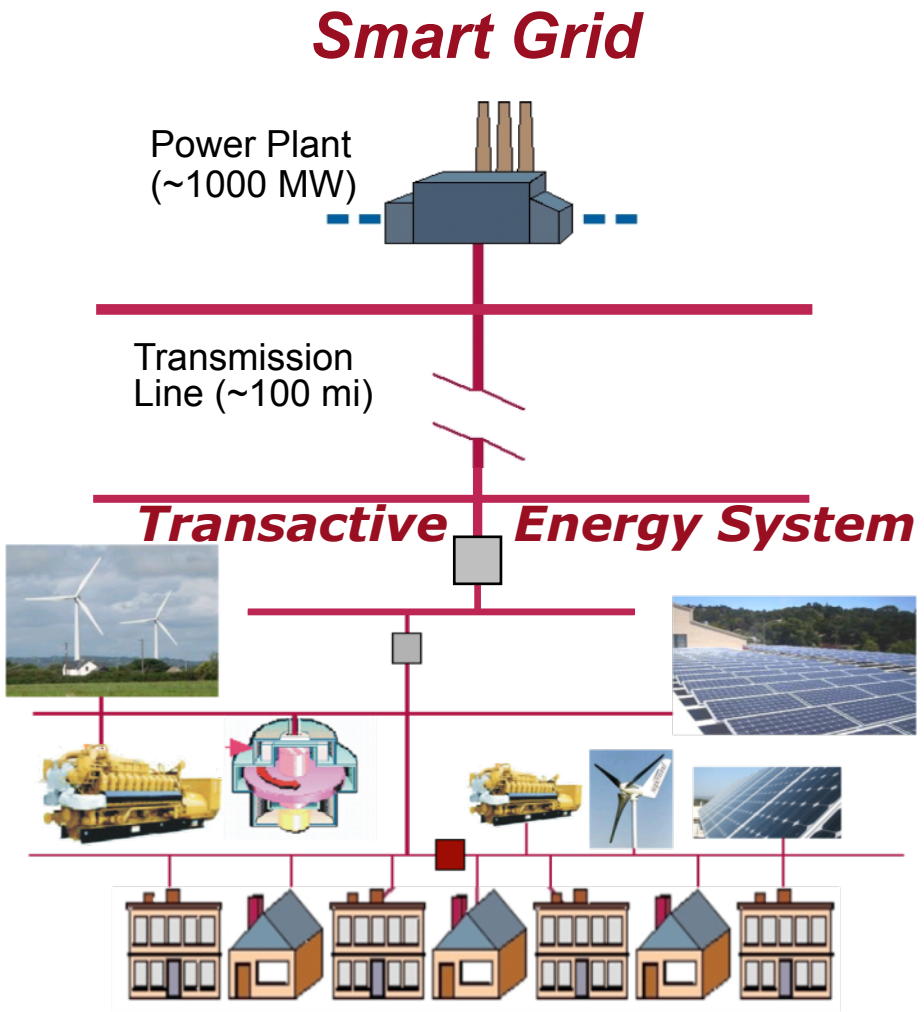
Vision – Smart Grid

«The infusion of advanced information technology and the growth of distributed energy resources present both opportunities and challenges for the continued improvement of electrification.

…

Transactive energy systems should enable a broad range of operational, business, regulatory, and incentive models to be supported by future systems.»

Ron Ambrosio, "*Transactive energy systems",* IEEE Electrification Magazine, 2016, vol.4, n.4, pp.4-7.



Vision – EU Winter Package (Nov 2016)

"Clean Energy For All Europeans"

- **By 2030, half of European electricity should be renewable**
- ***Consumers are the drivers of the energy transition***
- 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.
- Active consumers who decide to generate their own electricity will be able to fully benefit from the market either individually or in cooperatives, like renewable energy communities.
- Storage will benefit from appropriate pricing to have its flexibility and usage adequately remunerated.
- Non-discriminatory handling of metering data with commercial value by DSOs shall be ensured.

How to Get There—Step 1: E-LAN

LAN: In communication science a local area network (LAN) is "*a computer network within a small geographical area, which is composed of inter-connected units capable of accessing and sharing data and devices and is characterized by high data transfer rates and the lack of any need for leased communication lines*".

E-LAN: Similarly, an Energy LAN can be defined as "*an electrical network within a small geographical area, which is composed of loads and inter-connected energy resources capable of accessing and sharing power and data and is characterized by data and energy transfer ability and the lack of any need for leased communication and power lines*".

E-LANs vs Microgrids:
E-LANs extend microgrids operation to allow **independent control of the power flow at every network node or branch** even in presence of a limited set of controllable entities (e.g., renewable sources, energy storage systems, gas turbines …).

- From a topological viewpoint, this may call for **meshed grids**.
- From an operational viewpoint, this requires synergistic and **consensus-based** control of distributed energy resources.

The E-LAN candidates as technological infrastructure of IoE

Features of E-LANs

Owing to meshed architecture and synergistic control of distributed agents, E-LANs make possible:

- Independent demand response at multiple points of connection to DSOs (distribution system operators);
- Active and reactive *power steering* through specific grid paths
- Active compensation of load unbalance;
- Active clearing of currents for servicing grid lines w/o operating circuit breakers;
- …
- Stabilization of voltage profiles;
- Limitation of thermal stress in feeders;
- Limitation of power stress in energy sources;
- Limitation of current stress in grid-tied inverters;
- ….

How to get there—Step 2: IoE

Internet: Internet is defined as "large system of connected computers around the world that allows people to share information and communicate with each other" (English Dictionary).

By design, Internet is decentralized. Each Internet computer is independent. Operators can choose which Internet services to use and which local services to make available to the global Internet community.

Internet of Energy (IoE): Similarly, the Internet of Energy can be defined as a "large system of connected energy resources around the world that allows end-users to share data and power with each other".

In IoE, *each prosumer is independent, and can choose which services to use and which local energy and services* (power control, harmonic filtering, etc.) *to make available to the global community.*

IoE Challenges and Role of E-LANs

IoE challenges

- From the architectural and technological viewpoint, the IoE requires integration of power and data networks to allow individual prosumers (i.e., end-users acting as energy producers an consumers) to interact with each other and with electrical market operators (e.g., DSOs, ESCOs, aggregators).
- Ad-hoc ICT platforms and applications are needed to support energy control and trading services.
- For technology manufacturers, application developers and service providers, the IoE represents a new market with enormous growth potential.
- For electric market players, the IoE represents a paradigm shift toward advanced architectures, performances and services.
- For entrepreneurs and investors, the IoE offers an arena for innovative undertakings with high creation of value and ROI.

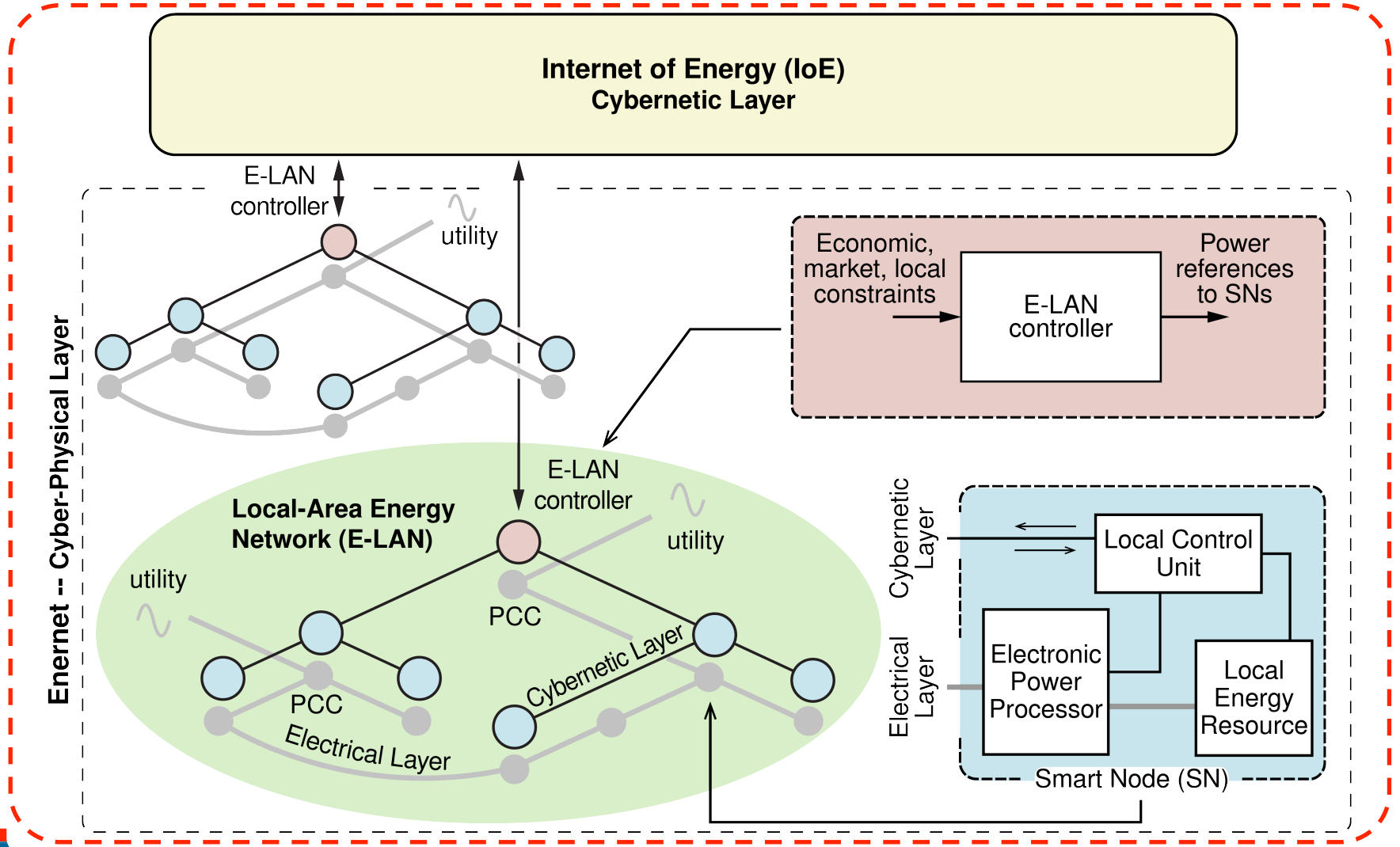
Role of E-LANs: E-LANs enable **end-users** to promptly, effectively and efficiently **share and trade energy and services in the electrical market**, while pursuing common objectives of the E-LAN community.

Internet of Energy

Processing & Networking data and energy

Internet of Things

Cyber-security !



The E-LAN Problem

Assuming E-LAN as candidate infrastructure for IoE, we need theoretical approaches, control algorithms, and application tools to:

- Analyze meshed network architectures of any structure and complexity, with dynamic management of plug-in & plug-out of loads and sources.
- Implement synergistic and consensus-based control of any dispatchable power source to pursue power steering across the grid and demand response at utility terminals.
- Optimize global and local performances (distribution and conversion efficiency, voltage stability, electrical and thermal stresses, power factor, load balancing, etc.)
- Investigate feasibility, technological bottlenecks, functional limits, operational performance of E-LANs to suit IoE requirements.
- Experiment the E-LAN under realistic operating conditions.

  - From a theoretical point of view the E-LAN problem can be approached and solved as a constrained optimum control problem.
  - An *ad-hoc* circuit theory and simulation tool were developed for E-LAN analysis and control.

Conclusions

After one century of stability, the electrical market is approaching a bottom-up revolution, under the pressure of environmental needs, limits of conventional infrastructure, ICT push, new investment strategies, and unprecedented citizen awareness and involvement. In this new scenario:

End-users (prosumers) will benefit of:

- ✓ Autonomy, energy savings, central role in the energy market;
- ✓ Independent trading and dynamic aggregation ability.

Energy distributors, service companies and aggregators will benefit of:

- ✓ Better exploitation of electric infrastructure;
- ✓ Extended availability and dispatchability of distributed generation;
- ✓ Participation of end-users to generation, storage and management of the electrical grid in the low-end segment;
- ✓ High flexibility, robustness and efficiency of generation and distribution.

Environment, Society & Economy will benefit of: green energy, citizen awareness and participation, new green collars;
new challenging arena for entrepreneurs, technology and application developers, service providers, regulatory boards, advisory agencies, antitrust authorities, …

Conclusions

Will traditional oligarchic electric market eventually evolve to a more "democratic" arrangement ?

This is the challenge for the next decade.

Thank you !