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Smart Grids for Smart Cities: the Potential of Local Energy Communities

Keynote

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University of Bologna – DEI

Jinan, September 18th, 2019

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Introduction

Why a smart city?

The population living in urban areas is expected to double by 2050

→ any new process will require **more than just an incremental upgrading of the cities' organization, infrastructure** and the **services** provided to its citizens.

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Services for a smart city

In the coming years, cities are expected to deal with an increasing number and type of services for their citizens

These services all have to do with overarching **goals**, such as

- **Sustainability**
- **Environment**
- **Quality of (working) life**
- ...

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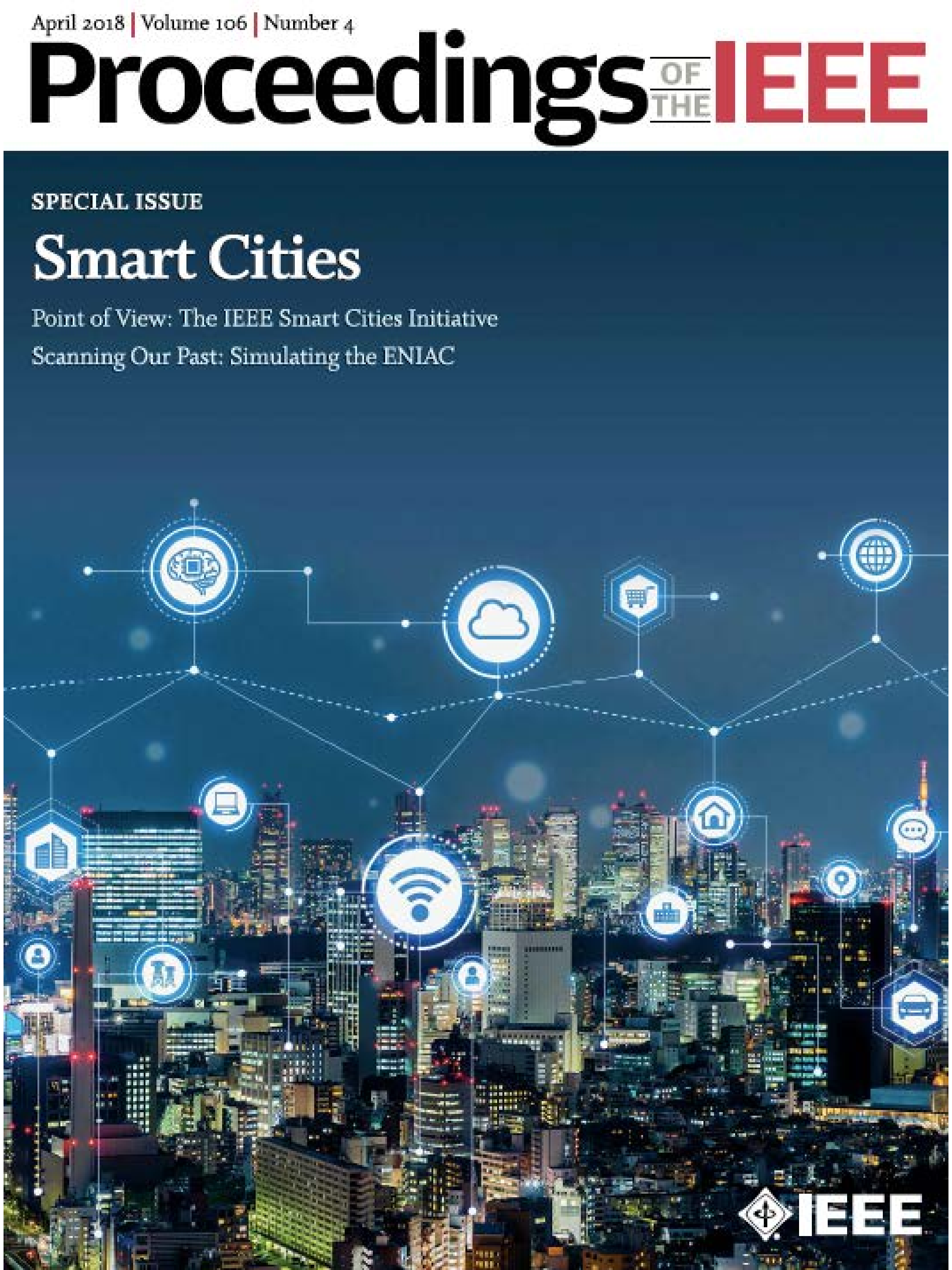

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SPECIAL ISSUE

SMART CITIES

Edited by G. Betis, C. G. Cassandras, and C. A. Nucci

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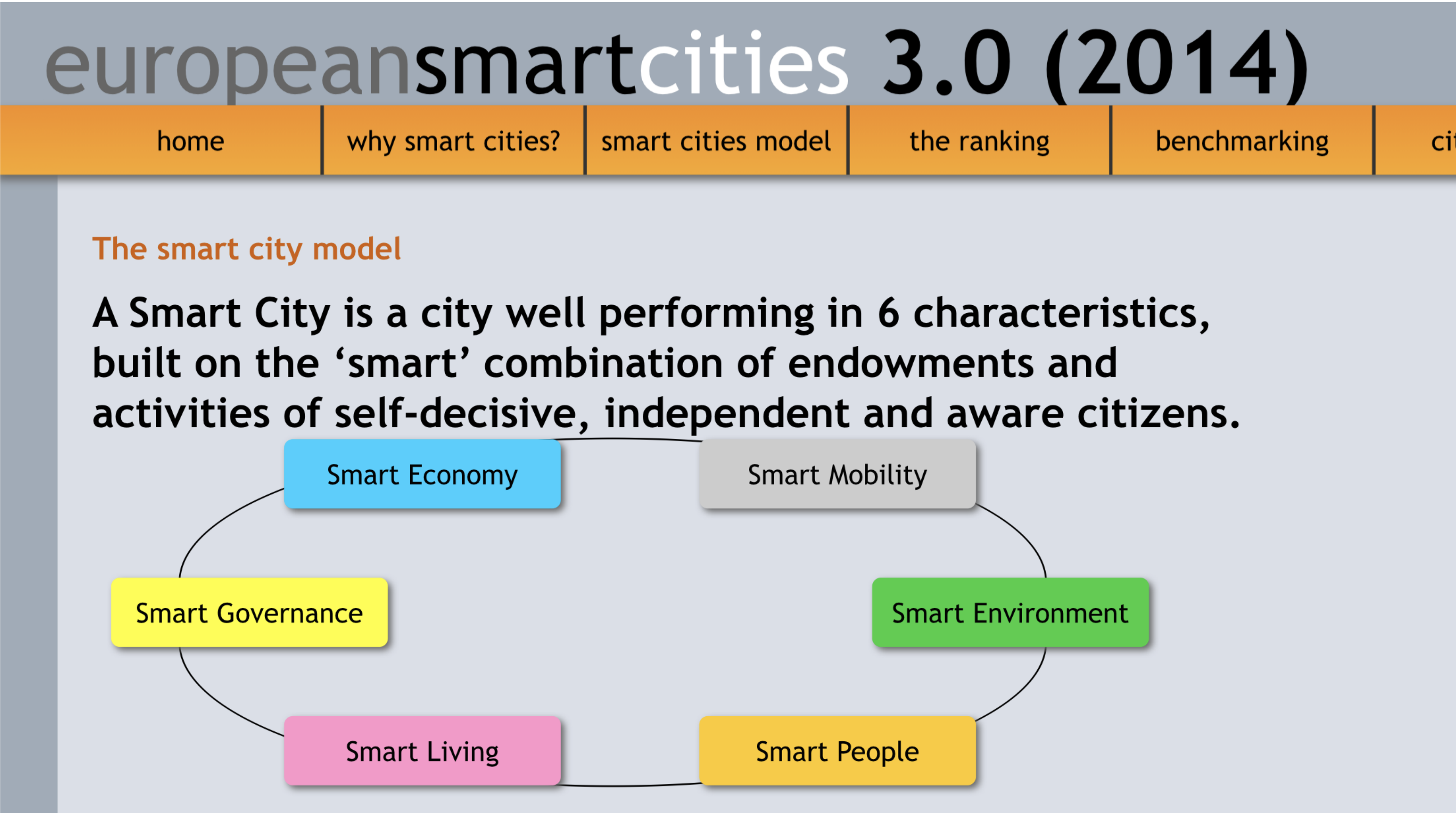
On the adjective ‘smart’

The relevant technologies are nowadays labeled with the ubiquitous word **smart**.

Technology has always been **smart** → **this adjective serves to underline the widespread use of Information and Communication Technologies (ICT), sensors and intelligence, e.g. software embedded in the various parts, components and infrastructures forming an urban area**.

→ we label people living in the city/using its facilities as **smart** as well, in that they own portable smart **devices** and **meters** communicating with existing ICT networks, which are instrumental to the accomplishment of such a goal.

The first definition



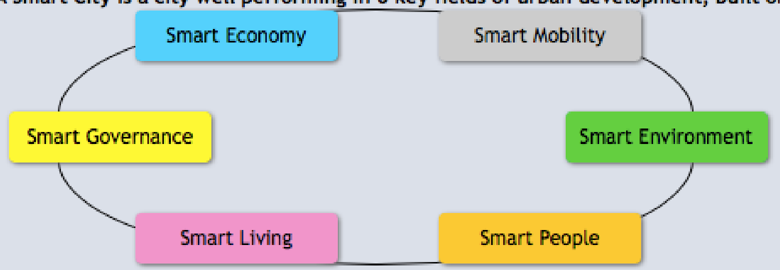
The methodology

europeansmartcities 4.0 (2015)

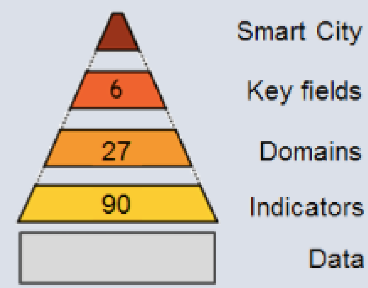
home | why smart cities? | smart cities model | benchmarking | city profiles | team & imprint

The smart city model

A Smart City is a city well performing in 6 key fields of urban development, built on the 'smart' combination of endowments and activities of self-decisive, independent and aware citizens.



Standardization and aggregation



To compare the different indicators it is necessary to standardize the values. One method to standardize is by z-transformation (see formular). This method transforms all indicator values into standardized values with an average 0 and a standard deviation 1. This method has the advantages to consider the heterogeneity within groups and maintain its metric information. Furthermore a high sensitivity towards changes is achieved.

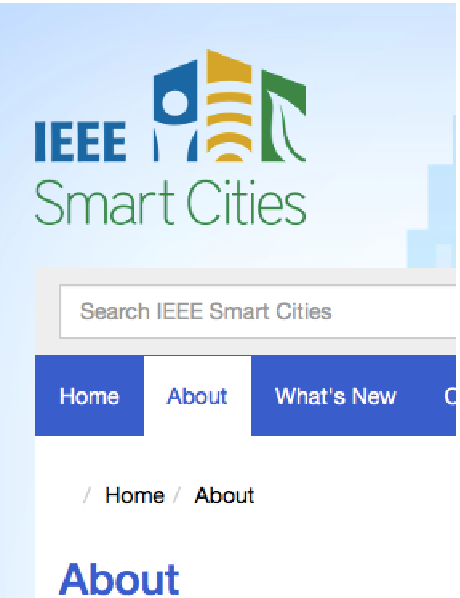
z-transformation

$$z_i = \frac{x_i - \bar{x}}{s}$$

To receive results on the level of factors, characteristics and the final result for each city it is necessary to aggregate the values on the indicator level. For the aggregation of a respective group of indicators to domains we consider also the coverage rate of each indicator. A certain result from an indicator of an indicator covering all cities weights therefore a little more than from an indicator covering only for instance 60 cities. Besides this small correction the results were aggregated on all levels without any weighting. The aggregation was done additive but divided through the number of values added. That allows us to include also cities which do not cover all indicators. Their results are calculated with the values available. Still, it is necessary to provide a good coverage over all cities to receive reasonable results.

TECHNISCHE UNIVERSITÄT WIEN
Vienna University of Technology

IEEE Smart City Initiative



- A smart economy
- Smart energy
- Smart mobility
- A smart environment
- Smart living
- Smart governance

IEEE Standards Help Enable Smart City Technologies for Humanity

Smart Grid
IEEE 1547™ Series DER
IEEE 1815™ Distributed Network Protocol
IEEE 2030™ Series Interoperability
IEEE C37™ Series Grid Critical Infrastructure

Learning Technologies
IEEE 1484™ Series eLearning Technologies
IEEE 1278™ Series Distributed Interactive Simulation
IEEE 1516™ Series Modeling and Simulation
IEEE 1730™ Series Distributed Simulation Engineering and Execution Process

Intelligent Transportation
IEEE 1609™ Series Wireless Access Vehicle Environment
IEEE 1901™ Series Power Line Communications (PLC)
IEEE 802.15.4p™ WPAN Rail Communications and Control
IEEE 1512™ Emergency Management System

Smart Home
IEEE 802® LAN/MAN
IEEE 1901™ Series PLC
IEEE 1905.1™ Home Network for Heterogeneous Technologies
IEEE 2030.5™ Smart Energy Profile

eHealth
IEEE 11073™ Series Medical Devices
IEEE 139™ RF Emission from ISM Equipment
IEEE 602™ Healthcare Facilities
IEEE 1363™ Series Encryption

eGovernance
IEEE P7002™ Data Privacy Process
IEEE P7004™ Child and Student Data Governance
IEEE P7005™ Transparent Employer Data Governance
IEEE P7006™ Personal Data Artificial Intelligence (AI) Agent

Energy Efficiency
IEEE 1801™ Low Power, Energy Aware Electronic Systems
IEEE P1889™ Electrical Performance of Energy Saving Devices
IEEE P1823™ Universal Power Adapter for Mobile Devices
IEEE P1922.1™-IEEE P1929.1™ Series for Energy Efficient Systems

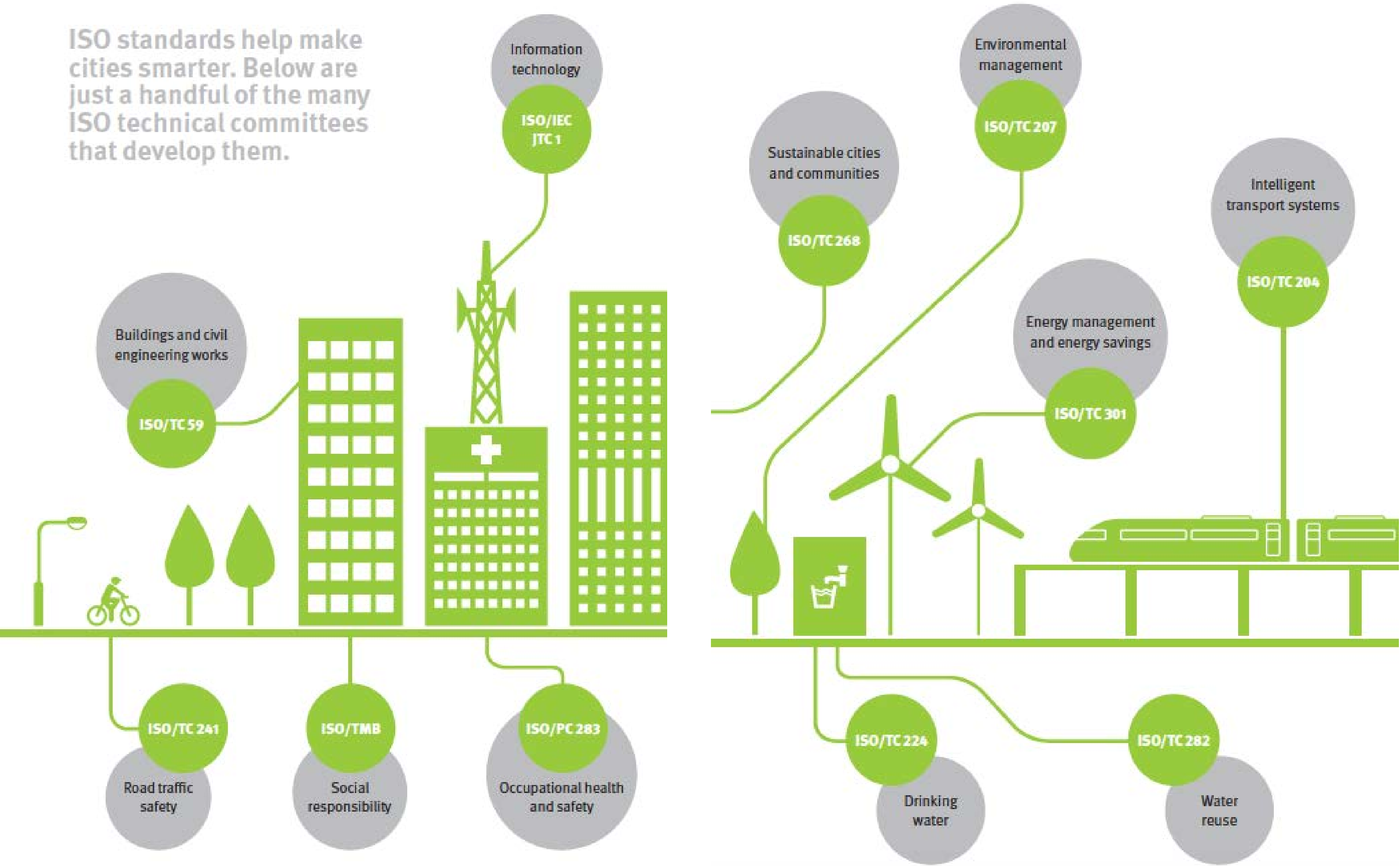
Cyber Security
IEEE P802E™ ePrivacy
IEEE 1363™ Series Encryption
IEEE 1402™ Physical Security
IEEE 1686™ Intelligent Electronic Devices (IEDs)

Internet of Things (IoT)
IEEE P2413™ IoT Architecture
IEEE 1588™ Precision Time Stamp
IEEE 1451™ Series Sensor Networks
IEEE P1451-99™ Harmonization of IoT Devices and Systems

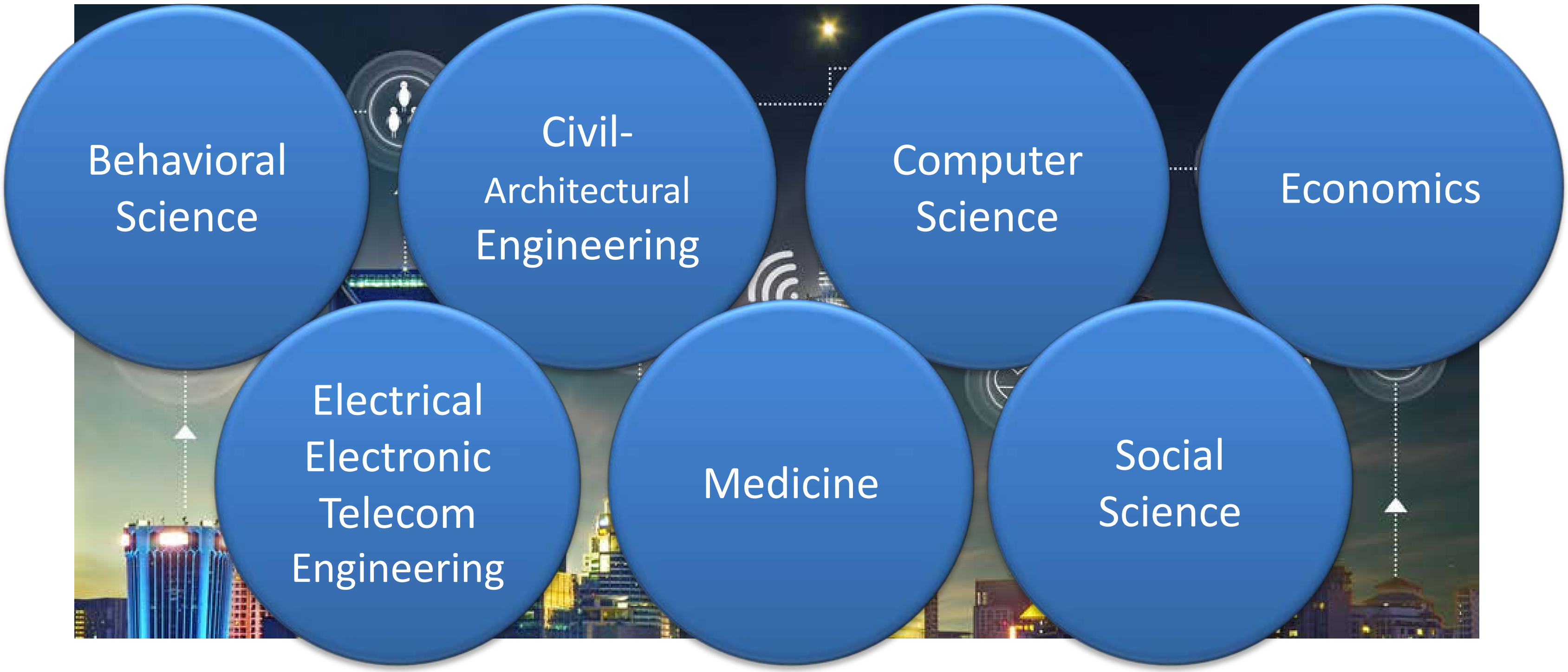
5G
IEEE P1914.1™ Fronthaul
IEEE P1918.1™ Tactile Internet
IEEE 802® LAN/MAN
IEEE P1915™-IEEE P1921.1™ Series Software Defined Networks

ISO Standards

ISO standards help make cities smarter. Below are just a handful of the many ISO technical committees that develop them.



The need for a multidisciplinary approach



To achieve the challenging **goals** mentioned above, drastic changes are required that involve a multitude of **new technologies** relevant to various disciplines e.g.

An Interesting Definition

SmartCitiesCouncil
LIVABILITY
WORKABILITY
SUSTAINABILITY

HOME | OUR PARTNERS | CITY RESOURCES | PREMIUM RESOURCES* | GLOBAL ALLIANCES | JOIN SCC |

Definitions and overviews

The smart city sector is still in the "I know it when I see it" phase, without a universally agreed definition. The Council defines a smart city as one that has digital technology embedded across all city functions; click on any of the articles below for additional perspectives.

The Smart Cities Council is a for-profit, Partner-led association for the advancement of the smart city business sector. It promotes smart cities in general and our Partners in particular.
Allied Telesis • Alstom Grid • Bechtel • Cisco • Cubic Transportation Systems - Enel • GE • IBM • Itron, Inc. • MasterCard • Mercedes-Benz • Microsoft • Ooredoo • Qualcomm • S&C Electric Co. • Schneider Electric

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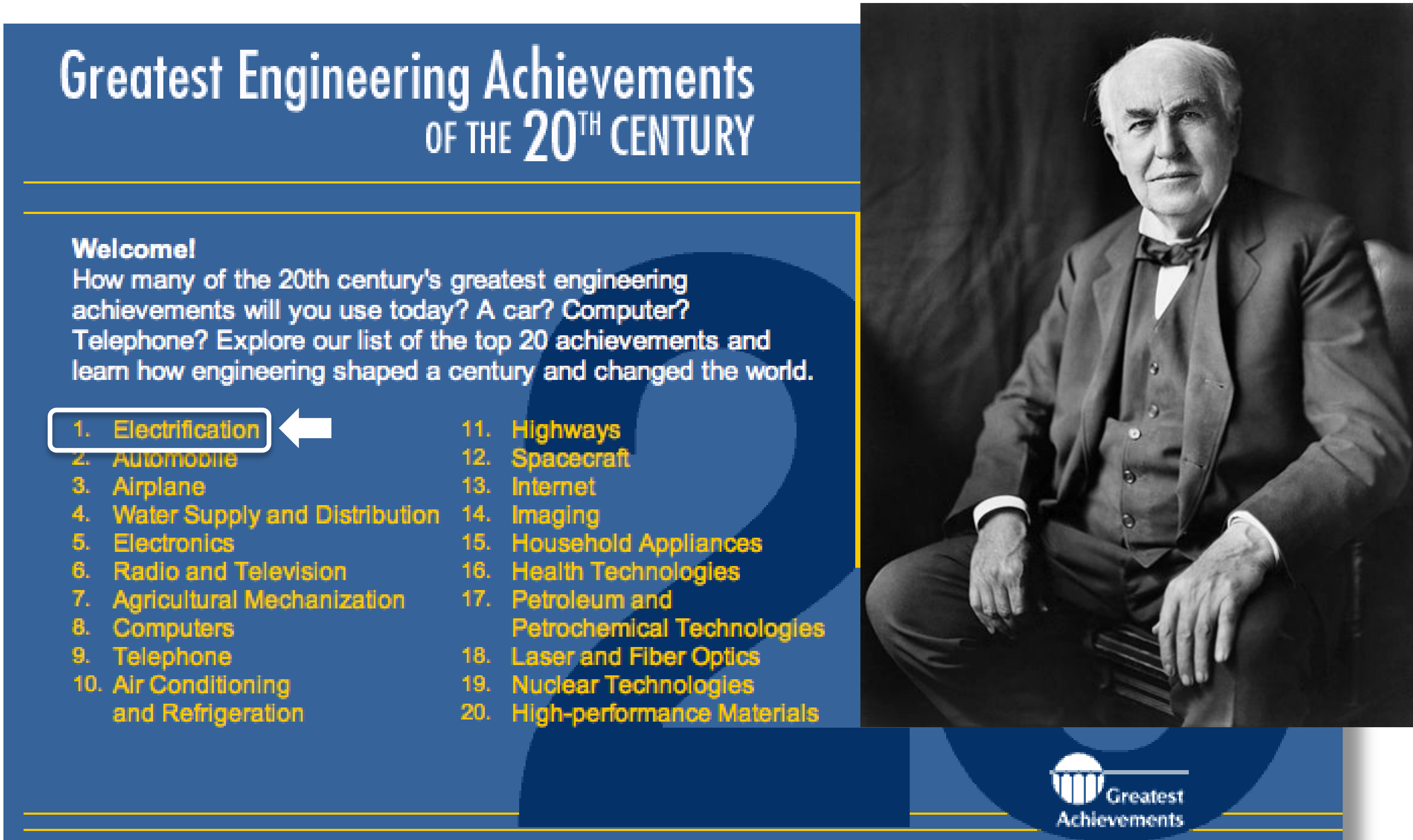
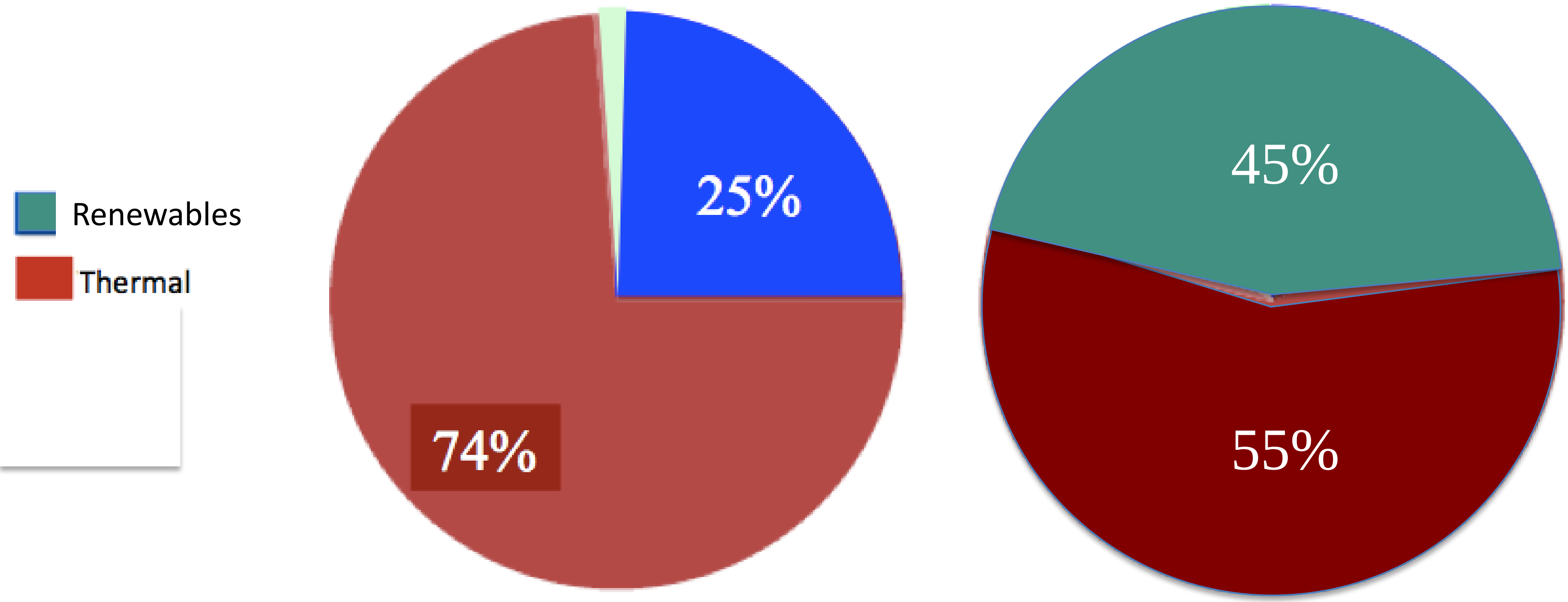
Smart Grid

Also the traditional power grid is *smart*



Italian Power Generation Mix

Classification	Plants (k)	Power (GW)	Plants (k)	Power (GW)
Hydroelectric	2	21,1	2,9	22,5
Thermal power	1,9	62,2	3,9	76,9
Wind	0,1	1,1	1,4	8,5
PV	0	0	559,4	18,5
Total	**4**	**84,4**	**567,6**	**126,4**

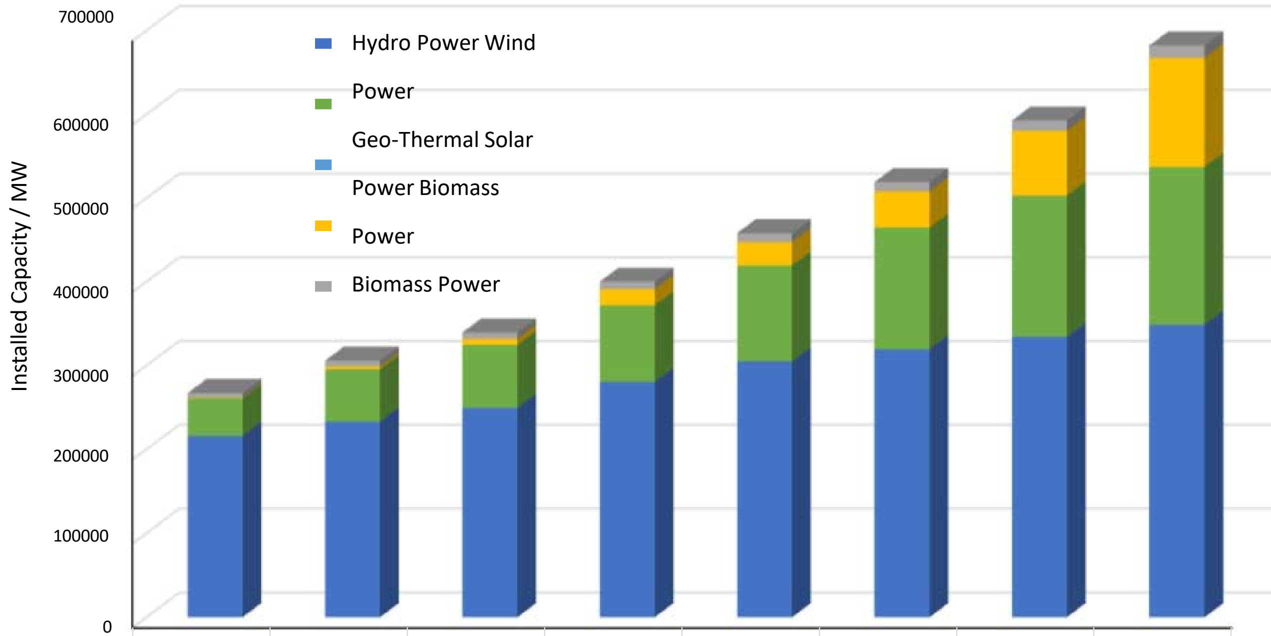


2004
Start of electricity market

2017
Generation mix further changes

China Trends in Renewables

Current Situation



	2010	2011	2012	2013	2014	2015	2016	2017
Biomass Power	5500	7000	7700	9000	10700	11199	12248	14760
Solar Power	890	3500	7000	19420	28050	43180	77420	130250
Geo-Thermal	28	30	30	30	30	30	30	30
Wind Power	44734	62364	75324	91413	114609	145362	168730	188392
Hydro Power	216060	232980	249470	280440	304860	319530	334200	348870

Courtesy of Prof. Chongqing Kang Tsinghua University, China

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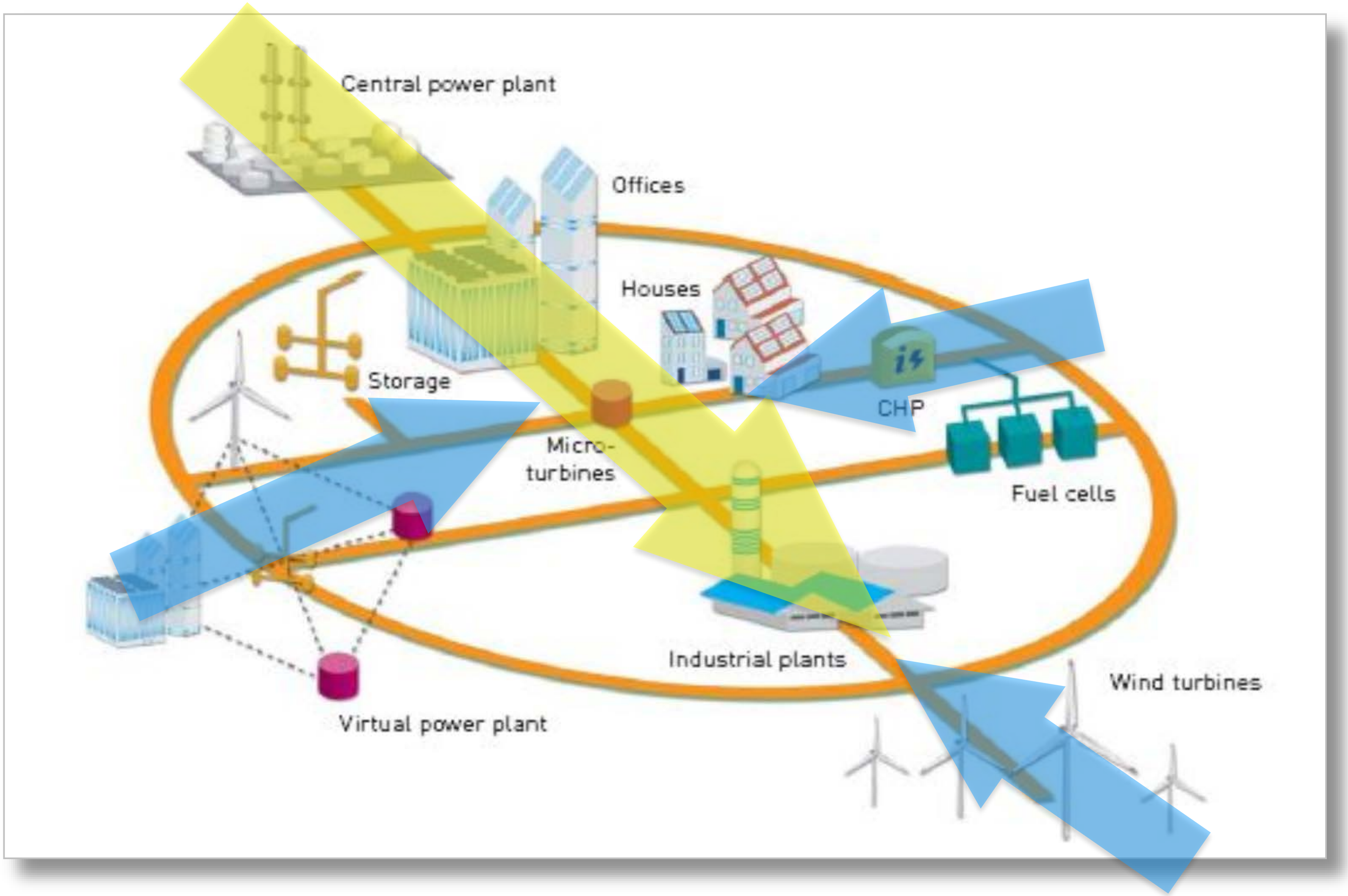
Smart grid – Europe Technology Platform



The smart grid – why it needs to be smart

Random availability of renewable sources

- *smarter* management of the system, **wide ICT deployment** (e.g. metering, co-simulation tools)
- Need for **storage resources**

Use of renewable sources →

- Deployment of **converters** (which replace synchronous generators) and therefore **loss of inertia and stability**

Diffusion of electric mobility →

- Network capacity needs to be assessed
- EV as potential power sources for the network

Market liberalization

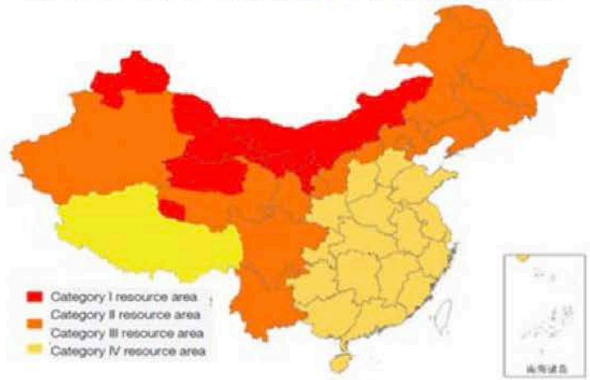
- From consumers to **prosumers**

Power-flow inversion

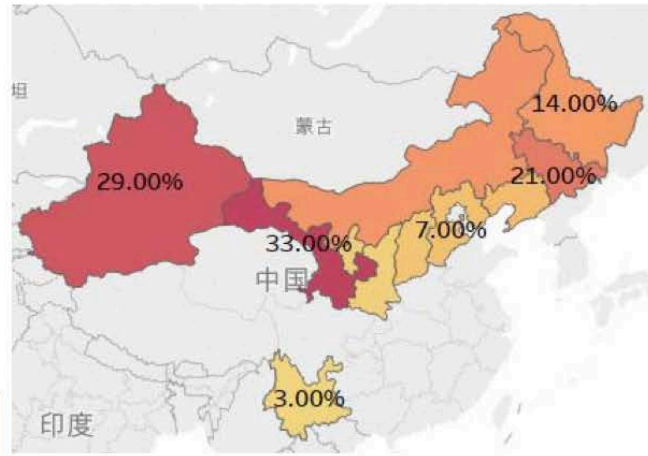
- **Transit limits**
- **Voltage profile variation** on the lines
- Abnormal behaviour of **protections**

Renewable Energy Curtailment in China

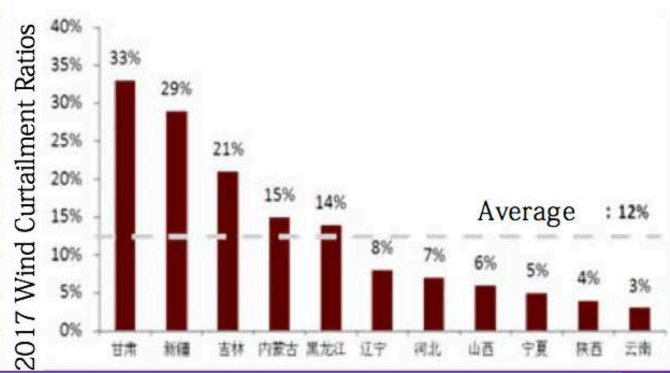
Renewable Resource Distribution



2017 Wind Curtailment Ratios



Province	Load (GW)	Wind Capacity (GW)	Theoretical generated energy (TWh)	Energy integrated (TWh)	Energy Curtailment (TWh)	Curtailment Ratio
Xinjiang	28. 04	18.06	45.15	31.9	13.25	29%
Inner Mongolia	30. 46	26.70	64.6	55.1	9.5	15%
Gansu	13. 90	12.82	27.98	18.8	9.18	33%
Jilin		5.05	10.96	8.7	2.26	21%
Hebei		11.81	28.33	26.3	2.03	7%
Heilongjiang		5.7	12.55	10.8	1.75	14%
Liaoning		7.11	16.32	15	1.32	8%
Shanxi		8.72	17.6	16.5	1.1	6%
Ningxia		9.42	16.27	15.5	0.77	5%
Yunnan		8.19	20.47	19.9	0.57	3%



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Courtesy of Prof. Chongqing Kang Tsinghua University, China

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Virtual Inertia Technique of DFIGs

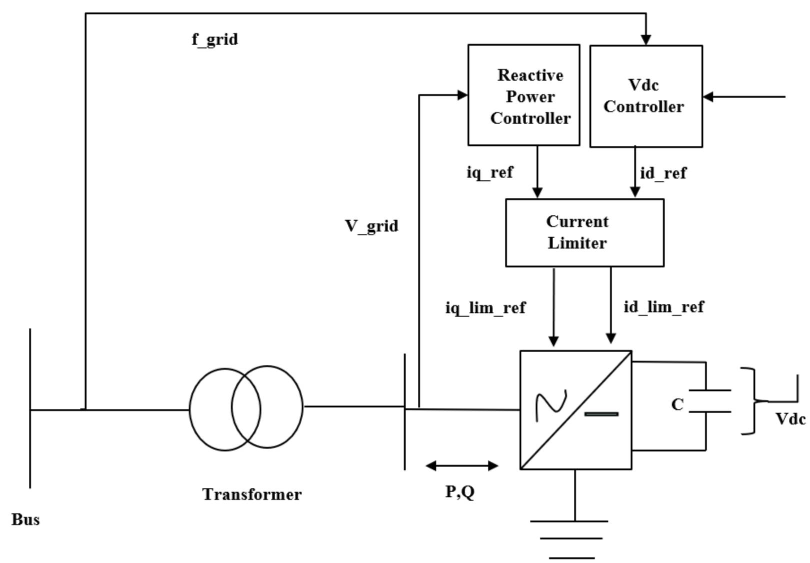
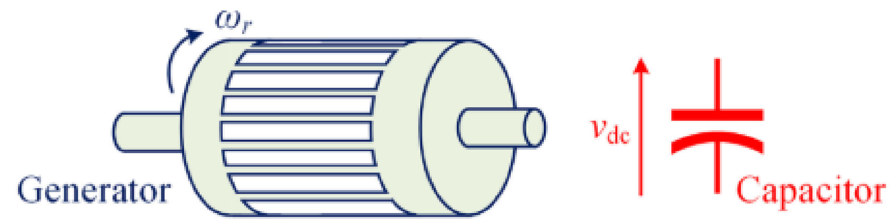


Figure Block diagram representation of GSC control



	Generator	Capacitor
Energy	$E_{gen} = J\omega_{ref}^2 / 2$	$E_{cap} = C_{dc}V_{dc}^2 / 2$
Inertia	$H = J\omega_{ref}^2 / (2VA_{rated})$	$H_c = C_{dc}V_{dc}^2 / (2VA_{rated})$

Power extracted from DC-link

$$P = \frac{1}{2} C \frac{dV_{dc}^2}{dt}$$

From J.A. Adu et al. Proc. SynEnergy Med 2019.

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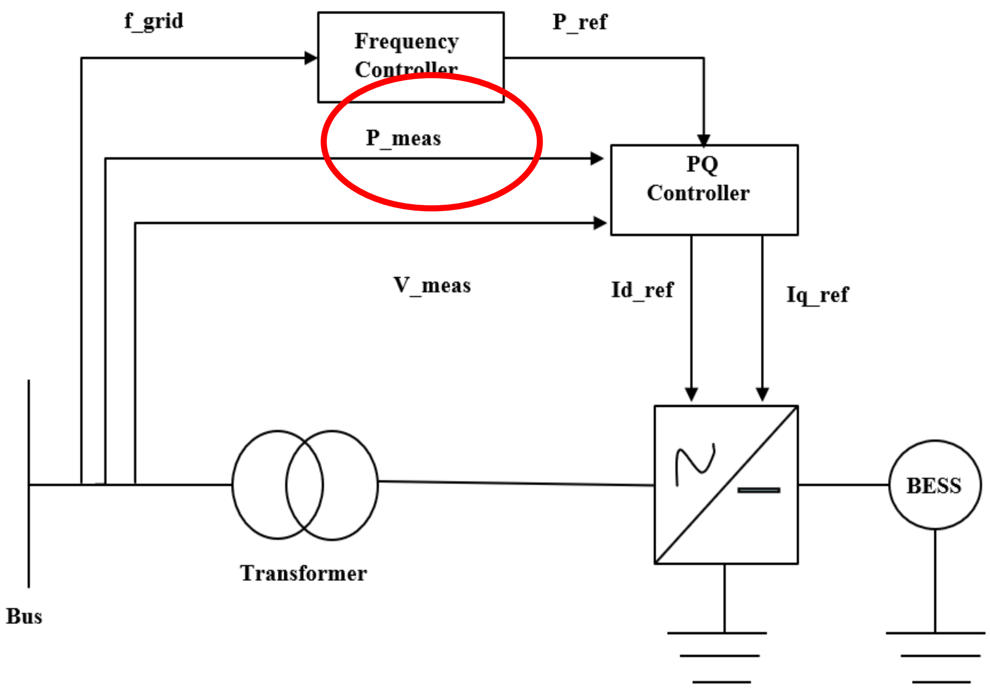
Virtual inertia technique of BESS



$$P_{ref} = K_d \cdot \Delta f + K_i \cdot \frac{d\Delta f}{dt}$$

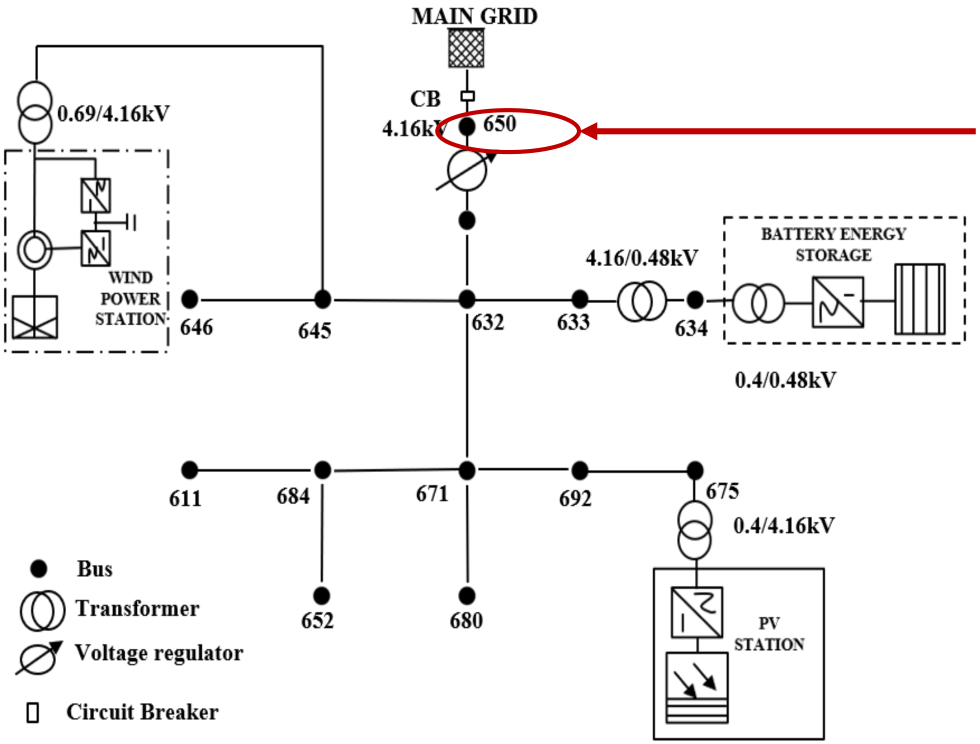
K_d gives the droop control and emulates the linear damping of a synchronous generator.

K_i provides a faster dynamic frequency response and helps to limit the ROCOF by emulating the inertia.

Figure Block diagram representation of BESS control

From J.A. Adu et al. Proc. SynEnergy Med 2019

IEEE modified 13-node feeder connected to an external grid.



At t=0 CB opens for islanding

The islanding causes a frequency deviation as the result of active power imbalance of 4.56 MW.

For continuous and safe operation of the microgrid, fast inertia response is critical to avoid abnormal frequencies and voltages.

Before islanding occurs, the network imports 4.56 MW and 1.58 Mvar active and reactive power, respectively, from the external grid.

From J.A. Adu et al. Proc. SynEnergy Med 2019

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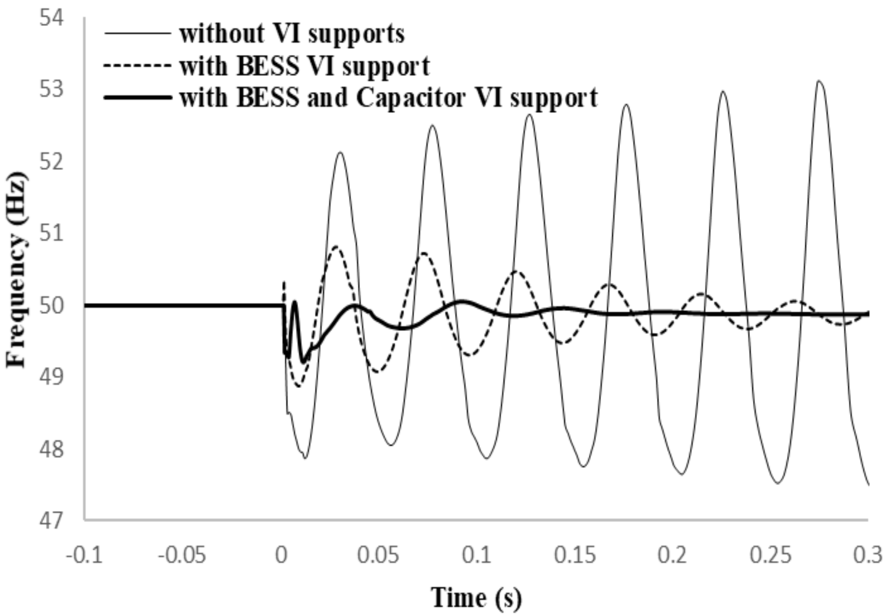
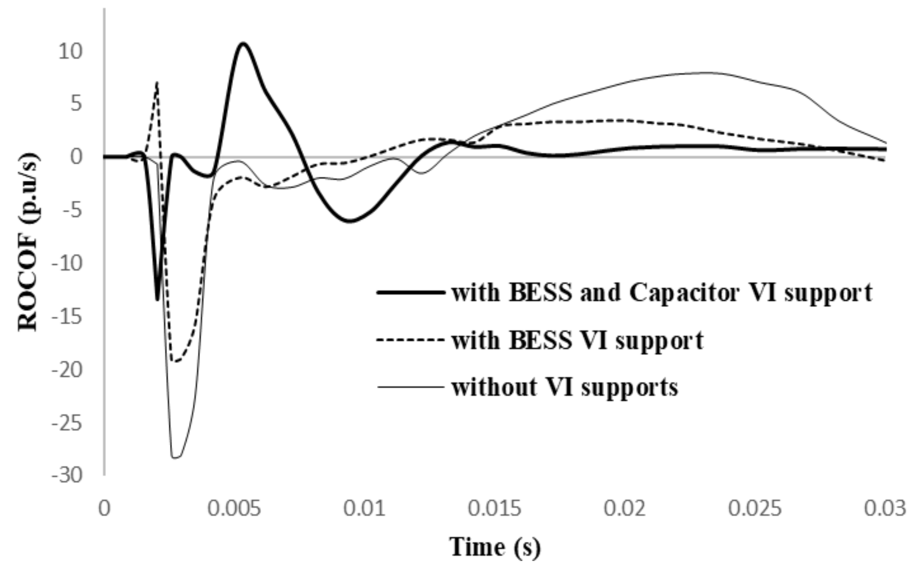
Frequency and ROCOF





- Unstable frequency with no virtual inertia implementation.
- In case the BESS virtual inertia scheme is introduced in the simulation model, the frequency nadir value improves, and it is maintained within acceptable limits.
- Frequency stability with very low frequency nadir values when the DC-link capacitor control is also considered.

From J.A. Adu et al. Proc. SynEnergy Med 2019

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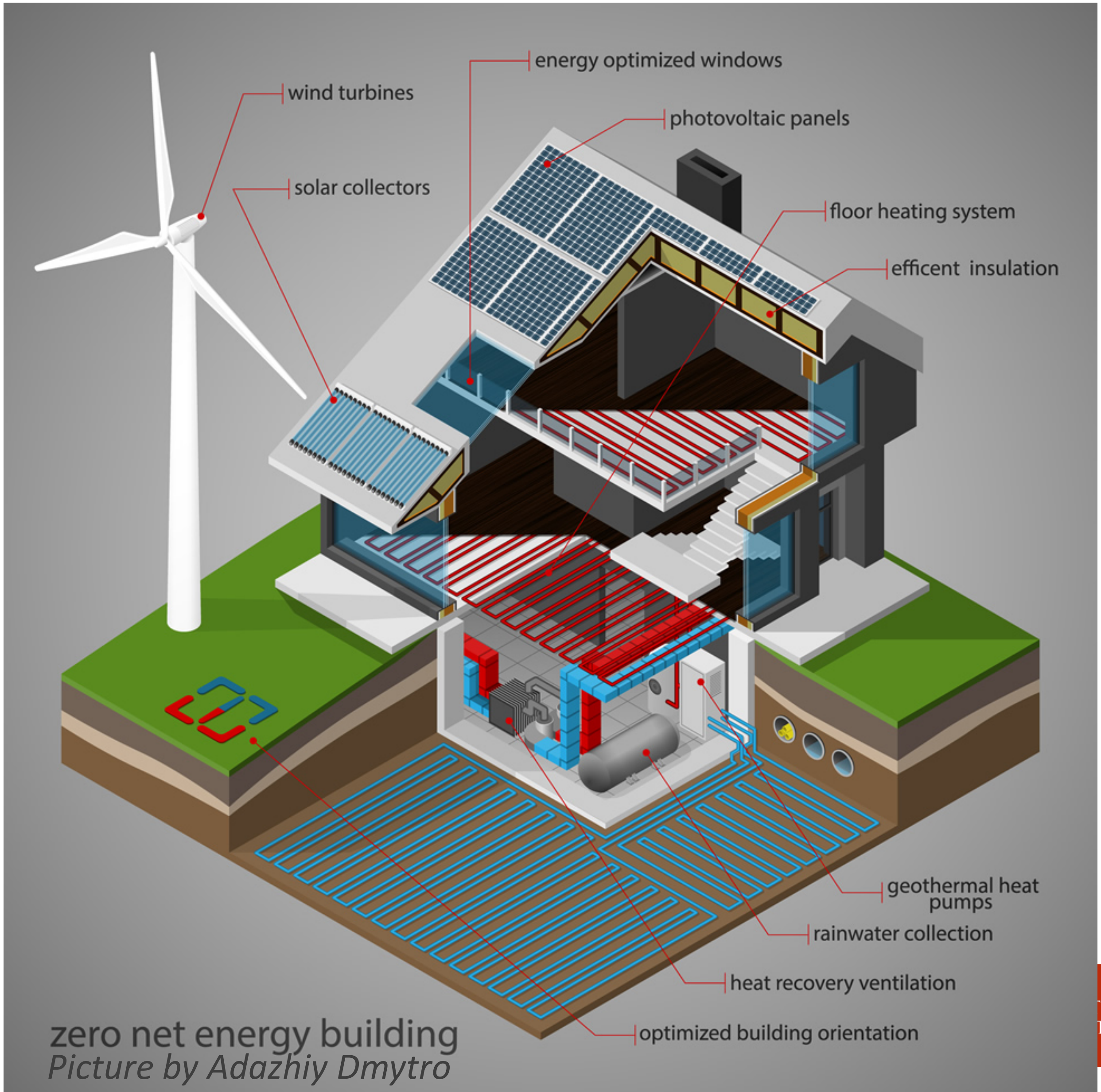
The role of Buildings



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The ‘Winter Package’

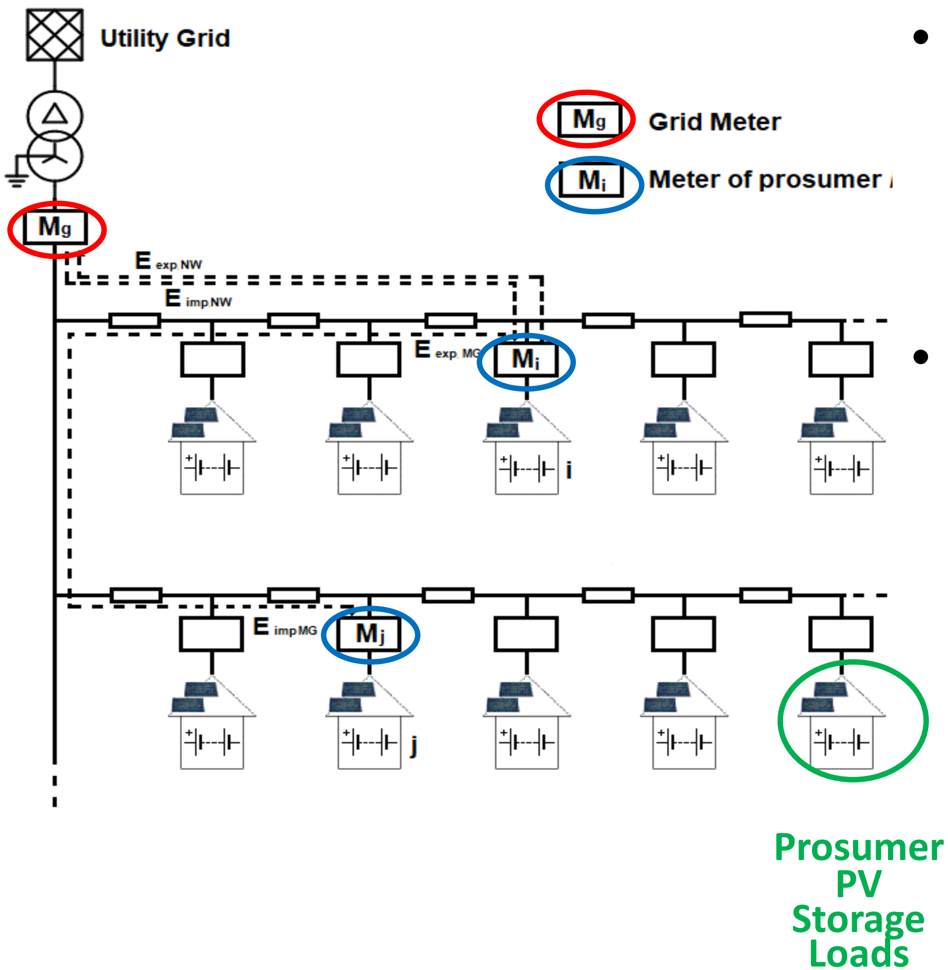
In **December 2018**, the European Union approved the first part of a comprehensive legislative package entitled ‘**Clean Energy for all Europeans (CEP)**’, also known as **Winter Package**. The EU Directive aims to put in place appropriate legal frameworks to enable the energy transition and give a special role to citizens and communities activities, introducing the Energy Community into the regulatory framework. **The CEP should be transposed into the national laws by March 2020.**

Member States should put in place appropriate measures such as **national network codes** and **market rules**, and incentivize distribution system operators through network tariffs which do not create obstacles to flexibility or to the improvement of energy efficiency in the grid.

3

Local Energy Communities

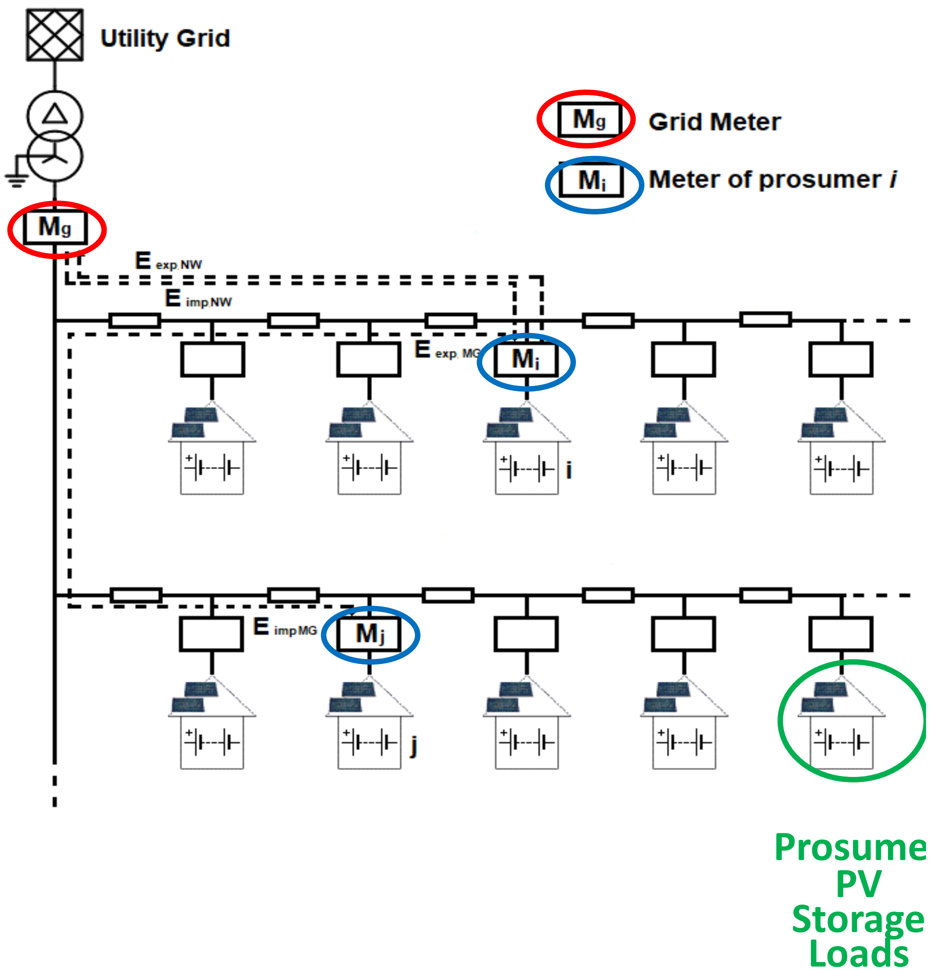
Local Energy Community (LEC)



- A LEC is a set of residential or small industrial sites, each connected to the **same distribution network** and acting as a **prosumer**.

- Aim of the community is to
  - **minimize** the **power exchanges** with the utility grid (reduce dependence, enhance self-consumption)
  - **reduce** the **energy procurement costs**
  - **trade** the **overproduction** with others

Billing scheme



a) In each time interval, if the LEC **buys** energy from the utility grid the relevant **cost** is allocated to each **consumer *i*** <u>proportionally</u> to **the ratio between its consumption and the total consumption** in the LEC.

b) If the LEC **sells** energy to the utility grid, the corresponding **revenue** is allocated to each **producer *j*** <u>proportionally</u> to the **contribution of *j* to the total LEC production**.

c) Each **consumer *i*** is also charged for the energy **bought** from the producers of the LEC. The corresponding **revenue** of **producer *j*** is estimated <u>proportionally</u> to the **contribution of *j* to the total LEC production as in step b)**.

Given the collaborative characteristic of the LEC, a prosumer cannot act as producer and as consumer in the same time interval

Objective

1. **Optimized day-ahead scheduling of the use of the batteries**, as DG from renewables is mainly not-dispatchable

2. **Calculation** of the **prices** of **energy transactions of each prosumer *j*** in each time interval and **allocate the network power loss for each energy exchange**

The problem has been addressed with the design of a specific **distributed optimization procedure** based on the adoption of the **alternating direction method of multipliers** approach (**ADMM**)

The ADMM solution is compared with the solution obtained by using a **centralized mathematical programming** model (**MILP approach**).

It is assumed that the prices of exchanges with the utility grid are predefined, although they vary according to the time of day.

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Different aspects

Planning (both users and grid investments)

Scheduling **day ahead**

Intraday scheduling and control

Settling (energy prices and network charges)

Services to the network

Centralized Approach

Network cost/revenue

MILP model

$$OF = \min \sum_{\substack{t \in T \\ i \in \Omega}} \left(\underbrace{\pi^t_{\text{buy}} P^t_{\text{buy\_Grid}\,i} - \pi^t_{\text{sell}} P^t_{\text{sell\_Grid}\,i}}_{} \right) \Delta t \qquad (1)$$

with the coupling **constraint equilibrium** between the **energy bought** from producer *i* by the other prosumers and the **energy sold** by producer *i*

$$P^t_{\text{sell}\,i,j} - P^t_{\text{buy}\,j,i} = 0 \qquad (2)$$

Equilibrium of energy bought prosumer *i – others* *(what is being offered is bought)*

and **other constraints** for each prosumer:

- **avoid simultaneous purchase and selling** by the same prosumer
- **In each time interval** ***t*****, purchases and sales are limited by constraints**
- **model of the BES units**
- **power balance** for the *i*-th prosumer

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$$\begin{cases} P^t_{\text{buy\_Grid}\,i} = 0 \text{ and } P^t_{\text{buy}\,i,j} = 0 \text{ if } u^t_i = 0 \\ P^t_{\text{sell\_Grid}\,i} = 0 \text{ and } P^t_{\text{sell}\,i,j} = 0 \text{ if } u^t_i = 1 \end{cases} \quad u^t_i \in \{1,0\}$$

no simultaneous purchase and selling (grid indicator constraint)

$$0 \le P^t_{\text{buy\_Grid}\,i} \le P^{\max}_{\text{buy}\,i} \quad 0 \le P^t_{\text{sell\_Grid}\,i} \le P^{\max}_{\text{sell}\,i} \quad 0 \le P^t_{\text{buy}\,i,j} \le P^{\max}_{\text{buy}\,i} \quad 0 \le P^t_{\text{sell}\,i,j} \le P^{\max}_{\text{sell}\,i}$$

$$E^t_{\text{BES}\,i} = E^{t-1}_{\text{BES}\,i} + (P^t_{\text{ch}\,i}\eta_{\text{ch}\,i} - P^t_{\text{dis}\,i} / \eta_{\text{dis}\,i})\Delta t$$

$$\begin{cases} E^{t=1}_{\text{BES}\,i} = E_{\max,i} + (P^{t=1}_{\text{BES}\,i}\,\eta_{\text{ch}\,i} - P^{t=1}_{\text{BES}\,i} / \eta_{\text{dis}\,i})\Delta t \\ E^{t_{\text{end}}}_{\text{BES}\,i} = E^{\max}_{\text{BES}\,i} \quad i \in \Omega \end{cases}$$

$$\begin{cases} P^t_{\text{ch}\,i} = 0 \text{ if } u^t_{\text{BES}\,i} = 0 \\ P^t_{\text{dis}\,i} = 0 \text{ if } u^t_{\text{BES}\,i} = 1 \end{cases} \quad u^t_{\text{BES}\,i} \in \{1,0\}$$

no simultaneous charge and discharge

$$0 \le P^t_{\text{BES\_dis}\,i} \le P^{\max}_{\text{BES}\,i} \quad 0 \le P^t_{\text{BES\_ch}\,i} \le P^{\max}_{\text{BES}\,i}$$

$$E^{\min}_{\text{BES}\,i} \le E^t_{\text{BES}\,i} \le E^{\max}_{\text{BES}\,i}$$

BES model

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Power balance

$$P_{\mathrm{G}\,i}^{t} + P_{\mathrm{BES\_dis}\,i}^{t} + P_{\mathrm{buy\_Grid}\,i}^{t} + \sum_{\substack{j\in\Omega \\ j\neq i}} P_{\mathrm{buy}\,i,j}^{t} = P_{\mathrm{D}\,i}^{t} + P_{\mathrm{BES\_ch},i}^{t}$$

$$+P_{\mathrm{sell\_Grid}\,i}^{t} + \sum_{\substack{j\in\Omega \\ j\neq i}} P_{\mathrm{sell}\,i,j}^{t} + \frac{1}{2}\sum_{b\in B} L_{b,i}^{t}$$

Power loss estimation – first stage

$$L_{b,i}^{t} = \frac{R_b}{3V_n^2}\left(F_{b,i}^{t}\right)^2$$

$$F_{b,i}^{t} = A_{\mathrm{Grid}\,b,i} P_{\mathrm{buy\_Grid}\,i}^{t} - A_{\mathrm{Grid}\,b,i} P_{\mathrm{sell\_Grid}\,i}^{t}$$

$$+\sum_{j\in\Omega} A_{b,i,j} P_{\mathrm{buy}\,i,j}^{t} - \sum_{j\in\Omega} A_{b,i,j} P_{\mathrm{sell}\,i,j}^{t}$$

Power balance

$$P_{\mathrm{G}\,k}^{t} + P_{\mathrm{BES\_dis}\,k}^{t} + \eta_{\mathrm{buy\_Grid}\,k}^{t} P_{\mathrm{buy\_Grid}\,k}^{t} + \sum_{\substack{j\in\Omega \\ j\neq k}} P_{\mathrm{buy}\,k,j}^{t} =$$

$$P_{\mathrm{D}\,k}^{t} + P_{\mathrm{BES\_ch}\,k}^{t} + \frac{P_{\mathrm{sell\_Grid}\,k}^{t}}{\eta_{\mathrm{sell\_Grid}\,k}^{t}} + \sum_{\substack{j\in\Omega \\ j\neq k}} \frac{P_{\mathrm{sell}\,k,j}^{t}}{\eta_{\mathrm{buy}\,j,k}^{t}}$$

Power loss estimation – second stage

$$\eta_{\mathrm{buy\_Grid}\,k}^{t} = 1 - \frac{\sum_{b\in B} L_{\mathrm{buy\_Grid}\,b,k}^{t}}{P_{\mathrm{buy\_Grid}\,k}^{t}}$$

$$\eta_{\mathrm{buy}\,k,j}^{t} = \frac{P_{\mathrm{buy}\,k,j}^{t}}{P_{\mathrm{buy}\,k,j}^{t} + \sum_{b\in B} L_{\mathrm{buy}\,b,k,j}^{t}}$$

$$\eta_{\mathrm{sell\_Grid}\,k}^{t} = \frac{P_{\mathrm{sell\_Grid}\,k}^{t}}{P_{\mathrm{sell\_Grid}\,k}^{t} + \sum_{b\in B} L_{\mathrm{sell\_Grid}\,b,k}^{t}}$$

Each prosumer *i* compensates for losses due to its transactions with the utility grid and sale transactions with other prosumers.

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Distributed Approach

Alternating Direction Method of Multipliers (ADMM)

$$OF = \min \sum_{t \in T} \begin{bmatrix} \pi^t_{\text{buy}} P^t_{\text{buy\_Grid}\,k} \Delta t - \pi^t_{\text{sell}} P^t_{\text{sell\_Grid}\,k} \Delta t + \\ \sum_{\substack{j \in \Omega \\ j \neq k}} \lambda^t_j P^t_{\text{buy}\,k,j} \Delta t - \lambda^t_k \sum_{\substack{j \in \Omega \\ j \neq k}} P^t_{\text{sell}\,k,j} \Delta t + \ell^t_k \end{bmatrix} \qquad (3)$$

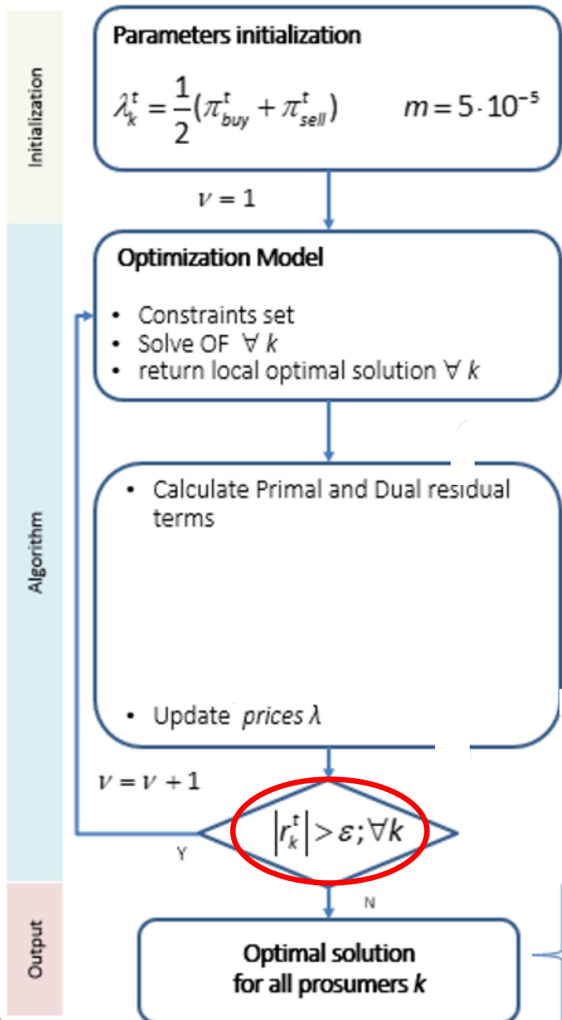
$$\ell^t_k = m \cdot \rho \cdot [\sum_{\substack{j \in \Omega \\ j \neq k}} (\hat{P}^t_{\text{buy}\,j,k} - P^t_{\text{sell}\,k,j})^2 + \sum_{\substack{j \in \Omega \\ j \neq k}} (P^t_{\text{buy}\,k,j} - \hat{P}^t_{\text{sell}\,j,k})^2] \qquad (4)$$

The distributed procedure :

- aims at minimizing the energy procurement cost of the LEC considering the power loss in the internal network;

- the internal network losses are allocated to each energy transaction between two prosumers or between a prosumer and the utility grid;

- the results obtained by the distributed algorithm are compared with those given by the centralized before described model that includes the same constraints and power loss allocation;



Results:
- Branch power flow
- Energy transactions i - j
- Prices λ of transactions
- BES units State of Energy

At each ADMM iteration, the **power bought** or **sold** by each **prosumer *j*** calculated in the previous iteration is made **known to all prosumers**.

These values are considered as parameters in the optimization problem solved by prosumer *k* at the current iteration and they are denoted by a hat in the model.

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Distributed ADMM approach iterative procedure

Lagrangian decomposition for each prosumer k

Hat → parameter

Network cost/revenue = OF

From Constraint "Equilibrium"

λ = Lagrange multiplier

$$OF_k = \min \sum_{t \in T} \pi^t_{\text{buy}} P^t_{\text{buy\_Grid}\,k} \Delta t - \pi^t_{\text{sell}} P^t_{\text{sell\_Grid}\,k} \Delta t + \sum_{\substack{j \in \Omega \\ j \neq k}} \lambda^t_j P^t_{\text{buy}\,k,j} \Delta t - \lambda^t_k \sum_{\substack{j \in \Omega \\ j \neq k}} P^t_{\text{sell}\,k,j} \Delta t + \ell^t_k$$

$$\ell^t_k = m \cdot \rho \cdot [\sum_{\substack{j \in \Omega \\ j \neq k}} (\hat{P}^t_{\text{buy}\,j,k} - P^t_{\text{sell}\,k,j})^2 + \sum_{\substack{j \in \Omega \\ j \neq k}} (P^t_{\text{buy}\,k,j} - \hat{P}^t_{\text{sell}\,j,k})^2]$$

Penalty parameter

Augmented by squared norm

Constraints are the same as those used in the Centralized approach, and to improve the convergence we have added two constraints:

$$\begin{cases} P^t_{\text{sell}\,k,j} \leq \hat{P}^t_{\text{buy\_Grid}\,j} + \sum_{\substack{i \in \Omega \\ i \neq j}} \hat{P}^t_{\text{buy}\,j,i} \\ P^t_{\text{buy}\,k,j} \leq \hat{P}^t_{\text{sell\_Grid}\,j} + \sum_{\substack{i \in \Omega \\ i \neq j}} \hat{P}^t_{\text{sell}\,j,i} \end{cases}$$

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Distributed ADMM approach
update of Lagrangian multipliers

ν = iteration

Prices update

Primal residual for prosumer *k*

$$\lambda_k^{\nu+1} = \lambda_k^{\nu} + 2m \cdot \rho \cdot r_k^{\nu} \Leftrightarrow r_k^t = \sum_{\substack{j\in\Omega \\ j\neq k}} P_{\text{buy}\, j,k}^t - \sum_{\substack{j\in\Omega \\ j\neq k}} P_{\text{sell}\, k,j}^t$$

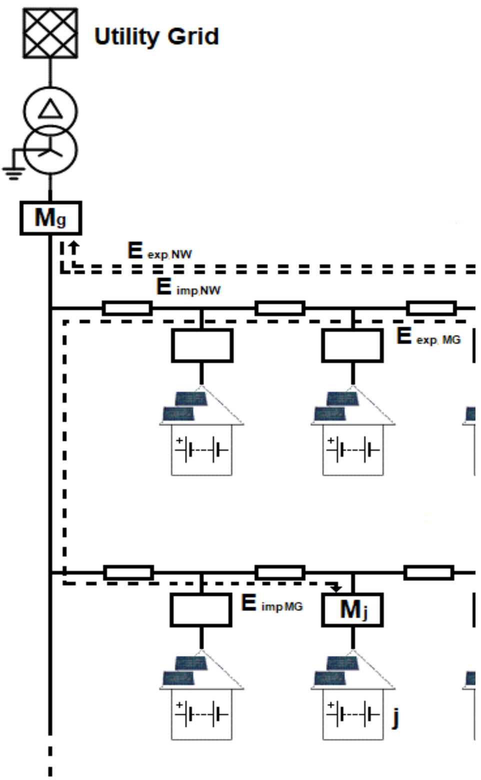
ρ update

Dual residual term

$$\rho^{\nu+1} = \begin{cases} 2\rho^{\nu} & \left\|r_k^{\nu}\right\|_2 > 10\left\|s_k^{\nu}\right\|_2 \\ \rho^{\nu}/2 & \left\|s_k^{\nu}\right\|_2 > 10\left\|r_k^{\nu}\right\|_2 \\ \rho^{\nu} & \text{otherwise} \end{cases} \Leftrightarrow s_k^t = \rho^{\nu}\left[\left(\sum_{j\in\Omega} P_{\text{sell}\, k,j}^t\right)^{\nu} - \left(\sum_{j\in\Omega} P_{\text{sell}\, k,j}^t\right)^{\nu-1} + \left(\sum_{j\in\Omega} P_{\text{buy}\, k,j}^t\right)^{\nu} - \left(\sum_{j\in\Omega} P_{\text{buy}\, k,j}^t\right)^{\nu-1}\right]$$

$$\boxed{\text{stop criteria: } \left|r_k^t\right| \leq \varepsilon}$$

Test case



1 day, divided into 96 periods of **15 minutes** each.

2 LV feeders, **each feeder** consists of **five lines**.

5 prosumers are connected to each feeder: prosumers 1-5 to a feeder and prosumers 6-10 to the other. Each prosumer is **equipped** with a **BES**, a **PV system** and a **load**.

The total daily consumption of the LEC is **313 kWh** and the corresponding **PV production is 231 kWh** (**73.8%** of the load).
The **total capacity** of the **BES units** is **30 kWh** (**13%** of the daily PV production).

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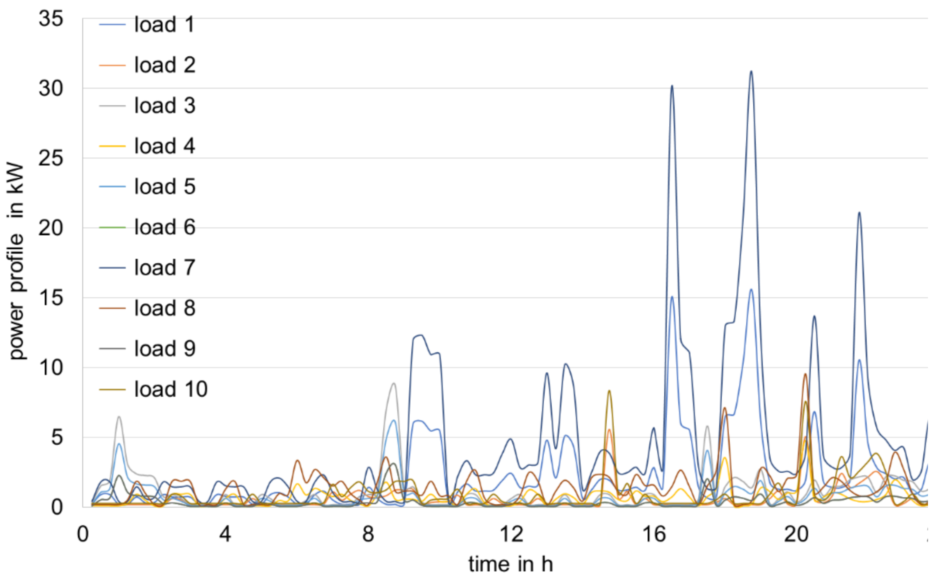
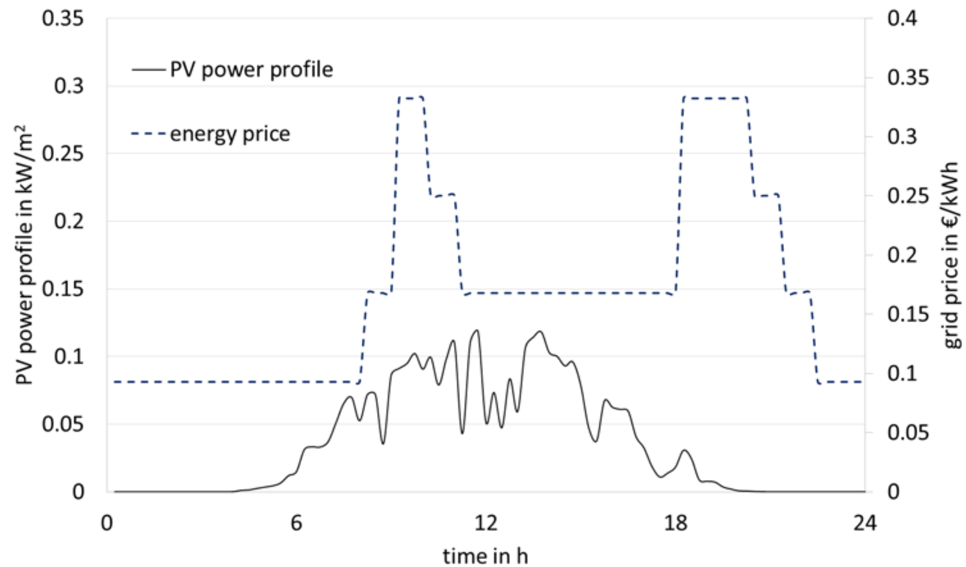
Load, PV production and price profiles





prosumer	1	2	3	4	5	6	7	8	9	10
area (m^2)	32	14	21	32	28	14	42	32	14	42
size (kWh)	5	3	4	2	3	1	2	2	2	6

PV panel surface for each prosumer and size of the BES units

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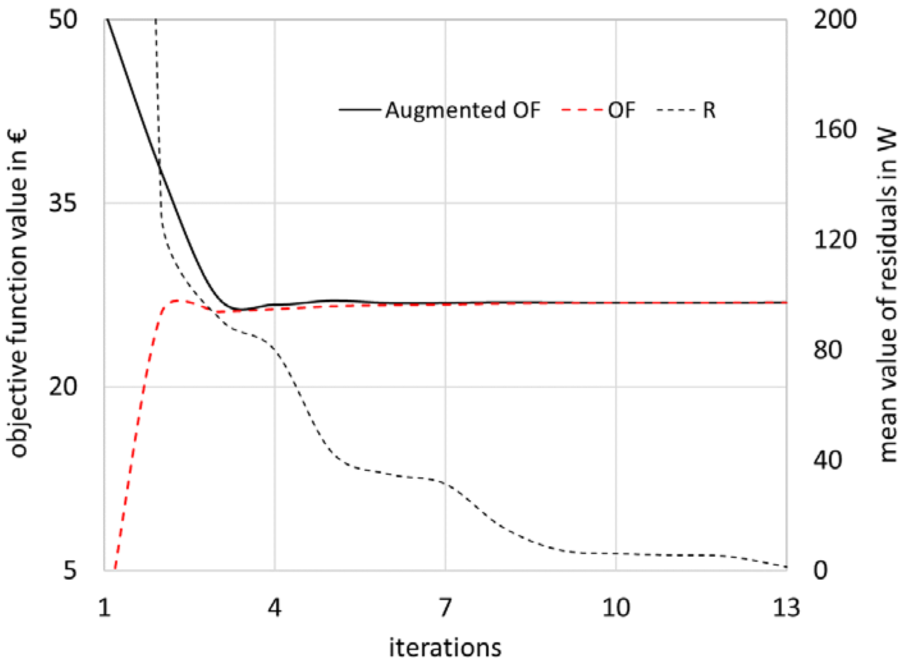
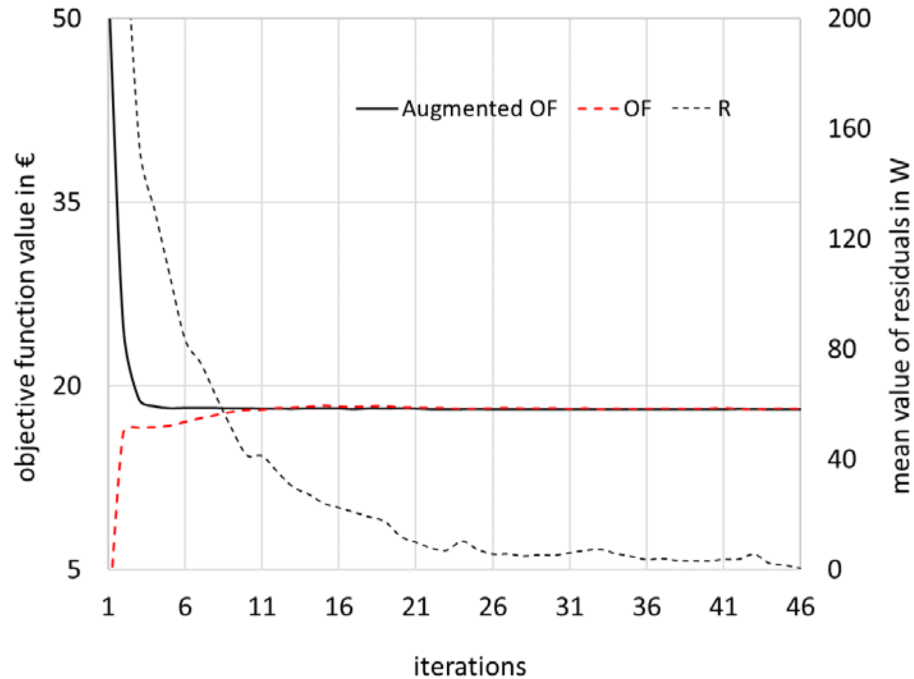
ADMM convergence

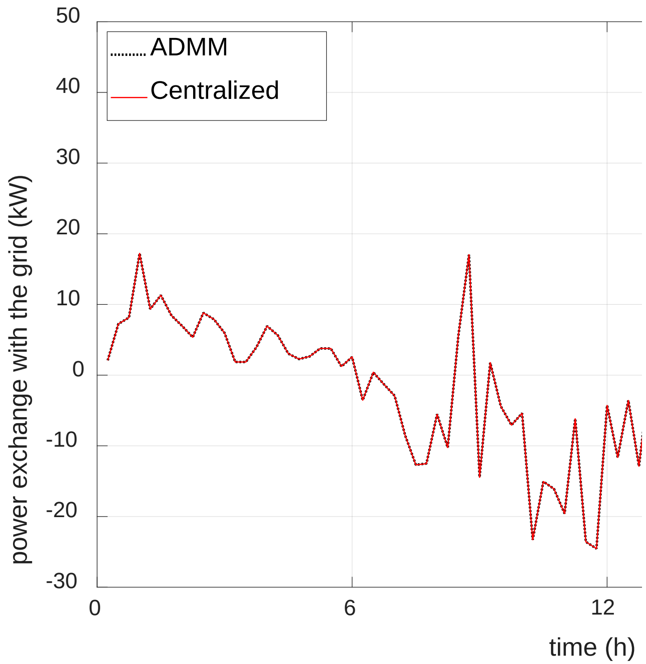


without BES units

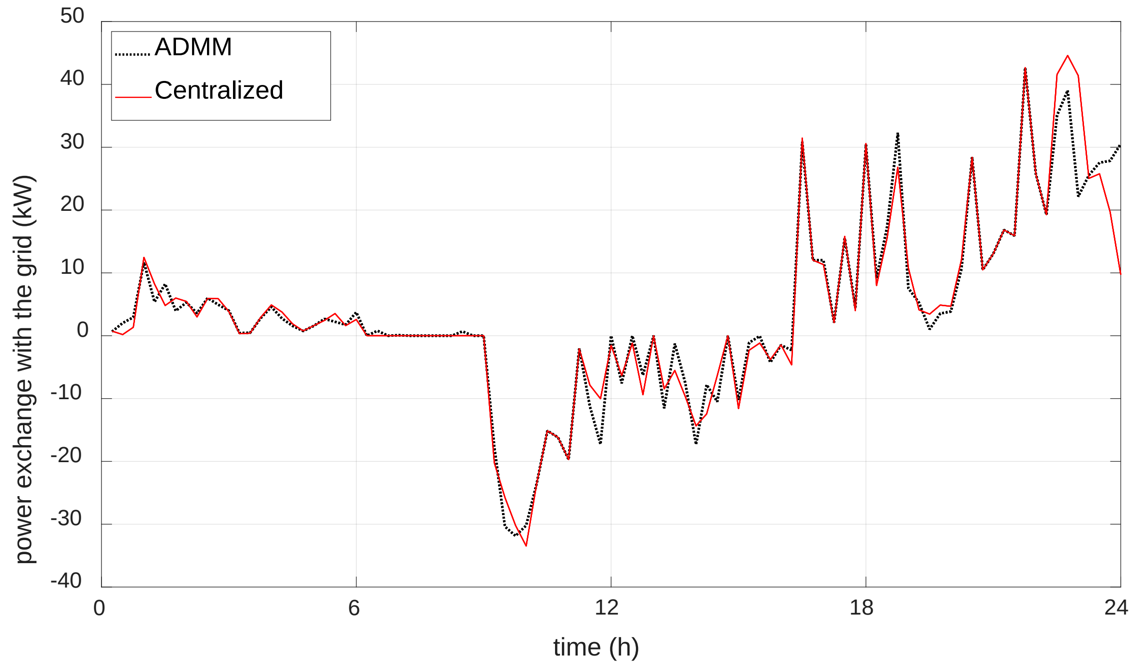


with BES units

Exchange of energy with the grid



without BES units



with BES units

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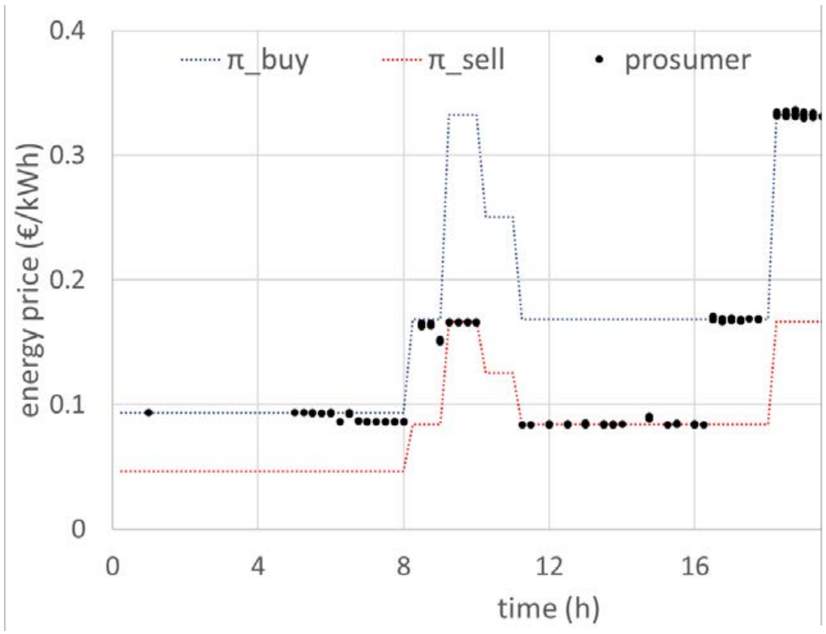
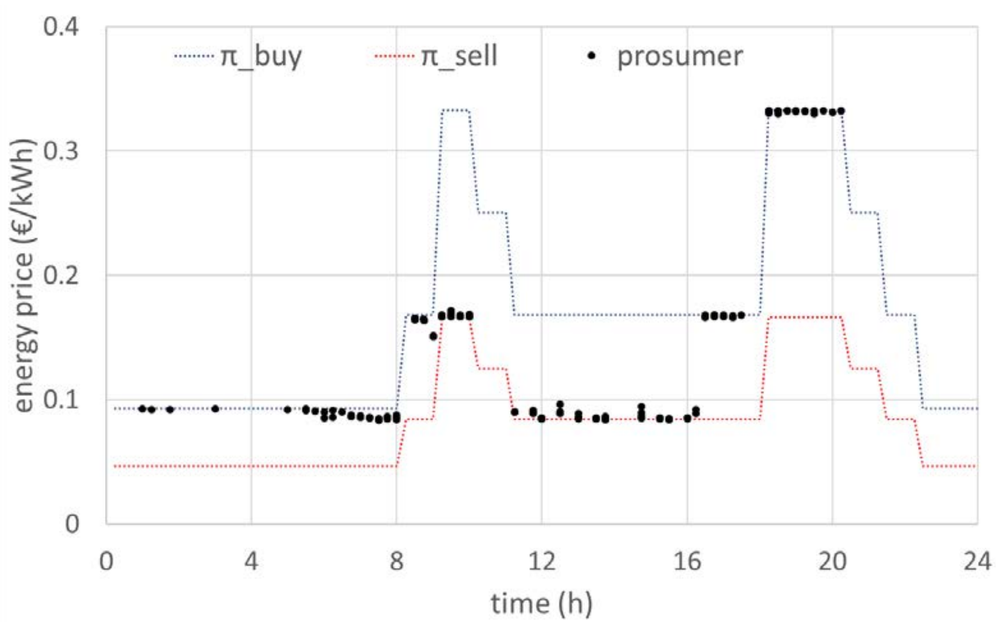
Price calculation

with BES units



centralized model



ADMM procedure

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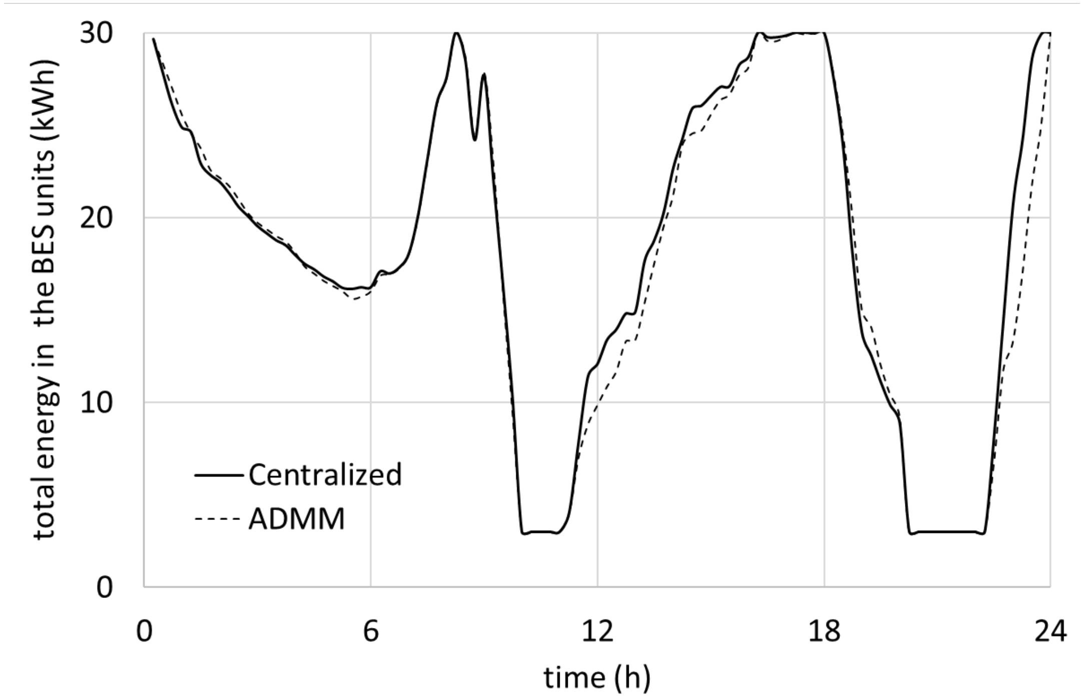
Energy in the battery energy storage



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OF and power loss

without BES units

	OF (€)	Losses (kWh)
Centralized	27.19	3.62
ADMM	27.18	3.63

with BES units

	OF (€)	Losses (kWh)
Centralized	18.06	3.41
ADMM	18.06	3.44

Advantages for the prosumers

Energy Procurement Cost in € (negative values indicate revenues) for each prosumer in Feeder 1 and 2 **without BES units**

prosumer	1	2	3	4	5
Centralized	6.82	0.87	2.09	-0.43	0.22
ADMM	6.83	0.89	2.08	-0.44	0.19
without internal exchanges	7.36	1.03	2.16	-0.20	0.37

prosumer	6	7	8	9	10
Centralized	-0.08	15.90	2.17	0.10	-0.65
ADMM	-0.08	15.95	2.17	0.09	-0.66
without internal exchanges	-0.16	17.45	2.40	0.18	-0.22

The total energy procurement cost of the LEC is around 11% less than the corresponding cost without internal transaction among the prosumers.

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Advantages for the prosumers

Energy Procurement Cost in € (negative values indicate revenues) for each prosumer in Feeder 1 and 2 with BES units

prosumer	1	2	3	4	5
Centralized	5.25	0.09	0.98	-0.97	-0.63
ADMM	5.25	0.10	0.99	-0.96	-0.61
without internal exchanges	5.47	0.29	1.12	-0.79	-0.43

prosumer	6	7	8	9	10
Centralized	-0.21	14.86	1.66	-0.45	-2.23
ADMM	-0.20	14.85	1.66	-0.44	-2.24
without internal exchanges	-0.14	16.47	1.74	-0.29	-1.63

The total energy procurement cost of the LEC is around 16% less than the corresponding cost without internal transaction among the prosumers.

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LEC – Conclusions of the study – recently accepted for publication on IEEE Trans on PWRS

Day-ahead Scheduling of a Local Energy Community: An Alternating Direction Method of Multipliers Approach

Stefano Lilla, *Student Member, IEEE*, Camilo Orozco, *Student Member, IEEE*, A. Borghetti, *Fellow, IEEE*, F. Napolitano, *Senior Member, IEEE*, F. Tossani, *Member, IEEE*

In the centralized procedure, the prices are the Lagrangian multipliers of the constraints (2). In the distributed procedure, the prices are updated at each iteration to reduce the mismatch between the energy sold by each prosumer *i* and the energy bought by the other prosumers from prosumer *i*. Notwithstanding these differences, the profiles of the prices are similar for both the cases with and without BES units.

For each prosumer, the results **confirm the cost reduction or revenue increase in the LEC compared to the case in which it can only transact with an external energy provider**.

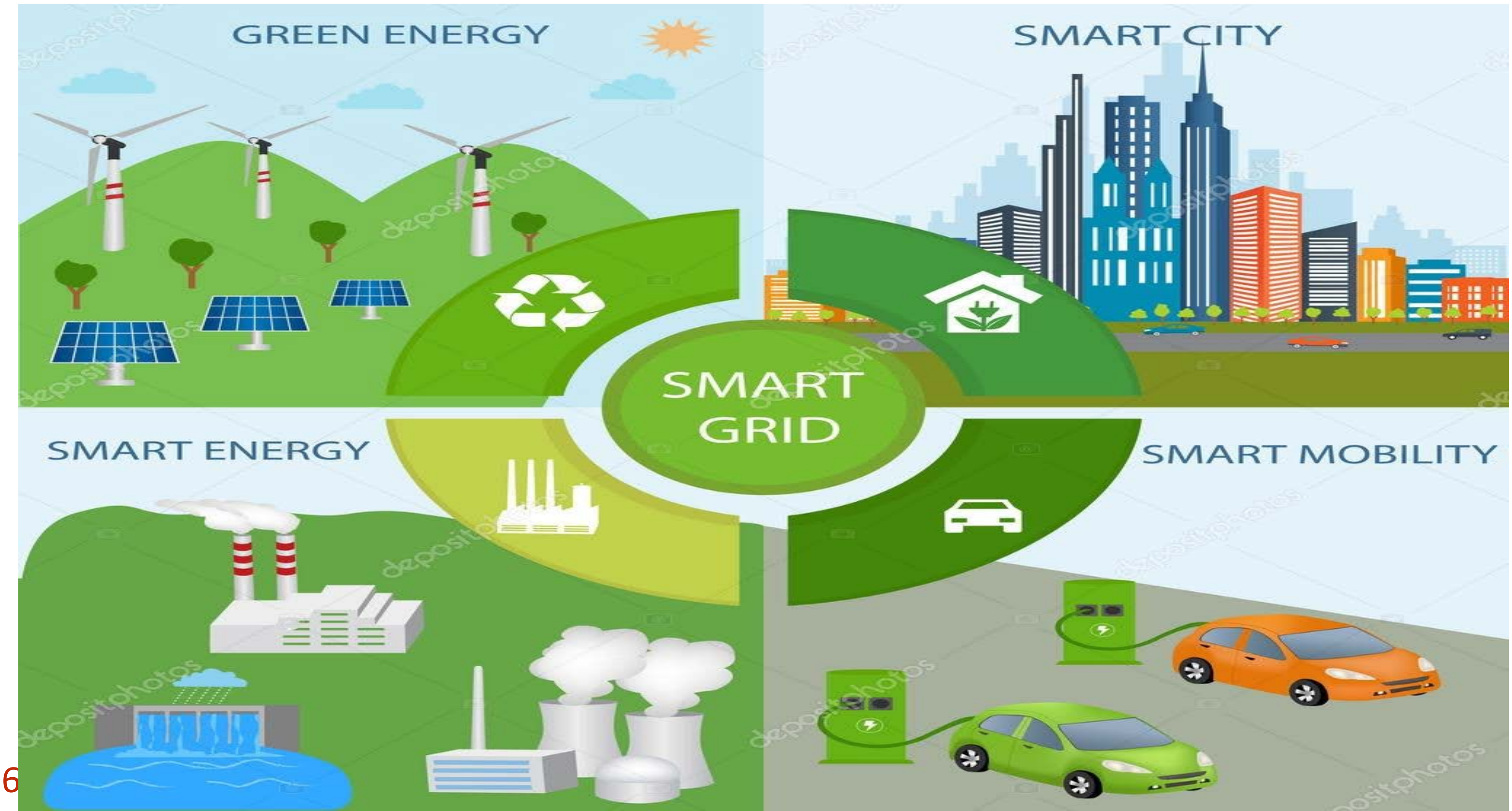
Day-ahead scheduling of a local energy community

The application of the ADMM procedure in a LEC is characterized by **novel aspects** with respect to the approaches already presented in the literature:

- presence of various **energy storage systems**,
- inclusion of the **power losses** of the local network and their allocation to each transaction
- **reduction of the information that each prosumer must share with the other prosumers or with a coordinator**

A centralized approach, in which a control unit performs the entire optimization → prosumers communicate all the details of the equipment features as well as the load and production forecasts.
ADMM-based distributed procedure → reduces the amount of shared information: the only information that every prosumer must communicate is the profile of the exchanges with the external grid and with the other prosumers for updating the multipliers at each iteration and for the evaluation of the transaction efficiencies.

4
Concluding Remarks



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GECO – Green Energy Community

Kick-off Meeting

FICO/CAAB, Bologna, 09/05/2019

eit Climate-KIC

ENEA agenzia per l'energia e lo sviluppo sostenibile

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5

For further reading

The need of multidisciplinary approaches and engineering tools for the development and implementation of the smart city paradigm. Andrisano, O.; Bartolini, I.; Bellavista, P.; Boeri, A.; Bononi, L.; Borghetti, A.; Brath, A.; Corazza, G., E.; Corradi, A.; de Miranda, S.; Fava, F.; Foschini, L.; Leoni, G.; Longo, D.; Milano, M.; Napolitano, F.; Nucci, C., A.; Pasolini, G.; Patella, M.; Salmon Cinotti, T.; Tarchi, D.; Ubertini, F.; and Vigo, D. Proceedings of the IEEE, 106(4): 738-760. 4 2018.

Electric power engineering education: cultivating the talent in the United Kingdom and italy to build the low-carbon economy of the future. Chicco, G.; Crossley, P.; and Nucci, C., A. IEEE Power and Energy Magazine, 16: 53-63. 2018.

Mixed integer programming model for the operation of an experimental low-voltage network. Lilla, S.; Borghetti, A.; Napolitano, F.; Tossani, F.; Pavanello, D.; Gabioud, D.; Maret, Y.; and Nucci, C., A. In 2017 IEEE Manchester PowerTech, pages 1\textendash6, 6 2017. IEEE

Comparison between multistage stochastic optimization programming and Monte Carlo simulations for the operation of local energy systems. C. Orozco, A. Borghetti, S. Lilla, G. Pulazza, and F. Tossani in IEEE International Conference on Environment and Electrical Engineering (EEEIC), 2018.

Robust optimization for virtual power plants. De Filippo, A.; Lombardi, M.; Milano, M.; and Borghetti, A. In Advances in Artificial Intelligence AI*IA 2017 , Lecture Notes in Computer Science, vol 10640., pages 17-30, 11 2017. Springer, Cham

An ADMM Approach for day-ahead scheduling of a local energy community. C. Orozco, A. Borghetti, S. Lilla, F. Napolitano, F. Tossani, IEEE PowerTech Conference, Milan, Italy, 2019.

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Day-ahead Scheduling of a Local Energy Community: An Alternating Direction Method of Multipliers Approach, S. Lilla, C. Orozco, A. Borghetti, F. Napolitano, F. Tossani, accepted for publication on IEEE Trans on PWRS, 2019.

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