S3PEnergy: Smart Mediterraneo

Best practices, innovation and pilot projects in smart grid development in the Mediterranean region

Best practices from the Italian case: the RES NOVAE project

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Outline

- **Introduction**
- The Urban Control Center
- Research Contribution and Position WRT Literature
- The UCC performance evaluation tools
- The UCC strategic decision support tools
- Case Study
- Conclusions

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Introduction

We worked within the following project (new things in IoT)

RES NOVAE

Reti Edifici Strade Nuovi Obiettivi Virtuosi per l'Ambiente e l'Energia

La nuova era delle città.

SMART CITIES

AND COMMUNITIES

AND SOCIAL INNOVATION

Municipalities of Bari and Cosenza in Southern Italy are finding ways to use ICTs and make life easier for their residents and visitors.

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Future Energy Networks

- Cities are becoming too big and too crowded.
- About half of the world's population now resides in cities and that proportion is expected to grow.
- The WHO (*) predicts that 60 % of the world's population will live in cities by 2030, and 70 % by 2050.
- Todays' energy infrastructures are approaching their expected life.
- Over 60 % of energy demand is concentrated in Cities (**).
- Around 75 % of EU population lives in urban areas responsible for 80 % of energy consumptions and global warming gas emissions (***).

(*) World Health Organization
(**) International Energy Agency, 2012
(***) Antonio Tajani, vice-President of the European Commission, Responsible for Industry and Entrepreneurship, 2012

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The Partners

GRANDI IMPRESE

Enel Distribuzione

IBM

GE Transportation

PICCOLE E MEDIE IMPRESE

ELETTRONICA GROUP

ASPERIENCE sviluppo, progetti e ricerca

UNIVERSITÀ E CENTRI DI RICERCA

UNIVERSITÀ DELLA CALABRIA

Consiglio Nazionale delle Ricerche

ENEA

Among the partners there is IBM.

Many cities received grants from IBM's Smarter Cities Challenge, the company's largest philanthropic initiative.

IBM is working closely with city leaders, giving useful recommendations on how to make cities more efficient.

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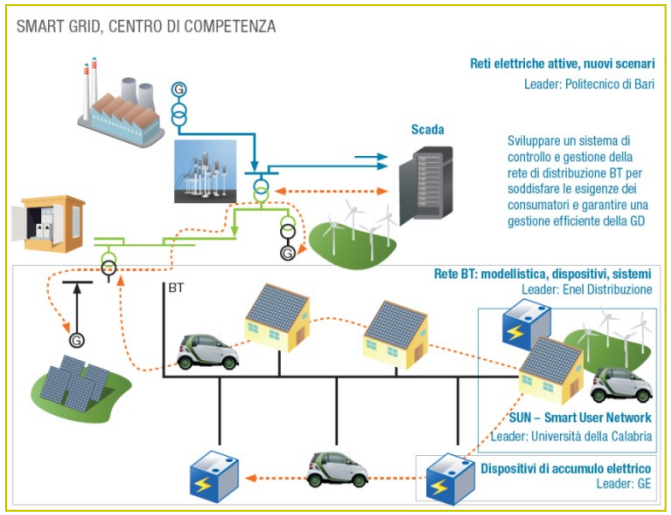
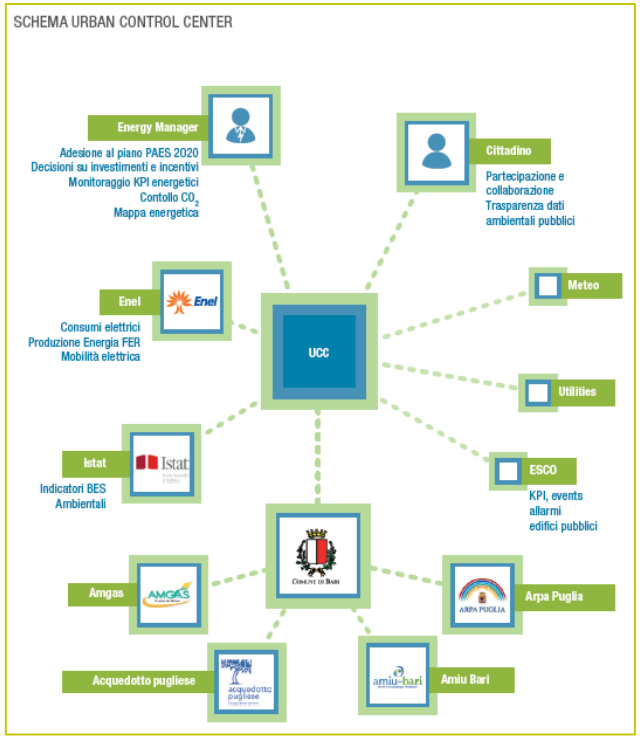
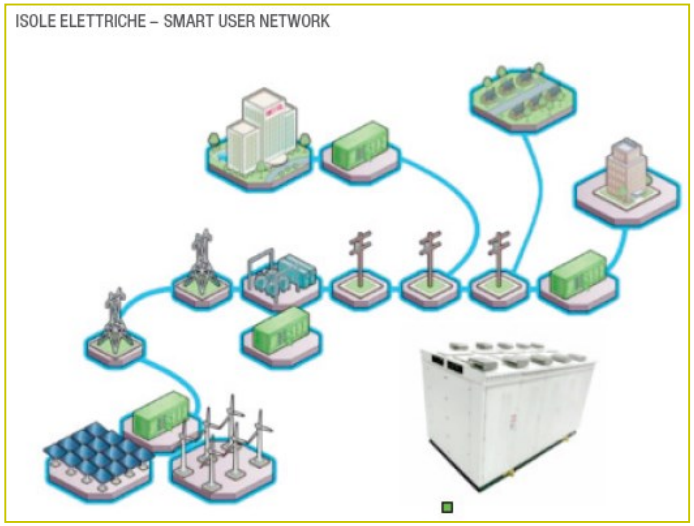
Three goals

Smart Cities Competency Center, a research center where will be monitored, studied and analyzed the new operating scenarios of low-voltage network.



Urban Control Center Data concentrators where information from distributed sensors and home/building monitoring systems will convey in order to supply information about resources and energy consumption.





Smart User Network electrical island, which integrates sources of renewable energy production and storage systems.

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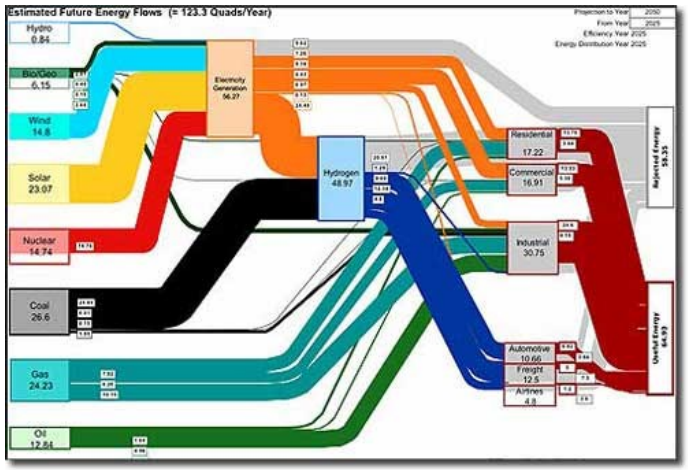
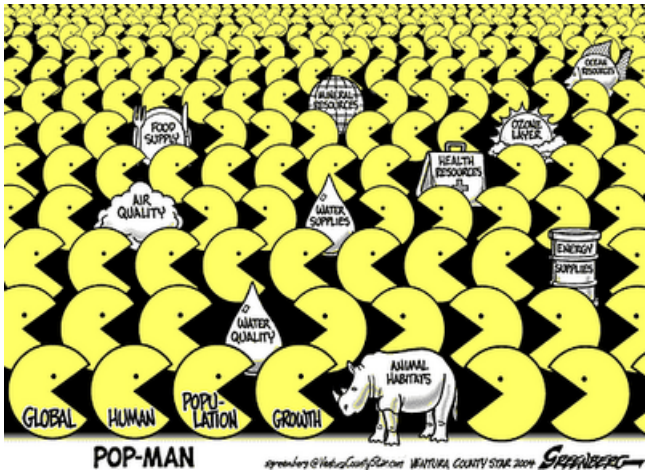
Achievements of the project

- Promoting the use of energy from renewable sources;
- Streamlining flows and energy consumption;
- Energy efficiency and development of new products and services for the citizen;
- Awareness on energy consumption;
- Creation of a modern national system of control with innovative features and management of energy resources available to the Public Administration;
- Raising awareness on environmental issues;
- Participation in the development path of the Smart City;
- Reduction of CO_2 emissions;
- Activation of new scientific and technological competencies through training courses.





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- **The Urban Control Center**
- Research Contribution and Position WRT Literature
- The UCC performance evaluation tools
- The UCC strategic decision support tools
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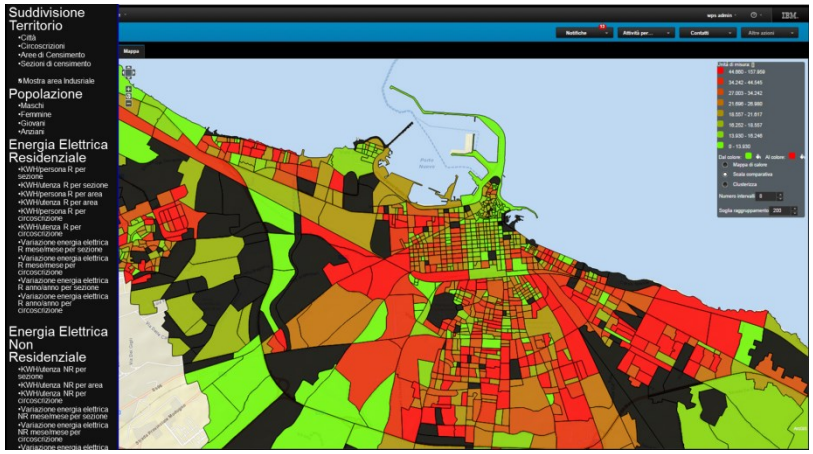
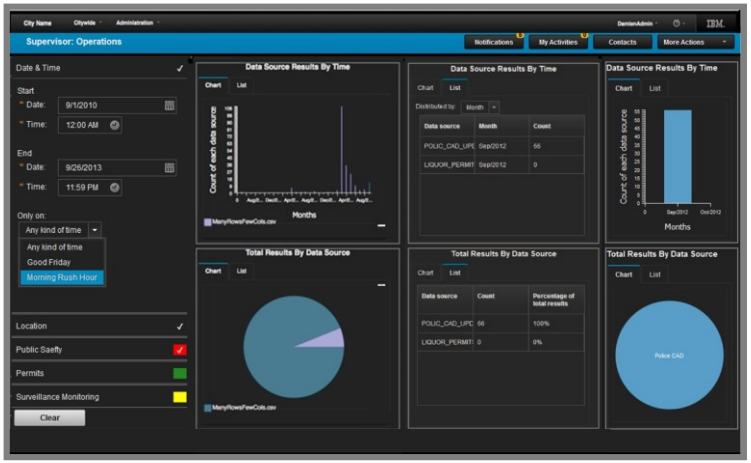
The Urban Control Center

- **The presentation remainder is focused on the Urban Control Center**
- **Objective**
  - **Presenting the innovative design of a Decision Support System (DSS) that helps the Public Administration (PA) of a smart city take decisions on energy efficiency: the so-called Urban Control Center (UCC).**





Excerpts from "Urban Control Center" human interface prototype

The UCC is being developed and prototyped by *IBM Rome Solution Lab* in collaboration with *Politecnico of Bari* for the Municipality of Bari (Italy)

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The Urban Control Center

- **What it is**
  - **Platform for monitoring/managing urban dynamics**

- **What it is for**
  - **ICT tool supporting energy governance for public administration**
  - **Enabling means for communication to citizens and participation of communities**

- **What are its features**
  - **Report and analysis of urban performances (current status, history, predicted state)**
  - **Urban modeling and business intelligence tools for strategic decision making and planning**
  - **Collaboration tool for citizens active involvement**

UCC overview

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The Urban Control Center

- **Based on the PA objectives, the energy manager determines the city policies and KPIs target values, defining a list of potential action plans towards the selected targets**
- **The UCC is a means for city monitoring and management**
  - **measuring and monitoring the smart city performance**
  - **Implementing strategic action programs as a result of decision making /planning**

1. Indicators dashboard

2. decision making tools

UCC

smart city

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Research Contribution and Position WRT Literature

- **Several ICT-based planning, management, and policy tools experienced worldwide**
- **Research efforts spent for DSS for energy use at an urban level:**
  - most works address the problem of city monitoring/management from the perspective of a single urban sector (e.g. buildings), or for specific case studies
  - minor efforts in the related literature to propose decision tools determining the energy governance strategy of a city as a whole (e.g., considering public buildings, street lighting, public transportation, etc.)
- **A city is a complex system :**
  - Urban elements are interrelated
  - A smart city objective is properly integrating and optimizing the set of its interacting and interdependent systems
- **The progress of this approach with respect to the cited literature:**
  1. the proposed DSS is effective in supporting both the PA in determining optimal energy government strategies, considering in an integrated way multiple urban systems.
  2. the strategic decision model is multi-criteria and hierarchical, addressing different urban sectors with an integrated, structured, and transparent planning

Identified literature gap in definition of an *integrated* DSS for smart city energy management

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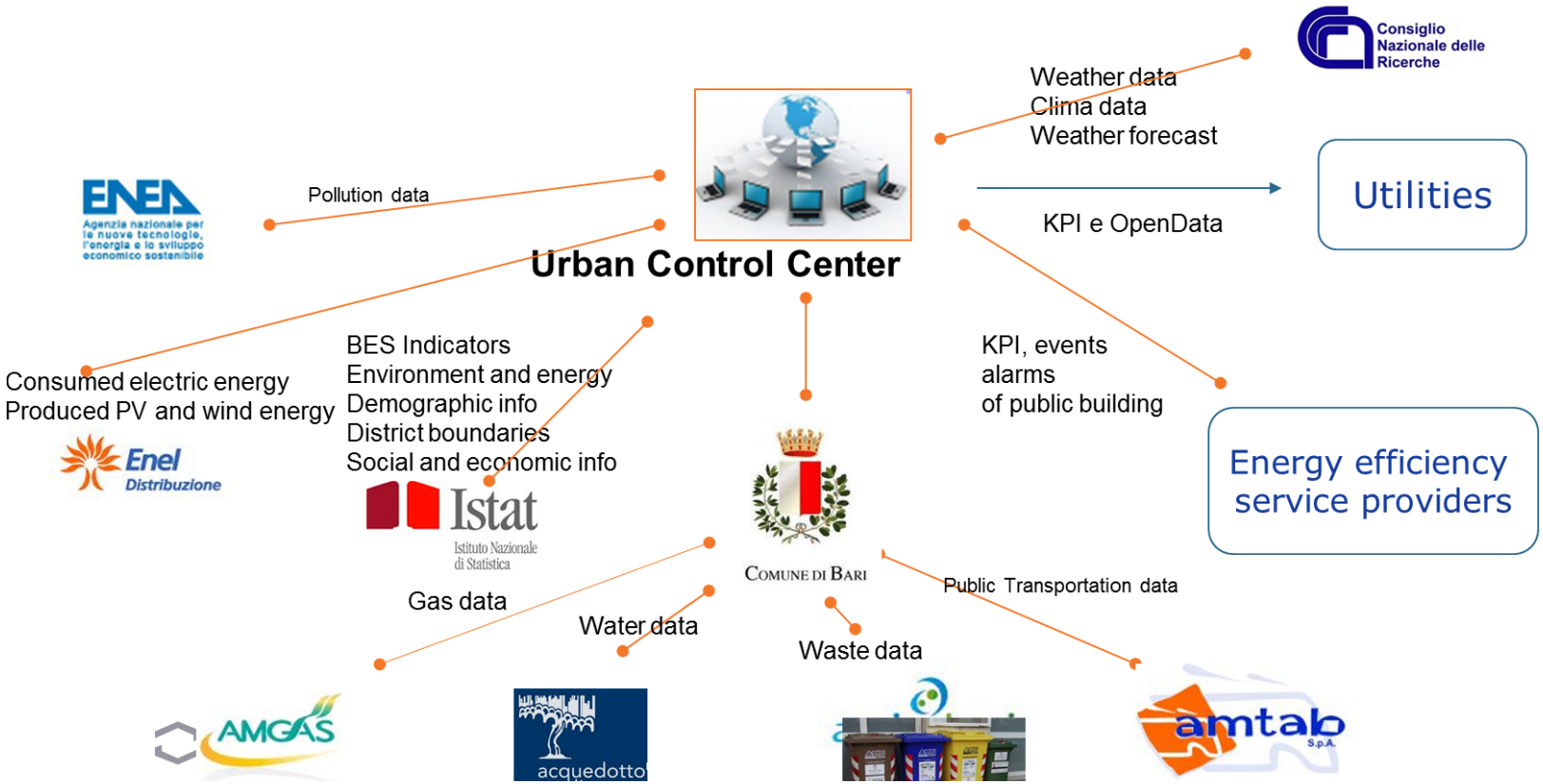
The UCC performance evaluation tools

- **Data collection and management**
  - **data are automatically collected, aggregated and elaborated from a variety of sources**
  - **plug in connectors enable the platform to access data using different protocols**



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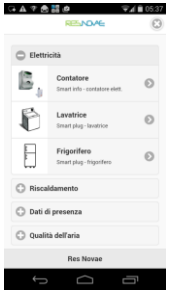
The UCC performance evaluation tools

- **Data reporting and exporting**
  - **A set of data reporting tools allows obtaining tables and charts filtered on date, time, location, and other categories**
  - **Data may be navigated on all dimensions, enabling data drilldown, slicing and dicing**
  - **Many built-in reports are provided by default to help the decision maker identify anomalies against benchmarks/target values and trends that require intervention.**



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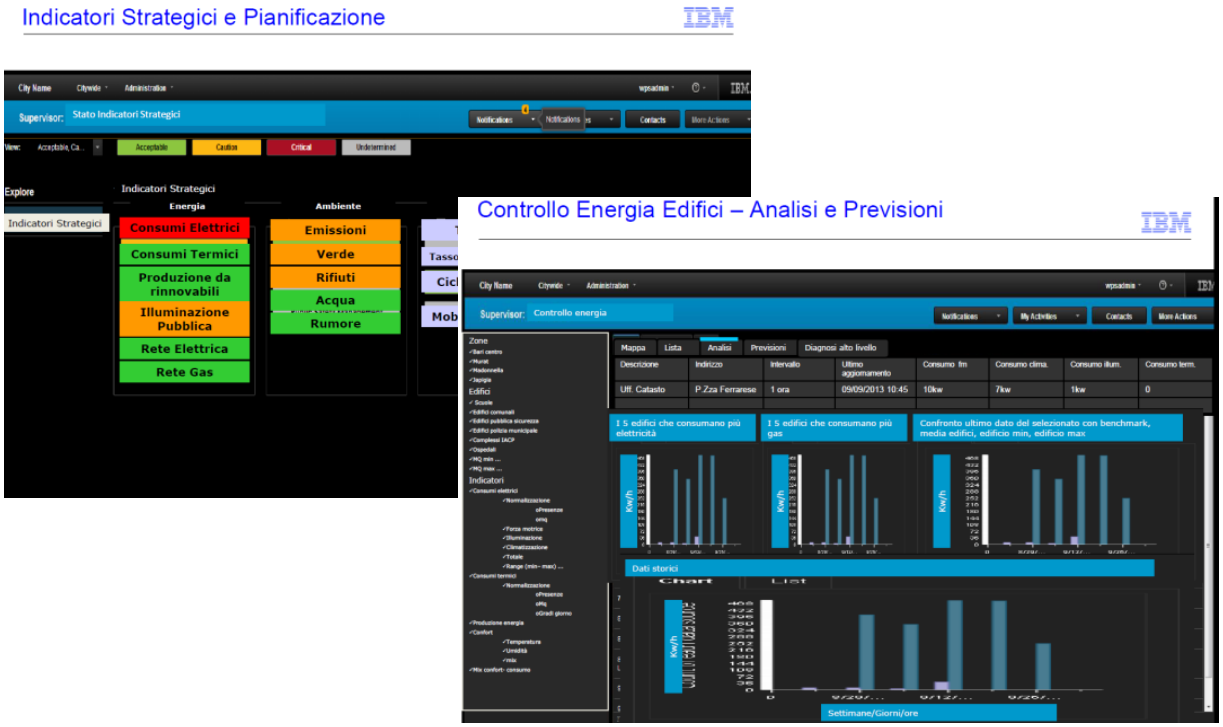
The UCC performance evaluation tools

- **KPI dashboard**
  - **KPIs are calculated using measured data and an aggregate function (e.g., average, maximum, minimum, summation, number of occurrences, standard deviation).**
  - **The UCC provides built-in KPIs on different domains such as pollution, energy, well-being, CO_2 level, sustainable energy action plans.**



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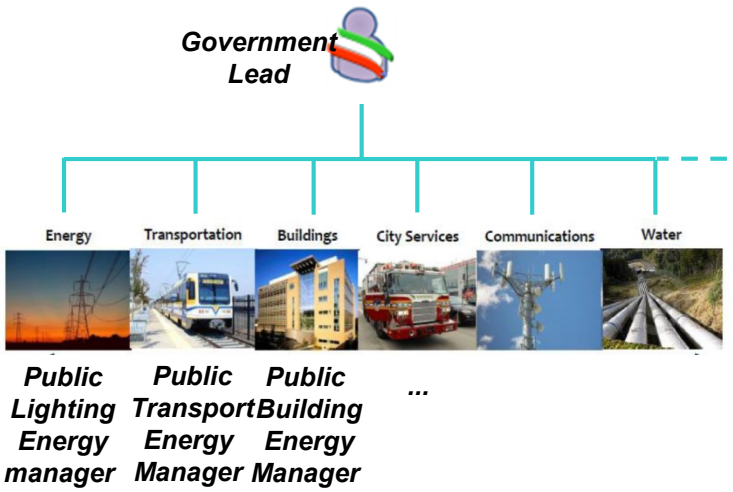
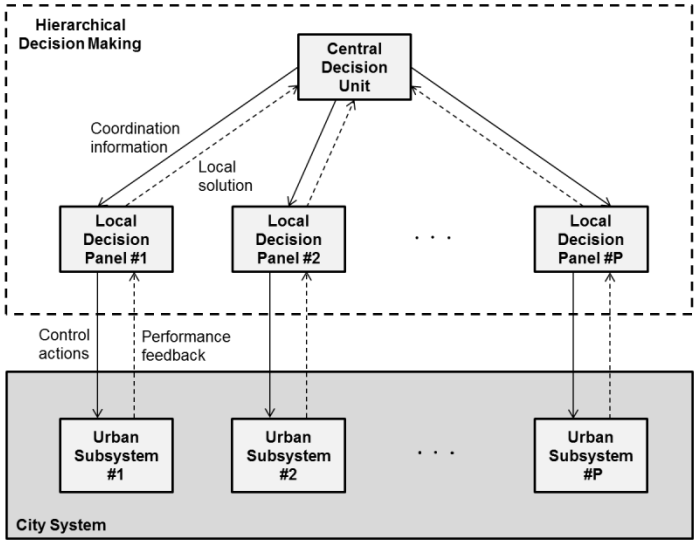
The Urban Control Center Decision Making Architecture

- **An effective smart city strategic programming requires a DSS:**
  - **able to deal with complexity:**
    - Conflicting objectives and requirements
    - Fragmented decision-making
    - Difficult sub-system cross-optimization
- **The proposed approach is hierarchical, based on the systems of systems view: Decision Units (Central Decision Unit and Low Level Decision Unit or Decision Panels)**
- **The UCC decision process employs Bi-Level Programming (BLP)**
  - **Decomposition of decision process in simpler decision sub-processes**
  - **Decision process resolution at single level**
  - **Coordination between several sub-problem solutions**





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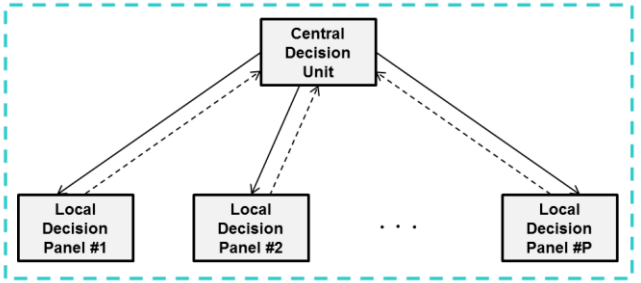
The UCC decision making: Bi-Level Programming

In BLP 4 Optimization problems:

1. a global (initial) optimization problem,
2. a set of local subsystem optimization problems,
3. a central optimization problem
4. a coordination problem.



1. Global optimization problem *

- The central decision maker has to optimize the financial resources allocation to the low level decision panels so as to balance the ratio between the individual panel achievement / objective function and claimed resources (equity distrib. criterion)

$$\max_{\mathbf{Y}} \mathbf{F}(\mathbf{Y},\mathbf{X}^1,\ldots,\mathbf{X}^p,\ldots,\mathbf{X}^P)$$

$$\text{s.t. } \mathbf{G}(\mathbf{Y},\mathbf{X}^1,\ldots,\mathbf{X}^p,\ldots,\mathbf{X}^P) \leq 0$$

Upper level decision problem

where each $\mathbf{X}^p$ $(p=1,\ldots,P)$ solves:

$$\max_{\mathbf{X}^p} \mathbf{f}^p(\mathbf{Y},\mathbf{X}^p)$$

$$\text{s.t. } \mathbf{g}^p(\mathbf{Y},\mathbf{X}^p) \leq 0$$

Lower level decision problem

$\mathbf{Y}$	: Central unit decision variables
$\mathbf{F}$ $\mathbf{G}$	: Central unit objective / constraint functions
$\mathbf{X}^p$	: Local unit decision variables
$\mathbf{f}^p$ $\mathbf{g}^p$	: Local unit objective and constraint functions
$\mathbf{P}$	: Number of local units

* Carli, R.; Dotoli, M., Pellegrino, R., "A Hierarchical Decision Making Strategy for the Energy Management of Smart Cities", *IEEE Transactions on Automation Science and Engineering* – under review, 2nd round

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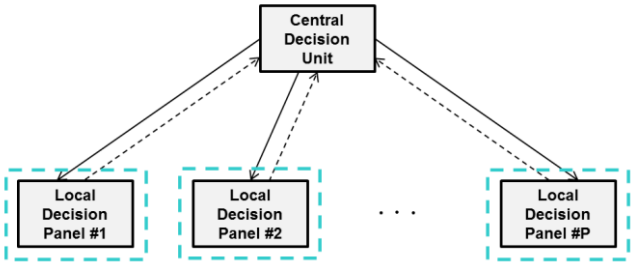
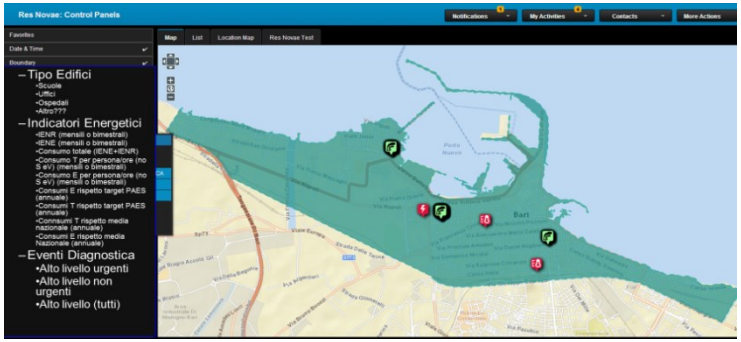
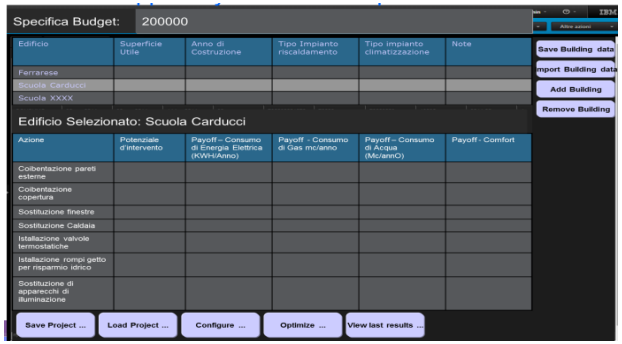
The UCC strategic decision support tools

2. Local optimization problem



- **Each lower level decision unit is devoted to optimizing the energy efficiency of a specific urban energy sector, e.g.:**
  - **the public buildings ***
  - **the city street lighting ****
- **The decision maker of each decision panel has to optimize the available financial resources allocation to the panel subsystems (i.e., buildings, or street lighting subsystems, or public transport subsystems, …) so as to increase the panel energy efficiency by multiple criteria that are in general conflicting**





Excerpts from "Public Buildings" Decision Panel data input

* Carli, R.; Dotoli, M.; Pellegrino, R.; Ranieri, L., «A decision making technique to optimize a building stock energy efficiency», *IEEE Transactions on Systems, Man and Cybernetics: Systems*, 2015.
** Carli R., Dotoli M., Pellegrino R., "ICT and optimization for the energy management of smart cities: The street lighting decision panel", IEEE ETFA 2015.

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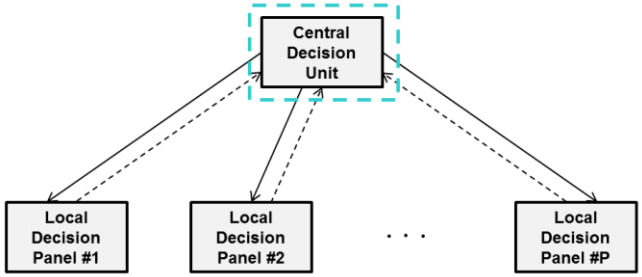
The UCC strategic decision support tools

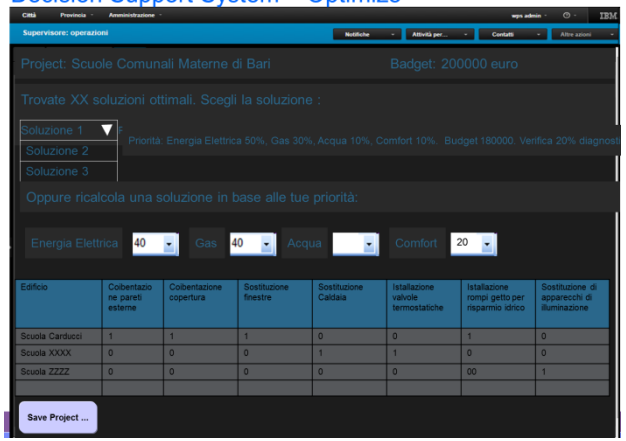
3. Central Unit Decision Making *



- **the central decision maker addresses the goal of distributing the budget while improving the city energy performance by the following criterion:**
  - **allocating the budget to the panels proportionally to their achieved payoffs.**

- **Having defined as panel action plan efficiency metric the ratio between the overall payoff actually achieved by the given panel and the assigned panel budget, the objective is to minimize the relative difference between the efficiency ratios of the panels.**

Decision Support System – Optimize



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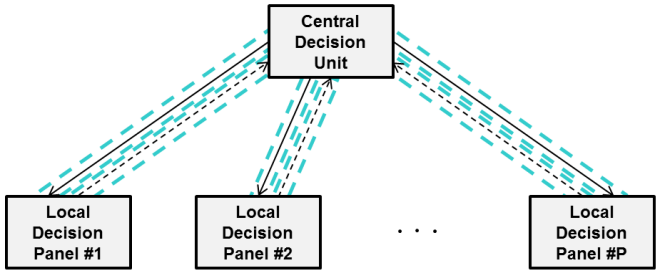
The UCC strategic decision support tools

4. Coordination problem



- The central decision maker and the local decision makers have their own decision variables and objective functions.
- The central unit can only influence the reactions of local units by means of his decision variables.
- The decision making structure requires a coordination, i.e., organizing joint actions among decision units in acting according to their own goals and producing the overall systems goal.

- **Resolution of Bi-level programming problem ***
  - The solution of the global optimization model consists in the subsequent resolution of the coordination problem and of the local sub-problems
  - A game theoretic approach is employed
    - The approach deals with sub-problems that could be solved in parallel speeding up the computational process. Furthermore, dealing with low order problem allows overcoming scalability issue (in case of a large number of decision panels).

* Carli, R.; Dotoli, M., Pellegrino, R., "A Hierarchical Decision Making Strategy for the Energy Management of Smart Cities", *IEEE Transactions on Automation Science and Engineering* – under review, 2nd round

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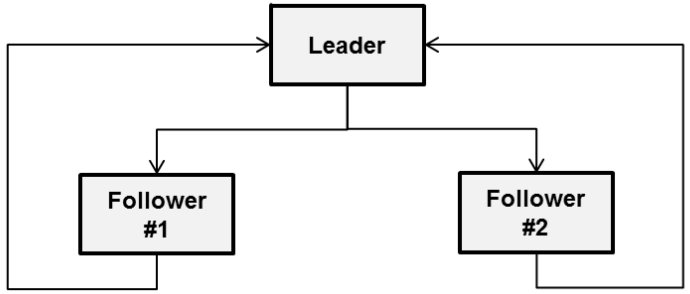
Case Study

- **Application of proposed approach to energy management of Bari (Apulia, Italy), currently engaged in implementing actions targeted at CO_2 reduction and energy efficiency increase**
- **Decision problem statement**
  - **supporting city energy manager in optimally dividing a given budget for energy retrofitting actions planning between P=2 panels, namely:**
    - **the street lighting subsystem**
    - **the public building subsystem**

Typical energy manager decision problem in city energy management

- **Decision making problem modeled as Bi-level Programming**
  - **3 Decision Units (DUs)**
    - **one upper level DU-> central decision maker (the energy manager)**
    - **two lower level DUs -> local decision makers (the facility managers)**



Bi-level Decision system architecture

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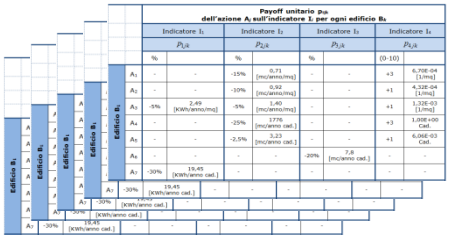
Case Study

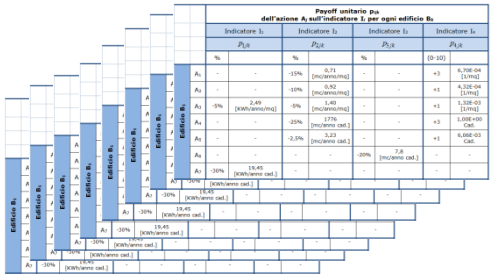
Overall decision making problem

TOTAL BUDGET

PAYOFFS AND COSTS FOR PUBLIC BUILDINGS PORTFOLIO



PAYOFFS AND COSTS FOR STREET LIGHTING SYSTEM



BLDP

OPTIMAL BUDGET ALLOCATION

OPTIMAL RETROFIT PLAN FOR STREET LIGHT. SYS.

Parameter		u_{st}									
Subsystem		1	2	3	4	5	6	7	8	9	10
Type	1	0	0	0	0	0	1	5	52	5	27
	2	27	0	0	0	0	2	18	2	24	18
Parameter		v_s									
Subsystem		1	2	3	4	5	6	7	8	9	10
		0	0	0	0	0	0	0	0	0	0
Parameter		w_s									
Subsystem		1	2	3	4	5	6	7	8	9	10
		1	1	1	1	1	1	1	1	1	1

OPTIMAL RETROFIT PLAN FOR PUBLIC BUILDINGS

		Action						
		A_1^{pb}	A_2^{pb}	A_3^{pb}	A_4^{pb}	A_5^{pb}	A_6^{pb}	A_7^{pb}
Building	B_1	0	0	0	1	1	1	1
	B_2	0	0	1	1	1	1	1
	B_3	0	1	0	1	1	1	1
	B_4	0	0	1	1	1	1	1
	B_5	0	0	1	1	1	1	1

- Replacing half the lamps, dimming of all lamps.
- Roof thermal insul. B_2, new windows B_2, B_4, B_5.
- All buildings: new boilers, thermostatic radiator valves, water tap aerators, high efficiency lamps.

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Conclusions

Contribution

- **Definition of an innovative Decision Support System for the smart city management, the UCC. The UCC:**
  - **supports the public administration and citizens in the city energy governance;**
  - **uses a hierarchical multi-criteria decision process that lets the energy manager govern the city energy system as a whole while addressing different urban sectors with an integrated, structured, and transparent planning;**
  - **Provides the city energy manager decision panels with business intelligence tools for strategic decision making and planning of urban sectors**

Future Research

- **Developing the decision making model of other urban energy subsystems, e.g., the urban mobility panel**
- **investigating scalability and convergence of decision-making process**
- **including goal programming in the decision making problem to introduce minimum targets for specific criteria**

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S3PEnergy: Smart Mediterraneo

Best practices, innovation and pilot projects in smart grid development in the Mediterranean region

Best practices from the Italian case: the RES NOVAE project

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