European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

**2nd International Workshop *EuNetAir* on**

***New Sensing Technologies for Indoor and Outdoor Air Quality Control***

**ENEA - Brindisi Research Center, Brindisi, Italy, 25 - 26 March 2014**

# The Urban Control Center: KPIs for Decisions Support of Smart Cities in Italy

**Mariagrazia DOTOLI , Raffaele CARLI**

Dept. of Electrical and Information Engineering

Polytechnics of Bari, Bari, Italy

{mariagrazia.dotoli, raffaele.carli}@poliba.it

COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract

# Outline

- **Introduction**
- **Urban Control Center**
- **Smart city performance indicators**
- **Decision support for smart city planning/programming**
- **Case study**
- **Conclusions**

# Introduction (1/3)

- The presentation was prepared:
  - in the framework of project «RES NOVAE»

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

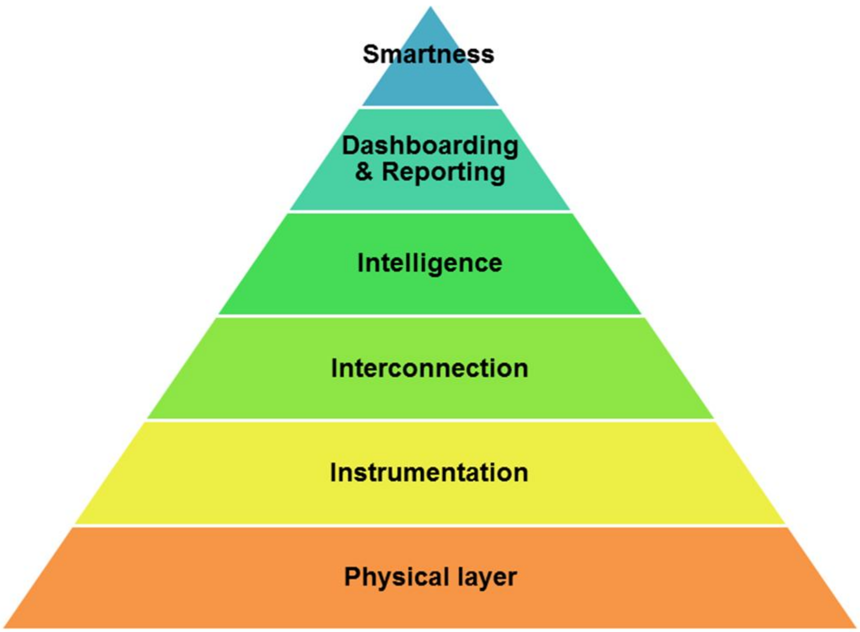
supported by the Italian University and Research Ministry "Smart Cities Communities and Social Innovation" research and competitiveness program

  - to describe the research activities carried out by the "Decision and Control Laboratory" group of the Department of Electrical and Information Engineering of the Polytechnic of Bari, Italy.

# Introduction (2/3)

- **Smart city concept peculiarities**
  - **Increase in the frequency of use of the term "smart city"**
  - **No clear and consistent understanding of the concept among practitioners and academia**

- **Core workspaces in smart city development**



# Introduction (3/3)

- City smartness...
  - established demand in identifying strategic plans and performing associated actions to make cities smarter
  - recognized cruciality to optimally and intelligently monitor and manage emerging smart cities
- ... requires at first «smart» governance …
  - continuously evolving  objectives of smart city strategic planning and programming


- … hence this motivates the effort in designing and developing the so-called Urban Control Center

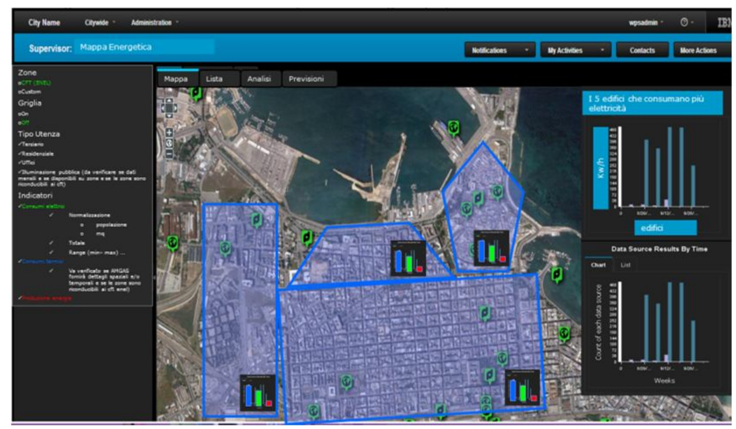
# Outline

- Introduction
- **Urban Control Center**
- Smart city performance indicators
- Decision support for smart city planning/programming
- Case study
- Conclusions

# Urban Control Center (1/3)

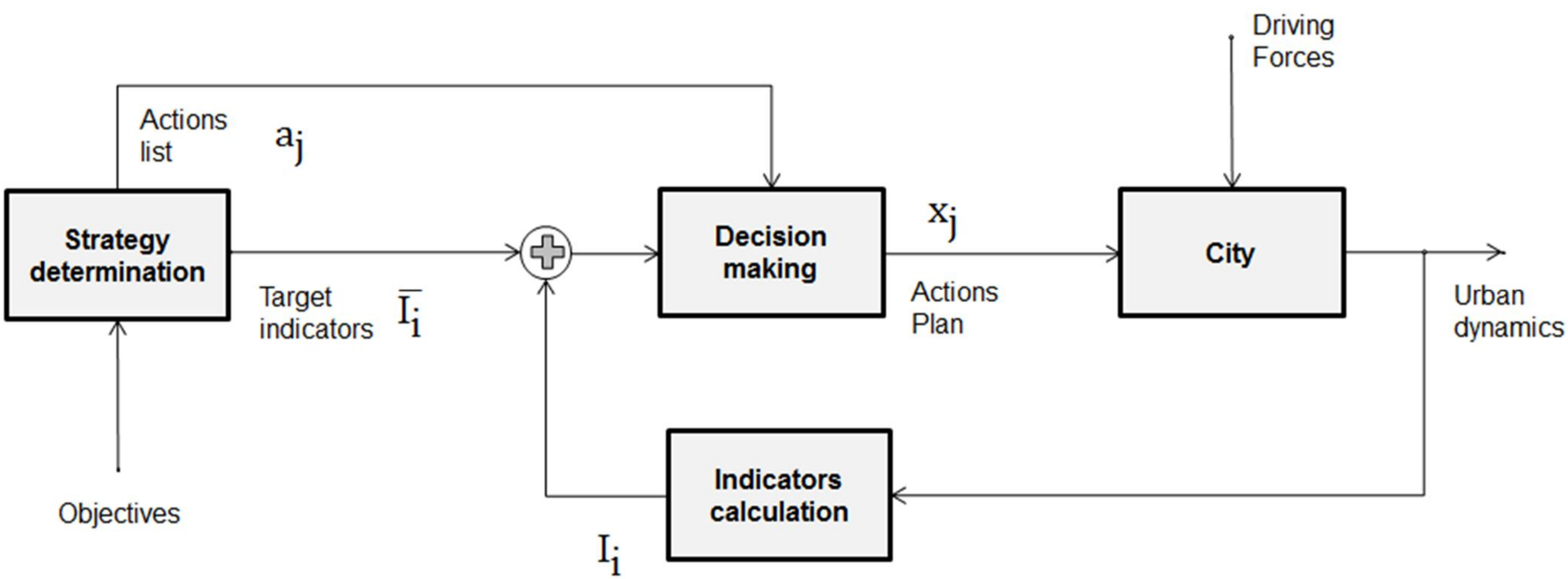
- **Objectives**
  - **Platform for monitoring and managing urban dynamics**
  - **Governance supporting tool for public administration**
  - **Enabling factors for communication to citizens and participation of communities**


- **Functionalities**
  - **Monitoring and analysis of urban performances (current status, history, predicted state)**
  - **Indicators dashboard**
  - **Urban modeling and business intelligence for strategic decision making and planning**
  - **Collaboration tool for citizens active involvement**



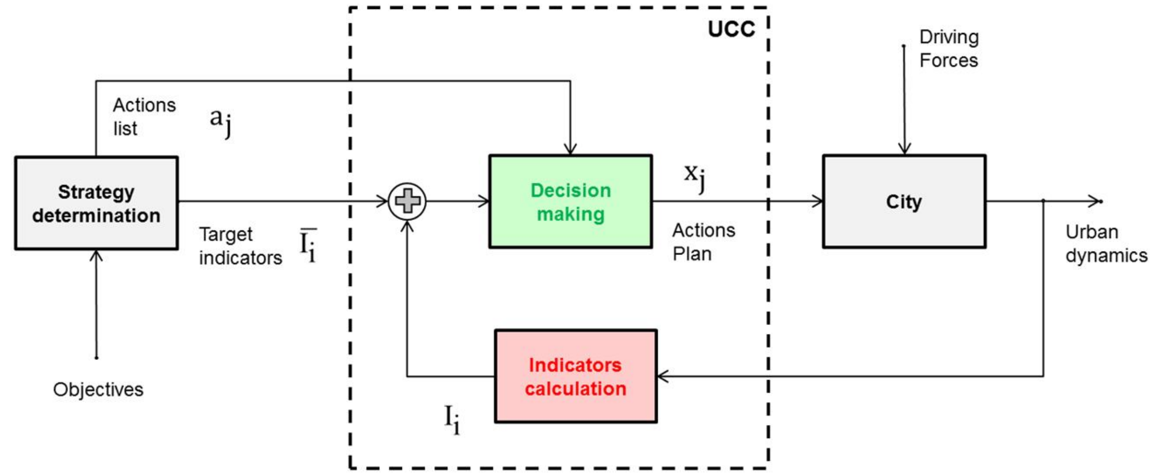
# Urban Control Center (2/3)

- **The UCC allows:**
  - **measure and monitor smart city performances**
  - **define strategic action programs as result of decision making and planning**



# Urban Control Center (3/3)

- **Main tools for smart city planning and programming:**




***1. Indicators dashboard***

***2. Decision making tools***

***UCC***

***smart city***

# Outline

- Introduction
- Urban Control Center
- **Smart city performance indicators**
- Decision support for smart city planning/programming
- Case study
- Conclusions

# Smart city performance indicators (1/4)

- Literature review
  - Lack of a set of indicators for measuring the performance of a city that is valid in each context and for each purpose
  - Some studies refer especially to a specific city and as such lack generality
  - Giffinger et al.* were the first to highlight the performance of smart city not only in traditional fields such as smart economy, smart people, smart governance, smart mobility, smart environment, but also in the field of the life quality of the citizens (smart living)

    * Giffinger, R., Fertner, C., Kramar, H., Kalasek, R., Pichler-Milanović, N., & Meijers, E. (2007) "Smart Cities: Ranking of European Medium-Sized Cities". Vienna, Austria: Centre of Regional Science (SRF), Vienna University of Technology. Available from: http://www.smartcities.eu/download/smart_cities_final_report.pdf
  - The few existing models in the related literature for valuing the smartness of a city are mostly based on the recalled model proposed by Giffinger et al.
  - Other recent studies only address the transformation and aggregation of city variables and indicators into a global final index

# Smart city performance indicators (2/4)

## Indicators developed by Giffinger et al.

- the model at a glance:
  - 6 characteristics
  - 31 factors
  - 74 indicators
- excerpt of characteristics and factors:

**SMART ECONOMY (Competitiveness)**

- Innovative spirit
- Entrepreneurship
- Economic image & trademarks
- Productivity
- Flexibility of labour market
- International embeddedness
- *Ability to transform*

**SMART PEOPLE (Social and Human Capital)**

- Level of qualification
- Affinity to life long learning
- Social and ethnic plurality
- Flexibility
- Creativity
- Cosmopolitanism/Open-mindedness
- Participation in public life

**SMART ENVIRONMENT (Natural resources)**

- Attractivity of natural conditions
- Pollution
- Environmental protection
- Sustainable resource management

**SMART GOVERNANCE (Participation)**

- Participation in decision-making
- Public and social services
- Transparent governance
- *Political strategies & perspectives*

**SMART MOBILITY (Transport and ICT)**

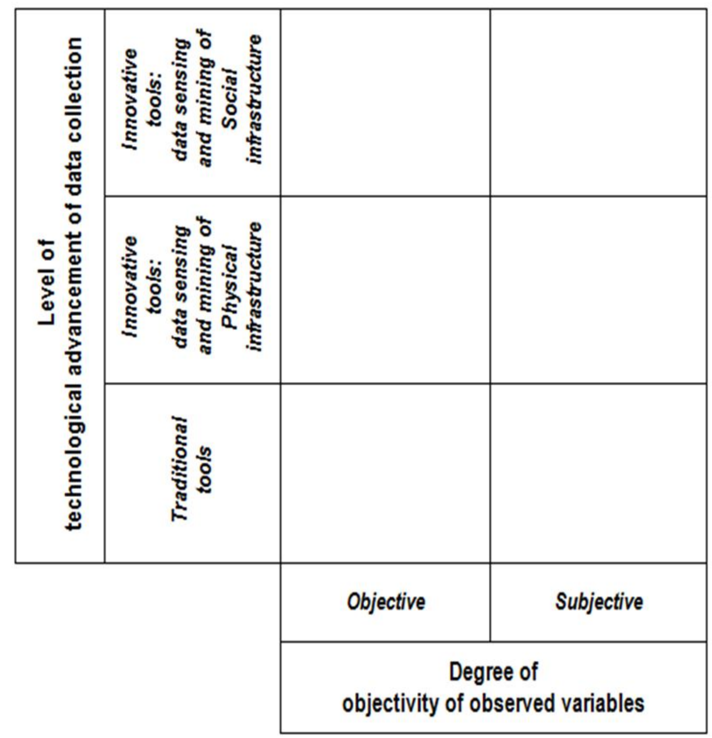
- Local accessibility
- (Inter-)national accessibility
- Availability of ICT-infrastructure
- Sustainable, innovative and safe transport systems

**SMART LIVING (Quality of life)**

- Cultural facilities
- Health conditions
- Individual safety
- Housing quality
- Education facilities
- Touristic attractivity
- Social cohesion

# Smart city performance indicators (3/4)

- Need of supporting tools for designing a significant set of indicators
  - Complexity of measurement of city smartness
  - Strong inter-relation and dependence of urban performances on physical and “social” infrastructure
- Features of city Key Performance Indicators definition
  - Methodological approach to classify indicators in accordance with  different dimensions, such as:
    - the degree of objectivity content of the observed variables / the level of technological advancement of data collection /etc
  - Indicators grouped in a set of single sector panels:
    - Energy, water, methane consumption / Waste / Pollution factors / Transportation and mobility / Land cover and use / Well-being indicators /etc




Framework for two-dimensional indicators classification

# Smart city performance indicators (4/4)

- **Set of indicators proposed in municipality of Bari - in collaboration with URBES project (led by Italian National Institute for Statistics):**
  - **Multi-dimensional classification of potential indicators**
  - **Excerpt of indicator panel about smart mobility**

| Level of technological advancement of data collection | | Objective | Subjective |
|---|---|---|---|
| | *Innovative tools: data sensing and mining of Social infrastructure* | **Smart People:**<br>Active population in no profit<br>**Smart Environment:**<br>Individual efforts on protecting nature | **Smart Economy:**<br>Self-employment rate on low carbon economy<br>**Smart People:**<br>Satisfaction with quality of educational system; Language skills<br>**Smart Governance:**<br>Satisfaction with transparency of bureaucracy<br>**Smart Mobility:**<br>Satisfaction with quality of public transport<br>**Smart Environment:**<br>Opinion on nature protection; Opinion on waste collection<br>**Smart Living:**<br>Satisfaction with personal housing situation |
| | *Innovative tools: data sensing and mining of Physical infrastructure* | **Smart Economy:**<br>Total annual tourist overnight stays<br>**Smart People:**<br>Population qualified at high levels; Percentage of young people on population<br>**Smart Governance:**<br>Number of web visitors per year; Fertility rate<br>**Smart Mobility:**<br>CO2 equivalent production; Particulate matter emission; Use of public transports<br>**Smart Environment:**<br>Use of energy produced by renewable energy sources; Green space share and land use; CO2 equivalent production; Pollution emission from public building; Water purification | **Smart Governance:**<br>Satisfaction with quality of e-governance service |
| | *Traditional tools* | **Smart Economy:**<br>R&D enterprise expenditure; New employment in low carbon economy; University spin-offs per existing companies; GDP per employed person; Employment rate; Activity rate; Finance services per inhabitants; Private consumption per capita<br>**Smart People:**<br>Life-long-learning adults participation; Number of women in managerial positions; Education and Care on population; People working in creative industries (i.e. multimedia, cinema, music, communication); Cultural consumption per capita<br>**Smart Governance:**<br>Private investment mobilised on total investments; Public expenditure on smart programme objectives; E-gov services on total; Digital divide (IT infrastructures); Female city representatives<br>**Smart Mobility:**<br>Use of green vehicles; Use of park and ride stalls<br>**Smart Environment:**<br>Pollution emission private building; Methane consumers; Water consumption; Waste sorting<br>**Smart Living:**<br>Expenditure of the municipal per resident; Poverty rate; Integrated homecare | **Smart Governance:**<br>Political activity of inhabitants<br>**Smart Living:**<br>Cultural & Social participation |
| | | *Objective* | *Subjective* |
| | | **Degree of objectivity of observed variables** | |

| | Indicator Definition | Measure | Unit | Update rate | Collection of data |
|---|---|---|---|---|---|
| Smart Mobility | Use of green vehicle | Percentage of green vehicles on total registered vehicles | - | yearly | Institutional counts |
| | Use of park and ride stalls | Number of parking in park and ride stalls | - | six-monthly | Utilities operator register |
| | CO2 equivalent production | Equivalent $CO_2$ per year | t $CO_2$e / year | monthly | Transportation-related emission estimation model based on vehicle activity metering |
| | Particulate matter emission | Particulate matter level | $\mu g/m^3$ | monthly | Environmental sensing through wireless sensor network |
| | Use of public transports | Passenger trips | - | three-monthly | City officials and transport operators register |
| | Satisfaction with public transport | Rate of satisfaction | - | six-monthly | Reality mining from user generated content |

**Legend:**

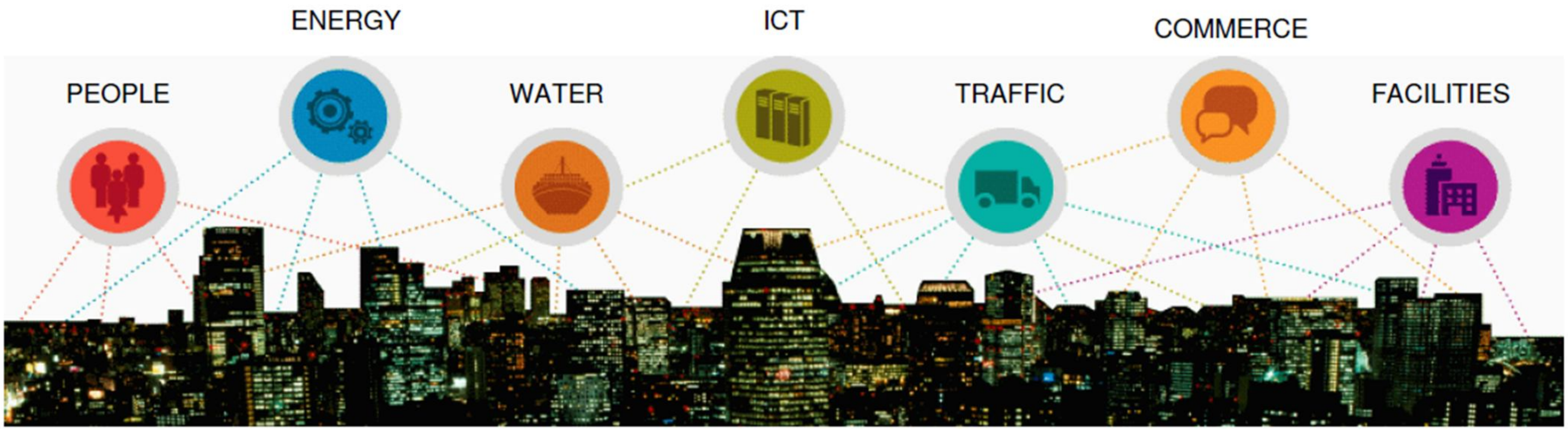
- Blue dashed line: **Objective indicator**
- Red dashed line: **Subjective indicator**
- Peach shading: **Traditional tool**
- Green shading: **Sensing and mining of Physical Infrastructure**
- Blue shading: **Sensing and mining of Social Infrastructure**

# Outline

- Introduction
- Urban Control Center
- Smart city performance indicators
- **Decision support for smart city planning/programming**
- Case study
- Conclusions

# Decision support in smart cities (1/5)

- City is a complex network of systems (*System of Systems*)…



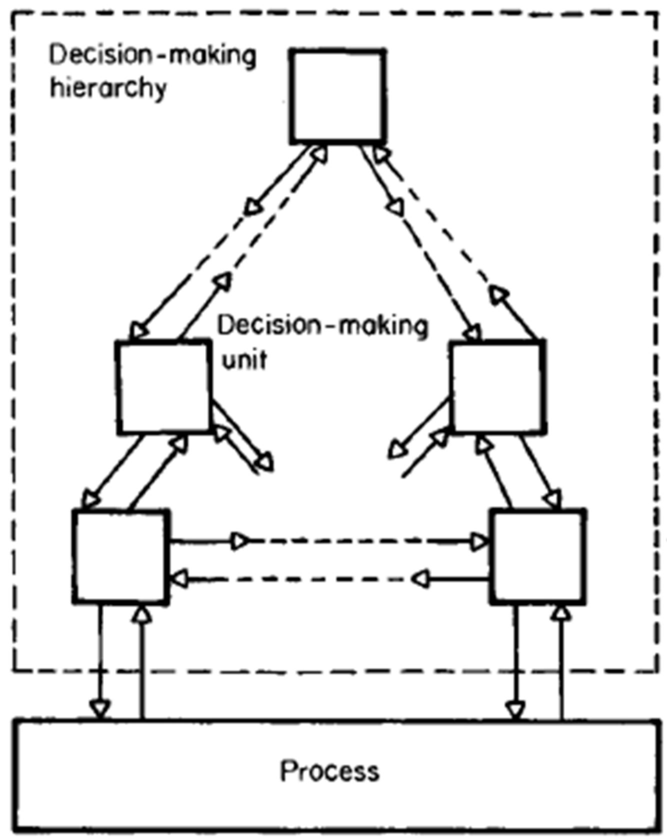

**<u>Definition</u>: A system is a set of interacting or interdependent components forming an integrated whole**

# Decision support in smart cities (2/5)

- ... hence city strategic programming requires a decision support system which is:
  - Intelligent  and articulated
  - Based on modern tools of research operation and business intelligence:
    - Hierarchical decision making (multi-level programming)
    - Integrated decision making techniques: multi-objective optimization, multi-criteria analysis, etc
  - Able to overcome obstacles due to context complexity, such as:
    - Conflicting objectives and requirements
    - Fragmented decision-making
    - Difficult sub-system cross-optimization

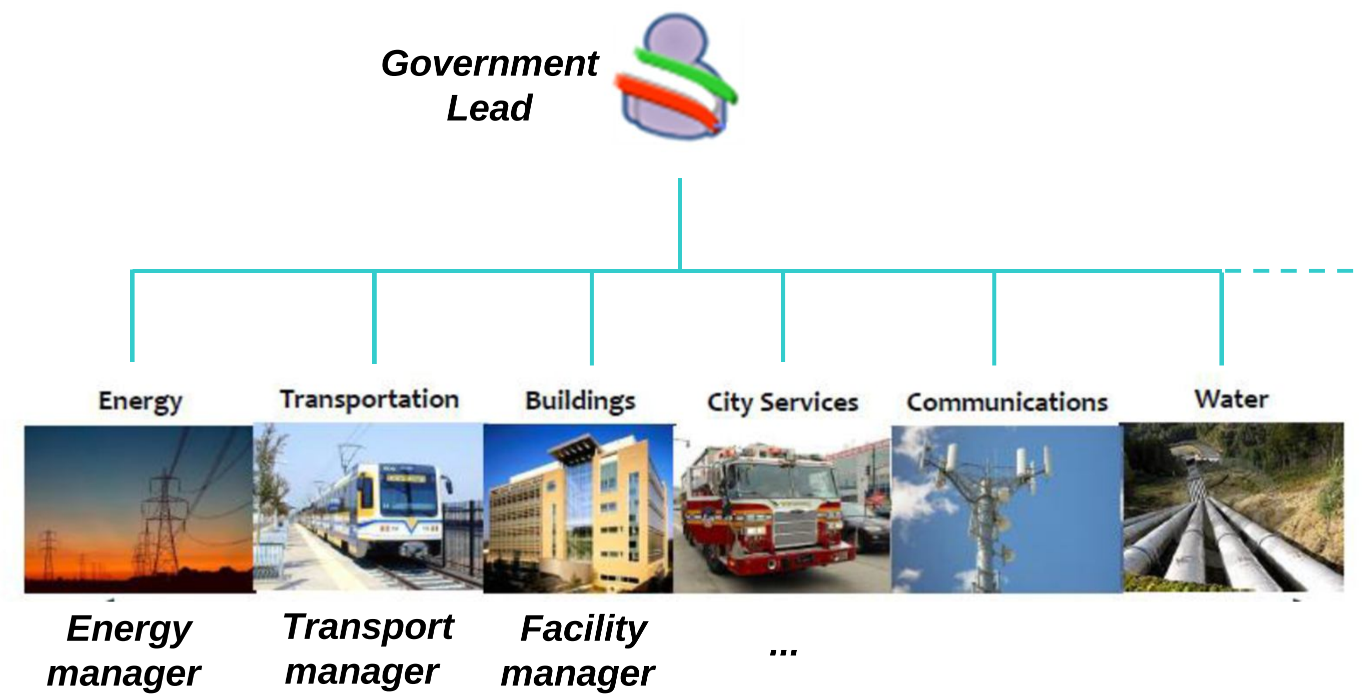

# Decision support in smart cities (3/5)

- **Approach for solving complex decision problem:**
  - **Decomposition of decision process in simpler decision sub-process**
  - **Resolution of decision process at single level**
  - **Coordination between several sub-problem solutions**
  - **Features:**
    - **Higher Level Units are concerned with a larger portion or broader aspects of the overall System/Process behavior**
    - **A Higher Level Unit is concerned with the slower aspects of the overall system/porcess behavior**
    - **Descriptions and problems on Higher Levels are less structured, with more uncertainties, and more difficult to formalize 1uantitatively**



# Decision support in smart cities (4/5)

- **From hierarchical organization of city…**



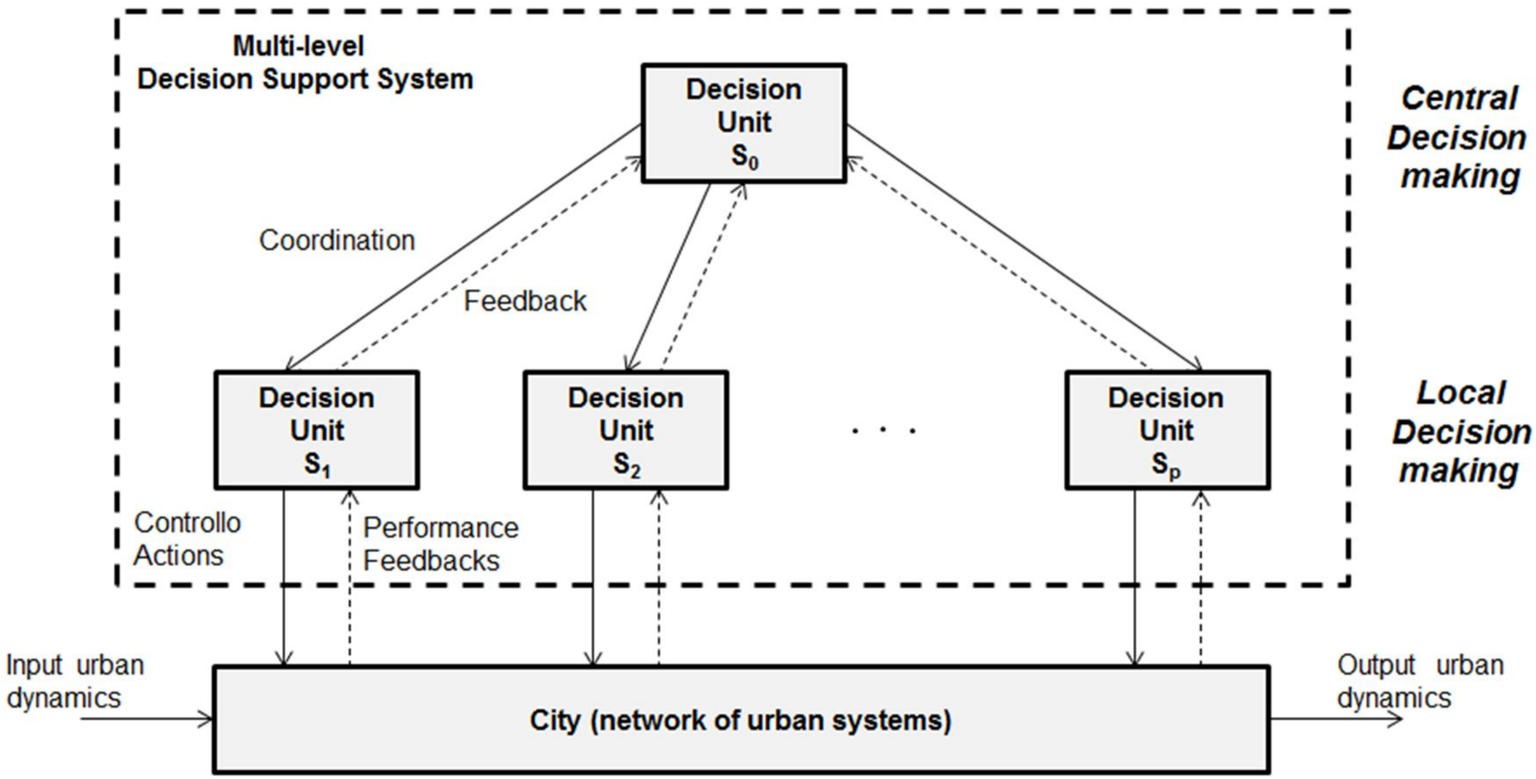

***Leader***
***High level***

***Sectors/ Departments***
***Low level***

**Abstraction of governance organizational hierarchy**

# Decision support in smart cities (5/5)

- ... to the architecture of the decision process

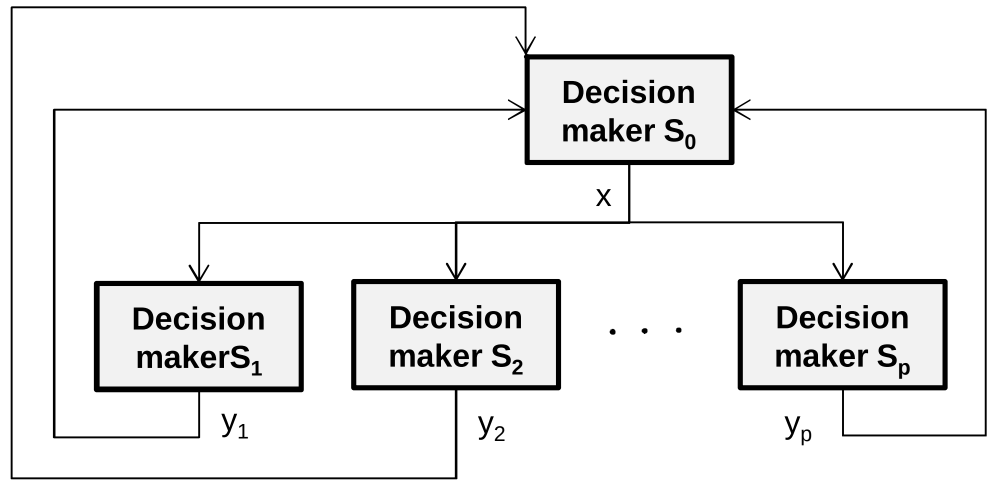



**Decision units and their interactions with urban dynamics**

# Step 1 – Overall decision process

- Integrated decision making of the whole system (Multi-level programming)

$$\max_{x} F(x, y_1, y_2, \dots, y_p)$$
$$\text{s.t. } G(x) \le 0$$
$$\text{where } y_i,\ i = 1, 2, \dots, p \text{ solves}$$
$$\max_{y_i} f_i(x, y_1, y_2, \dots, y_p)$$
$$\text{s.t. } g(x, y_1, y_2, \dots, y_p) \le 0$$




**Resource allocation** ← x : Central unit decision variables

**Actions** ← $y_i$ : Sector unit decision variables

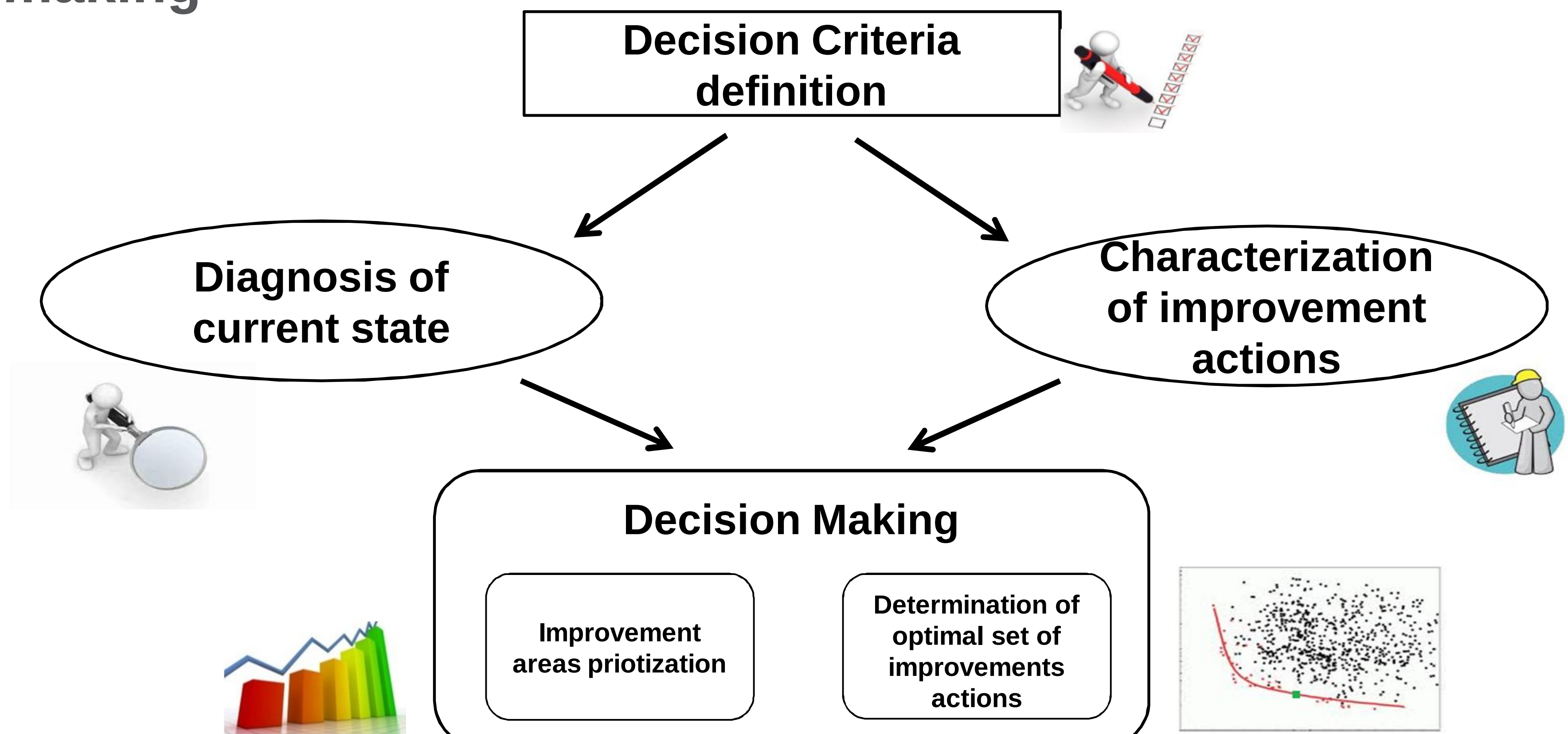
**Aggregated objectives** ← F and G : Central unit objective function and constraint

**Sector objectives** ← $y_i$ and g : Sector unit objective function and constraint

**Bi-Level Decentralized Programming Problem (BLDPP)**

# Step 2 – Decision process of single unit

- **Each unit is in charge of solving a multi-criteria decision making**




**Multi-Criteria Decision Making (MCDM)**

# Outline

- Introduction
- Urban Control Center
- Smart city performance indicators
- Decision support for smart city planning/programming
- **Case study**
- Conclusions

# Case Study (1/8)

- Decision panel: public buildings energy efficiency and renovation

- Decision problem
  - Definition: Determination of the optimal set of actions to be implemented in a given buildings portfolio in order to make buildings:
    - more energy efficient,
    - more environment sustainable,
    - more comfortable for occupants,

    not exceding the given budget constraint
  - Resolution: hierarchical decision process
    - Pareto solutions computation (Multi Objective Optimization)
    - Selection of the best alternative among the determined non-dominated solutions

# Case Study (2/8)

- **Scenario:**
  - Stock of K=5 public buildings located in the municipality of Bari (Italy)
    - $B = \{B_1, B_2, B_3, B_4, B_5\}$

- **Identification of decision criteria:**
  - 4 criteria aimed simultaneously at energy and resource saving and the individuals' well-being
  - H=4 performance indicators to be maximized are considered:
    - reduction of electrical energy consumption ($I_1$),
    - reduction of methane consumption ($I_2$),
    - reduction of water consumption ($I_3$), and
    - increase of occupants' internal comfort ($I_4$).

# Case Study (3/8)

- **Diagnosis of buildings:**
  - **the status of the entire buildings stock is synthesized in the so-called stock multi-criteria characterization matrix**

| | | Indicators | | | |
|---|---|---|---|---|---|
| | | $I_1$ [KWh/year] | $I_2$ [$m^3$/year] | $I_3$ [$m^3$/year] | $I_4$ [/] |
| Buildings | $B_1$ | 25290.0 | 14210.0 | 1950.0 | 4.2 |
| | $B_2$ | 39500.0 | 21000.0 | 2700.0 | 3.8 |
| | $B_3$ | 41026.0 | 18200.0 | 2250.0 | 3.0 |
| | $B_4$ | 43851.0 | 18235.0 | 2500.0 | 4.2 |
| | $B_5$ | 44582.0 | 18000.0 | 2400.0 | 2.8 |

- **Evaluation of retrofit action:**
  - **Identification of potential feasible actions**
  - **Each action is characterized from three perspectives:**
    - **the application potential,**
    - **the cost, and**
    - **its payoff**

# Case Study (4/8)

- **Evaluation of retrofit action:**

| Actions | Application potential of each action in each building | | | | | |
|---|---|---|---|---|---|---|
| | $a_{j1}$ | $a_{j2}$ | $a_{j3}$ | $a_{j4}$ | $a_{j5}$ | unit |
| $A_1$ | 1986.50 | 3321.86 | 2974.94 | 2344.16 | 1592.27 | $m^2$ |
| $A_2$ | 1541.50 | 1978.90 | 1005.00 | 2453.10 | 1683.51 | $m^2$ |
| $A_3$ | 506.92 | 250.60 | 393.02 | 292.50 | 107.43 | $m^2$ |
| $A_4$ | 2 | 1 | 1 | 1 | 4 | pc. |
| $A_5$ | 110 | 70 | 70 | 60 | 60 | pc. |
| $A_6$ | 50 | 50 | 40 | 40 | 30 | pc. |
| $A_7$ | 390 | 396 | 360 | 365 | 349 | pc. |

| | Actions | | | | | | |
|---|---|---|---|---|---|---|---|
| | $A_1$ | $A_2$ | $A_3$ | $A_4$ | $A_5$ | $A_6$ | $A_7$ |
| Actions unit cost | $c_1$ [€/m²] | $c_2$ €/m²] | $c_3$ [€/m²] | $c_4$ [€/pc.] | $c_5$ [€/pc.] | $c_6$ [€/pc.] | $c_7$ [€/pc.] |
| | 55.27 | 51.60 | 348.63 | 9,750.00 | 45.74 | 25.72 | 65.22 |

| Buildings | Actions | Unitary payoffs | | | |
|---|---|---|---|---|---|
| | | $p_{1jk}$ | $p_{2jk}$ | $p_{3jk}$ | $p_{4jk}$ |
| $B_1$ | $A_1$ | - | 0.71 [m³/year/m²] | - | 6.70E-04 [1/m²] |
| | $A_2$ | - | 0.92 [m³/year/m²] | - | 4.32E-04 [1/m²] |
| | $A_3$ | 2.49 [KWh/year/m²] | 1.40 [m³/year/m²] | - | 1.32E-03 [1/m²] |
| | $A_4$ | - | 1776.0 [m³/year/pc.] | - | 1.00E+00 [1/pc.] |
| | $A_5$ | - | 3.23 [m³/year/pc.] | - | 6.06E-03 [1/pc.] |
| | $A_6$ | - | - | 7.8 [m³/year/pc.] | - |
| | $A_7$ | 19.45 [KWh/year/pc.] | - | - | - |
| $B_2$ | $A_7$ | 29.92 [KWh/year/pc.] | - | - | - |
| $B_3$ | $A_7$ | 34.18 [KWh/year/pc.] | - | - | - |
| $B_4$ | $A_7$ | 36.04 [KWh/year/pc.] | - | - | - |
| $B_5$ | $A_7$ | 38.32 [KWh/year/pc.] | - | - | - |

# Case Study (5/8)

- **Decision variables definition:**

$$x_{jk} = \begin{cases} 1, \text{ if j-th action is applied to k-th building} \\ 0, \text{ else} \end{cases}$$

- **Objective function definition:**
  - **Maximization of:**
    - **reduction of electrical energy consumption,**
    - **reduction of methane consumption,**
    - **reduction of water consumption, and**
    - **increase of occupants' internal comfort.**

$$f_i(x_{jk}) = \sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot p_{ij} \cdot a_{jk}$$

- **Constraints:**
  - **The main constraint in the choice of the decision variables comes from the financial resources limitation**

$$\sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot c_j \cdot a_{jk} \le BDG$$

# Case Study (6/8)

- **Summing up:**
  - **Formulation of Multi-Objective problem:**

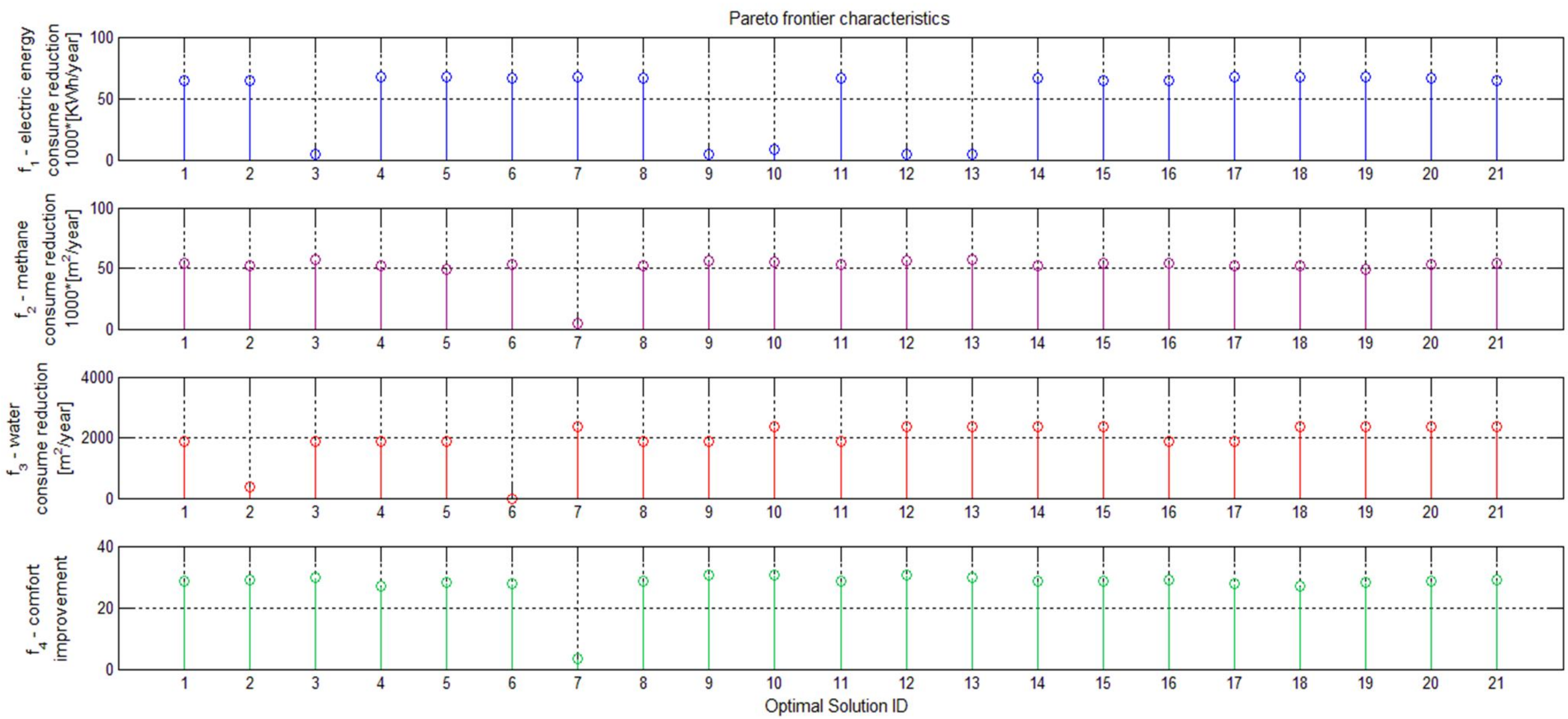
$$\begin{cases} [\max]\, f_1(x_{jk}) = \sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot p_{1j} \cdot a_{jk} \\ [\max]\, f_2(x_{jk}) = \sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot p_{2j} \cdot a_{jk} \\ [\max]\, f_3(x_{jk}) = \sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot p_{3j} \cdot a_{jk} \\ [\max]\, f_4(x_{jk}) = \sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot p_{4j} \cdot a_{jk} \end{cases}$$

s.t.: $x_{jk} \in \{0,1\}\, ,\, j = 1 \div J \quad k = 1 \div K$

$$\sum_{j=1}^{J}\sum_{k=1}^{K} x_{jk} \cdot c_j \cdot a_{jk} \leq BDG$$

# Case Study (7/8)

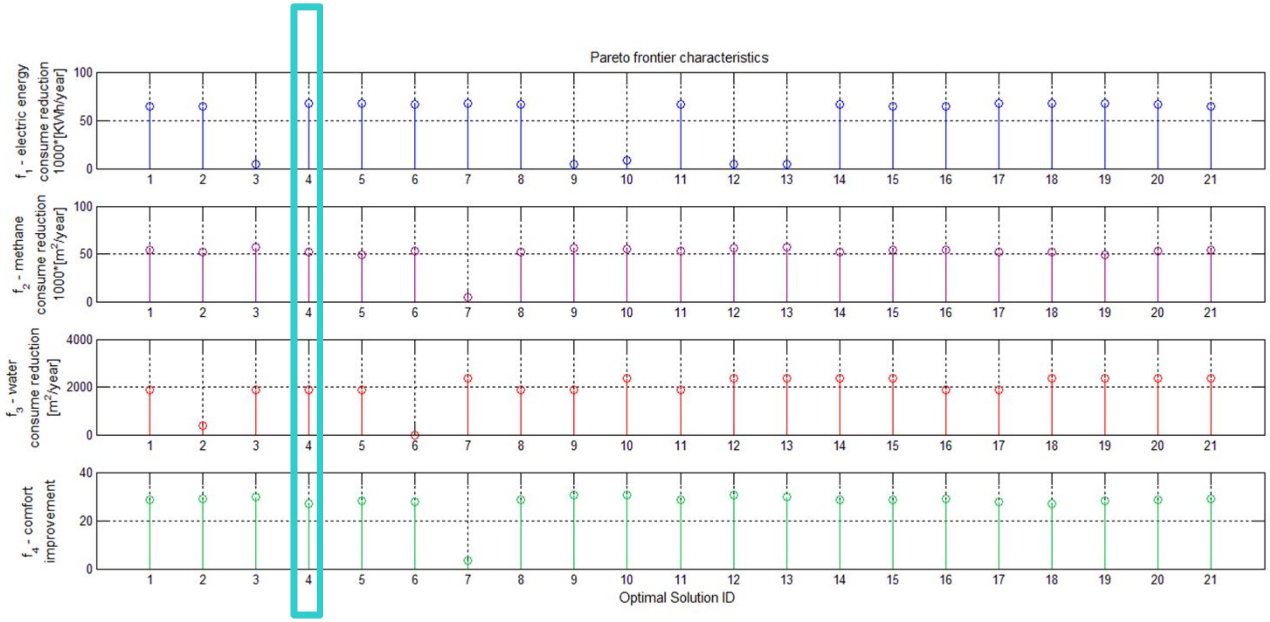
- **Results**
  - **Non-dominated solutions (Pareto) solutions**




**Use of MOGA (Multi-Objective Genetic Algorithm)**

# Case Study (8/8)

- **Results**
  - **Selection of the best alternative among the determined non-dominated solutions**




**Selection based on decision maker preferences (weights assigned to decision criteria $w_1$, $w_2$, $w_3$, $w_4$)**

**The result demonstrates the effectiveness of the proposed approach in providing the decision maker with a set of alternative solutions that present an optimal tradeoff between the various competing criteria.**

# Outline

- Introduction
- Urban Control Center
- Smart city performance indicators
- Decision support for smart city planning/programming
- Case study
- **Conclusions**

# CONCLUSIONS

- **Conclusions:**
  - **Set of smart city perfomance indicators**
    - **Definition of an innovative framework for classifying the smart city indicators**
    - **Application of framework as a supporting tool for developing indicators to monitor the smart city initiatives in the municipality of Bari**
  - **Decision support tools for smart city programming**
    - **Definition of the overall decision process architecture in accordance with a hierachical approach**
    - **Identification of sector decision making units**
    - **Definition of decision making tools for public building decision panel**

- **Path forward:**
  - **Finalization of Case studies for application of Urban Control Center functionalities in the municipality of Bari**

European Network on New Sensing Technologies for Air Pollution Control and Environmental Sustainability - *EuNetAir*

COST Action TD1105

**2nd International Workshop *EuNetAir* on**

***New Sensing Technologies for Indoor and Outdoor Air Quality Control***

**ENEA - Brindisi Research Center, Brindisi, Italy, 25 - 26 March 2014**

# The Urban Control Center: KPIs for Decisions Support of Smart Cities in Italy


Mariagrazia DOTOLI , Raffaele CARLI

Dept. of Electrical and Information Engineering

Polytechnics of Bari, Bari, Italy

{mariagrazia.dotoli, raffaele.carli}@poliba.it



COST is supported by the EU Framework Programme

ESF provides the COST Office through a European Commission contract