A Framework to Assess the Behavior and Performance of a City Towards Energy Optimization

Stella Androulaki, Haris Doukas, Evangelos Spiliotis, Ilias Papastamatiou and John Psarras

Abstract A Smart City Energy Assessment Framework (SCEAF) is introduced to evaluate the performance and behavior of a city towards energy optimization, taking into consideration multiple characteristics. The SCEAF aims to provide to city authorities a systematic and independent evaluation means of the actions taken towards energy efficiency in parallel with the transition to become a "Smart City". The framework consists of indicators that are structured on three major assessment axes (1) Political Field of Action, (2) Energy & Environmental Profile, (3) Related Infrastructures-Energy & ICT. The framework can be designed generally for the whole activities spectrum of a city, but it can also be customized per sector, providing more focused information.

Keywords Local authorities · Smart cities · Energy optimization · Energy assessment framework · Multidisciplinary data sources

1 Introduction

Energy is an essential component of life in cities, since it supports the whole spectrum of economic activities and provides high living standards to residents. Cities in the EU are essential actors for the fruition of the EU's short-, interim and long-term energy and climate objectives and the transformation of the EU into a low-carbon economy on a 2050 horizon (Energy Cities 2014). It is estimated that 80 % of the European population will live in urban areas by 2020 (European Commission 2010a) while urban areas are responsible for 80 % of energy consumption and CO_2

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emissions (Joint Research Centre 2013). Thus cities hold an important but untapped potential for the improvement of energy efficiency. As a result, there is an urgent need for developing strategies capable of reducing energy consumption, exploiting green technologies and reducing CO_2 emissions.

Although local authorities in the 28 EU Member States have a different degree of legal powers and responsibilities in climate and energy policy, they greatly determine the relations between energy consumers, regulators, advisors, energy producers and buyers, enabling them to actively contribute to energy efficiency at the city level.[1] Local communities demonstrate their willingness to implement sound local sustainable energy policies, especially through their participation in initiatives such as the Covenant of Mayors (ERENET 2011).

Cities tend to become "Smarter", with emphasis given on improving conveniences and welfare of residents. One of the major challenges, within this scope, is the increasing energy demand patterns of cities. To assure the transition to "Smart Cities" in parallel with the fulfillment of EU targets for energy efficiency and performance, cities should systematically monitor their activities, both per activity sector (i.e. residential sector, municipal buildings sector, industrial sector, transportation, waste management) and for the city as a whole.

In this scope, Cities are gradually directed to the use of tools and methodologies to monitor and support their actions towards energy optimization and sustainability. Such tools commonly concern long-term actions and strategies adopted by the City.

Nevertheless, a wide variety of multidisciplinary data available at the city level could be additionally exploited to provide support to city authorities to enhance sustainability and energy optimization at the city level, regarding short-term energy action plans. Such data concern weather forecasting data, social data, energy prices, energy profiles and energy production data.

Figure 1 depicts the holistic approach of a "Smart City" with emphasis on the need to promote a sustainable-energy—oriented "Smart City" concept.

The building sector, responsible for about 40 % of the EU's total final energy consumption and CO_2 emissions, provides many cost-efficient opportunities, while contributing to the welfare of EU citizens.[2] The EU has emphasized on the importance of energy performance of public buildings by promoting the directive 2010/31/EU that sets public buildings in priority in achieving nearly-zero energy consumption goals by December 2018 (European Commission 2010b).

Within this scope, the current book chapter introduces a Smart City Energy Assessment Framework (SCEAF) to evaluate the performance and behavior of a city, taking into consideration multiple characteristics. The SCEAF aims to provide to city authorities a systematic and independent evaluation means of the actions taken towards energy efficiency in parallel with the transition to become a "Smart

[1]Covenant Of Mayors commitment. Available at: www.eumayors.eu/IMG/pdf/covenantofmayors_text_en.pdf.

[2]GENERATION: Green Energy Auditing for a low carbon Economy. White Paper, Energy Efficiency in Public Buildings Recommendations for Policy Makers.

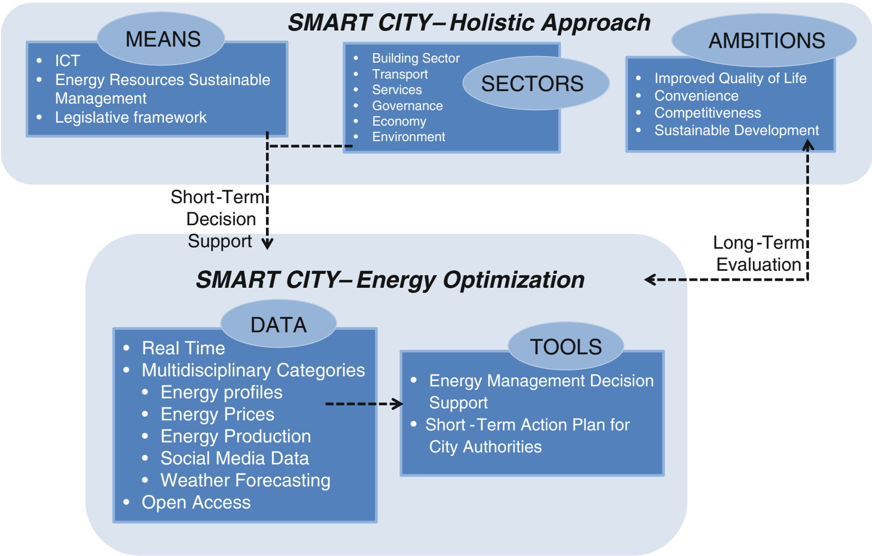

Fig. 1 "Smart-city" holistic and energy optimization approach

City". The added value of the prescribed SCEAF is that it is an assessment tool that clearly indicates underperforming sectors, providing to authorities a clear overview of the city performance per sector in order to be able to lead targeted energy action plans. The framework consists of indicators that are structured on three major assessment axes (1) Political Field of Action, (2) Energy & Environmental Profile, (3) Related Infrastructures—Energy & ICT.

This is done given the importance of acquiring a complete view of the City's behavior beyond pure energy performance measures, considering also its motivation in becoming "Smarter" with emphasis on energy efficiency. Each axis is further subdivided into specific pillars, and each pillar is described by one or more indicators. Figure 2 depicts the pillars per axis within the SCEAF structure. The additional axis 'General Characteristics' is incorporated to provide general information of the City, such as population and city area.

The set of indicators per pillar may differ between the *Whole City Level SCEAF* and the customized on the *Municipal Building Level SCEAF*. Through the SCEAF, the ex-ante and ex-post status of a Smart City, in relation to Energy Optimization issues can be assessed, in a coherent, transparent and integrated way, compared with the OPTIMUS city, which is the city that achieves the best performance in all proposed indicators.

The rest of the paper is structured as follows: Sect. 2 presents the relevant Policy Context while Sect. 3 provides a brief state-of-the-art survey, enumerating initiatives relevant to the ideas of optimizing the energy use in cities, and Sect. 4 analyzes the SCEAF methodology in terms of Axes, Pillars, and Indicators, as well as the aggregation method incorporated. Finally, Sect. 5 presents the Municipal

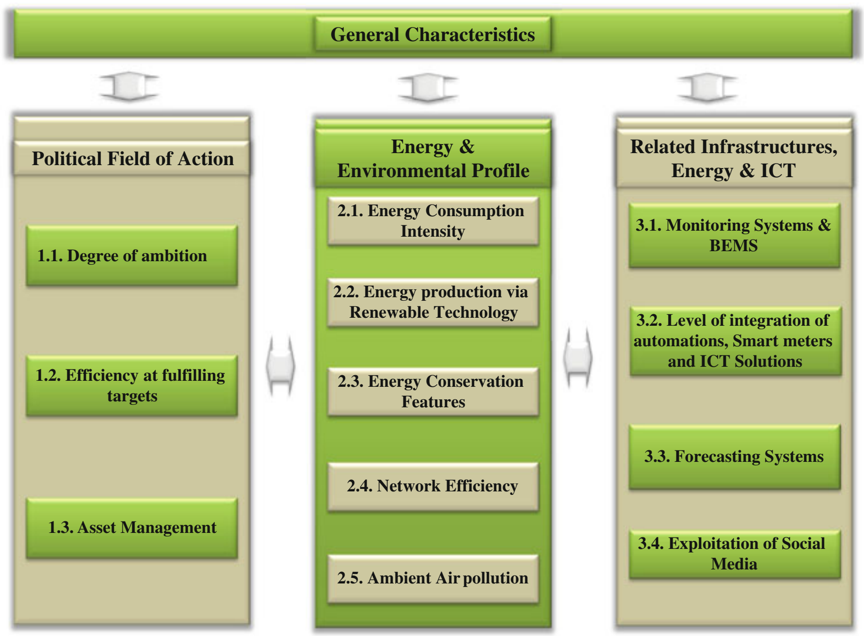

Fig. 2 SCEAF pillars and axes—whole city level and municipal building level

Building customized version of SCEAF, while Sect. 6 provides some conclusions with emphasis on the added value that the SCEAF gives to city authorities.

2 Policy Context

The EU tries to promote a shared European vision of sustainable urban development. European cities should be characterized by social progress and developed environmental consciousness, as well as economic growth based on a holistic integrated approach in which all aspects of sustainability are taken into account (European Commission 2011a). A number of European initiatives have been launched related to these ideas, as presented in the following paragraphs.

Cities, as consumers, demonstrate their willingness to implement sound local sustainable energy policies, especially through their participation in the Covenant of Mayors (CoM)[3] initiative. The CoM is a European initiative addressed to local and regional authorities, focused on the promotion of energy efficiency and renewable energy sources on their territories. By their commitment, Covenant signatories aim to meet the European Union 20 % CO_2 reduction objective by 2020.

[3] http://www.eumayors.eu/index_en.html.

The Energy-efficient Buildings Public Private Partnership in research (EeB PPP) (European Commission 2010c), launched under the European Economic Recovery Plan, represents the first step set by the industry to create more efficient districts and cities while improving the quality of life of European citizens. In addition, the Directive 2010/31/EU (EPBD recast) has indicated that the public sector has an important role in the field of energy performance of buildings, as new buildings occupied and owned by public authorities should be nearly zero-energy buildings, after 31 December 2018.

A new European Innovation Partnership (EIP) on Smart Cities and Communities (SCC) (European Commission 2012) was launched in July 2012 to promote the deployment of smart city solutions in Europe, focusing on the intersections of ICT, energy and transport. Cities themselves have also taken a pro-active role and launched the Green Digital Charter in 2009. The idea is that the cities signing up to the Charter commit to reduce the carbon footprint of their ICT and roll-out ICT solutions which lead to more energy efficiency in areas such as buildings, transport and energy.

The Smart Cities Stakeholder Platform[4] aims to support EU to achieve the target of 80 % reduction of GHG emissions by 2050 by promoting the development and market deployment of energy efficiency and low-carbon technology applications addressed to the urban environment.

The European Energy Research Alliance (EERA) Joint Programme on Smart Cities[5] was launched in September 2010. The main scope of the programme is to promote the development of tools and methods to enable a more sophisticated design, planning and operation of the energy system of a city in the near future.

Finally, two of the main pillars of Europe 2020 strategy are the Digital Agenda for Europe and the resource efficient Europe:

- Digital Agenda for Europe—DAE (European Commission 2010d): The Digital Agenda for Europe provides a policy framework aiming at delivering economic and social benefits from a digital single market based on internet and interoperable applications (Petrović et al. 2014). In this context, the EU promotes the use of ICTs in cities to enhance sustainability; buildings to become energy efficient; energy grids to transform into smart; climate change management. Cooperation between the public authorities and ICT sector is essential.
- Resource-efficient Europe (European Commission 2011b): The initiative for a resource-efficient Europe under the Europe 2020 strategy supports the shift towards a resource-efficient, low-carbon economy to achieve sustainable growth.

Based on the above, it is clear that EU places the issue of optimizing the energy-use in cities in the “heart” of its agenda. It is also treated as a necessary part of the research on Smart Cities. To this direction, the most suitable and available pilots for the first implementation of research are the municipal buildings.

[4] http://eu-smartcities.eu/.

[5] http://www.eera-set.eu/index.php?index=13.

3 Current Relevant Initiatives

Several initiatives have been identified in the international research scene, relevant to the ideas of optimizing the energy use in cities.

The technological approach of the SEMANCO initiative (Semantic Tools for Carbon Reduction in Urban Planning) is worth mentioning. The project is based on the integration of energy related open data, structured according to standards, semantically modelled and interoperable with a set of tools for visualizing, simulating and analysing the multiple relationships between the factors determining CO_2 production. The tools and methods in SEMANCO enable structuring energy related data, held in distributed sources and diverse formats, using data mining techniques (SEMANCO 2012).

The CitInES initiative (Design of a decision support tool for sustainable, reliable and cost-effective energy strategies in cities and industrial complexes) aims to design innovative energy system modelling and optimization algorithms to allow end-users to optimize their energy strategy using data sources on local energy generation, storage, transport, distribution and demand, including demand-side management and functionalities enabled by smart grid technologies. CitInES integrates information about local renewable energies, smart grid integration and demand-side management, as well as fuel price uncertainties (Page et al. 2013).

The ICT 4 E2B FORUM (European stakeholders forum crossing value and innovation chains to explore needs, challenges and opportunities in further research and integration of ICT systems for Energy Efficiency in Buildings) aims to the creation of a strategic research roadmap for ICT supported energy efficiency in construction, by bringing together all relevant stakeholders involved in ICT systems and solutions for energy efficiency in buildings, at identifying and reviewing the needs in terms of research and systems integration as well as at accelerating implementation and take-up. The roadmap produced (ICT 4 E2B FORUM 2012) consists of the Vision, the Strategic Research Agenda and it also provides suggestions and implementation activities.

In the framework of IREEN (ICT Roadmap for Energy Efficient Neighbourhoods) initiative the ways that ICT for energy efficiency and performance can be extended beyond individual homes and buildings to the wider context of neighbourhoods and communities are examined (IREEN 2013).

NiCE (2012) (Networking intelligent Cities for Energy Efficiency) promotes the implementation of commitments to the Green Digital Charter while in the framework of FINSENY (Future Internet for Smart Energy) initiative Future Internet technologies are exploited for the development of Smart Energy infrastructures, enabling new functionality while reducing costs (Fluhr and Williams 2011).

ENPROVE (Energy consumption prediction with building usage measurements for software-based decision support) provides an innovative service to model the energy consumption of structures supported by sensor-based data. The service makes use of novel ICT solutions to predict the performance of alternative energy-savings building scenarios in order to support relevant stakeholders in the procedure of identifying optimal investments for maximizing energy efficiency of an existing building (ENPROVE 2013).

The INTENSE[6] initiative (From Estonia till Croatia: Intelligent Energy Saving Measures for Municipal housing in Central and Eastern European countries) provides a holistic approach for planning energy optimized housing. The project comprises an analysis of legal preconditions, experience exchange on best practice examples, pilot planning activities at partner municipalities, and public awareness raising.

i-SCOPE (Interoperable Smart City services through an Open Platform for urban Ecosystems) delivers an open platform on top of which it develops, within different domains, a series of “smart city” services, based on interoperable 3D Urban Information Models (UIMs) (Patti et al. 2013).

In the framework of RESSOL-MEDBUILD[7] (RESearch Elevation on Integration of SOLar Technologies into MEDiterranean BUILDings) simulation models are developed for the optimization of building energy management and energy performance (RESSOL-MEDBUILD 2013).

The ENRIMA initiative (Energy Efficiency and Risk Management in Public Buildings)[8] specifies the development of a Decision Support System (DSS) engine for integrated management of energy-efficient sites, promoting adaptation of the DSS on buildings and/or spaces of public use (Cano et al. 2013).

TRACE (Tool for Rapid Assessment of City Energy) is a DSS tool designed and implemented by WorldBank within the Energy Sector Management Assistance Program (ESMAP) to assist municipal authorities in identifying and prioritizing Energy Efficiency actions. The methodology incorporated within the TRACE project initially evaluates the city performance focusing on energy consuming municipal sectors (passenger transport, municipal buildings, water and wastewater, public lighting, power and heat, and solid waste), and then it prioritizes energy efficiency improvement actions and interventions for the most energy intense sectors (Energy Sector Management Assistance Program (ESMAP) and WorldBank 2010).

Table 1 summarizes the main scope of each of the relevant identified initiatives. The table, based on the available literature (Page et al. 2013; ICT 4 E2B FORUM 2012; Fluhr and Williams 2011; ENPROVE 2013; Patti et al. 2013; RESSOL-MEDBUILD 2013; Cano et al. 2013; ESMAP (Energy Sector Management Assistance Program) and WorldBank 2010) indicates the main objectives that each initiative addresses. Most of the Initiatives presented deal with more technical issues, such as Smart Grids and ICT. The least covered scopes are those of DSS and Information Exchange, meaning weakness in participatory approaches and in combination of criteria to support actions.

[6]INTENSE ENERGY: Project leaflet. Available at: http://www.intense-energy.eu/uploads/tx_triedownloads/INTENSE_Leaflet_v3_final_web_11.pdf.

[7]RESSOL-MEDBUILD—RESearch Elevation on Integration of SOLar Technologies into MEDiterranean BUILDings project. Available at: http://www.ressol-medbuild.eu/.

[8]Energy Efficiency and Risk Management in Public Buildings (EnRiMa) project. Available at: http://www.enrima-project.eu/.

Table 1 Initiatives and Objectives

	DSS	ICT	Stakeholder participation	Smart grids	Information exchange	Policy support
SEMANCO		x		x		x
CitInES	x			x		x
ICT 4 E2B FORUM		x	x	x	x	x
IREEN		x	x	x	x	x
NiCE		x	x	x	x	
FINSENY		x		x		x
ENPROVE		x	x	x		
INTENSE			x	x	x	x
i-SCOPE		x		x		
RESSOL-MEDBUILD		x		x		
ENRIMA	x	x	x	x	x	
TRACE	x	x		x		x

Managing the energy use in municipal buildings requires a holistic approach to ensure optimum results in terms of energy consumption and CO_2 emissions reduction (Center for Climate and Energy Solution 2009).

Optimising the energy use in city areas with different types of demand to enable local balancing, demand response services, variable tariffs and easy change of supplier is integral to mitigating the threats posed by energy scarcity and climate change to the European cities' development in the coming decades. Taking into consideration that a city authority has often control over a large number of buildings, equipment and facilities, a systematic approach is necessary, in order to ensure a coherent and efficient energy policy covering the entire energy consumptions over which the local authority exercises control.

4 Description of the Framework

The main aim of the SCEAF (Smart City Energy Assessment Framework) is to direct "Smart Cities" to energy optimization by highlighting the strengths, the vulnerabilities and the opportunities arising given the existing energy strategy, environmental policy, municipal facilities and related infrastructures of each city. The determination of the above is done through an evaluation of the city in terms of energy efficiency, CO_2 emission intensity and fund savings. The advantage of using such a methodological tool is that the progress of each city can be revealed by analyzing and assessing its status on a systematic basis. For example, the proposed framework can be applied in parallel with the application of any decision support tool or energy management strategy, in an ex-ante and ex-post basis, as well as independently. In this scope, ex-ante SCEAF will provide a baseline picture of the situation of the municipality while ex-post SCEAF will depict the situation of the municipality after the improvements actions applied. Thereby, all the actions a city authority applies towards energy optimization can be evaluated directly for its effects on environmental and energy issues by tracing the evolution of the score achieved in the respective fields.

The SCEAF consists of three main axes composed by a number of corresponding pillars. Each pillar includes a number of appropriately defined, exhaustive and non-redundant indicators which describe satisfactorily its content and are used as criteria for its evaluation. The evaluation of each pillar provides a total assessment for each axis, as well as for the city as a whole.

The 'Political field of action' axis evaluates the level of ambition and activity of the city, its efficiency at fulfilling the targets set, and its performance regarding its asset management. It assesses the awareness of the city regarding environmental and energy problems as well as its environmental consciousness and its degree of adoption of the EU directives. It also includes the use of basic financial schemes and structures in the direction of saving funds related to energy consumption. The second axis, 'Energy & Environmental Profile' evaluates the energy consumption intensity of the city, the penetration degree of renewable energy sources (RES), the efficiency of the city energy networks and its energy conservation features, as well as the city's emission intensity. The evaluation of these pillars is based on city-level data, including energy consumption of municipal buildings, households, commercial buildings, public transport, municipal fleet, water treatment units, recycling centers and other related facilities. The last axis, 'Related Infrastructure & ICT', evaluates the integration of ICT solutions, automations and smart meters in the city aiming to energy optimization. It also includes the exploitation of monitoring systems, Building Energy Management Systems (BEMS), weather and energy consumption forecasting systems, and social media.

While most of the criteria incorporated within this framework are quantitative (Yager 1988) and directly measurable (e.g. energy consumption per capita), indeed not all of them can be evaluated using a clear measuring scale. For example, it is not easy to assign a clear quantitative assessment method to criteria, such as the Exploitation of Monitoring Systems and Social Media. For such criteria, the proposed framework incorporates also a qualitative assessment scale, with the exploitation of linguistic variables (Kundu 1997). Thus, the criteria incorporated within the SCEAF are categorized between *numeric* (*N*) and *linguistic* (*L*), according to their measuring scale. The application of linguistic decision analysis in the development of the theory and methods in decision analysis is very beneficial because it introduces a more flexible framework, allowing analysts and decision makers to represent the information in a more direct informative and adequate way when impossible to express it precisely (Herrera and Herrera-Viedma 2000; Herrera et al. 2005).

Information derived from the 'General Characteristics' is used to normalize the indicators, so that all indicators from each measuring scale category (*N, L*) are normalized and expressed on a common basis. In this respect, indicators in each axis and pillar can be easily aggregated, with the use of an additive value system to reach conclusions regarding the performance per axis and/or pillar.

All criteria are of strict increasing preference. Additionally, for the sake of simplicity it is considered that no strong evidence of significance between the grade of each pillar and the individual values of the corresponding indicators exists. Therefore, all criteria contribute equally in the additive value system, so that the higher their values, the better the grade of the pillar. Besides, the existence of *Linguistic* indicators which values are defined quite approximately makes it impractical to seek accuracy by precisely determining the weights of criteria.

Based on the above, the *Smart City Energy Performance* (*SCEP*) can be evaluated as the weighted sum of the performance of the city on each of the three axes [*Political Field of Action* (*PFA*), *Environmental & Energy Profiles* (*EEP*) and *Related Infrastructures & ICT* (*I&I*)].

The weights should add to one and are determined by the Decision Maker involved, according to his preferences. Similarly, the city's performance on each of the three axes (*PFAP, EEPP, I&IP)* is a function of the corresponding pillars.

According to the described evaluation framework an *OPTIMUS City* is an ideal city that achieves the highest scores at all the three axes of evaluation and therefore at the aggregation evaluation function.

The *OPTIMUS City* can be used as a benchmark for every city to monitor its performance, focusing either on specific performance axes or on the whole Smart-City energy performance. Moreover, the proposed framework can be exploited to compare cities with one another. Consider the two hypothetical Cities X (*PFAPx* = 0.8, *EEPPx* = 0.3, *I&IIPx* = 0.4) and Y (*PFAPy* = 0.4, *EEPPy* = 0.8, *I&IPy* = 0.3). In both cases the whole Smart-City Energy Performance is *SCEPx* = *SCEPy* = 0.5. Both cities appear to score half of the OPTIMUS City, but City X demonstrates high scores in the *PFAP* axis, accompanied by not very satisfactory results in the other two axes, while City Y performs adequately regarding the energy profiles axis but it lags on the other two. Figure 3 depicts the performance of Cities X and Y in comparison also with the *OPTIMUS City.*

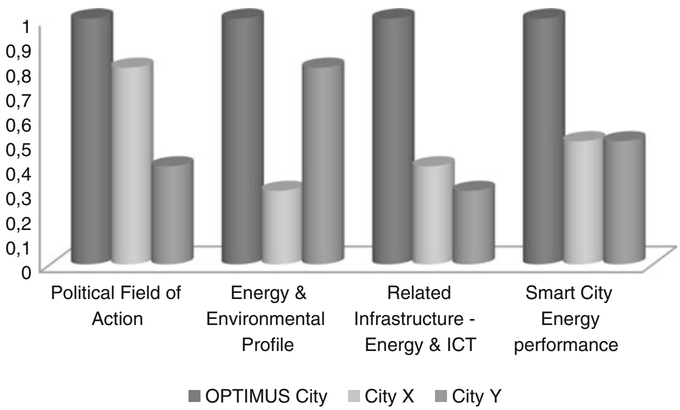

Fig. 3 Smart-city energy performance per axis, OPTIMUS city and cities *X* and *Y*

5 Municipal Building Level SCEAF

The building sector is responsible for about 40 % of the EU's total final energy consumption and CO_2 emissions and thus it provides many cost-efficient opportunities (see Footnote 2). The EU has emphasized on the importance of energy performance of public buildings by promoting the directive 2010/31/EU that sets public buildings in priority in achieving nearly-zero energy consumption goals by December 2018 (European Commission 2010b). In a similar direction, According to the EU Climate and Energy Package "20–20–20", energy savings will arise more directly if energy efficiency measures are applied on building level. Local authorities are the first to be activated by optimally managing loads of municipal buildings, acting that way as role models for citizens and helping transform cities into Smart energy ones.

Based on these facts, the customized on the *Municipal Building Level SCEAF (MB-SCEAF)*, designed to assist the evaluation of the municipal building sector, is outlined, with emphasis on the specific indicators per pillar and axis. An indication is provided on the measuring scale category per indicator as well as a description of each indicator, in terms of measuring scale.

As a result, important steps in energy efficiency of municipal buildings are made, as well as in energy monitoring in order to indicate smart solutions that will yield the desired improvements at the lowest possible cost.

MB-SCEAF consists from the axes of the *SCEAF*: *Political Field of Action, Environmental & Energy Profiles* and *Related Infrastructures & ICT*, but the pillars 'Network Efficiency' and 'Ambient Air Pollution' are not present. In addition, the pillars 'Monitoring Systems and BEMS' and 'Level of Integration of automations, Smart Meters and ICT solutions' have been merged into one pillar. A detailed structure of *MB-SCEAF* is presented in Table 2.

Indicators 1.1.1–1.1.3 evaluate the energy and environmental reduction targets of the municipal buildings set on a baseline year for 2020, which is the crucial year used by EU Climate and Energy Package "20–20–20" and the majority of word climate change organizations. The targets are expressed as a percentage of total energy consumption, emissions and penetration degree of RES respectively. The following three indicators (1.2.1–1.2.3) assess the efficiency of the city at fulfilling the above targets by calculating their coverage rate at the moment the framework is applied. The aim of pillar 1.2 is to ensure that no city will be highly graded thanks just to an environmental target issued, but also due to the efforts made in the direction of actually achieving it. Indicators 1.3.1 and 1.3.2 judge the management of funds devoted for energy needs. The first one normalizes the expenditures according to gross floor area of the municipal buildings, while the second assesses the switching ratio between energy providers based on price, consumption peaks and other data, a process which can become extremely profitable if organized

Table 2 Indicators of MB-SCEAF per pillar and axis

Key performance indicator		Type	Weather	Profile	Social media	Prices	Renewable production
(1) Political field of action		*Data input*					
1.1	CO_2 reduction target in municipal buildings till 2020: % of total emissions	N	✓				
1.2	Energy consumption reduction target in municipal buildings till 2020: % of total energy consumption (delivered energy)	N		✓			
1.3	Renewable energy sources in the final use target in municipal buildings till 2020: % of total energy consumption (delivered energy)	N		✓			✓
1.4	Medium term results for CO_2 reduction in municipal buildings: % of total goal (the goal refers to indicator 1.1)	N	✓				
1.5	Medium term results for energy consumption reduction in municipal buildings: % of total goal (the goal refers to indicator 1.2)	N		✓			
1.6	Medium term results for renewable energy sources in the final use in municipal buildings: % of total goal (the goal refers to indicator 1.3)	N		✓			✓
1.7	Funds devoted for renewable energy sources and energy efficiency: the funds to be given to energy efficiency and renewables' investments	N		✓			
(2) Environmental and energy profiles							
2.1	Energy consumption reduction in municipal buildings: % of energy saved compared to the benchmark year	N		✓			
2.2	Percentage reduction of fossil fuels: % reduction of fossil fuel energy consumption compared to the benchmark year	N		✓			
2.3	Average CO_2 emission factor: average emission factor of the building based on its energy mix	N		✓			
2.4	Renewable energy sources (RES) production intensity: % energy produced from RES per total energy consumption	N		✓			✓

(continued)

Table 2 (continued)

2.5	Ability of storing energy produced (thermal storage, electrical storage): % of total energy production	N		✓			
2.6	Cogenerating heat and power: % of total electricity consumption	N		✓			
2.7	Energy performance and envelope efficiency of the building: energy performance rate of the building based on its energy performance certificate (EPC)	L		✓			
(3) Related Infrastructures and ICT							
3.1	Monitoring systems, BEMS and BACS: evaluated based on the level of automation in the building according to prEN 15232:2006	L		✓			
3.2	Energy monitoring systems: % of energy consumption monitored with sub-meters compared to total energy consumption	N		✓			
3.3	Forecasting systems: existence of systems forecasting energy consumption, energy production and temperature	L			✓		
3.4	Level of switching energy providers (electricity and gas): flexibility of switching among energy providers based on price, consumption peaks, etc.	N		✓		✓	
3.5	Cost reduction for energy needs (gas, petroleum and electricity) in the municipal building: % reduction of energy cost compared to the benchmark energy bill records	N		✓		✓	

(continued)

Table 2 (continued)

3.6	Existence of social media (facebook, twitter): facebook page or twitter account for the municipal buildings	L			✓		
3.7	Building management action plans influenced by occupants'/inhabitants'/citizens' preferences: average number of days per week, when social feedback was taken into consideration for the development of an action plan	L			✓		

correctly and an open energy market exists. Finally, indicator 1.3.3 examines the funds devoted by the municipality for RES and energy efficiency purposes by dividing them by the number of inhabitants for normalization reasons.

Within the second axis, energy consumption intensity is evaluated through three indicators: Indicator 2.1.1 measures the amount of energy saved per number of inhabitants, while indicators 2.1.2 and 2.1.3 detect the percentage of fossil fuels and electricity in the total energy mix of the buildings. For environmental reasons, high electricity and low fossil fuel share is desired and that is why the decrease of the first one is actually examined. Production intensity from RES is evaluated through indicator 2.2.1 having divided total energy production by the area covered by the photovoltaic panels. This indicates that in *MB-SCEAF* renewable energy sources are exclusively considered as photovoltaic because of the building based analysis. The energy conservation features of the building are measured based on its storing abilities (thermal through boilers and electrical through batteries and hydrogen), the amount of electricity produced through Cogeneration and the exploitation of weather conditions for optimizing energy performance. The last indicator is calibrated qualitatively, like the rest of the linguistic indicators, in seven-class climate (unacceptable, very bad, bad, neutral, good, very good and excellent).

The last axis consists of three linguistic criteria related to monitoring Systems and BEMS, weather and energy consumption forecasting systems and exploitation of social media. All these automations and ICT based solutions provide information about future energy needs of the municipal buildings, highlight potential peaks in energy consumption and help program energy production and schedule energy intensive procedures such as preheating, HVAC use, cooking etc. The inability to evaluate precisely the utility and efficiency of that kind of infrastructures and their uneven distribution in the various municipal buildings are the main reasons for choosing the qualitative assessment approach proposed.

6 Conclusions

Cities are characterized by a concentration of people, communities, activities, flows and impacts leading to severe sustainability challenges. Energy is an essential component of life in cities, as it supports the whole spectrum of their economic activities, and secures a certain level of quality of life to residents. Nowadays cities tend to become “Smarter”, usually disregarding the issues of energy efficiency and sustainability.

Taking into consideration that a city authority has often control over a large number of buildings, equipment and facilities, a systematic approach is necessary, in order to ensure a coherent and efficient energy policy covering the entire energy consumptions over which the local authority exercises control. The current work provides City Authorities with an effective framework to assess the behavior and performance of a City, reflecting the clearly quantifiable energy related indicators, but also the related policy context performance and the integration of Smart infrastructure. Using appropriate indicators, the progress of a city in that direction can be revealed by analysing and evaluating its ex-ante and ex-post status across three axes: ‘Political Field of Action’, ‘Energy and Environmental Profile’ and ‘Related Infrastructures and ICT’. The framework can be designed generally for the whole activities spectrum of a city, but it can also be customized per sector, providing more focused information. In this respect, the customized on the *Municipal Building Level SCEAF* (*MB-SCEAF*) *was also presented*, designed to assist the evaluation of the municipal building sector.

Based on the proposed framework, a computerized software can be developed and applied in a city and/or building level, in order to evaluate its usefulness in a “real life environment”. An additional perspective for further research is to explore fusion methods and algorithms for merging multiple information, which is the case for many of the previously presented indicators.

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