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Smartainability: a methodology for assessing the sustainability of the smart city

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Abstract

The Smart City paradigm aims to improve citizens' quality of life in a scenario where the percentage of people living in urban areas is getting higher and higher. In this paper, a new methodological approach is presented to evaluate to what extent the smart cities' development pursues sustainable development goals. This methodology is called Smartainability. The *Smartainability* approach allows to estimate, with qualitative and quantitative indicators, how far smart cities are more sustainable (and smart) in environmental, economical, energetic and social fields, thanks to innovative technologies. Moreover, this estimate can be performed before the technologies deployment. The methodology has been tested on the case study of the Expo Milano 2015 site. The implementation on the Expo Milano 2015 site, demonstrates that Smartainability methodology is able to give decision makers useful information on benefits generated by smart solutions deployment. This aspect is due to three relevant issues: benefits are expressed with quantitative indicators; indicators are estimated before technologies or solutions implementation; benefits are connected to technologies or solutions deployment.

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Keywords: Smart city; Sustainability; Life Cycle Assessment; Key Performance Indicators; Energy efficiency

1. Introduction

The statistical data on world's population of the last years seems to suggest a growth of the population size and a trend of people moving to the big cities [1]. As a consequence, the energy and services demand will increase [2],[3], [4] and, to face this problem, future cities must be more and more efficient. For this reason the new concept of smart city, which is supposed to lead to a more and more efficient and energy saver city, is considered very promising. However, it is not easy to provide a single and comprehensive definition of the smart city [5], and several tentative

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definitions are already available in the literature. To the purposes of this paper, a smart city can be defined as a city able to facilitate and satisfy citizens, companies and organization needs, by an integrated and original use of Information and Communication Technologies (ICT), especially in communication, mobility, environment and energy efficiency fields [6]. In this definition is well underlined the important role of ICT in a smart city. Thanks to hese technologies is possible to improve citizens' quality of life, decreasing pollutant emissions, reducing energy consumptions and economic costs [7]. A smart city is indeed an environment that pays attention to people's needs, rational resources management, sustainable development and economic sustainability. A city with more efficient services, and with more environmental sustainable and smart energy usages.

To achieve these aims it's necessary to evaluate private and public measures and technologies effectiveness, in other words evaluate the sustainability of smart solutions. For these reasons a new analysis approach has been developed and proposed with the name of Smartainability [6], [8].

2. Methodology - *Smartainability*

The aim of the *Smartainability* approach is to estimate, with qualitative and quantitative information, to what extent smart cities are sustainable thanks to the deployment of smart technologies.

In this framework we had the opportunity to test, at least for Europe, the methodology on the "Expo Milano 2015" smart digital city. The universal exposition site "Expo Milano 2015" wanted to be an example of future city districts [9],[10]. Thanks to an ad hoc agreement with Expo 2015 SpA, the exposition district, which represents a particularly advanced model of smart city suitable to develop and validate the methodology, has been chosen as a first case study. Starting from the Expo Milano 2015 case-study the methodology is tested and developed to be extended and repeated in other and more complex contexts, like a city district or a whole city.

There are several available tools to analyse and evaluate smart city's performance and its sustainability, but to our knowledge, most of these instruments only allows to describe the existing situation of a city without connecting smart services with innovative technological solutions and benefits [11], [12], [13], [14]. In this framework, *Smartainability* has been developed in order to support decision makers to understand and quantify possible benefit deriving from deploying innovative technologies enabling smart services for the cities.

The word *Smartainability* originates from the two terms Smartness and Sustainability, while the methods is derived from two existing methodologies: *Guidelines for conducting a cost-benefit analysis of Smart Grid projects*, a study made by European Commission JRC [15], and *Smart Cities – Ranking of European medium-sized cities*, realized by Vienna University of Technology, University of Lubljana and Delft University of Technology to evaluate smart cities sustainability [13].

From the JRC study [15], *Smartainability* derived the Assets-Functionalities-Benefits methodology to examine smart technologies. The aim of this approach is to identify functionalities (services) enabled by one or more assets (enabling technologies). Functionalities create benefits that are evaluated with qualitative and quantitative performance indicators (KPI). An example of this methodology is the follow: in an hypothetical lighting system the *LED lamps* asset enables the *Advanced lighting management* functionality. This functionality is able to activate many benefits, and one of these is *Pollutant emissions reduction*. To quantify this benefit it's possible to consider *Greenhouse gases*, *Acid gases*, *Particulate* KPIs.

More generally, for each group of technologies, applied in an integrated way to a single field such as mobility, energy grids, buildings, the assets are identified. Then functionalities enabled by the assets are identified as well. A two-dimensional array is filled with assets and functionalities, in order to verify which functionalities are activated by the project's assets. The next step is to identify the potential benefits that can be enabled by functionalities. Like the previous case, a two-dimensional array is filled with functionalities and benefits: it is possible to understand which benefits are activated by each functionality. Benefits are then classified in different sustainable development dimensions (Environment, Economy, Energy, Living, etc.) and for each of this dimensions one or more indicators are identified to evaluate benefits in a quantitative (or at least qualitative) way. This ensures that all the dimensions of sustainability are taken into account. Finally a two-dimensional array is filled with benefits and KPIs. In Fig. 1 is explained and sketched the previous methodology.

ASSETS	FUNCTIONALITIES		
	Functionality 1	Functionality 2	Functionality n
Asset 1	X		X
Asset 2	X	X	
Asset n	X		X

FUNCTIONALITIES	BENEFITS		
	Benefit 1	Benefit 2	Benefit n
Functionality 1		X	X
Functionality 2	X	X	X
Functionality n			X

BENEFITS	KEY PERFORMANCE INDICATORS – KPI			
	Environment	Economy	Energy	Living
Benefit 1	X	X		
Benefit 2		X	X	X
Benefit n			X	

Fig. 1. Example of Assets-Functionalities-Benefits matrix scheme

From the document *Smart Cities – Ranking of European medium-sized cities* [13], *Smartainability* derived the concept of the dimensions of analysis suitable for a sustainable smart city.

For the specific case of Expo Milano 2015 *Smartainability* assessment, the dimensions considered are: Environment, Economy, Energy and Living. The Energy dimension, not present in [13] is added due to the relevant benefits that can be generated by "Expo technologies" [6], [8]. The Expo site is a specific analysis case, where people who can benefit from innovative technologies are not permanent inhabitants but only visitors. For this reason Governance and People dimensions are not considered and have been excluded from this specific study. The indicators represent the performance gain between the infrastructural smart technology and similar traditional technology. The indicators are quantified, where feasible, considering a life cycle perspective following the ISO 14040 [16]. Concerning the Environment and Energy dimensions, the assessment is realised evaluating the whole life cycle of the technology with a life cycle assessment approach [16].

Thanks to this methodology is possible to evaluate the performance of an activity, contemplating the whole life of a technology. For each asset the assessment takes into account the main life cycle phases: extraction and manufacturing, materials transport, construction, use, disposal. The assessment of all these phases allows to identify the emissions (solid, liquid, gas), the resources consumption (energy especially) and shows an evaluation of the environment influences of a technology during its life [17, 18, 19, 20].

For the Economy dimension purchase, management and disposal costs are considered .

For the Living dimension the assessment is realised following the method presented in [13], which evaluates with quantitative or qualitative indicators the smartness performance.

3. Case study: the Expo Milano 2015 digital smart city

Smartainability target is to measure, with qualitative and quantitative data, to what extent a smart city is more sustainable than a traditional one, thanks to the use of innovative technologies and the enabled services.

Starting from a simple case study, it is essential to test and verify the methodology, in order to extend and repeat the assessment with a complex case.

For this reason Ricerca sul Sistema Energetico – RSE SpA stipulated an agreement with Expo 2015 SpA in order to test the methodology on the Expo Milano 2015 site. This location, a greenfield, is a very advanced smart city model, extremely suitable to develop the methodology [9], [10].

Thanks to *Smartainability* it was possible to analyse all innovative infrastructural technologies implemented within the Expo Milano 2015 site needed the event. One of the target of Expo Milano 2015 is to satisfy citizens' needs, using resources in a rational way and promising a sustainable development. Concerning the boundaries of the analysis, for the Expo case study only infrastructural assets and technologies enabling services within the site have been taken into account.

4. Results

The analysis is organised following the three main layers of the smart technologies infrastructures: Energy (lighting and smart-grid), Telecommunication (advanced wireless mobile and optical fiber networks), Mobility (sustainable vehicles). As mentioned, for Expo Milano 2015 case are contemplated four dimensions of analysis: Environment, Economy, Energy and Living.

A crucial step of the methodology is the identification of traditional technologies (benchmark) which can offer the same service of smart ones. This phase is very important for the correct benefits quantification, as far as they are quantified as the difference between the performance of smart technologies and traditional ones.

Concerning the Expo case, the tender notices announced by Expo 2015 SpA for the site technological supply have been considered for the choice of traditional technologies (see www.expo2015.org).

Regarding the Energy layer the energy and lighting partners realized the smart grid of the exposition area and provided innovative assets to manage and supply electric energy and lighting for the whole manifestation site and areas outside the pavilions.

These technological solutions reduced the energy consumption and, as a consequence, also pollutant emissions and costs [8]. Furthermore, the network ability to integrate in an optimal way the energy produced by renewable resources allowed to reduce the amount of energy consumption produced by fossil fuels. *Smartainability* results for energy and lighting management on the Expo Milano 2015 site are resumed in Table 1. The detailed calculations and assumptions, related to the following results, are well explained in the research report "La *Smartainability* di Expo Milano 2015" [8].

Table 1. Expo Milano 2015 Energy distribution network and Lighting system KPIs quantification

Dimension	KPI	Quantification
Environment	Greenhouse Gases	-20 761 t CO_2-Eq
	Acid Gases	-34.31 t NOx
		-60.29 t SO_2
	Particulate	-5.19 t PM10
		-3,92 t PM2.5
Economy	Costs	-5 425 432 €
	Costs variation by service suspension	-58%
Energy	Energy used	-28 580 ÷ -36 580 MWh
	Renewable energy used	+5%
Living	Service suspension number	-25%
	Service suspension duration	-45%

Regarding the Telecommunication layer, the Expo Milano 2015 telecommunication network, it was built by technologies enabling data and information communication and transmission, within the Expo event and towards the site. Assets provided by the telecommunications partner can be divided in two groups: Telecommunication system, a fixed and mobile transmission network for data, video and voice, and Telepresence, an application enabled by the new telecommunication network performance, with a strong visibility impact and benefits potential. For the telecommunication technologies, like for the energy ones, we had realized a *Smartainability* assessment [8], comparing innovative and traditional technological solutions (
Table 2).

Table 2. Expo Milano 2015 Telecommunication network and Telepresence KPIs quantification

Dimension	KPI	Quantification
Environment	Greenhouse Gases	-702 t CO_2-Eq
	Acid Gases	-1.67 t NOx
		-1.77 t SO_2
	Particulate	-0.14 t PM10
		-0.11 t PM2.5
Economy	Costs	-838 843 €
Energy	Energy used	-836 MWh
Living	Saved time	High
	Information points	High
	Foiled cybernetic attaches	High
	Simultaneously connected users	High
	Services and applications availability	High
	Effectiveness decisions growth	+9.7%
	Exposure index	High

The Expo mobility partners provided vehicles for the sustainable mobility of the event. The fleet consists in electric and bio-methane vehicles. Some of the vehicles were equipped with a system monitoring driving behaviour and suggesting enhancements, and some where managed in car-sharing. These assets were used by Expo 2015 SpA employees, nations' delegations and event visitors within the Expo site perimeter. Comparing the performance of the innovative and traditional mobility systems, *Smartainability* allowed to estimate the possible benefits for all the analysis dimensions [8]. The results are resumed in Table 3.

Table 3. Expo Milano 2015 Mobility KPIs quantification

Dimension	KPI	Quantification
Environment	Greenhouse Gases	-132 t CO_2-Eq
	Acid Gases	-1.76E-01 t NOx
		-2.60E-01 t SO_2
	Particulate	-1.11E-02 t PM10
		-1.73E-02 t PM2.5
Economy	Costs	-69 651 €
Energy	Fossil energy used	-1 488 MWh
	Renewable energy used	+798%
Living	Customer engagement	High
	Saved time	+3.3%
	Driving stress level	Low

5. Future development

Currently, *Smartainability* development is focused on two aspects. The first aspect is the methodology consolidation and the definition of guidelines to replicate the assessment, the second one is the extension of *Smartainability* analysis from the Expo site to real city cases.

Regarding the methodology consolidation, we have realized guidelines that will allow the analysis use and replication in other context and will supply a set of indicators. For this reason we have compared various

methodologies and documents, regarding smart cities and infrastructure sustainability: standards ISO 37120:2014 [21] and ISO/TS 37151:2015(E) [22], Smart City Index 2014 [11], Smart Cities – Ranking of European medium-sized cities [13], Ecosistema Urbano report [12] and the Envision infrastructures sustainability methodology [23].
Summarizing the information extracted from these documents, the final result is the definition of a set of 28 indicators: 8 indicators for the Environment dimension, 8 indicators for the Economy, 3 for the Energy, 4 for the Living, and 5 for People the new dimension which evaluates the community life improvement.
Concerning the second aspect of the methodology development, *Smartainability* was adopted, actually in a preliminary way and shortly considering the new analysis guidelines, to evaluate an urban requalification project in Milan. The preliminary benefits and impacts evaluation is resumed in the following Table 4 and Table 5.

Table 4. Impacts and benefits preliminary evaluation for Milan assessed area: Building technology cluster

Asset	CO_2-eq (*kg*)	PM10 (*kg*)	NOx (*kg*)	SOx (*kg*)	Local employment (#)	Energy costs (€)
External insulation	-327 376	-2.47	-260	-84	63	-146 105
Building Management System					8	
Photovoltaic	-109 306	-193	-534	-1 359	7	-41 795
Solar thermal	-827	-0.02	-0.77	-0.88	2	-437
Hybrid/mechanical ventilation	-15 938	-28	-78	-198	4	-6 094

Table 5. Impacts and benefits preliminary evaluation for Milan assessed area: Transport technology cluster

Asset	CO_2-eq (*kg*)	PM10 (*kg*)	NOx (*kg*)	SOx (*kg*)	Saved time (*h*)	Local employment (#)	Energy costs (€)
Car sharing	-100 334	40	-107	456			-58 055
eLogistic	-44 941	26	-130	338		1	-18 757
eBike sharing	-23 891	-3.40	-46	17		1	-15 711
Smart Parking	-4 559	-2.82	-12	-11	1 659		-3 300
Photovoltaic recharging stations	-38 139	-68	-186	-474			

6. Conclusion

In this paper we presented an approach, named *Smartainability*, aimed to estimate with qualitative and quantitative indicators, to what extent enabling technologies for smart solutions contribute to increase energy efficiency and environmental sustainability in a city.

The final results show how *Smartainability* allows to estimate to what extent smart solutions achieve better performance than traditional assets for all identified indicators. For example, *Smartainability* allows to evaluate estimate that, thanks to the solutions deployed in Expo Milano 2015 digital smart city, it will be possible to avoid the emissions of 21 000 tons of CO_2 equivalent, 62 tons of SO_2 and 36 of NOx, to avoid the consumption of 80 000 ÷ 105 000 MWh of fossil primary energy and to save 6 million Euro [8].

The implementation on the Expo Milano 2015 site, demonstrates that *Smartainability* methodology is able to give decision makers useful information on benefits generated by smart solutions deployment. This aspect is due to three relevant issue: benefits are expressed with quantitative indicators; indicators are estimated before technologies or solutions implementation; benefits are connected to technologies or solutions deployment.

Compared with other proposed smart city assessment methodologies, *Smartainability* has confirmed the approach strictness and the ability to connect benefits to functionalities and enabling assets.

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