The concept of sustainability in smart city definitions

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Abstract

Smart cities have emerged as a possible solution to sustainability problems stemming from rapid urbanization. They are considered imperative for a sustainable future. Despite their recent popularity, the literature reveals the lack of conceptual clarity around the term of smart city, due to the plethora of existing definitions.

This comprehensive literature review has identified 31 smart city definitions recovered by non-technology focused literature. The definitions are assessed according to the dimensions of sustainability that they consider, environmental, economic or social, and the priority in which they accord the concept of sustainability.

The study reveals that not all approaches to smart city incorporate the notion of sustainability in the same way. Additionally, themes emerge according to the dimensions these definitions consider as well as according to whether they derive from the industry or not. Some definitions offer a more balanced holistic view while others appear to be more focused on different smart city goals or variant ways to achieve them.

The findings of this study contribute to knowledge and practice by aiding conceptual clarity and, in particular, by drawing attention to underlying assumptions about the role of sustainability in smart city development.

Introduction

It is estimated that by 2050, 66% of the globe will be residing in cities, compared to approximately 54% residing now (UNEP, 2018). This means that 2.4 billion people will potentially be added to the global urban population. Consequently, this will inevitably result in a significant expansion of existing urban environments and potentially lead to the need to create new ones. Cities use less than 2% of the earth's surface yet consume more than 7 % of the natural resources available globally. The United Nations Environment Programme (UNEP, 2018) estimates that the material consumption related to cities will augment to approximately 90 billion tonnes by 2050 compared to 40 billion tonnes in 2010. Some of these resources are primary energy, raw materials, fossil fuel, water and food (UNEP, 2012).

As a result, cities are expected to experience challenges related to growth, performance, competitiveness and residents' livelihood (McKinsey & Company, 2013). Deterioration of liveability functionalities related to challenging waste management, scarce resources, air pollution and traffic congestion that cause human health concerns, as well as ageing public infrastructure, are some of the

problems generated by rapid urbanization (Washburn *et al.*, 2009). In order to address these issues, the smart city concept has emerged as one of the possible solutions.

A smart city is a city that may aims to make itself 'smarter', more sustainable, efficient, equitable and liveable (NRDC, 2012). There are numerous definitions of smart city in the literature many of which are diverse in nature. Their diversity ranges from what elements a city needs to encompass to be deemed as smart, what resources it needs to employ, what characteristics it needs to present, to what are the smart city's goals, purpose and scope. Nevertheless this plethora of definitions creates additional confusion not only to the concept of smart city, but to the role of sustainability as well. This paper is a comprehensive literature review of the role of sustainability in smart city definitions. The goal of the study is to aid conceptual clarity by drawing attention to underlying assumptions about the pivotal role of sustainability in smart city development.

Sustainability as one of the strategic goals of smart cities

The steep growth in urban population and the subsequent increase in resource consumption will inevitably create numerous challenges for cities. This highlights the importance of shifting paradigms in the way cities work in terms of sustainability. To begin, it is important to establish a working definition of sustainability for the purposes of this study. Allen and Hoekstra (1993) highlight the importance of establishing the scale on which a system is being assessed in terms of sustainability. Achieving sustainability on a global scale requires different type of actions than on an urban scale. There is no single best-established definition in terms of sustainability in the urban scale nevertheless there is a commonly-used set of characteristics of urban sustainability. These include intergenerational equity, intra-generational equity (social, geographical and governance equity), conservation of the natural environment, significant reduction of the use of nonrenewable resources, economic vitality and diversity, autonomy in communities, citizen well-being, and gratification of fundamental human needs (Maclaren, 1996).

These characteristics incorporate the three dimensions of sustainability: the environmental, the economic and the social dimension (Lehtonen, 2004), where the environmental regards the ecological aspect and includes the conservation of the natural environment (flora and fauna) and resources and an energy production based economy, the social dimension includes equity, community autonomy, citizen well-being, and gratification of fundamental human needs, and the economic consists of the economic vitality and diversity of the urban area. For the context of this research an urban environment can be sustainable when social equity, conservation of the natural environment and its resources, economic vitality and quality of life are achieved. Urban sustainability appears to be one of the prevailing themes in smart city literature, but to what extent is the concept embedded in the understanding of smart cities and how comprehensively is it addressed?

Methodology

This research aims to provide a comprehensive review of the role of sustainability in smart city definitions in the literature. The definitions presented have been retrieved from academic papers on the conceptualization of smart cities, from organizational and government reports, as well as from documents and reports produced by industrial actors.

The academic definitions were searched through inserting relevant keywords in the Elsevier's Scopus database. Solely English language papers were selected. As the research field of smart city is multidisciplinary and diffused, the following subject areas were selected: social sciences, environmental science, energy and business management and accounting. Computer science, engineering and mathematics related papers were not consulted, in order to keep the focus on the conceptual part of the subject in question and not focus on the technological side of smart city. The keywords were ("smart city", "smart cities" AND "definition") occurring in the abstract. The most highly cited papers were selected and examined. From these, original definitions that explored the conceptualization of smart city were selected and included in the review.

Secondly, a list of smart city organizations was retrieved through the partnership list of the United Smart Cities organization, coordinated by the Organization for International Relations (OiER) and the United Nations Economic Commission for Europe (UNECE). Documents produced by these organizations were assessed and original definitions were retrieved. Finally, the list of industrial players was composed through a combination of the United Smart Cities organization industry partners database and the Future Cities Catapult industry database, the latter being the leading smart cities organization in the UK created by the Department for Business, Innovation and Skills (BIS). Reports produced by industrial partners were reviewed and original definitions were retrieved. Definitions that appeared repetitive were discarded in order to generate a streamlined/focused dataset. From the 117 articles found in Scopus, 17 original non-repetitive definitions were retrieved. From the 12 organizations found, six definitions were identified and from the 24 industry players, eight definitions have been included in this review.

The analytic method evaluated the definitions retrieved according to:

a. Whether sustainability, defined in this context as the coexistence of social equity, conservation of the natural environment, economic vitality and quality of life in the urban environment, is considered as one of the smart city goals;

b. Which dimensions of sustainability, environmental, social or economic, are taken into account;

c. How sustainability goals are prioritized. Prioritization was assessed according to whether sustainability appeared as a primary, secondary or tertiary goal, where primary was indicated as of fundamental importance, secondary as important but not fundamental goal and tertiary a goal of less importance compared to the other two categories. Although subjectively classified, the three level of priority offer an indication on the centrality of sustainability in smart cities definitions.

Findings

This study identified 31 definitions in the literature, the majority of which come from academia (17 definitions), while six were found in organizational/government

reports and eight in documents from the industry. An overview of the definitions is first presented, followed by more detailed examination of the variances in sustainability oriented and non sustainability oriented definitions. Subsequently, the dimensions of sustainability, namely the environmental, economic and social dimension, as well as the prioritization of sustainability as a smart city goal in the definitions, are presented.

Overview of Smart City definitions

Numerous definitions encompass all three dimensions of sustainability namely, environmental, economic and societal, while others examine only one or a combination of two. Subsequently, the definitions have been examined according to their priority as a primary, secondary and tertiary and categorized into a table according to their attributes (Table 1). Smart city definitions are heterogeneous in nature (Ponting, 2013), as there appears to be neither a predetermined template, nor a one-size fits-all definition of what the term smart city encompasses (O'Grady and O'Hare, 2012). As such, definitions tackle different perspectives of smart city development ranging from the adoption of Information and Communication Technology (ICT), user communication, e-governance and equitable development to education and sustainability.

Author	Keywords	Sustainability oriented	Environmental	Economic	Social	Priority
Academic Definitions						
Bakıcı et al. (2012)	High-tech, connections, ICT, sustainable, greener city, competitive, innovative	•	•	•	•	Primary
Barrionuevo *et al.* (2012)	Technology, resources, integrated, habitable, sustainable	•	x	x	•	Secondary
Batty et al. (2012)	ICT, infrastructures, coordinated, equitable, engaging	x	x	x	x	N/A
Bélissent (2010)	ICT, infrastructure, interactivity, efficiency	x	x	x	x	N/A
Caragliu et al. (2011)	Human and social capital, ICT, Infrastructure, sustainable economic growth, quality of life, participatory governance	•	•	•	•	Primary
Chen (2010)	Communications and sensor capabilities, infrastructures, optimization, quality of life	x	x	x	x	N/A
Lazaroiu and Roscia (2012)	Technology, interconnected, sustainable, comfortable, attractive and secure	•	x	x	•	Secondary
Giffinger et al., (2007)	Economy, mobility, environment, people, living, governance	•	•	•	•	Primary
Kourtit and Nijkamp (2012)	Knowledge-intensive creative strategies, socio-economic, ecological, logistic competitive, human capital infrastructural, social and entrepreneurial capital	•	•	•	•	Primary
Kourtit *et al.* (2012)	Productivity, education, knowledge intensive jobs, creative, sustainability oriented	•	x	x	•	Tertiary
Nam and Pardo (2011)	Information, infrastructure, efficiency, mobility, decision making	•	•	x	•	Primary

Schaffers et al. (2012)	ICT, social and environmental capital, competitiveness	•	•	x	•	Secondary
Thuzar (2011)	Sustainable urban development policies, equity, sustainable economic development, human social capital, natural resources	•	•	•	•	Secondary
Toppeta, D. (2010)	ICT, governance, sustainability, liveability	•	x	x	•	Primary
Zygiaris (2013)	Innovative socio-technical and socio-economic growth, green, interconnected, intelligent, knowledgeable, innovating, interactive	•	•	•	•	Secondary
Industrial Definitions						
Alcatel Lucent (2011)	ICTs, competitiveness, environmental sustainability, liveability.	•	•	•	•	Secondary
ARUP (2011)	Engaged citizens, efficient, interactive, engaging, adaptive and flexible city	x	x	x	x	N/A
CISCO (2012)	ICT, increase efficiencies, reduce costs, quality of life	x	x	x	x	N/A
Fiberhome Technologies, (2017)	Data integration, policy, technology, process, capital	x	x	x	x	N/A
HITACHI (2012)	Environment, safe, quality of life	•	•	x	•	Primary
IBM (2018)	Interconnected information, operations, optimization of resources	x	x	x	x	N/A
Schneider-Electric (2014)	Efficient, liveable, sustainable	•	•	x	•	Primary
Telefonica (2016)	Improving public services, quality of life, governance, sustainability	•	x	x	•	Tertiary
Organizational/Governmental Definitions						
BIS (2013)	Liveable, resilient, engaging, hard infrastructure, social capital	•	x	•	•	Tertiary
BSI (2014)	Integrative, physical, digital and human systems, sustainable, inclusive	•	x	x	•	Secondary
Azkuna (2012)	ICT, infrastructure, efficient, citizen awareness	x	x	x	x	N/A
EIP-SCC (2013)	Energy, materials, services and capital, sustainable economic development, resilience, quality of life	•	•	•	•	Primary
EIP-SCC (2013)	Technologies, environmental impact, better lives, governance	•	•	x	•	Primary
ICLEI (2017)	Operations, sustainable, resilient, physical and social capital	•	•	•	•	Primary
IDA (2012)	ICT, real-time analysis, sustainable economic development.	•	x	•	x	Primary
NRDC (2014)	Efficient, sustainable, equitable, liveable	•	•	x	•	Primary

Table 1: Keywords of the definitions retrieved by the literature, where the dot (•) means that this element is present in the definition while the cross (x) means that this element is not included. Table created by the author.

Smart cities can be viewed as cities performing well on six characteristics: environment, economy, mobility, people, living and governance (Giffinger and Pichler-Milanović, 2007). They derive from knowledge-intensive creative strategies that have as a goal the improvement of the socio-economic, ecological, logistic and competitive performance of cities and rely on a mixture of human, infrastructural, social and entrepreneurial capital (Kourtit and Nijkamp, 2012). These investments in human, infrastructural (transport and ICT) and social capital promote sustainable economic growth and a good quality of life, via participatory governance and by intelligently managing natural resources (Caragliu *et al.*, 2011).

Definitions that do not include sustainability as one of the smart city strategic goals, view it as a city that utilizes ICT to create more interactive and efficient components

and utilities of critical infrastructure (Azkuna, 2012). These components are suggested to be administration, education, healthcare, public safety, real estate, transportation and utilities (Bélissent, 2010). Smart cities adopt scalable solutions that utilize ICT to boost efficiency, decrease costs and improve quality of life (CISCO, 2012). They will use communications and sensor capabilities embroidered into the infrastructure of the city in order to optimize electrical, transportation and other logistical everyday operations in order to improve the quality of life (Chen, 2010). Such technologies provide an interaction space between citizens, authorities, businesses and other actors, to become actively engaged in the design and planning processes (Batty *et al.*, 2012). While the definitions above derive from academic literature and government papers, similar themes can be observed in definitions deriving from industrial actors. IBM (2009) considers that a city can become smart by optimally using all the available interconnected information to comprehend and regulate its operations, and optimize the utilization of available resources. Accordingly, others support that a smart city can be built by integrating platforms, terminals and data, through policy, technology and capital, in an efficient way (Fiberhome Technologies Group, 2018). From a different point of view, ARUP (2011), views the smart city as a city with clear and transparent structure of its urban systems, which are simple, responsive and adaptable with the use of technology and design methods. In this city, citizens are encouraged to interconnect with their wider ecosystem and collectively engage with it.

In summary, while sustainability oriented definitions appear to focus on the performance of the environment, the economy, mobility, people, quality of life and governance, non-sustainability oriented definitions are particularly interested in the efficiency of transportation, education and administration. Despite the common characteristics sustainability related smart city definitions present, they also demonstrate a number of variations. Different smart city definitions may include different dimensions of sustainability as their goal. Furthermore, the prioritization of sustainability as a strategic smart city aim appears to vary between definitions.

Sustainability oriented smart city definitions

Sustainability oriented smart city definitions from the selected sources were analysed according to the dimensions of sustainability they explore, namely the environmental, the social and the economic dimensions. This categorization allows for thematic patterns to emerge. Looking first at definitions which consider all three dimensions, which we term 'holistic approaches', they view the "smartness" of a city as a "certain intellectual ability that addresses several innovative socio-technical and socio-economic aspects of growth" (Zygiaris, 2013). Such perspectives speak to the perception of smart city as green, interconnected, intelligent, innovating and knowledgeable, terms which themselves have been the subject of a number literature reviews. These attributes contribute significantly towards the development and sustainability of cities (Zygiaris, 2013). This "smartness" is embedded into the city operations and is based on the analysis, monitoring and optimization of urban, physical (energy, water, waste, transportation and others) and social (equity, governance, citizen participation) systems, through transparent and inclusive communication structures (ICLEI, 2017). Similarly, smart cities can be

regarded as systems of humans, utilizing flows of energy, materials, services and capital to achieve sustainable economic development, resilience and high life quality (EIP-SCC, 2013). In order for smart cities to achieve these goals, equitable, participatory, sustainable urban development policies will be needed (Thuzar, 2011).

Interestingly, all sustainability oriented smart city definitions identified include a strong presence of the social dimension as well. When the concept of smart city was introduced, it was regarded as a strategic tool to underline the increasing importance of ICT and social and environmental capital in sculpting the competitiveness of modern cities (Schaffers *et al.*, 2012). Consequently smart city definitions that encompass the environmental dimension of sustainability frequently include the social dimension. Schaffers *et al.* (2012) support this view, arguing that this is due to the distinctive attributes that social and environmental capital can offer to smart cities compared to the "more technology-laden counterparts", frequently mentioned in the literature as digital or intelligent cities. Thus the distinction between digital or intelligent cities and smart cities appears to be the prevalence of the human element in the latter.

Indeed, numerous sources in the literature view sustainability in smart city as a predominantly social scope. The British Standards Institute (BSI) (2014), the national standards body of the UK, (BSI, 2014) supports the view that a smart city includes the efficient integration of physical, digital and human systems in the built infrastructure in order to create a sustainable, prosperous and inclusive future for its inhabitants. This emphasis on the habitability and inclusivity of the urban environments particularly underlines the social nature of smart cities. In other words they strive to improve city services and urban management for the citizens, by creating a socially advanced environment. The ultimate goal of these processes is improving the sustainability and liveability of the city (Toppeta, 2010). Through these definitions it can be observed that the combination of the human capital with technology can have an effect on urban services, city services, local actor interaction and quality of life, thus improving the social aspect of urban environments.

The identified literature includes few definitions that focus solely on the economic aspect of sustainable smart cities. Similarly to the environmentally oriented definitions, the economic oriented consider smart cities as cities that combine hard infrastructure with social capital, community institutions and technologies, but with an alternative purpose: that of boosting sustainable economic development and creating an attractive business environment (BIS, 2013). According to this approach, economic competitiveness along with environmental sustainability and general liveability become increasingly driven by ICT (Alcatel-Lucent, 2011). In the case of Singapore, the smart city has been defined as a local entity that holistically employs ICT and real-time analysis to promote sustainable economic development (IDA, 2006). Barcelona considers smart city as a sustainable, greener, highly-technological city with competitive and innovative commerce, and an enhanced quality of life that creates connections between people, information and urban elements, through the use of new technologies (Bakici *et al.*, 2012). This approach is a less theoretical and more practical one, where the need for sustainable development is recognized along with the need of the city to grow and flourish economically, through the combination of both hard and soft elements. However it is not clear if economic growth and enhanced quality of life are causally related, with economic

improvement leading to better quality of life, or if these two goals should be independently pursued.
In addition to variations in content, sustainability oriented definitions present a discrepancy in the prioritization of sustainability as a smart city goal. In numerous of the definitions presented, sustainability is regarded as one of the primary goals of smart city, along with liveability. Respectively, approximately one third of the definitions presented, feature sustainability as one of the secondary goals in smart cities along with liveability, efficient use of resources and governance. Three definitions present sustainability as a tertiary goal, diminishing its importance in the smart city agenda. The primary goal in tertiary definitions is the quality of life and governance.

Discussion

Sustainability oriented smart city definitions present some emerging themes that consistently appear in the literature. The themes are: the relatively anthropocentric focus of sustainability oriented approaches, the prevalence of result-focused definitions and the role of technology as a facilitator. They are related to the use of soft and hard capital, where soft capital is considered as human capital and societal structures and hard capital as the city infrastructure and material resources, combined through diverse technologies, with the purpose of enhancing environmental aspects of the city, boosting the economy and ensuring a high quality of life. In contrast, non-sustainability related definitions particularly highlight the importance of ICT in order to optimize the performance of the city and the use of resources, while the ultimate purpose of enhancing the quality of life remains unaltered. The variation to emerging themes between the two types of definitions demonstrates how the first type combines soft capital (the human and societal element), to hard capital (city infrastructure) while the second one focuses on the efficient utilization of resources through the use of ICT, thus underpinning the importance of hard elements. This can be specifically observed in definitions provided by technologically related industrial actors (CISCO, IBM and Fiberhome Technologies Group). Contrastingly, other actors in the ICT industry such as Hitachi (2012) and Schneider Electric (2014) provide more sustainability oriented, holistic definitions. This may be due to the fact that these firms are not solely ICT based but have a diversified portfolio that ranges from power and automotive systems to social infrastructure. In a similar alignment of sector and definition, ARUP a company related to the built environment define smart city as an urban system with structures focused on citizens and their neighbourhood, underlining the urban aspect.
Additionally, it can be observed that sustainability oriented definitions appear more results based, with non-sustainability oriented definitions more process based. Most sustainability oriented definitions highlight the results that smart cities aim to achieve answering to “why a city should be smart”, while the non-sustainability-oriented definitions appear to answer to “how these results can be achieved”, through expanding on the integration of different kinds of resources, such as human and infrastructure capital, in order to arrive to the smart city goals. This is furthermore noticeable in the role of technology, which in the first approach comes

across as a facilitator to an end result, while in the non-sustainability oriented approach technology takes a more prominent role.

Holistic approaches take into consideration all sustainability dimensions, the environmental, the social and the economic, and present a rather balanced point of view on what a smart city should be. Environmentally oriented definitions, which include the social dimension as well, support the cause of reduction of the environmental impact of urbanism, the enhancement of life quality and the efficient use of resources as the smart city goals. These may be achieved through the use of technology in almost all definitions. This approach emphasizes mitigating the impact of cities on the environment and rarely takes into account the economic growth or development of the city.

Similarly, social sustainability-oriented definitions demonstrate how smart cities integrate technology with governance to improve the sustainability and liveability of the city. In contrast to socially oriented definitions, -those focused on the economic dimension of sustainability propose the combination of hard infrastructure and soft capital with the purpose of creating competitive cities and boosting sustainable economic development.

A prevalence of socially related elements may be observed in smart city sustainability-oriented definitions. This is contrary to the urban sustainability literature where frequently the societal factor is overlooked or shadowed by the ecological aspect (Lehtonen, 2004). This phenomenon is extended to urban sustainability assessment (Berardi, 2013). Nevertheless, the human nature of urbanization and the social issues that rapid urban growth has caused, such as social inequality (Kim and Han, 2012), social deprivation, community disruption, public safety and health decrease (Bibri and Krogstie, 2017) have underlined the importance of the social aspect of smart cities and appear to have had a significant impact on the way in which scholars, organizations and industries define the term. On the other hand, a low number of definitions that take economic sustainability into account can be observed, which is contrary to the common connection between social and economic sustainability, frequently referred to as "socio-economic", indicating the strong connection between these two elements.

It is apparent that the diverse sustainability-oriented definitions of smart city do not view the goal of sustainability equally. Most definitions that take a holistic approach appear to view sustainability as one of the primary city goals. Interestingly, this is not the case for socially oriented definitions which focus more on quality of life and development or efficient use of the human capital, thus view sustainability as a desirable attribute, but has secondary or tertiary priority. This raises questions as to what trade offs the latter are willing to make in order to achieve quality of life over the preservation of the environment, as well as to what the cost of this trade off will be. Additional concerns are raised by the fact that no definition provides an explanation of what they mean by quality of life, what it incorporates and how it is defined. Undoubtedly, quality of life has different meanings for different parts of the world, as access to food, clean water and medicine as well as equity and equal opportunities are still an on-going problem in numerous parts of the globe.

Nevertheless, regardless of the number of sustainability-driven smart city definitions and its apparent high priority as a goal, some authors pose questions regarding the true impacts of smart city on ecological sustainability. One of the issues arising is the

potential psychological disconnection of citizens to the environment and disruption of the relationship of citizens with nature due to overexposure to technology (De Jong *et al.*, 2015). Additionally, some authors dispute the net contribution of smart cities to sustainability (Salvati *et al.*, 2013) (Viitanen and Kingston, 2014) and are supported by the findings of De Jong *et al.* (2015)'s network analysis of smart city concepts, which indicate a distance between the sustainable and the smart city. Whether these concerns are valid or not, largely depends on the way in which the smart city model is or will be embedded in a city's system, and the strategies and main goals that the authorities have set for the city, as well as the resources that will be used in order to achieve it.

Conclusions

This comprehensive literature review identified a number of emerging themes in smart city definitions. Sustainability oriented definitions often focus on the combination of soft capital, such as human and social capital, and hard capital, a city's physical infrastructure, in order to deliver a sustainable, liveable and efficient city. On the other hand, non-sustainability oriented definitions usually highlight the importance of ICT utilization to efficiently combine resources that will make the city more interconnected, intelligent and liveable.

Holistic approaches cover all sustainability dimensions, the environmental, the social and the economic one, and present a balanced point of view on what a smart city should be. Most environmental and social dimension focused definitions focus on how smart cities integrate technology with governance to improve the quality of life and reduce the environmental impact of urbanism. Diversely, economic oriented definitions propose the combination of hard infrastructure and soft capital with the purpose of creating competitive cities and boosting sustainable economic development. Interestingly, in contrast with most sustainability related literature, the social dimension of sustainability appears to be the prevailing one in smart city definitions. It is concluded that a number of the existing definitions take into consideration all salient aspects of urban sustainability in the literature. These are provided by Giffinger et al. (2007), Kourtit and Nijkamp (2012) and Zygiaris (2013). These definitions present a balanced view between the environmental, the economic and the social aspect of smart city and are recommended as comprehensive definitions in which sustainability is afforded a primary role.

Further research on the contribution of smart cities to achieving sustainable development is essential. As this research indicated, one of the main goals of smart city initiatives is the improvement of quality of life, yet no definition explained what this means and at what cost this "improvement" will came for the society and the environment. Thus, future attempts to define smart city should take the cause-effect relationship of improvement of quality of life through the use of modern technology into consideration and truly reflect on whether all dimensions of sustainability are equally represented.

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