Scientific and Practical Understandings of Smart Cities

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1 ABSTRACT

Cities are key agents in the transformation of energy systems, since the majority of the world population lives in cities and most energy is consumed in urban areas. In recent times, the concept of smart cities has raised the attention of both scientists and practitioners in different fields. Smart cities are envisioned to link different fields of action such as mobility; energy production, distribution, and consumption; buildings; governance and stakeholder processes; and urban planning. Information and communication technologies are seen as key to these interconnections. The overall goal of a smart city is to save energy and simultaneously to increase the quality of life for inhabitants.

Although a broad variety of descriptions of smart cities have been developed, the concept itself appears to be rather fuzzy and hard to grasp. A clear-cut, common definition of smart cities is still lacking. The goal of this paper is to better understand what a smart city constitutes and what it means from the perspective of science, as well as from a practical point of view.

In a thorough literature analysis, we identify different i) definitions, ii) approaches, iii) fields of actions and iv) technologies associated with smart cities. Our analysis is based on interdisciplinary scientific literature, as well as on practical documents (e.g. websites of pilot projects). In a subsequent step, we compare the different understandings of smart cities. In so doing, we focus on similarities and differences between scientific and practical approaches. In a final step, we identify opportunities and challenges arising from the identified similarities and differences.

Recognising these challenges and potentials is of particular interest for so-called transdisciplinary research in urban development, where scientists and practitioners work closely together. Differences between science and practice might on the one hand inform research on smart cities concerning practical implications and experiences. On the other hand, they can also inform practitioners about scientific innovation in urban development (e.g. cloud computing assessing sensor data in real time).

2 INTRODUCTION

Cities will be important agents of change in the upcoming energy transition. In 2010, it was observed that most people worldwide (52%) live in cities; this share is expected to grow to 67% by the year 2050 (United Nations, 2014). Furthermore, cities are responsible for as much as 75% of the global energy consumption (United Nations, 2011). This indicates a huge potential for energy efficiency improvements at the city level. In science and practice, the growing importance of cities in the energy transition has been recognised. Cities can be role models in the energy transition (e.g., by increasing energy efficiency of public buildings), and at the same time governing change by implementing national policies, setting legislation, providing infrastructure, and informing and empowering citizens. Furthermore, cities can disseminate their experiences, and in so doing, influence energy transition policies (Jollands, Kenihan, & Wescott, 2008).

In Switzerland, communities and cities are encouraged to promote energy savings in different domains such as developmental and spatial planning (e.g. a city's mission statement), public buildings and infrastructure (e.g. refurbishment of public buildings), energy supply and waste management, communication and cooperation (e.g. events, marketing), internal organisation (e.g. further education) and mobility (e.g. promotion of public transport; Horbaty, 2013). By November 2013, as many as 345 Swiss communities had received the 'Energiestadt' label (Swiss label corresponding to the European Energy Award; Energiestadt, 2013). This label acknowledges the engagement of cities in promoting energy efficiency in the mentioned domains. However, in order to go one step further to promote energy efficiency, cities need to link their activities in the mentioned fields. This means no piecemeal solutions; instead, integrated solutions are required.

In recent times, the concept of 'smart cities' has gained the attention of scientists and practitioners. Smart cities are supposed to link different fields of action such as mobility, energy, buildings, governance,

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stakeholder processes and urban planning (Smart City Schweiz, 2014b). Information and communication technology (ICT) is seen as key to these interconnections. The aim of a smart city is to reduce energy consumption while at the same time maintaining or even enhancing the quality of life of inhabitants.

2.1 Scientific definitions of smart cities

A multitude of different understandings of smart cities are evident, and there is no commonly accepted definition in the literature. Nam and Pardo's (2011) paper provides an overview of different definitions which have been developed. Here, we briefly review some key characteristics of smart cities as identified by Nam and Pardo (2011):

Smart cities

- adapt to the changing needs of users (Mars-Maestre, Lopez-Carmona, Velasco, & Navarro, 2008);
- use smart technologies that monitor and integrate infrastructure (e.g., ICT such as connected mobile terminals, sensors, and actuators; Hall, 2000);
- link smart economy (competitiveness), smart people (social and human capital), smart governance (participation), smart mobility (transport and ICT), smart environment (natural resources) and smart living (quality of life; Giffinger & Haindlmaier, 2010); and
- empower inhabitants to participate in decisions and to shape smart cities (Partridge, 2004).

These different perspectives are reflected in an operational definition by Caragliu, Del Bo and Nijkamp (2011): "We believe a city to be smart when investments in human and social capital and traditional (transport) and modern (ICT) communication infrastructure fuel sustainable economic growth and a high quality of life, with a wise management of natural resources, through participatory governance" (p. 70).

2.2 Practical understandings of smart cities

In addition to these scientific definitions, it is interesting to consider the practical perspective. We reviewed exemplary practice perspectives in three different countries which currently promote smart cities, namely, Switzerland, Germany and Austria. All countries also collaborate in a so-called D-A-CH project to exchange smart city experiences (D-A-CH Energieeffizienze Stadt, 2014) and provide rich databases on implemented, ongoing and planned projects.

In Switzerland, a smart city is understood to be a city which provides the maximum available quality of life at minimal use of resources thanks to intelligent connections of infrastructure (transport, energy, communication) at different hierarchical levels (building, quarter, city; Smart City Schweiz, 2014a). A smart city links topics such as urban energy master planning, smart buildings, smart grids and supply technologies, smart mobility, good governance and stakeholder processes (see Fig. 1).

Fig. 1: Understanding of smart cities in Switzerland (Smart City Schweiz, 2014b).

In Germany, the term 'energy efficient city' is used rather than 'smart city'. The overall goal of an energy efficient city is to integrate different innovative technologies in order to promote the energy efficiency of cities. Integrative planning is a key issue (EnEff:Stadt, 2014).

Finally, in Austria, smart cities are understood as cities which i) consider the balance of greenhouse gases, ii) use innovative technologies that are highly resource and energy efficient, iii) provide systemic solutions for optimising energy systems, iv) promote public transport and soft mobility, v) promote social and organisational innovation through participatory processes, vi) promote early inclusion of investors and vii) contribute to environmental sustainability (Smart Cities Austria, 2014).

2.3 Goal and research questions of the study

Scrutinising the understandings of a smart city in science and in practice reveals that there are similarities and differences within and between the scientific and practical perspectives. The goal of this paper is to better understand what constitutes a smart city and what it means from the perspective of science in relation to practice. The following research questions form the core of our study:

- How can the term smart city be characterised from both the scientific and practical perspectives?
- What are the similarities and differences between the two perspectives?

2.4 A two-dimensional grid: level of integration and socio-technical embedding

The backbone of our analysis is a two-dimensional grid on which scientific studies and practical projects are placed. The two dimensions have been deduced from our review on scientific definitions and practical understandings of smart cities (see above). The first dimension is *level of integration*. Integration is a key characteristic of a smart city, both in scientific definitions and practical understandings. This dimension refers to the extent to which a study or project integrates different technologies and topics (e.g. integrating retrofitting of buildings, connection of different buildings, energy supply and a mobility concept in a city quarter). Correspondingly, the two poles of this dimension are termed ‘single focus on topic/technology’ and ‘integrated approach’. The second dimension is *socio-technical embedding*. Many scientific definitions and practical understandings stress that a smart city should be built on participatory decisions. This means that smart cities should provide participatory processes and platforms where citizens and stakeholders can express their needs and opinions regarding city development, technological decisions and so on (Carabias, Moser, Wilhelmer, Kubeczko, & Nelson, under review). Hence, citizens and stakeholders should be encouraged and empowered to actively shape their smart city. This dimension refers to the extent to which a study or project takes a socio-technical perspective, that is, a coupled perspective on technologies and people. Correspondingly, the two poles of this dimension are referred to as the ‘purely technical perspective’ and the ‘socio-technical perspective’.

Our research approach includes a literature review of scientific papers on smart city issues, as well as a review of concrete projects that have been carried out under the umbrella of the smart city concept. These studies and projects are characterised and compared according to the identified analysis grid.

3 METHOD

The basis of our analysis comprises a literature review of scientific studies on smart cities and practical projects carried out under the umbrella of the smart city project.

3.1 Literature review of scientific studies

We searched research databases such as ‘Web of Science’ and ‘SpringerLink’ to find scientific articles, papers, book chapters and books on smart cities. As a keyword, the term ‘smart city’ was used. Identified matches were handpicked to select only those papers which provide an overview on the concept of smart cities and discuss the researchers’ understanding or give a definition of smart cities. Papers were carefully read and relevant information, including the following characteristics, was transferred to an Excel database: article information, (title, date, author, type, etc.), abstract, keywords, definition of ‘smart city’, topics, perspective (science or practice), technologies, country/region and project status. We experienced a certain saturation point at the end phase of article collection (a moment when further collection of data no longer provided additional contributions). In total, $N = 27$ research papers were included in the analysis.

3.2 Literature review of practical projects

We searched for practical projects carried out under the umbrella of the smart city concept in three online project databases provided by Switzerland, Austria and Germany. All databases are connected to official smart city websites or energy-efficient cities in the case of Germany[1]. The Swiss database contains 77 Swiss projects (58 concepts, 13 pilot projects and 6 implemented projects), the Austrian database contains 34 projects (25 projects that are getting started and 9 implemented projects) and the German database contains 22 projects. For practical reasons, we selected the 19 implemented and pilot projects in Switzerland, the 9 implemented projects in Austria and the 22 German projects. In total $N = 50$ projects were included in the analysis. All databases provide detailed descriptions of projects, contexts and related websites or documents. Project descriptions were carefully read and relevant information was transferred to the same Excel file as for the scientific studies.

3.3 Characterisation of scientific studies and practical projects

All identified studies and projects were located on the ‘level of integration/socio-technical embedding’ grid described above. This allocation was carried out qualitatively and rather intuitively, based on descriptions of studies and projects. This means that for each project or study, a decision was made as to whether it describes one specific topic or technology or takes an integrated perspective on several issues (dimension: level of integration). Furthermore, it was determined whether the project or study describes purely technical approaches or integrates people (dimension: socio-technical embedding).

As a first step, scientific studies and practical projects are characterised separately. For some quadrants, a few examples of studies and projects are described for illustrative purposes. In a second step, both approaches are compared.

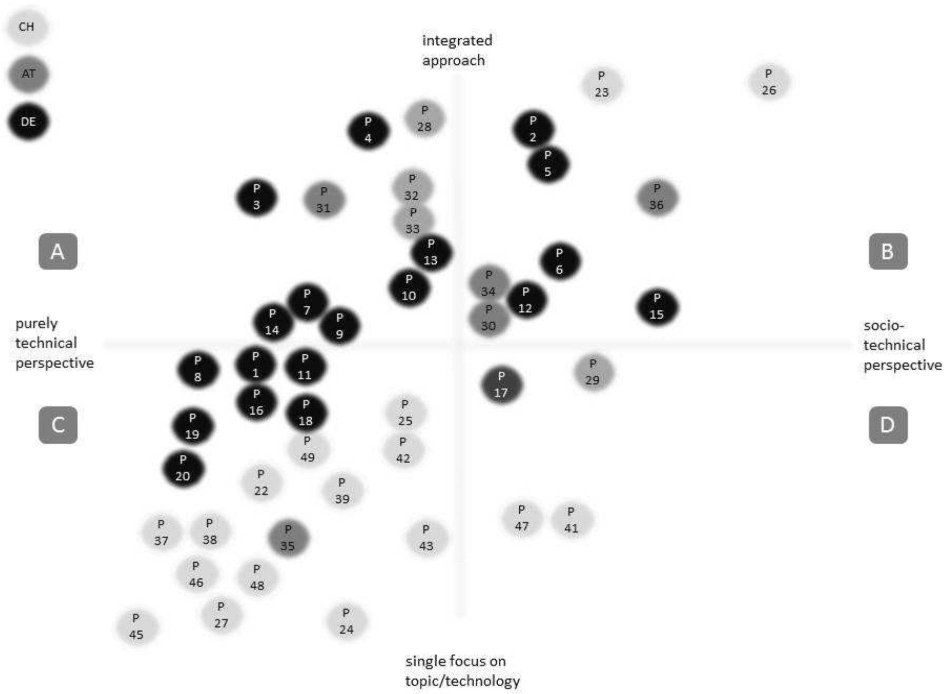

Fig. 3: Characterisation of practical smart city projects (pilot and implemented projects, $N = 46$ projects[2]). Black dots represent projects from Germany, dark grey dots represent projects from Austria and light grey dots represent projects from Switzerland. Numbers in circles represent numbers assigned to projects.

4 RESULTS

4.1 How can the term smart city be characterised from both the scientific and practical perspectives?

The allocation of the analysed scientific studies on the ‘level of integration/socio-technical embedding’ grid is displayed in Fig. 2. This indicates that almost all analysed research studies take an integrative perspective.

[1] Switzerland: http://ds1.dreifels.ch/smartcity/wprlist.aspx?LA=de (24.02.2014),
Austria: http://www.smartcities.at/stadt-projekte/smart-cities/ (24.02.2014),
and Germany: http://www.eneff-stadt.info/de/pilotprojekte/ (24.02.2014)

[2] Four projects could not be assigned to the grid, since they are accompanying research projects.

That is, they do not discuss single technologies in the context of smart cities (e.g. single focus on smart metering), but rather combine and link different topics and technologies (e.g. coupled perspective on building retrofitting and energy supply). Of course, this has to do with our literature research strategy, since we only included articles providing an overview on the smart city concept in our analysis. Many studies assign a key role to ICT in this integration endeavour (see, for example, Piro, Cianci, Grieco, Boggia, & Camarda, 2014; Ronay & Egger, 2014; Yovanof & Hazapis, 2009).

The analysed scientific studies seem to differ with respect to their degree of integrating societal issues. While about one-third of the analysed articles focus purely on integrated technologies, about two-thirds also consider the integration of people as an important characteristic of a smart city.

Table 2 provides examples of practical studies to illustrate different projects in all four quadrants. Typical examples of integrative projects are city quarter development projects which link topics such as buildings and their use, energy supply and mobility. The examples in Table 2 also indicate some key technologies of a smart city, such as e-mobility, ICT (for communication, monitoring and steering processes, as well as linking different systems), smart electricity grids, smart metering, district heating systems and so on.

ID, quadrant	Name & keywords	Technologies	Level of integration	Socio-technical embedding
P41, D	**E-cars** Pilot project, test of a series of e-cars; joint learning process and evaluation including all involved stakeholders	E-cars	Focus on one technology (e-mobility)	Project takes users' perspectives into consideration
P39, C	**Smart metering** Pilot project, installation of 1000 smart meters in a Swiss community	Smart metering, smart grid	Focus on distribution of electricity (smart metering and smart grids)	Households take part in pilot study by having a smart meter, no participatory processes described
P31, A	**Smart city quarter in Austria** Refurbishment of heritage protected buildings, realisation of a smart grid, establishment of car sharing infrastructure/e-mobility, district heating system, city-wide communication and information system	District heating, ICT, smart grid, refurbishment of buildings	Highly integrated (buildings, mobility, energy supply)	Rather technical focus, no participatory processes described
P15, B	**Net zero energy quarter** Links buildings and technical appliances, potential influences on electricity grid, analysis of user behaviour and raising awareness amongst users	Insulation, heat pumps, geothermal, monitoring technologies, ICT	Integrates buildings and energy supply without e.g. mobility	Includes user perspectives in project

Table 2: Illustration of practical projects.

4.2 What are the similarities and differences between the two perspectives?

When comparing the scientific understanding of smart cities and concrete implemented projects (i.e. comparing Fig. 2 and Fig. 3) in the context of smart cities in Switzerland, Germany and Austria, it becomes evident that the scientific and practical understandings have both similarities and differences. One similarity is that both understandings barely include projects which are singular and at the same time participatory (quadrant D). It also becomes clear that many of the analysed studies and projects in science as well as practice neglect participatory approaches, instead taking a rather technical perspective. Issues such as stakeholder processes, participation and integrating users' needs are often not at the core of the analysed studies and projects, although some definitions of smart cities stress these aspects (such as Caragliu et al., 2011).

There are also some differences between the analysed scientific and practical approaches: While from a scientific perspective, almost all analysed articles take an integrated perspective, this is not the case for the analysed implemented projects. There are many projects under the umbrella of smart cities (or energy-efficient cities in Germany) that take a rather narrow perspective on singular aspects or technologies (e.g., on smart grids, e-mobility, or ICT). Many analysed projects take a semi-integrated perspective. By this, we mean that they integrate topics such as buildings and energy supply but exclude, for example, the topic of mobility.

5 DISCUSSION AND CONCLUSIONS

The goal of this article is to better understand what a smart city constitutes and how this term is understood in scientific studies and concrete practice projects. We identified relevant overview research articles, as well as a number of concrete projects carried out in Switzerland, Germany and Austria. Based on a thorough literature review, two important dimensions characterising smart cities have been identified: *level of integration* and *socio-technical embedding*. All identified scientific studies and practice projects were characterised on a grid composed of these two dimensions.

Our analysis indicates that the scientific understanding of smart cities in the analysed studies is very integrative with respect to technologies and topics. However, not all analysed scientific studies integrate people as well. Only some take a so-called socio-technical perspective on smart cities, and thus, a coupled perspective including technologies and participatory processes for stakeholders and inhabitants. In contrast to scientific approaches, the analysed practical projects more often consider single technical approaches under the umbrella of a smart city. In general, the practical projects seem to have a narrower focus compared to the analysed scientific studies.

5.1 Critical reflections

The outcomes of our analyses are, of course, strongly dependent on the choice of research studies and practical projects. By only taking into account research studies that provide an overview on the smart city concept, research projects focusing on singular technologies of smart cities (e.g. smart grids) have been excluded. Since one of the goals of this paper was to better understand what a smart city constitutes in science in a general sense, this literature selection strategy seems appropriate. However, we need to be aware that including research articles covering specific single technologies of a smart city would probably alter the identified patterns illustrated in Fig. 2.

These considerations also apply to the practical projects. We decided to analyse three European countries which share experiences regarding smart cities (D-A-CH Energieeffiziente Stadt, 2014) and used their databases to select projects. These databases differ with respect to their structure, as well as the number and scope of included projects. For example, the Swiss database includes a greater number of projects than the German and Austrian databases. This, of course, makes comparisons between countries difficult. One possible explanation for the differing patterns of countries in Fig. 3 is that the Swiss database also includes projects which are related to single smart city technologies (such as e-cars, smart metering and smart grids), while the Austrian and German databases tend to include projects on city and quarter development, exhibiting a more integrative perspective.

5.2 Need for further research

Since all the analysed projects have been planned or implemented in Central Europe, a more international perspective could potentially offer important insights into the smart city concept as implemented in other regions of Europe and on other continents. It would also be interesting to consider the timelines of projects to better understand the interplay between research approaches and practical implementation. For example, one could analyse how the call for more integrative smart city approaches in science is reflected in practical projects, as well as how experiences in practical projects shape scientific ambitions.

Another line of future research could more systematically analyse and structure the technologies being used to realise smart cities. Such a structure could help in elucidating how different technologies are linked to connect infrastructures on different hierarchical levels (e.g. building, city quarter, city).

5.3 Implications of the findings

As mentioned above, integration of technologies and socio-technical embedding are key aspects of a smart city (Caragliu et al., 2011). In order to reach integration of technologies and people, many projects discuss the important role of ICT (Piro et al., 2014, Ronay & Egger, 2014, Yovanof & Hazapis, 2009). One can even say that ICT represents a backbone of smart cities. Such technologies allow connections between different types of infrastructure, monitoring and steering processes and the promotion of communication between people. They may also be used to promote participation of inhabitants and stakeholders in shaping decisions (e.g. e-governance). However, city administrations need to be aware that not all inhabitants are able or willing to use ICT. Successful participation strategies should therefore be appropriate to bridge the 'digital divide' amongst people (Hospers, 2012; Partridge, 2004). It is of vital importance that such alternative, complementary strategies for participation be developed in the process of becoming a smart city. In other words, ICT alone does not make a city smart.

The identified similarities and differences between science and practice bear challenges, but also opportunities. The analysed scientific studies ask for integrated approaches, while many analysed projects focus on specific technologies or topics. This difference represents a challenge and at the same time an opportunity for both science and practice. For practical projects, our findings may indicate that there is a need for more integration from the beginning of planning a smart city initiative, both with respect to technologies and topics and the involvement of people. The idea of a smart city is not one of piecemeal, topic-related solutions, but instead of integrated solutions which link infrastructure, ICT and people. This means that project teams should be composed of people with different backgrounds (in energy, mobility, city development, business, planning, architecture, social work, etc.). For scientific projects, our findings may indicate that more concrete ideas and methodological approaches are needed to reach the asked levels of integration. Concrete projects might also inform research studies on the practical feasibility of technical options, as well as on social conflicts (e.g. due to lack of acceptance of specific technologies) in projects. Moreover, research holds tremendous potential for interdisciplinary collaboration to develop integration methods jointly. The field of smart cities represents an interesting field for so-called transdisciplinary research (Häberli et al., 2001; Hirsch-Hadorn et al., 2008; Stauffacher, 2011), where science and practice collaborate closely to jointly develop technically sound and socially acceptable solutions for smart cities.

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