Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Smart City Research 1990-2016

Peter Ingwersen[1] and Antonio Eleazar Serrano-López[2]
[1] Aalborg University, Denmark - [2] Carlos III University Madrid, Spain

Abstract:

This scientometric analysis of the area of 'smart city(ies)' research covers 1990-2016, divided into three nine year periods: 1990-1998; 1999-2007; and 2008-2016. The methodology is partly based on the 'issue management' approach by Lancaster & Lee (1985) partly on common publication and citation analysis of the set of source documents (n=4,725), the set of their references (n=27,099) and the set of publications (n=7,863) citing the source documents. Median age analyses are included for the sets of references and citations to the source documents. DIVA-like diagrams (Database Information Visualization and Analysis system) are used to demonstrate the distribution of source documents over document types, time and volume of citations obtained. Social Network Analysis (SNA) is applied to topic modeling of the top-100 central WoS Categories of 'smart city(ies)' research and to the set of references.

Findings show that the first mention of the concept 'smart city(ies)' in publication titles takes place in 1999. The research area demonstrates a strong multidisciplinary nature and an exponential growth of research publications (in WoS) 2008-2016 dominated by China, Italy, USA, Spain and England. The same five countries are also among the most citing and cited countries. Aside from a constantly strong ICT (Information and Communication Technology) and Electrical/Electronic Engineering presence 'sustainability' elements (Energy, Transport, Environment) are also vital, in particular during the first and third analysis period. The references from the source documents have more distinct topical clusters than the source documents. Artificial Intelligence (AI) appears as a novel field among the source documents 2008-2016, but disappears from the top-25 list in the citing documents. Instead Economics, Water Resources and Meteorology & Atmospheric Sciences move into the list.

Proceedings papers, as in many other engineering and technology based research fields, are the dominant document type (70 %) but have small citation impact (0.6 c/p), thus decreasing the overall impact of the area to 3.6 c/p. Journal articles are the most cited type with 76 % of all citations received (impact 2008-2016: 7.5 c/p). Most citations to journal articles derive from journal articles themselves (76 %).

Keywords:

smart city research; publication and citation analysis; median age of references; median age of citations; topic modeling; social network analysis; clustering

Introduction

Our objectives are to follow the development of research in the field of 'smart cities' 1990-2016 and to observe how the central concepts involved in the field evolve and relate to each other. In addition, to analyze which journals, research fields, institutions and countries that contribute directly to 'smart city' publications over time, including their references (knowledge import) and citations to the research (knowledge export). The methodology is partly based on F.W. Lancaster's Issues Management approach (1985) partly on the methods applied in the SAPIENS (Scientometric Analyses of the Productivity and Impact of Eco-economy of Spain) project (Sanz-Casado et al., 2013).

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

The concept of ’smart cities’ is somewhat fuzzy and no agreed definition exists in the scientific and technical literature. Several definitions are put forward, depending on the meanings of the word “smart”: intelligent city, knowledge city, ubiquitous city, sustainable city, digital city, etc. (Cocchia, 2014). The concept embraces automated and intelligently flowing urban transport according to demand; seamless interurban transport; green energy; urban planning (roads, building construction, infrastructure, parks); intelligent houses, flats and shopping areas; learned societies; etc. Although the idea behind the concept seems well understood around the world in terms of intelligent technology involvement, incorporating certain aspects of AI, there is definitively more to the concept than digitalization. Nam & Prado view the concept in broader terms, involving three dimensions: technology; people; and community/institutions (p. 284-285). Also associated with three dimensions, Harrison et al. (2010) define the concept to concern an “instrumented, interconnected and intelligent city.” Instrumentation enables the capture and integration of live real-world data through the use of sensors, kiosks, meters, personal devices as well as social networks. Interconnected implies the integration of such data into institutional computational platforms and the communication of such information among the various city services. Intelligent refers to the inclusion of complex analytics, modeling, optimization and visualization in the operational institutional processes to make improved operational decisions.

The present study forms part of a range of scientometric analyses to investigate various aspects of the emerging field of ‘smart city(ies)’ research, e.g. Ricciardi and Za (2015) analyzing 100+ documents stored in the websites of two international conferences on smart cities. They map the interdisciplinary nature of the field. Su, Lyu, Yang et al. (2015) studied the global scientific production and development trends limited to construction and building technology research journals of ‘smart city(ies)’. “[The] data was collected from the Science Citation Index-Expanded (SCIE) database and Journal Citation Reports (JCR). The published papers from the subject of construction and building technology and their journals, authors, countries and keywords spanning over several aspects of research topics, proved that architecture/building research as such grew rapidly since the mid-eighties, and the trend still continues in the recent ‘smart city(ies)’ era.” (Su, Lyu, Yang et al., 2015, p. 449). The objectives of their study were to identify the journals in the field as well as to propose a quality evaluation of those journals. Ojo, Dzhusupova & Curry (2016) applied Scopus journal and proceedings papers data to examine the smart-city research field limited to the concepts of ‘smart cities’ and ‘intelligent cities’. Durán-Sánchez et al. (2017) based their analysis on WoS and Scopus data, with “[the] aim to describe an actual stage of scientific researches on the smart cities focused on sustainability and life quality.” In accordance with this purpose, “[a] comparative bibliometric study [was] done, analyzing correlations between growths, coverage, overlapping, dispersion, and concentration of articles in the two data sources.” (p. 159). Most recently Mora, Bolici & Deakin (2017) and Mora, Deakin & Reid (2018) made scientometric analyses of the extend of the ‘smart city(ies)’ research community, characteristics of publications, external influencing factors and influence of the research and researchers on the knowledge domain (Mora, Bolici & Deakin, 2017, p. 5). They included both academic publications and gray literature by applying a range of databases including WoS, Scopus, Google Sholar and IEEE Xplore as well as Science Direct and by searching the terms ‘smart city’ and ‘smart cities’ in title, abstract, keywords and text body 1992-2012. Their set of source documents for analysis was 1,067 publications. In Mora, Deakin & Reid (2018) the analyses are based on the same dataset as in the 2017 article, but make use of co-citation and text analysis in order to map the structure of the field and developing research themes. The two former analyses from 2015 are

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

published as book chapters while the two latter studies are in the form of journal articles. All four investigations are by researchers from within the 'smart city' community.

Our analysis is done by scientometricians outside the research field of 'smart city(ies)' and based on the discussions in Cocchia (2014), Nam & Pardo (2014) as well as Harrison et al. (2010). We have designed a conceptual retrieval profile for the present study applied to the Web of Science (WoS) databases, SCI-Expanded; SSCI; and the corresponding Proceedings Citation Indexes, covering 1990-2016, and consisting of the following concepts covering Nam & Pardo's three dimensions (Appendix 1):

"smart city" OR "smart cities" OR
"digital city" OR "digital cities" OR
"intelligent city" OR "intelligent cities" OR
"smart community" OR "smart communities" OR
"knowledge city" OR "knowledge cities" OR
"sustainable city" OR "sustainable cities" OR
"green city" OR "green cities"

One should take note of the fact that according to Nam & Pardo (2011) there exists a profound discrepancy between a *vision* of 'smart cities' and the *actual enabling* of or how-to-do 'smart cities' in the academic literature. However, to separate these two perspectives of 'smart cities' is not possible, neither in WoS or in the scientometric analysis.

As part of the analyzes we wish to observe how the involved concepts interact and the field develops through time. We have selected 1990 as the starting point for the analyzes in order to observe if concepts of 'smart cities' are in evidence prior to the raise of PCs and smart phones, the public Internet and social networks, i.e., central technical components of 'smart cities'. We have divided the period into three 9-year stages: 1990-1998; 1999-2007; and 2008-2016.

We work with three research questions (RQ):

1. How does research on 'smart city(ies)' develop?
2. What are the characteristics of the references (research import) in and the citations (research export) to the original source set of research publications on 'smart city(ies)'?
3. How do the top-topics representing the research field relate to one another?

Research question 1 seeks to pinpoint when the concepts appear and how the field of 'smart city(ies)' develops over the three periods with respect to document types, applied research fields, publishing sources as well as the most productive institutions and countries? The aim is to observe the main characteristics and development patterns of 'smart city(ies)' research.

Research question 2 investigates the top research fields and median age of the references (Egghe, Rousseau & Guns, 2018, p. 180) from which knowledge is imported to 'smart city(ies)' research over the three periods. For the last period 2008-2016 this is compared to the knowledge exported from 'smart city(ies)' research by means of the citations to the source documents.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Median age of the citations is investigated as are top-topics, institutions and countries publishing the citations. The motivation behind such analyses is 1) to observe if the topical and median age characteristics of source documents, references and citations are similar and 2) in particular to compare the original source set with the citing set of publications as to the latter three parameters and to observe if the export goes to new or mainly the same S&T fields.

Research question 3 seeks to understand the relationships between the central WoS Categories representing 'smart city(ies)' research by means of mapping technology, based on the WoS Categories of the articles and proceedings papers. We compare the set of source documents 2008-2016 with the set of their references.

The article is structured as follows. After the Introduction the methodology is described, followed by the result and discussion sections in accordance with the research questions. Concluding remarks bring the article to a close.

Methodology

We rely partly on Lancaster's 'issues management' methodology (1985), partly on the retrieval and analysis methods and tools developed in the SAPIENS project (Sanz-Casado et al., 2013; Sans-Casado et al, 2014); Serrano-López, Ingwersen & Sanz-Casado, 2017). The 'issues management' research methodology was originally presented by Lancaster[1] and investigated empirically by Lancaster & Lee (1985). The idea was to investigate the first-time appearance as well as the development over time and spreading into scientific journals and fields and further into applied science and technology of a particular concept, in their case 'acid rain'. In order to do so the range of bibliographic databases hosted by Dialog (ProQuest Dialog, 2017) was searched and analyzed by means of the Dialog analysis tools at that time. Then selected relevant databases were searched further in depth.

In the present case we initially searched online the TS= search fields of Web of Science (WoS), i.e. Science Citation Index, Social Science Citation Index as well as the corresponding conference proceedings indexes, by means of the retrieval profile (Appendix 1), i.e. the title, abstract and keyword plus (i.e. the 'TS=' fields). With respect to Research Question 1 the analyses were done online by means of the analysis tools embedded in WoS between November 1-30, 2017 and the download of records took place November 3-18 and December 6. In contrast to Lancaster & Lee (1985) we investigated a range of concepts, the retrieval profile outlined Appendix 1, and not only one concept. We also concentrated on one meta database (WoS) and did not investigate the distribution over several different disciplinary databases or Google Scholar (GS). By using WoS one has access to *all* the affiliations of all the authors of each published item indexed by WoS. Disciplinary databases do not provide data on all secondary authors and the coverage of GS is regarded too fuzzy for our purpose. Simultaneously, two subsets from WoS was retrieved and downloaded from the WoS databases covering the three periods: 1) 4,725 source records, including 116,043 references, and 2) 16,901 citations to the source records on 'smart city(ies)'

[1] In presentations during his Fulbright research visit at the Royal School of Library and Information Science, Copenhagen, 1984/85.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

distributed over the three analysis periods combined. The source documents, references and subset 2 constitute in total of 62.2 MB of research data 1990–2016 and were applied to Research Questions 2-3. The source and citing datasets were restricted to journal and review articles as well as conference proceedings papers and excluding document types like book reviews, news items and editorial materials.

Both datasets were reloaded into a local SQL database configuration in order to be able to extract a variety of data over the aforementioned three periods of time to form a range of analyses and indicators. The three citing windows were the same as the publication periods. Along this process both datasets were cleaned up with respect to institutional name forms. The following indicators and analyses became generated by means of the two datasets as well as the online WoS search and analyses of the entire 'smart city(ies)' research area (November 2017), divided into the three publication periods and citation windows:

First-time appearance of the search concepts (see above and Appendix 1) in publication titles in context of the development of the publication frequency (Fig. 1) found via the basic index (TS=) fields. In this conceptual issue management analysis we have used publication titles to assure that in this tracking process the publication focus is directly on the concept searched for. Frequency of the various retrieval concepts for the entire period (Fig. 2) and document type distribution follow. DIVA (Database Information Visualization and Analysis system)-like diagrams visualize annual distributions of publications over document types. Top-countries, institutions, journals and topical categories contributing to the field are then displayed in the form of tables, answering RQ1. DIVA is a set of MATLAB programs that can be used for mapping research specialties through samples of their journal literature. It was developed at Oklahoma State University, in Stillwater, Oklahoma, USA, by Morris (2002) and other students in the Electrical Engineering and Industrial Engineering Departments. The software is currently discontinued, so we developed some functions in R to make similar analyses and maps. These developments were based on Efrain-Garcia & Garcia-Zorita's (2016) method and include packages tidyr (Wickham, 2016), imputeTS (Moritz & Bartz-Beielstein, 2015), stringi (Gagolewski & Tartanus, 2016) and parsedate (Csárdi & Torvalds, 2017) in order to clean data, removing duplicate and incomplete records. In our case document type was used as factor, the publication date to make the timeline and the frequency of citations to source records for the point size. Also Efrain-Garcia & Garcia-Zorita (2016) was used to extract information from multi-valued fields as WoS categories, addresses, authors, etc. and also to extract specific data like countries. This method allowed us to obtain full information of each record, including affiliation of every author, not only reprint author.

With respect to RQ2 citation impact calculations was made for the three analysis periods. This is followed by analyses of the knowledge import based on the references in the source documents of the field and knowledge export based on the documents citing the source publications for the period 2008-2016, in terms of topical, institutional and country distributions.

Topic modeling of the top-100 central WoS Categories of 'smart city(ies)' research was done on the 4,283 articles and proceedings papers published during the most recent period 2008-2016 by means of SNA technique. We compared this map with a corresponding SNA (Social Network

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Analysis) diagram made of the top-50 WoS Categories to be readable of the 27,099 referenced documents that was indexed by WoS. We also tried out to construct the diagrams by means of top-200 author-generated abstract terms (Arun et al., 2010; Cao et al., 2009; Deveaud et al., 2014) and clustering technique, with stop and common/general words omitted (Griffith & Steyvers, 2004). However, the resulting diagrams did not provide meaningful displays, since the single terms could be interpreted in multiple ways. The SNA diagrams using WoS Categories thus offer a better understanding of the concept relationships and answer RQ3. SNA was defined by Wetherell, Plakans and Wellman (1994) through its main characteristics: "(1) conceptualizes social structure as a network with ties connecting members and channeling resources, (2) focuses on the characteristics of ties rather than on the characteristics of the individual members, and (3) views communities as 'personal communities', that is, as networks of individual relations that people foster, maintain, and use in the course of their daily lives." (p. 639).

Findings

The distribution of the 'smart city(ies)' publications is highly skewed with a highly exponential growth during the recent period, 2008-2016, Fig. 1. Thus, our analysis extends the exponential curve initially demonstrated by Mora, Bolici & Deakin (2017, p. 7) up to 2012.

The first retrieval concept to appear on 'smart city(ies)' in publication titles is 'sustainable city(ies)', 1991 in a 'Solar Energy' conference. No publications appeared in the field in 1990 according to the searched profile. The major aspect of research is 'sustainability' during the first analysis period. The digital and engineering aspects appear initially in 1994 with 'intelligent city(ies)', still in the first period, 1990-1998, and obtains even more attention in 1999: 'smart city(ies)', 'digital city(ies)' and 'smart community(ies)'. 'Knowledge city(ies)' is a more recent concept (2008). The last analysis period 2008-2016 is domineered by the 'smart city(ies)' concept itself, and digital as well as engineering/infrastructural dimensions of the field are predominant. For the total 27 year period, 'smart city(ies)' is the leading retrieval concept, followed by 'sustainable city(ies)', Fig. 2.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

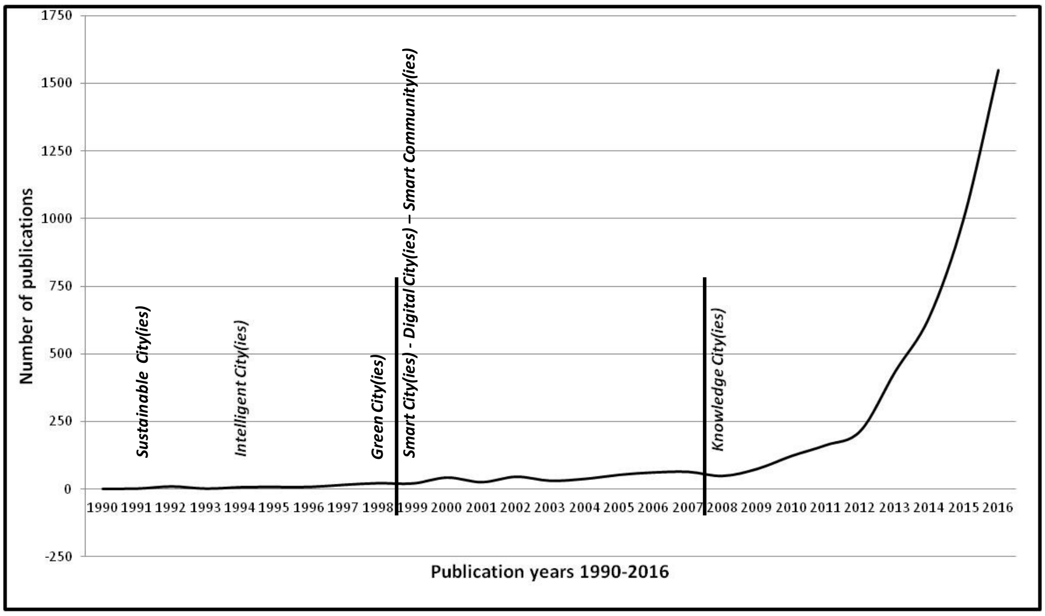

Fig. 1. Publications on "smart city(ies) 1990-2016 (n=4,725), divided into three analysis periods (vertical lines). The first appearance in publication titles of the central concepts from search profile shown vertically. WoS, Nov. 2017.

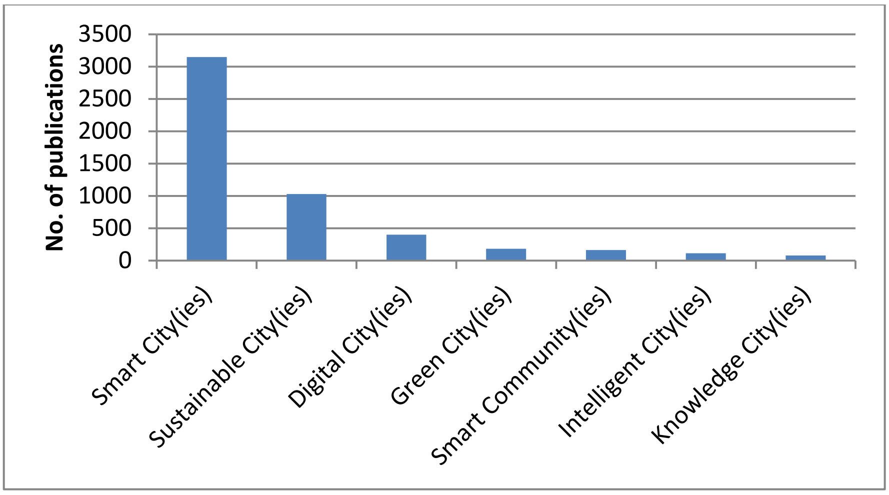

Fig. 2. Number of publications on 'smart city(ies)' concepts retrieved from the total dataset 1990-2016 (n=4,725) in titles, abstracts and keyword plus, WoS, Nov. 2017.

Table 1. Distribution of document types covering 'smart city(ies)' over the three analysis periods 1990-2016 (n=4,725), WoS, Nov. 2017.

1990-1998:	**No.**	**%**	**1999-2007:**	**No.**	**%**	**2008-2016:**	**No.**	**%**
Proceedings Papers	32	47.8	Proceedings Paper	190	50.7	Proceedings Paper	3012	70.3
Proc. Papers - Article	6	9.0	Proc. Papers - Article	84	22.4	Proc. Papers - Article	34	0.8
Journal Articles	25	37.3	Journal Article	95	25.3	Journal Article	1170	27.3
Review Articles	4	5.9	Review Article	6	1.6	Review Article	67	1.6
n:	67	100		375	100		4283	100

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

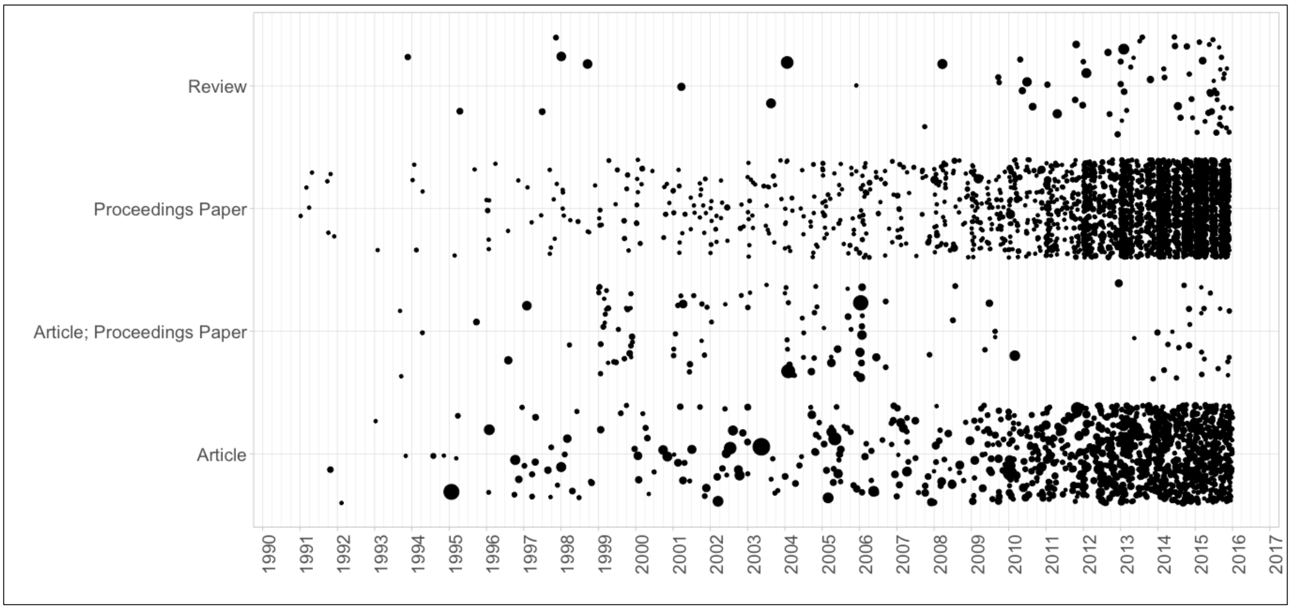

Fig. 3. DIVA-like diagram of publication evolution 1990-2016 through document types and times cited (dot size), (n=4,725). WoS, Nov., 2017.

The distribution of document types is significant, Table 1. The proceedings papers, also in the form of journal articles, as well as actual journal articles and review articles are constant over the last two periods (approx. 70 % for proceedings papers; 25 % for journal articles; and 1.6 % for review articles). However, the proportion of the proceedings papers proper is increasing significantly over the years (from 50.7 % to 70.3 %) whilst the proportion of proceedings papers in the form of articles decreases (22.4 % to 0.8 %). This phenomenon coincides with the contents of the field becoming increasingly about digitalized, technical and applied matters, that is, within engineering and computer science disciplines for which proceedings papers constitute the common publishing channel. The DIVA-like diagram, Fig. 3, demonstrates the concentration of the various document types during the total analysis period, 1990-2016. The concentration of conference proceedings papers initiates 2014, whereas it starts a year later for journal articles. Proceedings papers in the form of journal articles have distinct periods without published items, e.g. 2008 and 2013-2014. Simultaneously, one may observe that the proceedings papers hardly possess items that are heavily cited, whereas journal article proceedings papers, research articles and review articles all display source items that are substantially cited (larger dots), even from older publication years. See also Table 6 for document type citation impacts.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Top countries, universities, topics and sources

As in many other (sustainable) engineering fields (Sans-Casado et al., 2013; 2014) China has become the most productive country during the last decades, Table 2. In the first period, with a small production in the 'smart city(ies)' research field, the top countries are mainly European. During the next period China, Japan and USA top the list and the European countries are pushed down the ranking. In the recent highly productive period, 2008-2016, Fig. 4, China continues to be the predominant country, followed by Italy and the US (intense green on figure). Japan loses ranking and Brazil, South Korea and several smaller European countries appear in the last period.

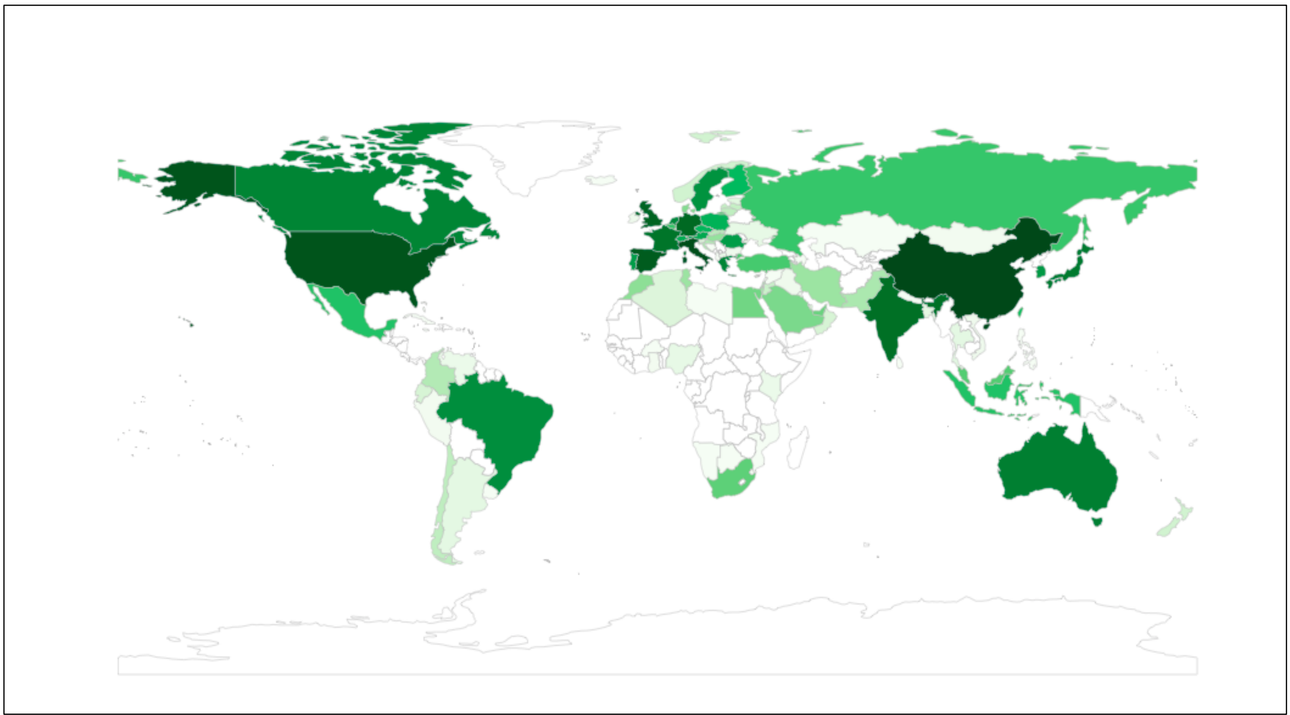

Fig. 4. The most productive countries of research on 'smart city(ies)' during the period 2008-2016. Legend: the more intense green, the higher productivity. WoS, Nov., 2017.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Table 2. Development of top-25 publishing countries in 'smart city(ies)' research over three periods, 1990-2016, WoS, Nov. 2017.

		Publishing Countries			
1990-1998 (n=67):		1999-2007 (n=375):		2008-2016 (n=4,283):	
ENGLAND	15	PEOPLES R CHINA	75	PEOPLES R CHINA	643
USA	8	JAPAN	44	ITALY	538
NETHERLANDS	6	USA	43	USA	467
GERMANY	5	ENGLAND	35	SPAIN	358
ITALY	4	AUSTRALIA	19	ENGLAND	244
CANADA	2	NETHERLANDS	16	GERMANY	194
DENMARK	2	PORTUGAL	15	INDIA	178
KENYA	2	ITALY	14	FRANCE	176
SCOTLAND	2	CANADA	13	JAPAN	168
SWITZERLAND	2	GERMANY	7	AUSTRALIA	161
		GREECE	7	CANADA	126
		INDIA	6	GREECE	124
		SCOTLAND	6	NETHERLANDS	113
		SPAIN	6	BRAZIL	108
		FINLAND	5	SWEDEN	96
		SINGAPORE	5	SOUTH KOREA	86
		SOUTH AFRICA	5	PORTUGAL	85
		BELGIUM	4	ROMANIA	82
		MALAYSIA	4	IRELAND	67
		SWEDEN	4	SINGAPORE	65
		TAIWAN	4	AUSTRIA	64
		AUSTRIA	3	SWITZERLAND	61
		CHILE	3	POLAND	59
		FRANCE	3	CZECH REPUBLIC	58
		LITHUANIA	3	FINLAND	57

Table 3. Development of research institutions producing research on 'smart city(ies)' over three periods, 1990-2017. WoS, Nov., 2017.

		Research Institutions			
1990-1998 (n=67):		1999-2007 (n=375):		2008-2016 (n=4,283)	
UNIVERSITY OF LONDON	3	KYOTO UNIVERSITY	20	CHINESE ACADEMY OF SCIENCES	64
VRIJE UNIVERSITEIT AMSTERDAM	3	CHINESE ACADEMY OF SCIENCES	10	UNIVERSITY OF BOLOGNA	47
FREE UNIV AMSTERDAM	2	NIPPON TELEGRAPH TELEPHONE CORP.	10	CENTRE NATIONAL DE LA RECH. SC. CNRS	40
LEEDS METROPOLITAN UNIVERSITY	2	UNIVERSITY OF TOKYO	8	POLYTECHNIC UNIVERSITY OF TURIN	39
POLYTECHNIC UNIVERSITY OF MILAN	2	PEKING UNIVERSITY	7	ROYAL INSTITUTE OF TECHNOLOGY	39
UNIVERSITY COLLEGE LONDON	2	TSINGHUA UNIVERSITY	7	POLYTECHNIC UNIVERSITY OF MILAN	37
UNIVERSITY OF BRISTOL	2	UNIVERSITY OF TORONTO	7	WUHAN UNIVERSITY	35
UNIVERSITY OF GEORGIA	2	UNIVERSITY OF HONG KONG	6	UNIVERSITY OF LONDON	33
UNIVERSITY OF KENTUCKY	2	WUHAN UNIVERSITY	6	UNIVERSITY OF CALIFORNIA SYSTEM	32
UNIVERSITY SYSTEM OF GEORGIA	2	SHANGHAI JIAO TONG UNIVERSITY	5	UNIVERSITY OF NAPLES FEDERICO II	32
		UNIVERSITY OF AMSTERDAM	5	CZECH TECHNICAL UNIVERSITY PRAGUE	31
		UNIVERSITY OF SALFORD	5	TECHNICAL UNIVERSITY OF BERLIN	30
		UNIVERSITY OF SHEFFIELD	5	VIENNA UNIVERSITY OF TECHNOLOGY	29
		CONSIGLIO NAZIONALE DELLE RICERCHE CNR	4	DELFT UNIVERSITY OF TECHNOLOGY	28
		MASSACHUSETTS INSTITUTE OF TECHNOLOGY	4	STATE UNIVERSITY SYSTEM OF FLORIDA	28
		MURDOCH UNIVERSITY	4	NATIONAL TECHNICAL UNIVERSITY OF ATHENS	26
		NATIONAL TECHNICAL UNIVERSITY OF ATHENS	4	INRIA	25
		UNIVERSITY OF NAPLES FEDERICO II	4	POLYTECHNIC UNIVERSITY OF BUCHAREST	25
		ARTILLERY ACAD	3	POLYTECHNIC UNIVERSITY OF CATALONIA	25
		HONG KONG POLYTECHNIC UNIVERSITY	3	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	24
		INDIANA UNIVERSITY SYSTEM	3	SAPIENZA UNIVERSITY ROME	24
		JAPAN SCIENCE TECHNOLOGY AGENCY JST	3	UNIVERSITE PARIS SACLAY COMUE	23
		NAT. INST. OF INF. COMM. TECH. NICT JAPAN	3	UNIVERSITY OF MELBOURNE	21
		NATIONAL UNIVERSITY OF SINGAPORE	3	UNIVERSITY OF TRENTO	21
		NEWCASTLE UNIVERSITY UK	3	ZHEJIANG UNIVERSITY	21

Table 3 demonstrates the development of publishing institutions 1990-2016. Whilst the first period is characterized by Anglo American institutes, the second period is dominated by Japanese and Chinese research institutions. In the third period one observes the high productivity by Italian and French players, such as, University of Bologna, Polytechnic Universities of Turin and Milan and CNRS, although France is ranked only as no. eight on the country list. Other European institutes

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

also enter the top-25 list with a few additional US representatives. Notice that Kyoto University disappears from the list in 2008-2016, but was ranked 1 in the previous period.

Table 4. Development of WoS Categories for 'smart city(ies)' research over three periods, 1990-2016. WoS, Nov., 2017.

WoS Categories					
1990-1998 (n=67):		**1999-2007 (n=375):**		**2008-2016 (n=4,283):**	
URBAN STUDIES	16	URBAN STUDIES	97	ENGINEERING ELECTRICAL ELECTRONIC	1285
ENVIRONMENTAL SCIENCES	15	COMPUTER SCIENCE THEORY METHODS	68	COMPUTER SCIENCE INFORMATION SYSTEMS	849
ENERGY FUELS	13	ENGINEERING CIVIL	63	COMPUTER SCIENCE THEORY METHODS	819
ENVIRONMENTAL STUDIES	13	COMPUTER SCIENCE INFORMATION SYSTEMS	62	TELECOMMUNICATIONS	629
PLANNING DEVELOPMENT	11	ENVIRONMENTAL STUDIES	62	COMPUTER SCIENCE INTERDISCIPLINARY APP.	435
CONSTRUCTION BUILDING TECHNOLOGY	8	ENGINEERING ENVIRONMENTAL	54	URBAN STUDIES	330
ENGINEERING CIVIL	7	ENVIRONMENTAL SCIENCES	49	COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE	326
ENGINEERING ENVIRONMENTAL	6	PLANNING DEVELOPMENT	38	COMPUTER SCIENCE HARDWARE ARCHITECTURE	326
GEOGRAPHY	4	COMPUTER SCIENCE INTERDISCIPLINARY APPL.	34	GREEN SUSTAINABLE SCIENCE TECHNOLOGY	283
COMPUTER SCIENCE INTERDISCIPLINARY APP.	3	COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE	29	ENVIRONMENTAL SCIENCES	252
COMPUTER SCIENCE INFORMATION SYSTEMS	2	ECOLOGY	25	ENERGY FUELS	234
COMPUTER SCIENCE THEORY METHODS	2	GEOGRAPHY	25	COMPUTER SCIENCE SOFTWARE ENGINEERING	221
ECOLOGY	2	REMOTE SENSING	22	ENVIRONMENTAL STUDIES	221
ECONOMICS	2	ARCHITECTURE	21	ENGINEERING MULTIDISCIPLINARY	154
EDUCATION SCIENTIFIC DISCIPLINES	2	SOCIAL SCIENCES INTERDISCIPLINARY	21	PLANNING DEVELOPMENT	144
GREEN SUSTAINABLE SCIENCE TECHNOLOGY	2	ENGINEERING ELECTRICAL ELECTRONIC	20	MANAGEMENT	126
INFORMATION SCIENCE LIBRARY SCIENCE	2	CONSTRUCTION BUILDING TECHNOLOGY	19	GEOGRAPHY	116
PUBLIC ENVIRONM. OCCUPATIONAL HEALTH	2	TRANSPORTATION	18	TRANSPORTATION SCIENCE TECHNOLOGY	116
SOCIAL ISSUES	2	GEOGRAPHY PHYSICAL	16	AUTOMATION CONTROL SYSTEMS	110
SOCIAL SCIENCES INTERDISCIPLINARY	2	COMPUTER SCIENCE SOFTWARE ENGINEERING	14	REMOTE SENSING	106
TRANSPORTATION	2	GREEN SUSTAINABLE SCIENCE TECHNOLOGY	14	CONSTRUCTION BUILDING TECHNOLOGY	104
WATER RESOURCES	2	TELECOMMUNICATIONS	14	SOCIAL SCIENCES INTERDISCIPLINARY	103
		IMAGING SCIENCE PHOTOGRAPHIC TECHNOLOG	12	ENGINEERING ENVIRONMENTAL	99
		MANAGEMENT	12	ENGINEERING CIVIL	98
		GEOSCIENCES MULTIDISCIPLINARY	11	INSTRUMENTS INSTRUMENTATION	98

The development of topical categories across the three periods, Table 4, demonstrates the *sustainable aspects* of ‘smart city(ies)’ dominating the initial period, 1990-1998. This in line with the findings concerning the central concepts associated with ‘smart city(ies)’, displayed in Fig. 1. Although ‘Urban Studies’ serves as the leading category in the second period, the ‘*Engineering Electrical Electronic*’ category jumps from rank 16 to rank one in the recent period. *ICT* (Information*,* Communication Technologies) becomes more central to the field as does *urban infrastructure* research (Engineering Civil; Planning Development; Architecture; Construction Building Technology; and Transportation). *Environmental S&T* research with ‘Green Sustainable Science Technology’ and ‘Environmental sciences’ return in strength, again to become important. See Figure 7 for a demonstration of the topical relationships in the source document set 2008-2016.

In Table 5, in the initial period 1990-1998, the top-source or channel names mirror the sustainability categories. There is a mix of conferences and journals. In the second period, 1999-2007, the conferences are quite dominant on the top-25 list, but sustainability still plays a central role, according to conference titles. During the same period one observes the first appearance of conferences on ‘Digital Cities’ (1994). However, the general trend in period 1-2 is that papers on ‘smart city(ies)’ are published in conferences on related but more general topics. In the third period, 2008-2016, conferences specifically on ‘smart city(ies)’ as well as ‘knowledge city(ies)’ appear, with novel conceptual inventions finding their way among the conference titles:

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Smartgreens 2015 (penultimate source) and journals reappear strongly on the list, corresponding to findings in Fig. 3.

Knowledge import and export: Reference and citation analysis

The import of knowledge to the 4,725 source documents on 'smart city(ies)' 1990-2016 is represented by the 27,099 references that are cited by those documents *and* found in WoS. This condition reduces the original number of references from 116,043 records to 27,099. The knowledge export is represented by the 16,901 citations (in 12,425 records) to the source documents, covering the entire period 1990-2016. The overall citation impact for the entire period is thus *3.6*.

Table 5. Development of publishing channels for 'smart city(ies)' research over three periods, 1990-2016. WoS, Nov., 2017. Journals are in *italics*.

Publication Sources					
1990-1998 (n=67):		**1999-2007 (n=375):**		**2008-2016 (n=4,283):**	
REBUILD THE EUROPEAN CITIES OF TOMORROW	4	LECTURE NOTES IN COMPUTER SCIENCE	55	LECTURE NOTES IN COMPUTER SCIENCE	135
AMBIO	3	*ADVANCES IN ARCHITECTURE SERIES*	30	IEEE SECOND INTERNATIONAL SMART CITIES CONF. 2016	70
PROCEEDINGS OF THE NATIONAL PASSIVE SOLAR CONF.	3	*WIT TRANSACTIONS ON ECOLOGY AND THE ENVIRONMENT*	26	*SENSORS*	69
UTOPIAS AND REALITIES OF URBAN SUSTAINABLE DEVEL.	3	DIGITAL CITIES	23	*PROCEDIA SOCIAL AND BEHAVIORAL SCIENCES*	49
1991 SOLAR WORLD CONGRESS	2	SUSTAINABLE CITY II URBAN REGENERATION AND SUSTAIN.	15	*COMMUNICATIONS IN COMP. AND INFORMATION SC.*	46
ENVIRONMENT AND PLANNING B PLANNING DESIGN	2	DIGITAL CITIES II COMPUTATIONAL AND SOC. APPROACHES	13	*PROCEDIA COMPUTER SCIENCE*	42
ENVIRONMENTALLY SUSTAINABLE DEVELOPMENT PROC.	2	DIGITAL CITIES III	12	*SUSTAINABILITY*	41
HUMAN FACE OF THE URBAN ENVIRONMENT	2	SUSTAINABLE CITY IV URBAN REGENERATION AND SUSTAIN.	10	2015 IEEE FIRST INTERNATIONAL SMART CITIES CONF.	39
IFIP TRANSACTIONS A COMPUTER SC. AND TECH.	2	*LANDSCAPE AND URBAN PLANNING*	9	*APPLIED MECHANICS AND MATERIALS*	39
INT. JOURNAL OF ENVIRONMENT AND POLLUTION	2	PROCEEDINGS OF SPIE	9	LECT. NOTES OF THE INST. FOR COMP.SC., SOC. INFORM.	39
PROC. OF THE 17TH NATIONAL PASSIVE SOLAR CONF.	2	SUSTAINABLE CITY III URBAN REGENERATION AND SUSTAIN.	9	*CITIES*	36
RENEWABLE ENERGY	2	IEEE INT. SYMP. ON GEOSCIENCE AND REMOTE SENSING	8	INT. ARCHIVES OF THE PHOTOGRAM. REMOTE SENS. & SP.	34
URBAN STUDIES	2	SUSTAINABLE DEVELOPMENT AND PLANNING III	8	ADVANCED MATERIALS RESEARCH	31
		JOURNAL OF INDUSTRIAL ECOLOGY	7	*PROCEDIA ENGINEERING*	30
		SUSTAINABLE DEVELOPMENT AND PLANNING II	7	*IEEE ACCESS*	29
		CITIES	6	*JOURNAL OF URBAN TECHNOLOGY*	28
		ENVIRONMENT AND URBANIZATION	6	*INTERNATIONAL JOURNAL OF DISTR. SENSOR NETWORKS*	24
		SUSTAINABLE CITY URBAN REGENERATION AND SUSTAIN.	6	PROC. OF THE 6TH KNOWLEDGE CITIES WORLD SUMMIT	24
		DURABILITY OF BUILDING MAT. AND COMP. 8 PROC.	4	*ENERGY PROCEDIA*	23
		ENVIRONMENT AND PLANNING B PLANNING DESIGN	4	ACSR ADVANCES IN COMPTUER SCIENCE RESEARCH	22
		IGARSS 2004 IEEE INT. GEOSCIENCE AND REMOTE SENSING	4	*TRANSPORTATION RESEARCH PROCEDIA*	21
		INTERNATIONAL FEDERATION FOR INFORMATION PROCES.	4	*WIT TRANSACTIONS ON ECOLOGY AND THE ENVIR.*	21
		LECTURE NOTES IN ARTIFICIAL INTELLIGENCE	4	ADVANCES IN INTELLIGENT SYSTEMS AND COMPUTING	19
		PROC. OF THE SOC. OF PHOTO OPTICAL INSTR. ENGINEERS	3	SMARTGREENS 2015 PROC. OF THE 4TH INT. CONF.	18
		TALL BUILDINGS FROM ENGINEERING TO SUSTAINABILITY	3	*SUSTAINABLE CITIES AND SOCIETY*	18

Table 6 provides an overview of the citations and impact for 'smart city(ies)' research covering the three analysis periods according to document types. The three citation windows are identical to the nine-year publication periods. Like for publications the number of citations is growing exponentially, in particular for journal articles. The first citation appears in 1996, 6 years after the first publication on 'smart city(ies)'. The highest growth rate for impact is reached by the few proceedings papers published as journal articles. As in other technical (engineering) fields (Sanz-Casado et al., 2013; 2014) the pure proceedings papers only possess very low impact, although they are the preferred publishing channel. It is also evident that the proportion of proceedings papers vs. journal articles is opposite when observing source publications vs. citations. Since 1999 this pattern is consistent.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Table 6. Citations and citation impact per publication period equal to citation windows, 1990-2016. WoS, Nov., 2017.

Document	**1990-1998 (n=67)**			**1999-2007 (n=375)**			**2008-2016 (n=4,283)**		
Type	**Citations**	**Publ.**	**Impact**	**Citations**	**Publ.**	**Impact**	**Citations**	**Publ.**	**Impact**
Proceed. Papers	0	32	**0.0**	32	190	**0.2**	1791	3012	**0.6**
Proc. Papers - Art.	5	6	**0.8**	130	84	**1.5**	231	34	**6.8**
Journal Article	12	25	**0.5**	362	95	**3.8**	8425	1170	**7.2**
Review Article	6	4	**1.5**	79	6	**13.2**	699	67	**10.4**
SUM / Mean:	23	67	**0.3**	603	375	**1.6**	11145	4283	**2.6**

Table 7. Top 25 countries in references found in WoS, source and citing documents about 'smart city(ies)', 2008-2016. WoS, Nov. 2017.

References 2008-2016 (n=27,099)		**Source docs. 2008-2016 (n= 4,283)**		**Citing docs. 2008-2016 (n=7,863)**	
USA	8452	PEOPLES R CHINA	643	USA	1365
ENGLAND	2863	ITALY	538	PEOPLES R CHINA	1256
PEOPLES R CHINA	2602	USA	467	ITALY	791
ITALY	1634	SPAIN	358	ENGLAND	707
CANADA	1612	ENGLAND	244	SPAIN	596
GERMANY	1412	GERMANY	194	AUSTRALIA	473
AUSTRALIA	1312	INDIA	178	GERMANY	373
SPAIN	1221	FRANCE	176	CANADA	362
NETHERLANDS	1069	JAPAN	168	FRANCE	292
FRANCE	950	AUSTRALIA	161	NETHERLANDS	291
SOUTH KOREA	680	CANADA	126	SOUTH KOREA	247
TAIWAN	649	GREECE	124	INDIA	239
SWEDEN	642	NETHERLANDS	113	SWEDEN	227
JAPAN	633	BRAZIL	108	JAPAN	198
SWITZERLAND	562	SWEDEN	96	BRAZIL	177
GREECE	494	SOUTH KOREA	86	PORTUGAL	165
INDIA	455	PORTUGAL	85	FINLAND	156
SINGAPORE	430	ROMANIA	82	GREECE	148
AUSTRIA	383	IRELAND	67	TAIWAN	147
FINLAND	381	SINGAPORE	65	SINGAPORE	145
BELGIUM	370	AUSTRIA	64	SWITZERLAND	140
DENMARK	364	SWITZERLAND	61	MALAYSIA	134
SCOTLAND	308	POLAND	59	TURKEY	127
PORTUGAL	291	CZECH REPUBLIC	58	AUSTRIA	115
BRAZIL	264	FINLAND	57	BELGIUM	113

Table 7 compares the distributions of publishing countries in the references found in WoS (n=27,099) from source documents, in the original source records (from Table 2; n=4,283) and in the 7,863 records citing the source documents from the rich recent analysis period, 2008-2016 (11,145 citations). The foundation research represented by the references in the source documents, also going back prior to 1990, adheres mainly to USA, England and China (51.3 %), but several Larger EU, e.g. Germany and Spain, and smaller Far East countries, South Korea and Taiwan, are high on the list.

In the original set of source records five countries constitute the spearhead: China, Italy, USA, Spain and England representing 52.5 % of the records[2]. The front research represented by the citations to the source set 2008-2016 is constituted by USA and China, followed by Italy, England and Spain (combined 59.9 %). In the references from the source documents those same countries, with Spain ranked 8 though, form the top ranks. It is thus fair to state that these five countries serve as the global centers producing research on 'smart city(ies)', and to a large extend are feeding on their own research over time. Note that Denmark and Scotland are referred to

[2] Due to international cooperation the overall percentage will exceed 100%.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

substantially, ranked 22 and 23 among the references, but not appearing in source or citing documents, in contrast to the lower ranked Portugal and Brazil.

Table 8. Top 25 institutions in references found in WoS, source and citing source documents about 'smart city(ies)', 2008-2016. WoS, Nov. 2017.

References found in WoS 2008-2016 (n=27,099)	#	Source docs.2008-2016 (n= 4,283)	#	Citing docs. 2008-2016 (n=7,863)	#
UNIVERSITY OF CALIFORNIA SYSTEM	1146	CHINESE ACADEMY OF SCIENCES	64	CHINESE ACADEMY OF SCIENCES	196
UNIVERSITY OF LONDON	533	UNIVERSITY OF BOLOGNA	47	UNIVERSITY OF LONDON	89
UNIVERSITY OF CALIFORNIA BERKELEY	420	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, CNRS	40	ARIZONA STATE UNIVERSITY	84
CHINESE ACADEMY OF SCIENCES	381	POLYTECHNIC UNIVERSITY OF TURIN	39	UNIVERSITY OF CALIFORNIA SYSTEM	71
MASSACHUSETTS INSTITUTE OF TECHNOLOGY MIT	345	ROYAL INSTITUTE OF TECHNOLOGY	39	UNIVERSITY OF MELBOURNE	67
STATE UNIVERSITY SYSTEM OF FLORIDA	338	POLYTECHNIC UNIVERSITY OF MILAN	37	CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, CNRS	63
UNIVERSITY SYSTEM OF GEORGIA	314	WUHAN UNIVERSITY	35	TSINGHUA UNIVERSITY	62
UNIVERSITY OF TEXAS SYSTEM	301	UNIVERSITY OF LONDON	33	DELFT UNIVERSITY OF TECHNOLOGY	61
UNIVERSITY OF ILLINOIS SYSTEM	277	UNIVERSITY OF CALIFORNIA SYSTEM	32	STATE UNIVERSITY SYSTEM OF FLORIDA	59
CENTRE NATIONAL DE LA RECHERCHE SCIENTIFIQUE, CNRS	275	UNIVERSITY OF NAPLES FEDERICO II	32	UNIVERSITY OF NAPLES FEDERICO II	58
UNIVERSITY OF BRITISH COLUMBIA	267	CZECH TECHNICAL UNIVERSITY PRAGUE	31	GHENT UNIVERSITY	55
ARIZONA STATE UNIVERSITY	266	TECHNICAL UNIVERSITY OF BERLIN	30	WUHAN UNIVERSITY	55
HARVARD UNIVERSITY	264	VIENNA UNIVERSITY OF TECHNOLOGY	29	CONSIGLIO NAZIONALE DELLE RICERCHE CNR	53
PENNSYLVANIA COMMONW. SYST. OF HIGH. ED., PCSHE	262	DELFT UNIVERSITY OF TECHNOLOGY	28	UNIVERSITE PARIS SACLAY COMUE	53
UNIVERSITY OF NORTH CAROLINA	254	STATE UNIVERSITY SYSTEM OF FLORIDA	28	AALTO UNIVERSITY	51
UNIVERSITY SYSTEM OF MARYLAND	250	NATIONAL TECHNICAL UNIVERSITY OF ATHENS	26	UNIVERSITY SYSTEM OF MARYLAND	51
UNIVERSITY OF MICHIGAN SYSTEM	248	INRIA	25	NATIONAL UNIVERSITY OF SINGAPORE	50
UNIVERSITY OF MICHIGAN	246	POLYTECHNIC UNIVERSITY OF BUCHAREST	25	ETH ZURICH	48
UNIVERSITY OF TORONTO	242	POLYTECHNIC UNIVERSITY OF CATALONIA	25	COMMONW. SCIENTIFIC INDUST. RES. ORG., CSIRO	46
STANFORD UNIVERSITY	238	MASSACHUSETTS INSTITUTE OF TECHNOLOGY	24	ROYAL INSTITUTE OF TECHNOLOGY	46
UNITED STATES DEPARTMENT OF ENERGY, DOE	228	SAPIENZA UNIVERSITY ROME	24	UNIVERSIDADE DE LISBOA	46
UNIVERSITY COLLEGE LONDON	227	UNIVERSITE PARIS SACLAY COMUE	23	UNIVERSITY OF BOLOGNA	45
STATE UNIVERSITY OF NEW YORK SUNY SYSTEM	223	UNIVERSITY OF MELBOURNE	21	BEIJING NORMAL UNIVERSITY	44
UNIVERSITY OF CAMBRIDGE	214	UNIVERSITY OF TRENTO	21	UNIVERSITY COLLEGE LONDON	43
UNIVERSITY OF CALIFORNIA LOS ANGELES	213	ZHEJIANG UNIVERSITY	21	UNIVERSITY OF MANCHESTER	43

The corresponding research institutions demonstrate a more complex pattern among the top-25 institutions, Table 8. In the set of references from the source documents US research entities essentially form the top-25 institutions. The Chinese Academy of Sciences rank 4, CNRS only as no. 10 and University College of London and Cambridge University, UK rank low, as no. 22 and 24 respectively. As stated above (in relation to Table 3), this pattern shifts 2008-2016 to a range of European institutions forming the top-25 producers of the source documents. The institutions responsible for the documents citing the source documents 2008-2016 are a mixture of US, Chinese, Italian and other European institutions, with a few Asian entities like University of Melbourne ranking 5 and National University of Singapore ranking 16. However, we observe the return of University College, London, on the top-25 list and *new players*, such as, University of Manchester, Aalto University, ETH Zurich and University System of Maryland. An increasing number of countries take part in the ‘smart city(ies)’ research moving from source documents to citing documents.

Table 9 demonstrates the top-25 distributions of the WoS Categories over the source references (found in WoS), the source documents themselves and the documents citing the source documents, 2008-2016. The references are dominated by ICT fields, environmental and energy fields and urbanization. In the source documents (see also Table 4) the ICT fields still dominate together with urban studies, AI appears as a novel category as rank 7 but the environmental and sustainable fields are less central to the research, i.e. are ranked lower. In the front research the citing documents demonstrate that the ICT fields are still dominant but the environmental and sustainable fields return in strength and AI disappears from the list. Novel WoS Categories in the citing documents *importing* knowledge from the source documents are Economics, Water

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Resources and Meteorology & Atmospheric Sciences. See also the topical maps, Figures 6 (source set) and 7 (reference set) below.

Table 9. Top 25 WoS Categories in references found in WoS, source and citing source documents about 'smart city(ies)', 2008-2016. WoS, Nov. 2017.

References 2008-2016 (n=27,099)		Source docs.2008-2016 (n= 4,283)		Citing docs. 2008-2016 (n=7,863)	
COMPUTER SCIENCE INFORMATION SYSTEMS	4760	ENGINEERING, ELECTRICAL & ELECTRONIC	1285	ENGINEERING, ELECTRICAL & ELECTRONIC	1475
TELECOMMUNICATIONS	4472	COMPUTER SCIENCE, INFORMATION SYSTEMS	849	COMPUTER SCIENCE, INFORMATION SYSTEMS	1057
ENGINEERING ELECTRICAL ELECTRONIC	4091	COMPUTER SCIENCE, THEORY & METHODS	819	ENVIRONMENTAL SCIENCES	988
ENVIRONMENTAL STUDIES	3022	TELECOMMUNICATIONS	629	TELECOMMUNICATIONS	930
ENVIRONMENTAL SCIENCES	2679	COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIONS	435	ENVIRONMENTAL STUDIES	844
URBAN STUDIES	2045	URBAN STUDIES	330	COMPUTER SCIENCE, THEORY & METHODS	814
ECONOMICS	1968	COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	326	GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY	667
ENERGY FUELS	1904	COMPUTER SCIENCE, HARDWARE & ARCHITECTURE	326	ENERGY & FUELS	633
GEOGRAPHY	1904	GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY	283	URBAN STUDIES	610
COMPUTER SCIENCE THEORY METHODS	1509	ENVIRONMENTAL SCIENCES	252	COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIO	436
COMPUTER SCIENCE ARTIFICIAL INTELLIGENCE	1367	ENERGY & FUELS	234	GEOGRAPHY	421
ENGINEERING CIVIL	1346	COMPUTER SCIENCE, SOFTWARE ENGINEERING	221	COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	393
COMPUTER SCIENCE SOFTWARE ENGINEERING	1165	ENVIRONMENTAL STUDIES	221	ENGINEERING, ENVIRONMENTAL	363
MANAGEMENT	1137	ENGINEERING, MULTIDISCIPLINARY	154	COMPUTER SCIENCE, HARDWARE & ARCHITECTURE	329
COMPUTER SCIENCE HARDWARE ARCHITECTURE	1127	PLANNING & DEVELOPMENT	144	ENGINEERING, CIVIL	329
OPERATIONS RESEARCH MANAGEMENT SCIENCE	1106	MANAGEMENT	126	ECOLOGY	298
PLANNING DEVELOPMENT	1105	GEOGRAPHY	116	COMPUTER SCIENCE, SOFTWARE ENGINEERING	269
ECOLOGY	1096	TRANSPORTATION SCIENCE & TECHNOLOGY	116	PLANNING & DEVELOPMENT	265
ENGINEERING ENVIRONMENTAL	1013	AUTOMATION & CONTROL SYSTEMS	110	CONSTRUCTION & BUILDING TECHNOLOGY	242
TRANSPORTATION SCIENCE TECHNOLOGY	992	REMOTE SENSING	106	ECONOMICS	241
COMPUTER SCIENCE INTERDISCIPLINARY APPLICATIOI	927	CONSTRUCTION & BUILDING TECHNOLOGY	104	INSTRUMENTS & INSTRUMENTATION	220
CONSTRUCTION BUILDING TECHNOLOGY	811	SOCIAL SCIENCES, INTERDISCIPLINARY	103	GEOGRAPHY, PHYSICAL	205
GREEN SUSTAINABLE SCIENCE TECHNOLOGY	792	ENGINEERING, ENVIRONMENTAL	99	MANAGEMENT	193
TRANSPORTATION	726	ENGINEERING, CIVIL	98	WATER RESOURCES	181
GEOGRAPHY PHYSICAL	679	INSTRUMENTS & INSTRUMENTATION	98	METEOROLOGY & ATMOSPHERIC SCIENCES	179

Median age of citations and references

Fig. 5 demonstrates the commonly and logically diminishing annual median age of citations to the publications published from 1999 to 2016 and cited 1999-2016. 'Median age of citations' has also been named 'citing half-life' in earlier citation studies. But this concept has ambiguous meanings. 'Median age of citations' is a diachronous citation analysis (Ingwersen, Larsen & Wormell, 2000; Ingwersen et al., 2001) that implies to calculate the number of years it takes to reach 50 % of the accumulated citations within a given period (*y* to *y´*) given to publications published in a specific year *j*.

$$M_{age}\text{cit} = \frac{1}{2}\sum_{k=y}^{y'}\left(\mathrm{C_{pub=j}}\right) \quad (1)$$

In our median age of citation calculations the publication year *j* equals the first citation year *y* (e.g. 1999, Figure 5) and the last year *y´* of citations given to the publications published in year *j* equals 2016. Thus, for each year under analysis one obtains a median age of citations value. Since the publications 1990-1998 demonstrate high variability of median age values, from 15.5 years to 'no value' due to no citations, we excluded this initial period from the display, Figure 5. The source publication year 1999 of research on 'smart city(ies)' is the starting year. Including that year it took 12.2 years (= February 2010) to obtain 50 % of the citations given to 1999 publications. According to Egghe, Rousseau & Guns, (2018, p. 181), depending on when the first and last citations are given across the year, one may actually reduce the calculated value by 0.5 year. We have not done

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

that on Figure 5, but it is done in Table 10. The year 2000 publications were not cited much but quite fast, in contrast to the following years. Hence a low median age of citations value for that that year (5.5 years). For every year the median age of citation values are plotted on Figure 5. According to Figure 5 the overall linear R^2 value = 0.8228, signifies a significant correspondence between citations and time: the more current the source publications the smaller the annual median age of citations. As stated, this is not surprising and common to most median age of citations analyses.

From 2001 to 2016 the decreasing linear trend of median age of citations values are quite constant and even stronger correlated with time, R^2 = 0.9763. During the last highly productive analysis period, 2008-2016 the average annual median age of citations is 3.6 years, with max.= 7 years and min.= 1 year (in 2016). The formula to calculate the average annual median age of citations for a given source publication period *J-J'* is:

$$\text{Av.}\, M_{age}{}^{\text{cit}} = \sum\nolimits_{k=j}^{j'} \left(M_{age}{}^{cit}\right) \frac{1}{(j'-j)+1} \quad (2)$$

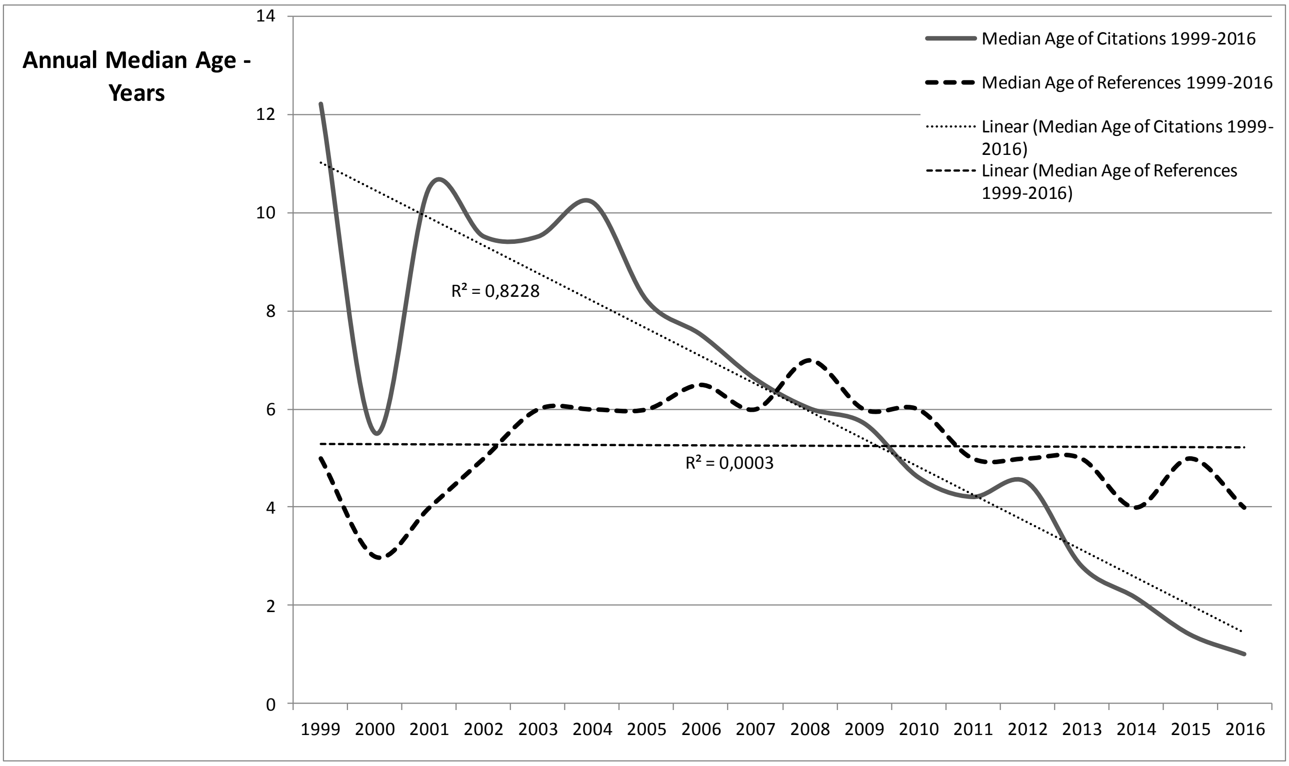

Fig. 5. Annual median age of citations (n=16,901) to source publications (n=4,725), fat line – with trend line (thin line); and annual median age of references (n=27,904), fat dashed line – with trend line (dotted), found in the source documents on 'smart city(ies)' 1999-2016. WoS, Nov., 2017.

The median age of the references found in the source documents is a synchronously calculated value (Ingwersen et al., 2001), so that for each source document publication year *j* the annual

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

number of references *R* are accumulated back in time (Y-Y´) until 50 % of all the references from the publications published that year is reached. That point in time signifies the median age of references for that source document publication year:

$$M_{age}\text{ref} = \frac{1}{2}\sum_{k=y}^{y\prime}(\text{R}_{\text{pub=j}}) \quad (3)$$

For instance, for publication year *j* = 1999 the median age of references is 5 years back from 1999, i.e. 1995. An average value of all the annual median age of references can be calculated using a variation of formula (2) as above for a given publication period (*j* – *j´*):

$$\text{Av.}M_{age}{}^{\text{ref}} = \sum_{k=j}^{j\prime}\left(M_{age}{}^{ref}\right)\frac{1}{(j\ \ -j\prime)+1} \quad (4)$$

Like for the annual median age of citations the annual median age of references also demonstrates highly variable values during the initial analysis period 1990-1998. This owes to the rather few references found in WoS made by the few source documents during that period. In total more than 116,000 references were detected during the entire period 1990-2016; however this amount was reduced to 27,904 references found in WoS in order to ensure correct reference publication year, out of which 27,099 belong to the last analysis period 2008-2016, Tables 7-10. We observe that the overall trend line for the median age of references is horizontal, R^2 = 0.0003, signifying that no correspondence between median age of references and time exists.

The average median age of references 1999-2016 is quite constant over time, Table 10. However, these average values cover more variability. Figure 5 demonstrates how the annual median age of references from 2000 curves by initially increasing from 3.5 years to almost 7 years (2008) and then slowly decreasing towards 2016 to 4 years, hence the insignificant horizontal linear trend line and correlation value. Table 10 displays the average median age of references as well as citations. The average median age of references is surprisingly extensive for an emerging research field 2008-2016 (4.72 years), with max.= 7 years and min.= 4 years, whereas the average median age of citations for the same period is much shorter (3.1 years). This means that the front research represented by the citing documents makes faster use of earlier research than done by the source documents.

Table 10. Averaged annual median age of references from the source documents and averaged annual median age of citations given to source documents per analysis period. Citation window is from source publ. year including 2016. WoS, Nov. 2017.

Period	# Source items	Av. Annual Median age of cits.	Av. Annual Median age of Refs.
1990-1998	37	..	4.50
1999-2007	353	8.35	4.77
2008-2016	4205	3.10	4.72

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Clustering of topics in 'smart city(ies)' research 2008-2016

This analysis concerns research question 3. The relationships between the top-100 WoS Categories classifying the journals of the source documents 2008-2016 are displayed in the clustering analysis using SNA technique, Fig. 6. There are five large and smaller but significant clusters (for frequencies of WoS Categories in the clusters, see Appendix 2, Table A):

1. Electrical/electronic engineering, telecom, information and communication technology (ICT) and computer science, named *ICT*;
2. Energy and construction/building, named *Energy*:
3. Urbanization, sustainability and environment, named *Urbanization*;
4. Management and economics; named *Eco-management*;
5. *Instrumentation*

Cluster (1) is highly dominant, containing computer science and ICT disciplines, including a strong element of Artificial Intelligence, but somewhat separated from the remaining clusters. Minor groupings of publications bridge this cluster with the remaining 4 clusters, e.g. 'Automation & Control Systems' bridging to the remote Cluster (5) and 'Operations Research' and 'Geography, physical' to Cluster (3). The latter is rather closely linked to Cluster 2. Cluster (4) on 'Eco-management' is strongly connected to 'Urbanization' (3) through the smaller groupings 'Planning & Development' and 'Geography'.

In order to observe whether the conceptual relationships in the source WoS Categories, Fig.6, are similar to the source references (imported knowledge), Fig. 7 demonstrates the WoS Category relationships of the latter through a SNA of their top-50 categories. Top-50 categories for the references is applied in order to make the display less dense. Due to the large volume of references compared to source documents the number of edges would be too high. Appendix 2, Table B, displays the frequency of the involved WoS Categories in the clusters. The two structures are somewhat dissimilar. The references representing the knowledge import from back in time beyond 1990 to the source documents demonstrate more distinct clusters and variation in the cluster structure than in the diagram, Fig. 6. Cluster (1) on *ICT & Computer Science* is again highly dominant and to some extent remote from the other groupings. The largest node is 'Comp. Sc., Information Systems'. The *Urbanization* cluster in Fig. 6 is split into three clusters: 'Environmental Sciences/Sustainability' (3a); 'Environmental Studies' (3b); and 'Urban Studies' (3c). All three clusters overlap one another. *Energy* (2) is neighbor to cluster (3a) but now also neighbor to *Economics* which includes *Transportation* as sub-cluster (4b), and separated from the new discrete *Management* cluster (4a). In Fig. 6 'Transportation' belonged to the large *Urbanization/Sustainability* cluster. The *Management* cluster links the dominant *ICT* cluster and a novel significant cluster on *Public services* (6), Fig. 7, including 'Public Administration', 'Occupational Health' and 'Leisure'. *Instrumentation* (5) is more substantial and integrated into the reference cluster structure, Fig. 7, than it was on Fig. 6. A novel dense cluster, *Remote Sensing* (7),

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Figure 7, connects quite strongly to the *Economics & Transport* cluster, the *Environmental Sc.* Cluster and the *Energy & Construction* cluster.

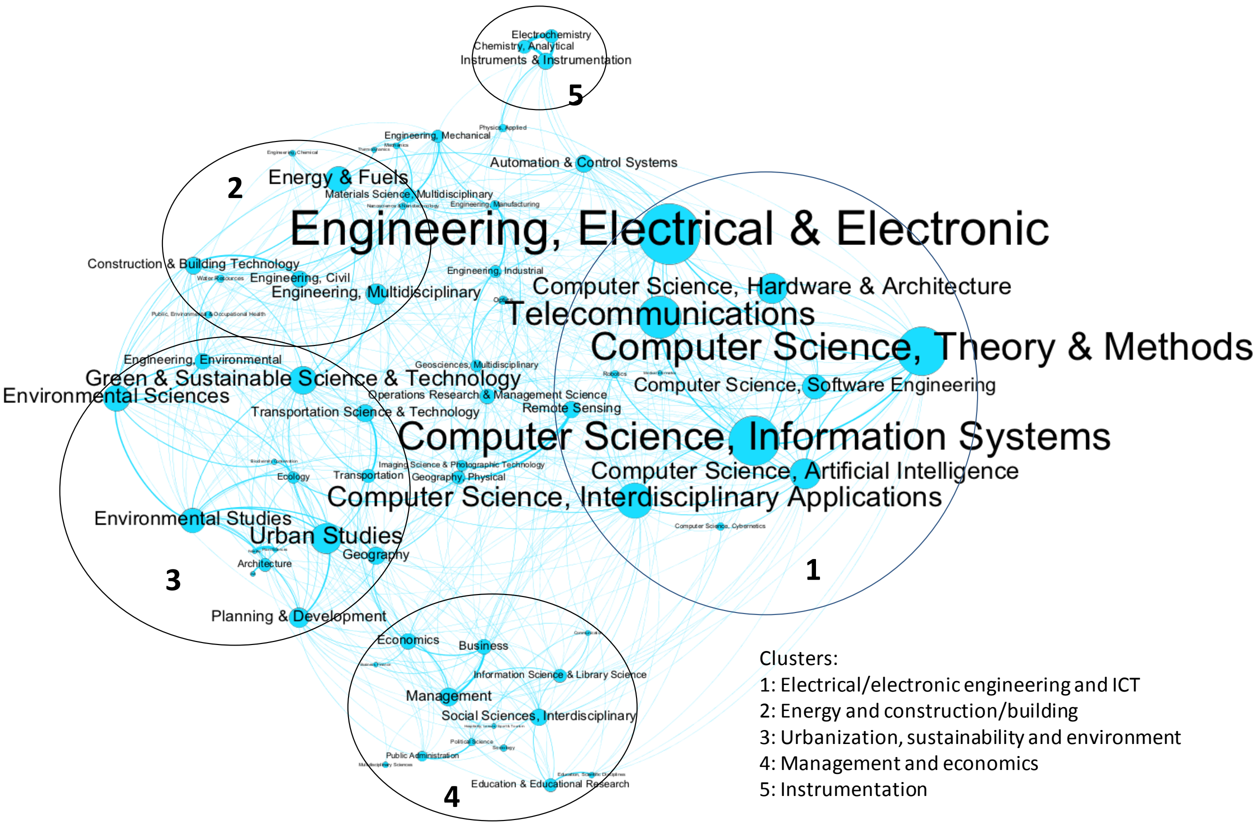

Fig. 6. Topic modeling into 5 major clusters, based on top-100 WoS Categories of the journals publishing research on 'smart city(ies)' 2008-2016 (n = 4,283) applying SNA technique. WoS, Nov. 2017. Point size = volume of publications; edge width = strength of association.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

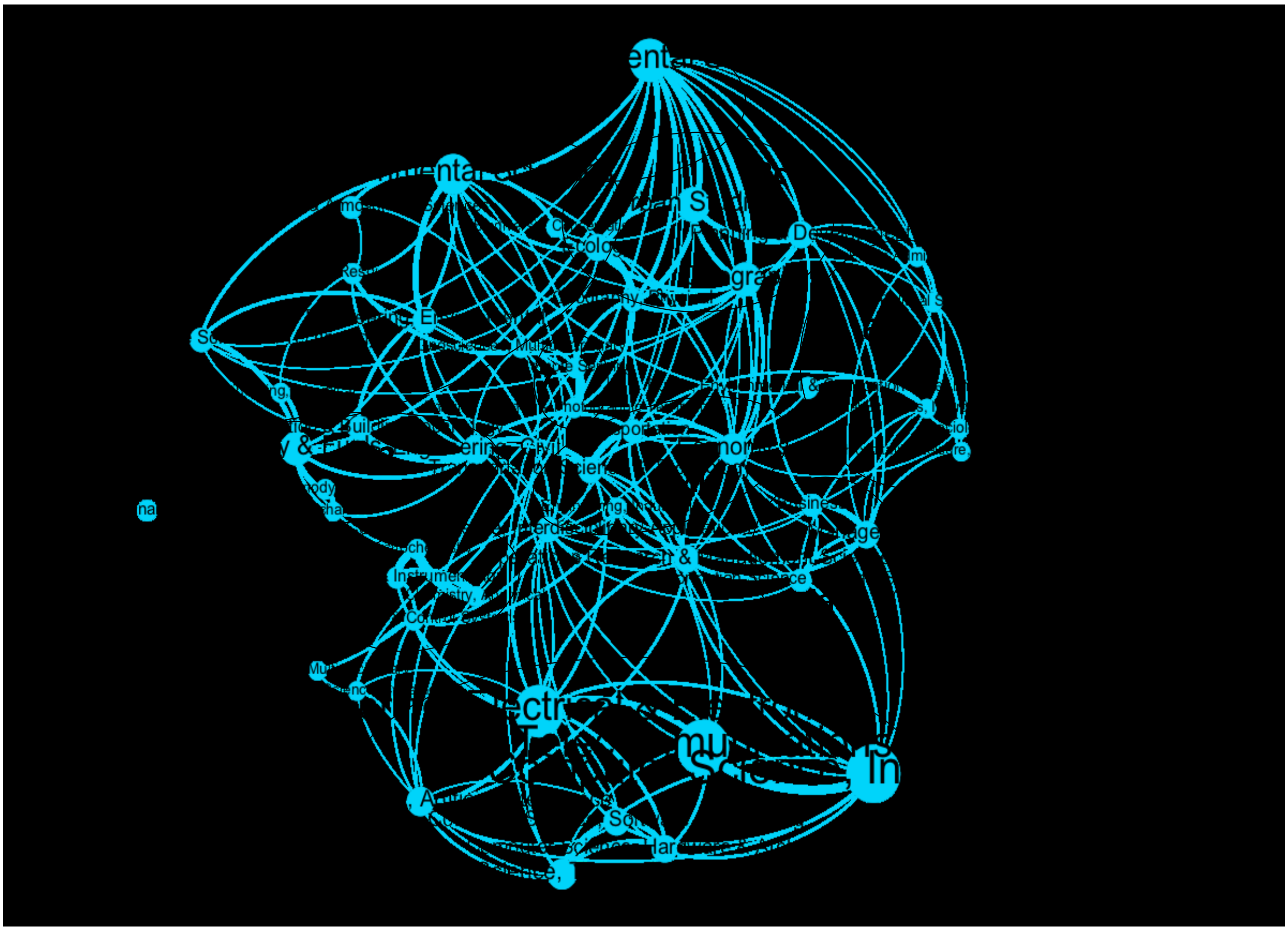

Fig. 7. SNA of top-50 WoS Categories from the journals in the reference set of records 2008-2016 (n=27,099) on 'smart city(ies)'. WoS, Dec. 6, 2017. Legend as in Fig. 6; Cluster 3a: Environment Sc./Sustainability; Cluster 3b: Environmental Studies; Cluster 3c: Urban Studies; Cluster 4a: Management; Cluster 4b: Economics & transportation; Cluster 6: Public Services; Cluster 7: Remote Sensing. Point size = volume of publications; edge width = strength of association.

Discussion

Research Question 1

With respect to *RQ1: How does research on 'smart city(ies) develop?,* the proceedings paper type is the major drive behind the exponential shape of the curve, Fig. 1, see also the DIVA-like diagram, Fig 3. The explosion of both proceedings papers (from 2013) and journal articles (from 2015) takes place in the later part of the most recent analysis period. This development continues the findings by Mora, Bolici & Deakin (2017), including research published until 2012.

China constitutes the leading publishing country on 'smart city(ies)' research from 1999 to 2016, Table 2. China is far more productive than the second country (Italy). As a matter of fact it is surprising that the usual first or second country on most research lists, USA, is placed behind *Italy* with a large margin. Spain and England are located further down the ranking with a substantial margin to USA, 2008-2016. These five countries constitute the major players throughout the entire period.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Concerning the citations Fig. 3, supplemented by Table 6, demonstrates the low citation impact of the proceedings papers (0.6). In order to observe from where the citations given to the various document types of the source set derive, a novel online analysis was made in WoS on the period 2008-2016 on March 20, 2018, Table 11 (publications and citations from 2017-2018 are excluded). Due to WoS updates since November 2017, catching a few additional source documents and more citations, Table 11 below show slightly higher numbers and impact scores for the other document types than shown in Table 6 above. Proceedings papers published as journal articles obtain 7.0 in impact score and genuine journal articles obtain 7.5.

Table 11. Distribution over document types of source documents and documents citing the source documents, 2008-2016. WoS, March 20, 2018.

Document Type - Source Publ.	2008-2016 (n=4,332) Source Publ.	Citations	Impact	Documents citing source publ. (n=8,529) Proceed. Papers	Journ. Art.	Other	Total
Proceed. Papers	3034	1852	**0.6**	866	640	3	1509
Proc. Papers - Art	34	238	**7.0**	25	183	16	224
Journal Article	1195	8727	**7.5**	1613	4295	235	6143
Review Article	69	713	**10.6**	153	476	24	653
SUM / Mean:	4332	11530	**2.7**	2657	5594	278	8529

The high weight of the proceedings papers degrades the overall impact of the field, in particular 2008-2016, Tables 6 or 11: *2.6 or 2.7*. For the entire analysis period, 1990-2016, the citation impact reaches 3.6. Almost no single proceedings items obtain a sizeable number of citations, Fig. 3.

During 2008-2016 the top-country China publishes 473 proceedings papers (74 % of 643 publ., Table 7). Those papers have received 376 citations during the same period, providing an impact of *0.8*, which is slightly above the average impact for that type (0.6), Tables 6 or 11. This is in contrast to the common pattern in other engineering-based fields, for which China commonly obtains much lower impact scores for proceedings papers than the average of that particular field (Sans Casado et al., 2013; 2014). Only 109 of the 337 citing publications (32 %) are from China itself. China has 7 highly cited journal articles in the field, according to WoS, out of 32 highly cited for all countries. China's 165 journal articles in the period provide 1001 citations, giving *6.1* in impact, below the article impact of the field (7.5). In comparison Italy, ranked two in productivity, demonstrates impact scores of *0.93* (proc. papers) and *13.7* (journ. articles) – well above the Chinese as well as average scores. The proportion of Italian proceedings papers is larger than China's (76 %). The two countries cover together 29 % of all proceedings papers for the third analysis period.

One may in addition observe that during the third period the top-25 country list displays a rather global picture (Table 2) with many continents represented, whilst in the same period the top productive institutions are in general *European*, Table 3, mixed with a few Chinese and US universities. During the same period *digital aspects* of 'Smart city(ies)' become central to the field. Urban Studies and urban planning, construction and transport are still important but ranked a bit

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

lower on the top-25 topical WoS Category list. However, already in 1999-2007 new aspects of 'smart city(ies)' appear among the significant top-25 categories, such as 'Management' and 'Social Sciences Interdisciplinary' to become much more important 2008-2016.

Conceptually, the expression 'smart city(ies)' serve as the dominant one, followed by 'sustainable city(ies)'. Sustainability was present from the start in the field, and the initial papers on 'smart city(ies)' research was actually published in conferences of fields like 'solar energy' research.

With respect to publication sources our approach is wider than that applied by Su, Lyu, Yang et al. (2015) who concentrated their analyses on characteristics of building and construction journals in 'smart city(ies)' research. Owing to the large volume of proceedings papers in the field conferences ought to play a dominant role. However, this is solely the case in the intermediate period, 1999-2007. Journals are the strong publishing channels in the Top-25 sources during the most recent period, Table 5. During the same period book (proceedings) series appear within the field, signifying an increasing maturity of the research which spreads out into a wide range of topics. Since Mora, Bolici & Deakin (2017) apply a wider range of databases, including Google Scholar, they obtain a wider range of document types and a wider range of application fields associated with research and development of 'smart city(ies)', e.g. business-related sources.

Research question two

RQ2: What are the characteristics of the references in and the citations to the original set of research publications on 'smart city(ies)'? concerns knowledge import indicated by the references in the publication set on 'smart city(ies)' and knowledge export observed through the citations given the publication set, across the three periods.

By comparative analysis of the top-25 ranked lists of countries (Table 7), institutions (Table 8) and WoS categories (Table 9) from the original set of publications on 'smart city(ies)', their references and citations obtained 2008-2016 it is possible to observe if the knowledge import to and export from the original source set stem from the same set of countries, institutions and topics or from a wider range including new institutions or categories.

Five countries serve as the global centers producing research on 'smart city(ies)', that is, 50-60 % of global output, in the references, source set and citing documents: China; Italy; USA; England and Spain. To a large extend they are feeding on their own research over time. However, the US is the overall dominant country from which knowledge is imported to the source documents 2008-2016 (31 % alone). In the source items USA sink to third rank, but returns as the dominant country (17 %) with China (16 %) citing the source items.

The US dominance among the top-25 research *institutions* responsible for the references cited by the source documents 2008-2016, Table 8, corresponds to the pattern from the unproductive first analysis period, Table 3. The source documents themselves are published mainly by top-25 European institutions, contrasting the country distribution. The documents citing the source documents are predominantly made by Chinese, US and European institutions, in line with the top-25 country distribution, Table 7. When moving from source documents to citing documents

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

new institutional players enter the top-25 list, such as, University of Manchester, Aalto University, ETH Zurich and University System of Maryland. An increasing number of countries produces 'smart city(ies)' research during the last analysis period and providing citations.

With respect to the distributions of top-25 WoS Categories Artificial Intelligence appears as a novel field in the source documents 2008-2016; but the field disappear again from the top-25 list in the citing documents. Instead Economics, Water Resources and Meteorology & Atmospheric Sciences move into the list.

Median age analyses were not done by Su, Lyu, Yang et al. (2015) nor by Mora, Bolici & Deakin (2017) and Mora, Deakin & Reid (2018). Our analyses of median age of references and citations demonstrate a great variation 1990-1999. The period 2000-2016 displays a less varied *median age of references* that initially (2000) is 5 years dropping to 3 years (2001), then curves up slowly to 7 years (2008) for gradually to decline back to 4 years (2016). This pattern supported by the horizontal trend line (R^2 = 0.0003) informs that no correlation exists between the median age of references and time. However, the *average* annual median age of references for the three analysis periods is almost stable with a slight decrease towards 2008-2016 (4.5 > 4.72 years), Table 10. This suggests that the field of 'smart city(ies)' research imports somewhat recently, but not immediately published knowledge in its emerging development.

Aside from the initial strong variation, the pattern of the *median age of the citations* given 1990-2016 to the source documents published during the same period is quite different from the median age of reference pattern. The initial publications from 1990-1995 received very few citations over the entire citation window 1990-2016. Citations took off only from 1996. Hence we omitted the scores 1990-1998 from display, Table 10. From 2001 to 2016 the median age of citations trend was constantly decreasing and strongly correlated with time, R^2 = 0.8228: the more current the publications the smaller the annual median age of citations, Fig. 5. During 2008-2016 the average annual median age of citations was 3.6 years. This indicates that the knowledge export from the source documents goes quite faster, for the same period, than the import.

The additional analysis, Table 11 above, right hand side, demonstrates special characteristics of the *citing* documents with respect to the distribution over document types. Table 11, left hand-side, shows the same pattern as Table 6. During the period 2008-2016 the distribution of document types in the source documents was dominated by proceedings papers (3034 records = 70 %, Table 11) followed by journal articles (1195 = 28 %). However the distribution of citations was the opposite: 76 % citations was given to journal articles and 16 % citations was received by proceedings papers, Table 11. With respect to journal articles 4,295 (70 %) of the documents citing this source type was journal articles themselves against 26 % from proceedings papers. In contrast 57 % of the records citing proceedings papers was proceedings papers against 42 % journal article records; review articles was mainly cited by journal articles (476 records = 73 %). Although the proceedings papers serve as the main communication channel this is not the case with respect to the citations provided for the same period. The majority of the citations (8,727 records = 76 %) derives from journal articles and goes basically to journal articles. Journal articles thus seem to possess a much higher *authority* than proceedings papers as to giving and receiving citations,

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

which in particular can be observed in the case of proceedings papers published as thematic journal articles. In addition, it is our opinion that this publication pattern, Table 11, is a factor influencing the difference demonstrated between the average median age of references from source documents and the average median age of citations given the source documents 2008-2016. Depending on how often conferences associated with the field of 'smart city(ies)' research take place the median age of citations may rely more on journal articles than conference papers.

Research question three

RQ3: How do the top-topics representing the research field relate to one another? is answered by two conceptual maps, one for the source documents 2008-2016 made out of top-100 (WoS-generated) Categories assigned each journal and thus the articles published by each journal, and one similarly based on top-50 Web of Science Categories of the references from the source documents. Both maps are based on SNA principles. However, while the source map covers a finite period (2008-2016) the reference map is open-ended towards the past. The two maps differ in number of clusters, density and structure.

In the source-based map, Figure 6, five distinctive clusters are visible, out of which two are close and slightly overlapping neighbors: (3) *Urbanization/Sustainability/Transport*; and (2) *Energy/Construction*. The cluster (1) *Electrical/Electronic Engineering/ICT* is isolated but bridged to the two former clusters by small nodes on 'Industrial Engineering', 'Operations Research' and 'Physical Geography'. Also quite isolated are the clusters on *Instrumentation* and *Management/economics/sociology*, the former connected to cluster (1) by the node on 'Automation & Control Systems' and the latter weakly connected to the *Urbanization, Sustainability & Environment* cluster (3). Due to less involved frequencies of the WoS Categories in this map, and thus less possible edges, the connections between and within clusters are less strong compared to the map, Figure 7, see Appendix 2 for category frequencies. Mora, Deakin & Reid (2018, Table 3) perform co-citation and co-word analyses. The latter is comparable with our categorical analysis. They demonstrate 5 major clusters as well: (1) ICT; (2) Urban Development & Economics; (3) Public Service & Life Quality; (4) Energy; and (5) Smart City. Clusters (1), (2) and (4) are similar to our clusters.

The reference map, Fig. 7, informs that a larger variety of topics serve as knowledge input to the source documents. New clusters appear on the reference map, e.g., the *Public Services* grouping (6) and *Remote Sensing* (7). The *Urbanization/Sustainability/Environment* cluster (3), Fig. 6, is split into three distinct but overlapping clusters (3a-3c): *Environmental Sc., Environmental Studies* and *Urban Planning*, Fig. 7. Similarly, the *Eco-management* cluster, Fig. 6, is split into two separate clusters: *Management* (4a) and *Economics* (4b), the latter including 'Transportation', which on Fig. 6 was included into cluster (3) on *Urbanization/Sustainability/Environment*. The co-citation map by Mora, Deakin & Reid (2018, Figure 2) may to an extend be compared with our reference-based map, Figure 7, since there exists a time overlap where our references equal their citations to source documents. But the two datasets are not the same. Mora, Deakin & Reid (2018) displays five central clusters also found by co-word analysis, but several more distinct minor

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

clusters (not named) are also shown. As in our case with the top cluster (1) *ICT*, Figure 7, their most central cluster, *Internet of Things* (1), is somewhat isolated from other clusters. Their second cluster, *Ubiquitous Cities & Infrastructure*, has some similarity to our *Urban Planning* (3c). Their third cluster is called *Corporate* path and is highly based on IBM initiatives. We do not have a similar cluster in our structure, probably owing to the difference in databases used to collect data. Their fourth major cluster is about *Energy & Sustainability/Environment*, which can be seen as comparable to our clusters (2) and (3a) in combination, Figure 7. Their fifth cluster is named *Holistic* or the *Digital City* and is not demonstrated in our cluster structure except as part of our ICT cluster (1).

Concluding remarks

This article demonstrates the development of 'smart city(ies)' research 1990-2016. Initially the research is born out of sustainable energy fields but already in the 1990s the central concepts associated with 'smart city(ies)' appear directly in publication titles. The research publication growth is exponential 2008-2016 for both proceedings papers and journal articles, with 'smart city(ies)' as the dominating concept. This is in line with the findings by Mora, Bollici & Deakin (2017) and Ojo, Dzhusupova & Curry (2016). Sustainable fields return to be central to the research area during 2008-2016. One should bear in mind that the concept of sustainable, green city(ies) does not necessarily imply elements of 'smart city(ies)', but according to our topical modeling 'smart city(ies)' research does imply strong elements of sustainability fields like energy, transport or environment. 70 % of all research publications are proceedings papers and 27 % journal articles. Only a fraction is proceedings papers in the form of journal publications. Five countries dominate the research production, the knowledge import (references) and the knowledge export (citations) since 1998: China; Italy; USA, England; and Spain. China is by far the most productive country. However, during the last 9-year analysis period mainly European universities dominate the top-25 research institutions.

Since the proceedings papers are scarcely cited (0.6 c/p) the huge amount of this document type degrade the overall citation impact of the field to 2.7 c/p, with journal articles obtaining 7.5 c/p on average. In contrast to some other technology and engineering disciplines like wind power or solar energy the Chinese citation impact for proceedings papers is slightly higher than the average impact of the discipline itself (0.8 c/p), and 2/3 of the citations to this document type is from outside China. This knowledge export ratio is common for mature research areas in a country and assures higher than average impact. Of all citations given to the source documents 2008-2016 76 % was to journal articles and 16 % to proceedings papers. 76 % of the citations derives from journal articles. Citations to proceedings papers originate from proceedings papers (57 %) themselves and from journal articles (42 %). These proportions between proceedings papers and journal articles are quite different from the publication distribution over document types in the source documents for the same period. It is significant that 70 % of the citations given to journal articles comes from journal articles themselves and only 26 % from proceedings papers. Clearly, journal articles have a much higher status and authority in this research area than proceedings papers, although the latter type is the dominant one.

The annual median age of references provided by the source documents demonstrates small variations from 2001 and onwards, between 4 and 7 years and 4.72 years on average for the last analysis period 2008-2016. No correlation is found between publication age and median age of references. This in contrast to the annual median age of citations given to the source documents. From 2001 to 2016 the annual median age of citation trend is constantly decreasing and strongly correlated with time, R^2 = 0.8228: The more current the publications the smaller the annual median age of citations. During 2008-2016 the average annual median age of citations was 3.6 years.

The conceptual maps of WoS Categories from the source documents as well as their references 2008-2016 clearly demonstrate the multi-disciplinary nature of the current 'smart city(ies)' research. In both conceptual maps the ICT and Electrical/Electronic Engineering fields constitute the dominant cluster, in both cases somewhat isolated from the remaining topical relationships. The source document clusters are fewer and more tightly connected than the structure of references which demonstrates greater variety of topical relationships. The source documents are feeding on knowledge from a wider range of subject areas than found in the sources themselves.

The limitation of this analysis is its descriptive nature. We see the analysis as an attempt to establish a broader characteristic of a new evolving multidisciplinary research area.

Acknowledgements:
This research was funded by the Spanish Ministry of Economy and Competitiveness under the project CSO 2014-51916-C2-1-R. Titled "La investigación en eficiencia energética y transporte sostenibles en el medio urbano: análisis del desarrollo científico y la percepción social del tema desde la perspectiva de los estudios métricos de la información" "(Research on energy efficiency and sustainable transport in the urban environment: analysis of the scientific development and the social perception of the topic from the perspective of the metric studies of information)"

References

Arun, R., Suresh, V., Madhavan, C.E.V. & Murthy, M.N.N. (2010): On Finding the Natural Number of Topics with Latent Dirichlet Allocation: Some Observations. In: Zaki et al. (eds.), *Advances in Knowledge Discovery and Data Mining* (pp. 391–402). Berlin: Springer.

Cao, J., Xia, T., Li, J., Zhang, Y., & Tang, S. (2009). A density-based method for adaptive LDA model selection. *Neurocomputing*, 72(7), 1775-1781.

Csárdi, G., & Torvalds, L. (2017). parsedate: Recognize and Parse Dates in Various Formats, Including All ISO 8601 Formats. https://CRAN.R-project.org/package=parsedate. Accessed 17 November 2017.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, ***Issue 2****, pp 1205–1236. DOI:* https://doi.org/10.1007/s11192-018-2901-9

Cocchia, A. (2014). Smart and Digital City: A Systematic Literature Review. In: R. P. Dameri and C. Rosenthal-Sabroux (eds.), *Smart City: How to Create Public and Economic Value with High Technology in Urban Space* (pp. 13-44). Berlin: Springer. DOI: 10.1007/978-3-319-06160-3_2.

Durán-Sánchez, A., de la Cruz del Río-Rama, M., Sereno-Ramírez, A. & Bredis, K. (2017). Sustainability and Quality of Life in Smart Cities: Analysis of Scientific Production. In M. Peris-Ortiz, D.R. Bennett, & D. Pérez-Bustamante Yábar, (eds.), *Sustainable Smart Cities: Creating Spaces for Technological, Social and Business Development* (pp. 159–181). (Cham: Springer, 2017).

Deveaud, R., SanJuan, É. & Bellot, P. (2014): Accurate and effective latent concept modelling for ad hoc information retrieval. *Document Numérique*, 17(1), 61–84.

Efrain-Garcia, P., & Garcia-Zorita, C. (2016). Desktop Scientometrics: a methodology using the R statistical software with data from WoS. *Revista Espanola De Documentacion Cientifica*, 39(1).

Egghe, L., Rousseau, R. & Guns, R. (2018). *Becoming Metric-Wise: A Bibliometric Guide for Researchers*. Cambridge, MA: Chandos Publishing.

Gagolewski, M., & Tartanus, B. R. package stringi: Character string processing facilities; 2016. https://doi. org/10.5281/zenodo, 19071, 385.

Griffiths, T.L. & Steyvers, M. (2004): Finding scientific topics. *Proceedings of the National Academy of Sciences*, 101(suppl. 1), 5228–5235.

Harrison, C., Eckman, B., Hamilton, R., Hartswick, P., Kalagnanam, J., Paraszczak, J., & Williams, P. (2010). Foundations for Smarter Cities. *IBM Journal of Research and Development*, *54*(4), 1-16.

Ingwersen, P., Larsen, B., Rousseau, R. & Russell, J. (2001). The publication-citation matrix and its derived quantities. *Chinese Science Bulletin*, 46(6), 524-528.

Ingwersen, P., Larsen, B. & Wormell, I. (2000). Applying diachronic citation analysis to ongoing research program evaluations. In B. Cronin & H. B. Atkins (eds.), *The Web of Knowledge: A Festschrift in Honor of Eugene Garfield* (pp. 373-387). Medford, N.J.: Information Today, Inc. & American Society for Information Science.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Lancaster, F.W. & Lee, J.L. (1985). Bibliometric techniques applied to issues management: A case study. *Journal of the Association for Information Science & Technology***,** Vol. 36(6), 389–397.

Mora, L., Bolici, R. & Deakin, M. (2017). The first two decades of smart-city research: A bibliometric analysis. *Journal of Urban Technology*, 24:1, 3-27.

Mora, L., Deakin, M., & Reid, A. (2018). Combining co-citation clustering and text-based analysis to Reveal the main development paths of smart cities. *Technological Forecasting and Social Change*, DOI: https://doi.org/10.1016/j.techfore.2018.07.019. Accepted manuscript.

Moritz, S., & Bartz-Beielstein, T. (2015). ImputeTS: Time series missing value imputation in R. R package version 0.4. https://cran.r-project.org/web/packages/imputeTS/vignettes/imputeTS-Time-Series-Missing-Value-Imputation-in-R.pdf Accessed 17 November 2018.

Morris, S., DeYong, C., Wu, Z., Salman, S., & Yemenu, D. (2002). DIVA: a visualization system for exploring document databases for technology forecasting. *Computers & Industrial Engineering*, 43(4), 841-862.

Nam, T & Pardo, T.A. (2011). Conceptualizing smart city with dimensions of technology, people, and institutions. In: *The Proceedings of the 12th Annual International Conference on Digital Government Research* (pp. 282-291). June 12–15, 2011, College Park, MD, USA.

Nenadic, O., & Greenacre, M. (2007). Correspondence analysis in R, with two- and three-dimensional graphics: The ca package. *Journal of Statistical Software, 20*(3), 1–13.

Ojo, A., Dzhusupova, Z. and Curry, E. (2016). Exploring the nature of the smart cities research landscape. In J.R. Gil-Garcia, T.A. Pardo, and T. Nam (eds.), *Smarter As the New Urban Agenda: A Comprehensive View of the 21st Century City* (pp. 23–47). Berlin: Springer, 2016.

ProQuest Dialog (2017). History, see: https://en.wikipedia.org/wiki/ProQuest_Dialog ; Web Location: http://www.proquest.com/products-services/ProQuest-Dialog.html . Accessed 2 July 2018.

Ricciardi, F. & Za, S. (2015). Smart city research as an interdisciplinary crossroads: A challenge for management and organization studies. In L. Mola, F. Pennarola, & S. Za (eds.), *From Information to Smart Society: Environment, Politics and Economics* (pp. 163–171). Cham: Springer.

Sanz-Casado, E., Garcia-Zorita, J. C., Serrano-López, A. E., Larsen, B., & Ingwersen, P. (2013). Renewable energy research 1995–2009: A case study of wind power research in EU, Spain, Germany and Denmark. *Scientometrics*, 95(1), 197–224.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Sanz-Casado, E., Lascurain-Sánchez, M. L., Serrano-López, A. E., Larsen, B. & Ingwersen, P. (2014). Production, consumption and research on solar energy: The Spanish and German case. *Renewable Energy*, 68, 733-744.

Serrano-López. A. E., Ingwersen, P. & Sanz-Casado, E. (2017). Wind power research in Wikipedia: Does Wikipedia demonstrate direct influence of research publications and can it be used as adequate source in research evaluation? *Scientometrics*, 112, 1471–1488

Su, L.-X., Lyu, P.-H., Yang, Z., et al. (2015). Scientometric cognitive and evaluation on smart city related construction and building journals data. *Scientometrics*, 105(1), 449-470.

Wetherell, C., Plakans, A., & Wellman, B. (1994). Social networks, kinship, and community in Eastern Europe. *The Journal of Interdisciplinary History*, 24(4), 639-663.

Wickham, H. (2016). Easily tidy data with 'spread ()' and ‘gather ()’ functions. 0. CRAN R Package http://cran/R-projectorg/package= tidyr version, 41 Accessed 17 November 2018.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Appendix 1: Retrieval Profile in Web of Science:

(TS=("smart city" OR "smart cities" OR "digital city" OR "digital cities" OR "intelligent city" OR "intelligent cities" OR "smart community" OR "smart communities" OR "knowledge city" OR "knowledge cities" OR "sustainable city" OR "sustainable cities" OR "green city" OR "green cities")) *AND* **DOCUMENT TYPES:** (Article OR Proceedings Paper OR Review)
Refined by: PUBLICATION YEARS: (2016 OR 2009 OR 2015 OR 2014 OR 2013 OR 2012 OR 2008 OR 2011 OR 2010)
Indexes=SCI-EXPANDED, SSCI, CPCI-S, CPCI-SSH Timespan=1990-2016

Appendix 2: Web of Science Categories in the clusters, Figure 6-7.
Download of WoS Categories and SNA analysis made December 6, 2017, thus frequencies are slightly higher than on Table 9, made in November 2017.

Table A. Source document SNA clusters; WoS Categories, Figure 6.

Cluster #	*Cluster name*	*WoS Categories - sub-clusters*	*Freq.*
1	ICT	ENGINEERING, ELECTRICAL & ELECTRONIC	1305
		COMPUTER SCIENCE, INFORMATION SYSTEMS	875
		COMPUTER SCIENCE, THEORY & METHODS	842
		TELECOMMUNICATIONS	635
		COMPUTER SCIENCE, INTERDISCIPLINARY APPLICATIOI	456
		COMPUTER SCIENCE, ARTIFICIAL INTELLIGENCE	333
		COMPUTER SCIENCE, HARDWARE & ARCHITECTURE	328
		COMPUTER SCIENCE, SOFTWARE ENGINEERING	223
		REMOTE SENSING	107
		COMPUTER SCIENCE, CYBERNETICS	27
		ROBOTICS	25
2	Energy	ENERGY & FUELS	237
		ENGINEERING, MULTIDISCIPLINARY	154
		CONSTRUCTION & BUILDING TECHNOLOGY	105
		ENGINEERING, CIVIL	99
		WATER RESOURCES	26
		PUBLIC, ENVIRONMENTAL & OCCUPATIONAL HEALTH	22
		NANOSCIENCE & NANOTECHNOLOGY	18
3	Urbanization	URBAN STUDIES	330
		GREEN & SUSTAINABLE SCIENCE & TECHNOLOGY	283
		ENVIRONMENTAL SCIENCES	252
		ENVIRONMENTAL STUDIES	221
		PLANNING & DEVELOPMENT	144
		TRANSPORTATION SCIENCE & TECHNOLOGY	116
		GEOGRAPHY	116
		ENGINEERING, ENVIRONMENTAL	99
		TRANSPORTATION	72
		ARCHITECTURE	64
		GEOSCIENCES, MULTIDISCIPLINARY	53
		ECOLOGY	52
4	Eco-management	MANAGEMENT	127
		SOCIAL SCIENCES, INTERDISCIPLINARY	107
		ECONOMICS	96
		BUSINESS	87
		INFORMATION SCIENCE & LIBRARY SCIENCE	66
		EDUCATION & EDUCATIONAL RESEARCH	65
		PUBLIC ADMINISTRATION	40
		POLITICAL SCIENCE	23
		EDUCATION, SCIENTIFIC DISCIPLINES	16
		MULTIDISCIPLINARY SCIENCES	16
5	Instrumentation	INSTRUMENTS & INSTRUMENTATION	99
		CHEMISTRY, ANALYTICAL	70
		ELECTROCHEMISTRY	70

Stand-alone and low-frequency Categories are not shown.

Received: 12 May 2018
SCIENTOMETRICS: Akademiai Kiado, Budapest, Hungary May 2018; Published online 2018/08/31; print November 2018, Volume 117, Issue 2, pp 1205–1236. DOI: https://doi.org/10.1007/s11192-018-2901-9

Table B. Reference document SNA clusters; WoS Categories, Figure 7.

Cluster #	*Cluster name*	*WoS Categories - sub-clusters*	*Freq.*
1	ICT - Computer Science	COMPUTER SCIENCE, INFORMATION SYSTEN	4777
		TELECOMMUNICATIONS	4476
		ENGINEERING, ELECTRICAL & ELECTRONIC	4092
		COMPUTER SCIENCE, THEORY & METHODS	1510
		COMPUTER SCIENCE, ARTIFICIAL INTELLIGEN	1367
		COMPUTER SCIENCE, SOFTWARE ENGINEERI	1167
		COMPUTER SCIENCE, HARDWARE & ARCHITI	1127
2	Energy & Construction/building	ENERGY & FUELS	1905
		ENGINEERING, CIVIL	1346
		CONSTRUCTION & BUILDING TECHNOLOGY	814
		THERMODYNAMICS	335
		MECHANICS	212
3a	Environmental Sc. & Sustainability	ENVIRONMENTAL SCIENCES	2679
		ECOLOGY	1096
		ENGINEERING, ENVIRONMENTAL	1013
		GREEN & SUSTAINABLE SCIENCE & TECHNOL	794
		METEOROLOGY & ATMOSPHERIC SCIENCES	561
		GEOSCIENCES, MULTIDISCIPLINARY	405
		WATER RESOURCES	378
		ENGINEERING, CHEMICAL	276
		BIODIVERSITY CONSERVATION	236
3b	Environmental Studies	ENVIRONMENTAL STUDIES	3024
3c	Urban Studies	URBAN STUDIES	2046
		GEOGRAPHY	1914
		PLANNING & DEVELOPMENT	1112
		ECOLOGY	1096
		GEOGRAPHY, PHYSICAL	679
4a	Management	MANAGEMENT	1140
		BUSINESS	623
		INFORMATION SCIENCE & LIBRARY SCIENCE	604
4b	Economics & Transportation	ECONOMICS	1611
		TRANSPORTATION SCIENCE & TECHNOLOGY	997
		COMPUTER SCIENCE, INTERDISCIPLINARY AP	930
		TRANSPORTATION	730
		ENGINEERING, INDUSTRIAL	323
5	Instrumentation	INSTRUMENTS & INSTRUMENTATION	495
		AUTOMATION & CONTROL SYSTEMS	391
		ELECTROCHEMISTRY	311
		CHEMISTRY, ANALYTICAL	296
6	Public Services	PUBLIC, ENVIRONMENTAL & OCCUPATIONAI	499
		SOCIOLOGY	291
		PUBLIC ADMINISTRATION	245
		POLITICAL SCIENCE	230
		SOCIAL SCIENCES, INTERDISCIPLINARY	215
		HOSPITALITY, LEISURE, SPORT & TOURISM	204
7	Remote Sensing	REMOTE SENSING	364
		IMAGING SCIENCE & PHOTOGRAPHIC TECHN	299

Stand-alone and low-frequency Categories are not shown.