

Scientific literature analysis on *big data* and *internet of things* applications on *circular economy*: a bibliometric study

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Abstract Circular economy (CE) is a term that exists since the 1970s and has acquired greater importance in the past few years, partly due to the scarcity of natural resources available in the environment and changes in consumer behavior. Cutting-edge technologies such as big data and internet of things (IoT) have the potential to leverage the adoption of CE concepts by organizations and society, becoming more present in our daily lives. Therefore, it is fundamentally important for researchers interested in this subject to understand the status quo of studies being undertaken worldwide and to have the overall picture of it. We conducted a bibliometric literature review from the Scopus Database over the period of 2006–2015 focusing on the application of big data/IoT on the context of CE. This produced the combination of 30,557 CE documents with 32,550 unique big data/IoT studies resulting in 70 matching publications that went through content and social network analysis with the use of ‘R’ statistical tool. We then compared it to some current industry initiatives. Bibliometrics findings indicate China and USA are the most interested countries in the area and reveal a context with significant opportunities for research. In addition, large producers of greenhouse gas emissions, such as Brazil and Russia, still lack studies in the area. Also, a disconnection between important industry initiatives and scientific research seems to exist. The results can be useful for institutions and researchers worldwide to understand potential research gaps and to focus future investments/studies in the field.

Keywords Circular economy · Big data · Internet of things · Bibliometrics · Sustainability · Consumer behavior

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Mathematics Subject Classification 90B50**JEL Classification** Q50 · Q55**Introduction**

The world population in 1950 was 2.5 billion people. As of August 2016, it was estimated as 7.4 billion. By 2050 it will be nearly 9.8 billion, an increase of 392% in 100 years (United Nations 2015). Natural resources consumption is also significantly growing, as a consequence of its current observed positive correlation with country's *per capita* GDP (World Bank 2014; SERI and Dittrich 2014) which indicates that the country's wealth has a direct influence on its natural resources consumption. Proportionally but in the opposite direction, we find natural resources availability to support this economic growth. For example, assuming no changes occurring in global economic growth tendencies and no actions taken, oil reserves will end by 2057 and natural gas, by 2070 (Guardian 2011). Moreover, resources consumption results in waste generation that returns to the environment. Despite known market and government regulatory actions in order to promote recycling initiatives, only a very low part of recyclable wastes are actually recycled (Ellen MacArthur Foundation 2016). Currently there are nearly 150 million tons of plastic on the oceans and by 2050 there will be more plastic than fish (World Economic Forum 2016). One of the main causes of this situation is the current linear economic model ("take, make, use, dispose/waste"), present since the industrial revolution and considered nowadays an unsustainable practice. This calls for an alternative model and circular economy (CE) is being advocated as a solution (Andrews 2015).

The CE model consists in a continuous and positive development model focused on preserving and enhancing natural capital, optimizing resource yields and minimizing system risks, by managing finite stocks and renewable flows, and keeping products, components and materials at their highest utility and value at all times (Ellen MacArthur Foundation 2016). Despite the concept existence for decades and the benefits of the model being clear, the acceptance of CE business models is still modest, as the key lever for change relies not only on rational but also on non-rational motives of consumer behavior, which includes habits and routines of individuals (Planing 2014). The emergence of new technologies leveraged by the Internet, mobility, tagging/tracking, low costs etc., along with changes on consumer behavior (e.g. access over ownership) might have been what was missing. Such technologies can be summarized into two complementary subjects: big data and internet of things (IoT).

Data has never been so important for enterprises/other entities as it is now and may become the biggest trading commodity in the future (Xiao et al. 2014). IoT, leveraged by big data, is considered by specialists as the next Internet evolution, allowing a huge step towards data gathering, analysis and distribution, which can be converted into useful information (Evans 2011). There are ongoing projects such as reducing the gap between the poor and the rich and better resource distribution, and helping people to be more proactive against nature events (earthquakes, tsunamis, polar ice cap melting etc.) for example, all based on IoT/big data (Hart and Martinez 2015; Evans 2011). It is also noticed that the plateau of productivity for these technologies will occur in the next 5–10 years (Gartner 2015), fostering researches on the subject.

By understanding the basics behind the concepts of CE, big data and IoT, it is not hard to realize how integrated they can be with each other, and their role on the development of a better society. Selected industry cases presented on the document show the potential of this integration and how it will change the world from the environment preservation and human behavior perspectives.

The purpose of this research is to understand, from a bibliometric perspective on scientific literature, the state-of-art of CE and the role of IoT/big data in this context, and compare it with some of the current initiatives being undertaken by the corporate world, also allowing the gap between industry/private sector initiatives and scientific research to be better understood.

As this is a preliminary but also unprecedented study, we expect the results/conclusions of this research will motivate future exploratory/practical studies in the field of CE leveraged by cutting-edge technologies, and with a higher level of integration between industry/private sector and scientific research, fostering and accelerating researches in the area with the use of methodologies that promote practical actions and creating knowledge/theories at the same time, such as action researches (Coughlan and Coughlan 2001).

Main findings indicate there are only a few CE studies (<0.25%) considering the application of IoT/big data, although a growing interest has been observed on the last three years. The results further indicate a research agenda linking IoT/big data to CE, suggesting areas currently in development, such as carbon emissions reduction, smart cities, water economy, waste management and renewable sources. Cloud computing has been an additional enabler. There are also areas to be explored, such as bioeconomy and carbon biofixation. Also, a disconnection between industry/private sector and scientific research seems to exist, as the scientific studies found are not related whatsoever to the important industry/private sector example studies used in this research.

The remainder of the paper is organized into five sections, starting with insights on academic researches × industry/private sector initiatives, followed by a methodology section, which includes the data collection steps used on the bibliometric research. The last three sections contain the results, policy implications and conclusions of the study.

CE with big data and IoT in the industry/private sector and the academy

The CE principles adoption, which in most cases will be achieved with the support of technologies such as big data and IoT, can create net benefits for the economy of about €1.8 trillion by 2030 only in Europe, representing €0.9 trillion more than the current development path—the traditional “take, make, use, dispose/waste” linear model, and achieve savings of up to USD 1 trillion on materials savings (Ellen MacArthur Foundation 2015a). Nevertheless, the practical effects and results measurement of big data and IoT remain a question mark, as they are in their early days, so the potential for value creation is still unclaimed (Groves et al. 2013), which may justify somehow the low amount of academic work that combines both subjects.

Some recent scientific publications have been questioning the low amount of researches on the field of environmental sustainability with the support of information systems. The Journal of the Association for Information Systems, for example, made a call for papers on IS solutions for environmental sustainability and managed to publish only one due to the low amount of papers submitted and researches scope (Gholami et al. 2016). Although the demand for scientific research in the area is high and continues to grow, scholars seem to

lack what is needed to fill the gap between the researches being undertaken and practical actions to solve environmental problems. Some barriers for researchers seem to exist, as described in a recent study (Gholami et al. 2016): incentives misalignment, the low status of practice science, data analysis poverty, identification of the proper research scope, and research methods. Given these barriers on conducting this kind of research, one possible path to be followed by scholars is the application of action research as the preferred method for such turbulent research environments (Daniel and Wilson 2004), in order to approach practice (which seems to be far more advanced on CE with big data/IoT) with theory. In addition, along with the action research method, the application of concepts of engaged scholarship, which overcomes the barriers of individual researches and also allows the partnering and gathering inputs/valuable advice from practitioners, customers, users, sponsors and other stakeholders, can generate outcomes that exceeds the traditional knowledge production way (Van de Ven 2007). This may allow social researches to result into valuable insights not only for the academy but also to practical use for the industry/corporate world.

In order to set some comparison parameters to understand the distance between current academic publications for CE with big data/IoT and the corporate world, we selected some examples of cutting-edge industry/private sector initiatives, which also illustrates the importance of those concepts when bound together, for different purposes/applications.

Philips lighting¹

The Spanish Volkswagen subsidiary (SEAT) established a partnership with Philips Lighting to replace its exterior light sources by connected LED lighting, which is more efficient and sustainable, enabling the company to save 80% on energy consumption, amounting to over 900 MWh per year. And the relationship model is also new and different. They implemented the light as a service model, so all the installations are owned by Philips, who provides the lighting services to SEAT. This represents a CE initiative that promotes the “access over ownership” model (Ellen MacArthur Foundation 2013). Upon full project conclusion, more than 1200 fixtures will be replaced by a more environmentally efficient system. With the use of technology, lightning needs can be controlled and monitored online and real time, including inventory management support with the geolocation system of all fixtures (IoT). This enables the partnership to fully monitor and control the installations, obtain direct information from each light fixture (big data) and supervise improvements in energy expenditure management as well as in maintenance, generating savings for both partnership and environment.

Cisco’s sport shoes²

A collaboration of Cisco, Cranfield University and The Clearing institutions resulted in a project to explore in detail a specific real-world application combining big data, IoT and digital technology to drive a new, circular model for production and consumption of sport shoes, which allowed the implementation of a re-distributed manufacturing (RdM) system in UK. This term is used to describe the transformational shift from centralized to decentralized (usually smaller-scale) manufacturing, powered by digital technologies.

¹ https://www.volkswagenag.com/en/news/2016/12/SEAT_ecolighting.html, <http://www.lighting.philips.com/main/education/lighting-university/lighting-university-browser/webinar/circular-economy.html>.

² <http://gblogs.cisco.com/uki/re-distributed-manufacturing-the-end-of-take-make-dispose-part-1/>.

Consumers deliver the orders by scanning their feet with a cell phone app and use virtual reality to assemble their shoes based on hundreds of options according to their requirements (visual, comfort, performance etc.). 3D printers are used to assemble the modular and customized product in a location close to the customer, so the manufacturing occurs decentralized, allowing lower distribution costs and raw materials savings. Also, consumers don't actually own the products, as they pay an ongoing subscription to the vendor. Products come with an intelligent component (IoT) that tracks location/shoes condition (according to consumer accordance) and identifies replacement/upgrades needs. Upon lifecycle end, consumers return the shoes for remanufacture in a take-back model to a location close to their home/work. The shoes' modular design allows them to be easily disassembled for refurbishing/recycling. Bottom-line: low production costs, highly customized products, circular economy application, "access over ownership" model, satisfied consumers, big data and IoT acting as enablers.

Arup's circular building³

The company used big data/IoT technologies to maximize utilization of components and materials on a building construction. The facility was designed for easy disassembly, and with the use of non-toxic and pre-fabricated components made to be taken apart without damaging them. They used an innovative digital tool called building information modelling⁴ (BIM), which allows data communication among stakeholders during all phases of an asset's lifecycle. It envisages the virtual construction of a facility prior to its actual physical construction, in order to reduce uncertainty, improve safety, work out problems, and simulate and analyze potential impacts. Contractors from every trade can input critical information into the model before beginning construction, with opportunities to pre-fabricate or pre-assemble some systems off-site. Waste can be minimized on-site and products delivered on a just-in-time basis rather than being stock-piled on-site. BIM also enables optimized design processes and supports the efficient performance and maintenance of buildings. By incorporating information on materials, it can help communicate any negative externalities as well as opportunities for recycling and remanufacture. Moreover, as BIM is also a database containing all components used on the construction, the building also acts as a "material bank" for components reuse.

Other companies that have been promoting this revolution include: Uber (currently the world's largest taxi company that owns no cars, but fosters the higher use of the current car fleet rather than putting more cars on the streets), AirBnB (largest accommodation provider without one single room on its own, but helping people better use their available spaces), all with the support of big data and IoT.

Those concepts of CE, big data and IoT, when bound together, offer a large set of opportunities for both business and society. The use of enhanced tracking/tagging capabilities, for example, presents significant economic opportunities to save materials, reduce waste and make use of resources previously considered to be disposed. Therefore, IoT plays a key role in providing valuable big data about things like energy use, under-utilized assets, and material flows to help make businesses more efficient (Ellen MacArthur Foundation 2016).

³ <http://publications.arup.com/~media/Publications/Files/Publications/C/Circular-Economy-in-the-Built-Environment-270916.ashx>, <https://www.ellenmacarthurfoundation.org/publications/india>.

⁴ https://en.wikipedia.org/wiki/Building_information_modeling.

General overviews on basic concepts of CE, big data and IoT are presented in Appendix 5.

Methodology and data collection for the bibliometrics analysis

The first step consisted in identifying publications from a robust and reliable database. Scopus was the chosen database as it is considered one of the largest abstract and citation databases of peer-reviewed literature, including scientific journals, books and conference proceedings, all part of the scope of the study. The research scope focused on publications in a ten-year time interval (2006–2015).

The research initially retrieved publications regarding only CE to serve as the baseline for the comparisons. The initial query on the term “circular econom*” in the titles, abstracts and keywords resulted in 915 documents. Nevertheless, publications containing terms and expressions semantically different but with the same meaning/or a subset of CE were not retrieved by the query. Those terms include “Circulatory Economy”, “Circular Supply Chain”, “Circular Ecology” etc., and they had to be added to the research filters. Additionally, publications fostering CE initiatives and opportunities do not necessarily utilize this expression within its body, partially because the regular use of the term is relatively recent (18 occurrences in 2006 × 151 in 2015, an increase of >800% according to the Scopus database).

Many CE-type studies make use of other key expressions along with terms like “sustainability” or “sustained development”. For example, a study focused on carbon dioxide conversion into organic compounds that can be synthesized into hydrocarbon fuels (Whipple and Kenis 2010), cited more than 230 times, is indeed a CE study but the expression is not used throughout the document. A keyword for this study would be “CO₂ Reduction”. On the other hand, some CE terms may be applied to other concepts not related to the research scope. One example is the one of the CE’s schools of thought term “blue economy” (Pauli 2010; Ellen MacArthur Foundation 2015b), also used in studies regarding economic perspectives and governance between ocean and land (Smith-Godfrey 2016) and confirmed as a separate subject in discussions/events (e.g. Rio + 20) (Silver et al. 2015) and for that reason considered as out of scope for this study.

The sensibility of the CE terms required a more detailed approach for the keywords definition. Therefore, a taxonomy research was conducted in order to map the keywords for the research and a number of publications were found with different definitions and classifications, which led to the need of a broader keywords search. For example, although the classical 3R concepts (reduce, reuse, recycle), closely related to CE, are still up to date (Terazono et al. 2006; Agamuthu and Fauziah 2011; Tian and Chen 2014; Nagalingam et al. 2013), some authors have included a 4th R standing for recover or reclaim or refuse or reorganize or refurbish (Nagalingam et al. 2013; Rehman and Shrivastava 2014; Hickey et al. 2014). 6R definitions were also found, adding new terms (Kuik et al. 2011; Yan and Feng 2014). Furthermore, despite the existence of a taxonomy for the end of life (EoL) projects and processes based on the strategies starting with the prefix “Re” (e.g. reduce, reuse, repair, recycle etc.) (Sihvonen and Ritola 2015), it does not intend to cover comprehensively all expressions related to CE. Therefore, in the absence of a reliable and up to date taxonomy for CE, the complete collection of keyword terms was obtained as follows: from the original “circular econom*” search results, all data from the keyword field was extracted, generating a list of 2488 additional unique terms. The list was then reviewed

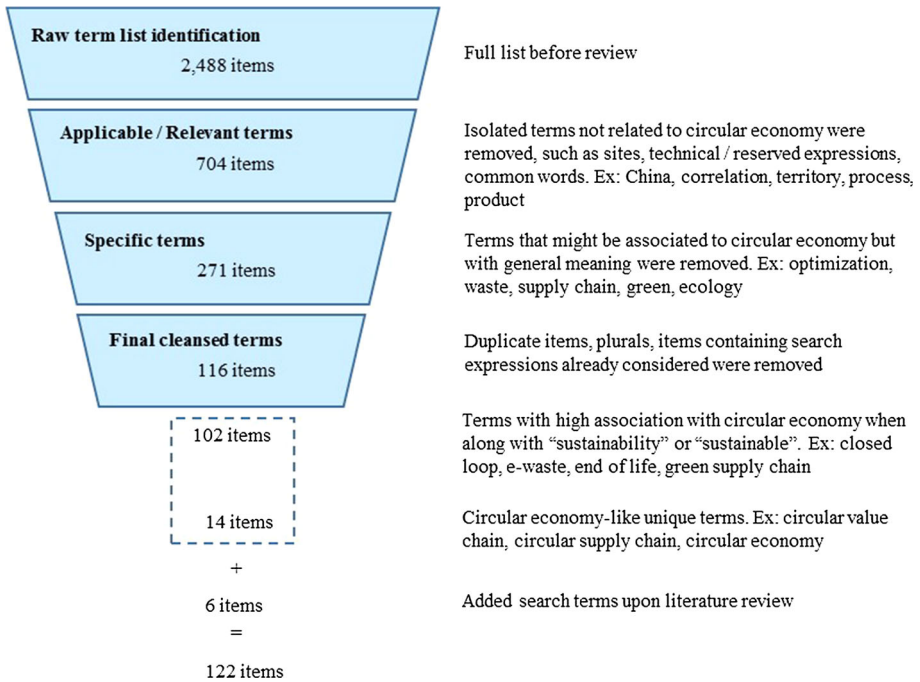


Fig. 1 CE keyword search mapping process

according to the steps shown on Fig. 1, resulting in 116 terms. New terms were added based on literature review (cradle-to-cradle, biomimicry, regenerative design, resource recirculation, regenerative econom*, restorative econom*), generating a final version of 122 items.

The query logic was then formulated, according to Fig. 2. A special treatment was given to the keywords “Reduce”, “Reuse”, “Recycle”: taken together, they represent the 3R concept, but when searched separately, some out of scope results may be retrieved. The final CE query applied on Scopus Database containing all research terms is available in Appendix 1.

Previous studies indicate the need to include proceeding papers in citation impact comparative researches rather than relying only on journal articles because of the significant influence this document type has on citation impact (Ingwersen et al. 2014). Therefore, considering the inclusion of scientific journals, books and conference proceedings, the final CE query resulted in 30,557 documents.

Similar treatment was given to the search criteria for “Big Data” and “Internet of Things”. In contrast to the previous search, in this case more consistent taxonomies were identified (Debortoli et al. 2014; Bajaber et al. 2016). However, some terms when searched separately, such as “Machine Learning” presented results out of the scope and had to be combined with other terms. The resulting query logic is represented in Fig. 3.

The final big data and IoT query applied on Scopus Database containing all research terms returned 32,550 documents and is available in Appendix 2.

Two main bibliometric indicators were used in this research: CPP (citations per paper) and PNC (percentage of non cited papers) (Van Raan 2005), along with absolute numbers

```
TITLE_KEYWORD_ABSTRACT = (<List of Terms> OR
  "Reduc*" AND "Reus*" AND "Recycl*") AND
  ("sustainability" OR "sustainable")) OR
  (<Circular economy-like unique terms>)

AND PUBLICATION_YEAR (>=2006 AND <=2015)
```

Fig. 2 CE query logic

```
TITLE_KEYWORD_ABSTRACT = (<List of Terms> OR
  ("Spark Streaming" OR "Mlib" OR "Spark R" OR "Machine Learning") AND "Apache") OR
  ("Hdfs" OR "Cfs") AND "File System") OR
  ("Mizan" AND "Kaust") OR
  ("Presto" AND "SQL"))

AND PUBLICATION_YEAR (>=2006 AND <=2015)
```

Fig. 3 Big data and IoT query logic

for publications and citations, grouped by country.⁵ Standard deviation and maximum number of citations were also used as auxiliary fields to better results description. When assessing publication impact with the use of citations per paper (CPP) and percentage of non cited papers (PNC) indicators, we should consider that the citation peak of an article occurs around the 4th full year since its publication (Li and Ho 2008) and the 6th year (Hassan et al. 2014).

Given the citation peak publications characteristic and the importance of recent research on CE and big data/IoT, we did not use citations over time windows analysis in this study.

We also used greenhouse gas emissions and gross domestic product (GDP) data from the World Bank to generate proportional comparisons with publications.

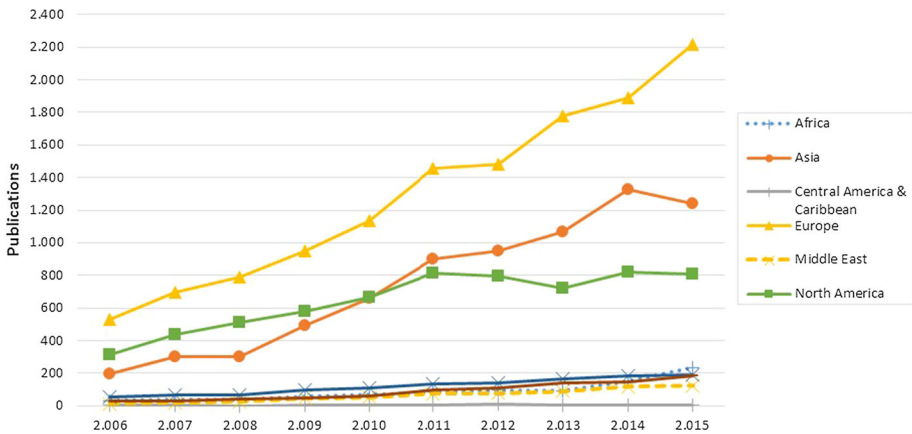
Results were obtained with the use of R statistical software (R Core Team 2016), and R additional packages (Feinerer et al. 2008; Bouchet-Valat 2014; Wickham 2009; Fellows 2014; Hornik et al. 2009; Csardi and Nepusz 2006).

Findings and results

Publication numbers for CE

This section shows the analysis on publications concerning CE. Figure 4 shows the number of publications between 2006 and 2015 grouped by region, all showing a growing interest on the subject. Europe leads with a big gap, while Asia demonstrates more concern for CE than North America in recent years. We observed a 219% growth in publications from

⁵ Scopus database export does not show country names. We assigned documents do countries according to data availability (in this order of priority): author affiliation—main author affiliation—conference location—journal location—source title location. From the original 30,557 documents, only 74 (0.24%) could not have the country mapped.



Region	Total	2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Africa	882	32	37	37	57	67	82	95	93	147	235
Asia	7,443	196	301	304	495	660	902	950	1,067	1,328	1,240
Central Am,	45	3	4	1	2	4	3	10	7	7	4
Europe	12,917	527	699	790	949	1,137	1,457	1,479	1,776	1,889	2,214
Middle East	635	12	20	25	46	51	74	77	91	116	123
North Am.	6,461	314	439	509	577	663	814	795	720	819	811
Oceania	1,210	54	68	68	95	112	137	140	163	184	189
South Am.	889	32	29	39	47	60	97	112	140	149	184
Total	30,482	1,170	1,597	1,773	2,268	2,754	3,566	3,658	4,057	4,639	5,005

Fig. 4 Publication profile on CE by region 2006–2015

2011/2015 against 2006/2010. In South America the growth was of 329%, followed by the Middle East with 312%, both higher than other regions, which indicates the concern on CE in Asia and North America, for example, is more consistent. Given that circular economy initiatives and researches have become more intense since the creation of the Ellen MacArthur Foundation in 2010, this contributes and justifies the higher publications discrepancy in the past five years. Nevertheless, the 37% publication growth from 2012 to 2015 also confirms there is a growing interest on the subject.

The bibliometric descriptive results for 80% of all publications on CE from 2006 to 2015, along with a comparison on greenhouse gas emissions, summarized by country, is presented in Table 1. United States is the country with more publications, and also has the most cited paper, although almost half of the country’s papers (46.94%) don’t have a single citation. China follows with a gap of nearly 2000 publications. Switzerland and Sweden are the countries with the highest publications/greenhouse gas emissions ratio (7.5 and 6.9). Although both countries together don’t have a high number of publications (behind Canada), greenhouse gas emissions are low, showing a genuine concern with the subject. At the other end, Brazil and China have the lowest ratio (0.21 and 0.28), indicating more scientific studies need to be conducted and applied in these countries in order to produce more tangible results.

Regarding CPP, considering the growth tendency for publications on CE in recent years (Fig. 4), for this study this index was used as a reference for comparison in country level only. As the citation peak occurs around the 4th publication year, it is expected that for years 2012–2015 the number of citations might increase significantly. In order to provide a

Table 1 Countries representing 80% of all publications on CE compared to greenhouse gas emissions—2006–2015

Country	Pubs	Citations	CPP	SD	PNC	Max cites	Pub/GHGE
United States	5428	64,682	11.92	55.73	46.94	2676	0.8556
China	3450	20,670	5.99	19.96	55.48	323	0.2770
UK	2502	30,806	12.31	33.30	37.77	571	4.2712
Germany	1543	15,823	10.25	38.50	43.16	652	1.6213
Italy	1504	12,876	8.56	41.74	39.16	1504	3.1162
India	1361	11,067	8.13	23.96	46.88	339	0.4532
Australia	1053	11,915	11.32	41.87	34.38	1162	1.3825
Canada	869	10,708	12.32	34.85	39.82	439	0.8461
France	814	11,341	13.93	46.93	37.10	599	1.6308
Spain	780	8561	10.98	26.34	32.18	402	2.2397
Netherlands	777	11,367	14.63	36.80	32.05	476	3.9668
Brazil	634	4469	7.05	25.39	43.38	525	0.2121
Malaysia	620	7507	12.11	32.99	40.97	328	2.2214
Japan	619	4582	7.40	26.29	41.20	496	0.4186
Sweden	455	4134	9.09	18.19	30.11	165	6.9183
Switzerland	406	5573	13.73	26.26	29.56	200	7.5035
Turkey	382	6076	15.91	37.17	29.06	314	0.8572
Austria	361	3670	10.17	23.32	41.00	241	3.9907
Belgium	331	5060	15.29	42.16	32.33	504	2.4817
Greece	328	3175	9.68	17.33	31.10	111	3.2614
Finland	327	2196	6.72	10.53	34.56	90	4.7341

Greenhouse gas emissions (GHGE) Million Tons in 2012—*Source* The World Bank (<http://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE>, retrieved 03/sep/2016)

CPP citations per publication, *PNC* % of not-cited papers

method for binding publications to a specific region and avoid overlapping in cases of collaboration among countries from separate regions, for each publication the country/region of the main author's affiliated institute was considered. This applies to all charts and tables of this research.

We have also developed the social network analysis⁶ for CE publications for the year 2015 in order to understand the current research trends in terms of keywords associations. As we can see in Fig. 5, the terms “Life Cycle Assessment” and “Renewable Energy” are the nodes with higher betweenness centralities, as they form the densest bridges with other nodes. The word China is directly connected to CE and the central node renewable energy, confirming the high country's concern with the subject, as no other country name is part of the network.

⁶ Most relevant nodes shown. Sustainability and Sustainable Development terms removed from the analysis, as they are central research keys. Auxiliary terms present on keywords also cleansed (pdf, literature review, old for example).

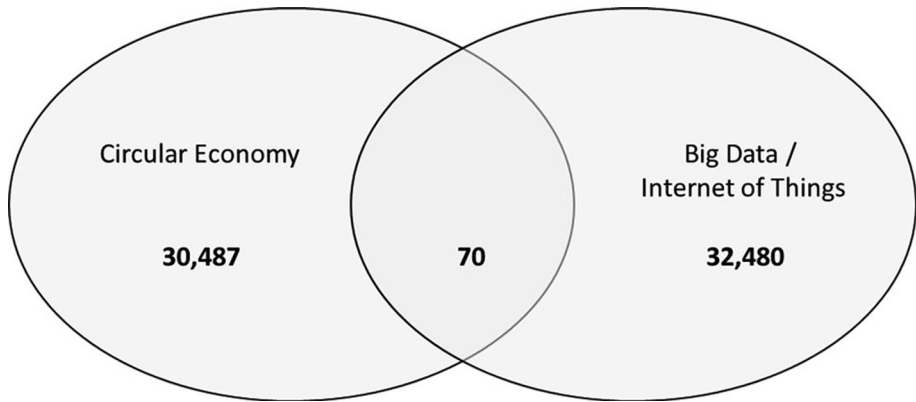


Fig. 6 CE and big data/IoT docs search summary 2006–2015

Publication numbers for CE with big data/IoT

The combination of CE and big data/IoT queries resulted in 70 documents⁷ that discuss both subjects, as shown on Fig. 6.

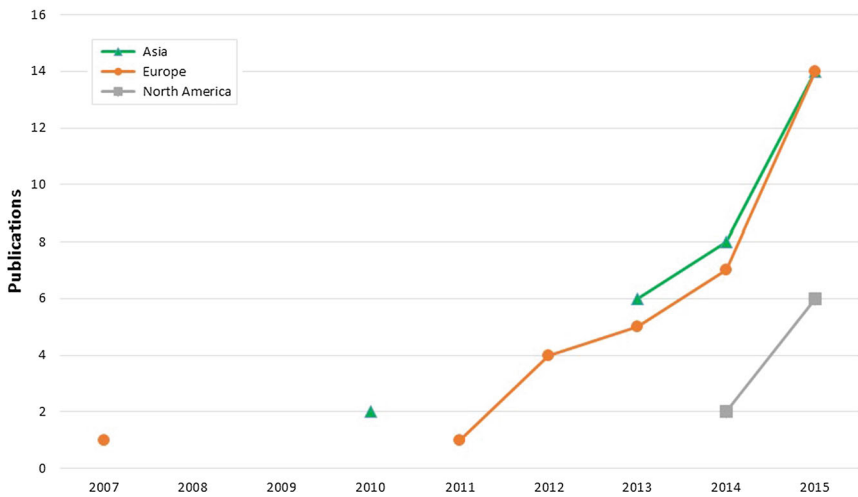
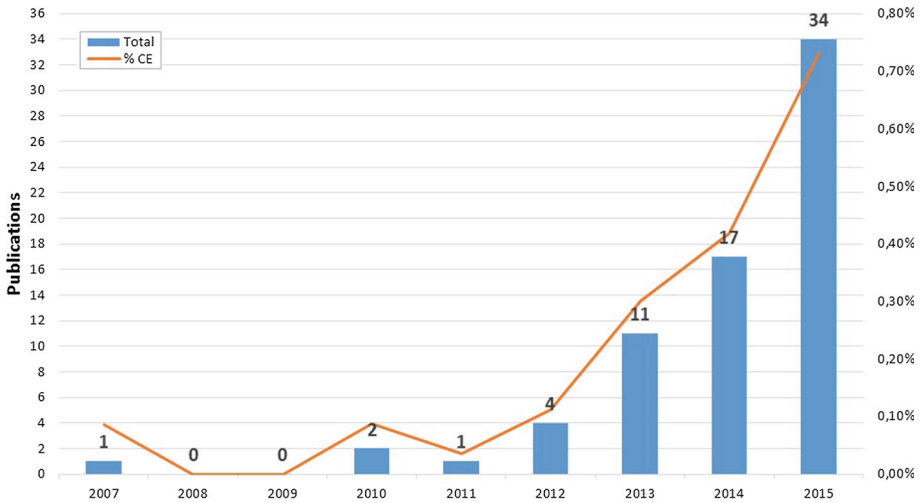
By filtering the CE results on big data/IoT (Fig. 7), we observed similar trends for Europe, Asia and North America. No publications for Africa, Central America & Caribbean, Middle East, Oceania or South America were found.

Although the use of cutting edge technologies is considered an advantage for CE initiatives, only 0.23% of the published studies considered the use of big data and/or IoT technologies. Nevertheless, a growing interest on the subject has been observed on the last three years.

Table 2 contains the bibliometric descriptive results for all publications on CE along with big data/IoT from 2006 to 2015, along with a comparison on greenhouse gas emissions (GHGE) and gross domestic product (GDP), summarized by country. 23 countries published studies on the subject. China leads in publications, although 74% of their studies have not been cited yet. 52% of all publications are concentrated in China, United States and Germany, and 61% of the countries have only one single publication. We noticed the presence of smaller economies like Romania, Pakistan and Kazakhstan and the absence of big economies, such as Brazil, Japan and Russia. The use of GHGE and GDP data helped confirm the strong relation between GDP and emissions, but not necessarily with publications. For example, Serbia, Finland and Greece appear with better publications/GDP ratios, while France, United States, and Canada show poor results. Also, Pakistan produces more greenhouse gases than Finland, but have fewer publications. India, Canada, United States and China have the lowest publication/emissions ratios, meaning stronger investments in technology for Circular Economy could have been done by those countries.

We also extracted data at institution level. By analyzing the results in Table 3, we noticed a Finnish university is the most cited institution on the subject, although it produced only two publications. China is the country with most institutions (four), followed by USA (three) and Finland, Italy, UK with two institutions each. The complete institutions list is on Appendix 3.

⁷ The combined query retrieved initially 71 documents. One was an erratum of another document and was therefore removed from the results.



Region	All Years	2007	2008	2009	2010	2011	2012	2013	2014	2015	
Asia	30				2			6	8	14	
Europe	32	1				1	4	5	7	14	
North America	8								2	6	
Total	70	1	0	0	2	1	4	11	17	34	
% CE ⁹		0,23	0,09	0,00	0,00	0,09	0,04	0,11	0,30	0,42	0,73

Fig. 7 Publication profile on CE and big data/IoT by region 2007–2015 (no data for year 2006)

Content and social network analysis: CE with big data/IoT

The corresponding articles⁸ were submitted to content analysis throughout the entire articles contents (references excluded). After documents cleansing (prepositions, numbers,

⁸ Total of 52 articles. Not included publications: non English language, conference reviews (not articles), not available documents.

Table 2 Countries with publications on CE and big data/IoT compared to greenhouse gas emissions—2007–2015

Country	Pubs	Citations	CPP	SD	PNC	Max cites	Pubs/GHGE	Pubs/GDP
China	23	72	3.13	7.12	73.91	26	0.0018	0.0022
United States	7	7	1.00	1.53	57.14	4	0.0011	0.0004
Germany	7	3	0.43	1.13	85.71	3	0.0074	0.0018
UK	6	3	0.50	0.53	50.00	1	0.0102	0.0020
Italy	4	11	2.75	4.86	50.00	10	0.0083	0.0019
Finland	3	37	12.33	16.29	0.00	31	0.0434	0.0110
Greece	2	1	0.50	0.71	50.00	1	0.0199	0.0085
India	2	0	0.00	0.00	100.00	0	0.0007	0.0010
Malaysia	2	0	0.00	0.00	100.00	0	0.0072	0.0059
Hong Kong	1	3	3.00	0.00	0.00	3	0.0171	0.0034
Sweden	1	3	3.00	0.00	0.00	3	0.0152	0.0018
Belgium	1	1	1.00	0.00	0.00	1	0.0075	0.0019
Spain	1	1	1.00	0.00	0.00	1	0.0029	0.0007
Austria	1	0	0.00	0.00	100.00	0	0.0111	0.0023
Canada	1	0	0.00	0.00	100.00	0	0.0010	0.0006
France	1	0	0.00	0.00	100.00	0	0.0020	0.0004
Kazakhstan	1	0	0.00	0.00	100.00	0	0.0027	0.0044
Pakistan	1	0	0.00	0.00	100.00	0	0.0027	0.0041
Portugal	1	0	0.00	0.00	100.00	0	0.0138	0.0043
Romania	1	0	0.00	0.00	100.00	0	0.0082	0.0050
Serbia	1	0	0.00	0.00	100.00	0	N/A ^a	0.0226
Singapore	1	0	0.00	0.00	100.00	0	0.0179	0.0033
Switzerland	1	0	0.00	0.00	100.00	0	0.0185	0.0014

Greenhouse gas emissions (GHGE) Million Tons in 2012—*Source* The World Bank (<http://data.worldbank.org/indicator/EN.ATM.GHGT.KT.CE>, retrieved 04/sep/2016)

Gross Domestic Product in US\$ (GDP)—*Source* The World Bank (<http://data.worldbank.org/indicator/NY.GDP.MKTP.CD>, retrieved 04/sep/2016)

CPP citations per publication, PNC % of not-cited papers

^a Greenhouse gas emissions for Serbia not available

punctuation, common words), we came up with a list of the most frequent words (word-stem), detailed on Fig. 8, which presents terms that lead to researches more related to the public sector/sponsored by government agencies. The additional omitted common words list is presented on Appendix 4. Main research words were also omitted: data, information, system, big data, sustainability, sustain, circular economy. Words such as environment, service, power, efficiency shown in high positions suggest a higher research focus on these areas.

Besides the high incidence of common terms, the identification of some other relevant keywords indicate current researches occurring in areas such as carbon emissions reduction, smart cities, water economy, environment, waste management and renewable sources as well. Cloud computing has been an additional enabler.

Table 3 Institutions with cited publications on CE and big data/IoT—2006–2015

Affiliated institute	Country	Pubs	Citations	CPP
Aalto University	Finland	2	36	18.00
Chinese Academy of Sciences	China	3	32	10.67
Huazhong University of Science and Technology	China	2	18	9.00
Tsinghua University	China	1	17	17.00
University of Bergamo	Italy	1	10	10.00
Jilin University	China	1	5	5.00
University of Florida	United States	1	4	4.00
Fraunhofer IPK	Germany	1	3	3.00
Hong Kong Polytechnic University	Hong Kong	1	3	3.00
Royal Institute of Technology	Sweden	1	3	3.00
Ohio State University	United States	1	2	2.00
Caterpillar	United States	1	1	1.00
Cheshire Henbury	UK	1	1	1.00
EIT ICT LABS	Italy	1	1	1.00
Outotec Oyj	Finland	1	1	1.00
Plymouth University	UK	1	1	1.00
Technological and Educational Institute of Piraeus	Greece	1	1	1.00
Unilever—Colworth Park	UK	1	1	1.00
Université Catholique de Louvain	Belgium	1	1	1.00
University of Alicante	Spain	1	1	1.00

CPP citations per publication

The social network analysis (Fig. 9) based on all articles’ keyword fields shows some new terms highly central and connected nodes with betweenness centralities, such as “Open Data”, “Energy Efficiency”, “Environment” in one network, and a balance among terms on the other network. The high frequency and connections of the term “Sustainable HCI” (human–computer interaction) deserves to be pointed out as an interesting finding, along with “ICT Research Strategy”, showing a real interest for information and technologies research on the area, not necessarily bound to big data/IoT.

We depicted the cited papers on CE with the use of big data/internet of things on Table 4, along with their SNA-related keywords. Some of the researches focus on initiatives possibly related in a way with government agencies and the public sector in general, given the regular use of terms such as smart grid, sustainable cities, utilities, and environmental politics, also present on the word cloud analysis. Other interesting finding is the variety of applications encountered: closed loop product lifecycle management, establishment of sustainable cities, energy grid optimization, ecologically designed products and buildings, sustainable agriculture, for example, meaning the use of the concepts applies to almost every action we take in our personal or business lives.

We also selected the articles with more than ten citations from the 70 papers found to explore in more detail the researches being undertaken in the area of CE with the support of big data/IoT:

Table 4 Cited papers on circular economy with the use of big data/internet of things

Title	Country	Affiliated institute	References	Cites	SNA-related keywords ^a
Sustainable PLM through intelligent products	Finland	Aalto University	Främling et al. (2013)	31	Life cycle assessment;
The planning, construction, and management toward sustainable cities in China needs the environmental internet of things	China	Chinese Academy of Sciences	Zhao et al. (2013)	26	Environment; smart city
Key technologies of electric power big data and its application prospects in smart grid	China	Huazhong University of Science and Technology	Peng et al. (2015)	18	Smart grid
Ecodesign in consumer electronics: past, present, and future	China	Tsinghua University	Li et al. (2015)	17	Design; environment; recycling
Smart City by multi-agent systems	Italy	University of Bergamo	Roscia et al. (2013)	10	ICT for sustainability; smart city;
Automotive recycling information management based on the internet of things and RFID technology	China	Jilin University	Zhang et al. (2010)	5	Automotive industry; recycling
An integrated system for urban environmental monitoring and management based on the environmental internet of things	China	Chinese Academy of Sciences	Su et al. (2013)	5	Environment; environmental politics; smart city
P2P data synchronization for product lifecycle management	Finland	Aalto University	Kubler et al. (2015)	5	Life cycle assessment
Towards sustainable in situ server systems in the big data era	United States	University of Florida	Li et al. (2015)	4	Energy efficiency
Advanced technologies in life cycle engineering	Germany	Fraunhofer IPK	Stark et al. (2014)	3	Life cycle assessment
Implementing smart urban metabolism in the Stockholm Royal Seaport: Smart city SRS	Sweden	Royal Institute of Technology	Shahrokni et al. (2015)	3	Environmental politics; smart city;
Enhancing environmental sustainability over building life cycles through green BIM: a review	Hong Kong	Hong Kong Polytechnic University	Wong and Zhou (2015)	3	Environmental politics
Big data issues and opportunities for electric utilities	United States	Ohio State University	Schuelke-Leech et al. (2015)	2	Energy efficiency; smart grid

Table 4 continued

Title	Country	Affiliated institute	References	Cities	SNA-related keywords ^a
The role of the internet of things in enabling sustainable agriculture in Europe	UK	Cheshire Henbury	Kidd (2012)	1	Biodiversity; conservation agriculture; ICT research strategy; integrated pest management; interoperability; new business models; precision agriculture; sustainable agriculture/production; systems-level approaches
Leveraging technology evolution for better and sustainable cities	Italy	EIT ICT LABS	Saracco (2012)	1	Smart city
The design and implementation of energy consumption monitoring platform oriented to public green buildings	China	Chinese Academy of Sciences	Lin et al. (2013)	1	Energy efficiency;
Green SoCs for a sustainable internet-of-things	Belgium	Université Catholique de Louvain	Boll et al. (2013)	1	Environmental politics
Cloud enabled big data business platform for logistics services: a research and development agenda	UK	Plymouth University	Neaga et al. (2015)	1	new business models
A computational method based on radio frequency technologies for the analysis of accessibility of disabled people in sustainable cities	Spain	University of Alicante	Gilart-Iglesias et al. (2015)	1	Smart city
Lead, zinc and their minor elements: enablers of a circular economy	Finland	Outotec Oyj	Reuter et al. (2015).	1	Recycling
A low-cost and fast PV I–V curve tracer based on an open source platform with M2M communication capabilities for preventive monitoring	Greece	Technological and Educational Institute of Piraeus	Papageorgas et al. (2015)	1	Smart grid
The role of science in shaping sustainable business: Unilever case study	UK	Unilever - Colworth Park	Sim et al. (2015)	1	Environment; life cycle assessment
The big data application strategy for cost reduction in automotive industry	United States	Caterpillar	Ge and Jackson (2014)	1	Automotive industry

^a For documents with no keywords, entries were made manually by the authors upon paper analysis. Some SNA keywords not shown on the table as only cited documents were listed. SNA keywords revised in order to generate alignment among synonyms/similar words

improve the automation level of the power systems where it has already been implemented (Peng et al. 2015).

IoT and big data have also been playing a fundamental role on the development of smart cities. The concept of environmental internet of things (EIoT), for example is being studied in China, due to the country's population and pollution growth. By implementing and integrating sensors for mobile (e.g. aircrafts, boats, cars, cell phones) and stationary assets, the technology can monitor soil, water, wind etc. providing on-line and real-time environment information, and supports decision-making processes for the management of future sustainable cities (Zhao et al. 2013). It is also recognized that smart city concepts are still immature and will require a lot of planning and standardization in order to allow different infrastructures, subsets and devices to properly communicate and interact in an acceptable manner. Some researchers are already trying to come up with a smart city model to be used as a repeatable and exportable standard, such as the Intelligent Distributed Autonomous Smart City—IDASC, which is a conceptual model that embraces diversity of technology, operators, and connection (Roscia et al. 2013).

The consumer electronics industry is also taking advantage from the benefits CE leveraged by technology. The recent advances in electronic technology has shortened the life cycle of components, leading to the growth of electronic and electric waste (e-waste), which has been raising concerns about the environment. Ecodesign models are now being applied to such components, resulting in the development of more environmentally friendly materials. And IoT has a crucial role on the success of e-waste reduction, as consumer electronics logistics in all supply chain network (including material selection, product distribution and e-waste collection) tends to be improved through equipping components with RFID tags and other types of sensors already available at low cost. The use of supporting databases, geolocation/decision support/integrated environmental information systems will provide a huge contribution to e-waste management, saving resources from materials use (Li et al. 2015).

We should also mention some key CE terms not shown on our big-data/IoT research. Those indicate studies opportunities are even broader for researchers: bioeconomy, carbon biofixation, carbon capture, carbon recovery, climate bond, circular ecosystem, eco industry, end of waste, sharing cities, waste recovery, waste to value.

Policy implications

There are some ways in which our findings would support a move towards more motivation in researches on CE with big data/IoT, and, as a consequence, more actions on moving from the linear to the circular model, leveraged by technology. First, the gap found between the types of current scientific researches on the field and corporate initiatives can be reduced by the time they work closer, in a complimentary way, as both sides will benefit from such initiatives. This may then act as an incentive to make them work more closely to each other (by making action researches, for example). Second, as the keywords search queries presented in the methodology section were obtained empirically due to the lack of predefined taxonomies for CE, they can in future researches be organized and transformed in structured taxonomies, turning the scientific exploration of CE less complicated. Also and consequently, as the subject of this research is relatively new, some papers might not have been part of the query results, as the respective authors might not have used the selected keywords.

Moreover, the findings can also serve as an alert to those countries identified as with a high rate greenhouse gas emissions compared to scientific studies, so they can be motivated to start moving towards a circular approach.

In addition, by understanding the studies being undertaken in the field, we can suggest a key orientation to organizations, which is to start thinking about CE from the design phase of their products, as it is a concept present through all chains on the production system. By designing products with modular components, for an extended life-cycle, reusable, trackable, easily disassembled and made from renewable sources rather than only being concerned about the product's visual aspect, this will be far more acceptable by consumers (which are becoming more and with more environmental awareness) than using only a visual appealing product that harms the environment.

Conclusions

Undoubtedly, the attractiveness of CE is growing globally and changes in consumer behavior are playing an active role in this transformation, fostering researches all over the world. The application of technologies such as big data and IoT, being also enablers, has been showing a consistent growth interest on recent years but still requires more studies in the field. Some large economies in terms of geographic area, economy and greenhouse gas emissions (therefore with potential interest on technology applied to CE) such as Brazil (along with the rest of South America) and Russia are still not generating any publications in the field. Specifically in Brazil, we noticed a growing interest on the subject leveraged by independent entrepreneurs, which are collaborating with successful countries and fostering local initiatives, such as the Exchange 4 Change⁹ organization.

Some fundamental principles belonging to the CE framework require attention, as they are still not being scientifically studied globally with the support of technology, such as bioeconomy and waste recovery.

Moreover, as most scientific studies found on this research consist on conceptual models, ongoing projects, prospects, tendencies, pilots, they are more now like “imagining the possibilities” than actually developing cases studies based on already established programs for benefits measuring. On the other hand, there are already interesting industry/private sector cases waiting to be scientifically explored by researchers, such as the examples illustrated in this document.

Additionally, the study can help researchers develop more detailed and specific CE bibliometric analysis to areas other than big data/IoT with the use of the preliminary keyword taxonomy mapped in this research.

⁹ <http://www.e4cb.com.br>.

Appendix 1

Scopus Database query for circular economy.

```
(TITLE-ABS-KEY((
(
"3R" OR "5R" OR "6R" OR "Bioeconom*" OR "Biomimicry" OR "Carbon Biofixation" OR
"Carbon Capture And Storage" OR "Carbon Capture And Utilization" OR "Carbon Dioxide
Recovery" OR "Carbon Emission Reduction" OR "Carbon Footprint Reduction" OR "Carbon
Sequestration" OR "Climate Bond" OR "Closed Loop" OR "Co2 Emissions Reduction" OR
"Collaborative Consumption" OR "Collaborative Econom*" OR "Collaborative Model" OR
"Collaborative Technolog*" OR "Complex Circular Ecosystem" OR "Cradle to Cradle" OR
"Development Model In Circular" OR "E-Waste" OR "Eco Cycle Industry" OR "Electronic
Waste" OR "Emission Cutting" OR "Emission Reduct*" OR "End Of Life" OR "End Of
Waste" OR "Environmental Efficiency" OR "Environmental Oriented Supply Chain
Cooperation" OR "Environmental Supply Chain Cooperation" OR "Environmentally
Responsible Manufacturing" OR "Extended Producer Responsibility" OR "Green Econom*"
OR "Green Manufactur*" OR "Green Remanufactur*" OR "Green Supply Chain" OR
"Industrial Ecology" OR "Industrial Symbiosis" OR "Integrated Waste Management" OR
"Intra County Cyclic Econom*" OR "Life Cycle Assessment" OR "Life Cycle Management"
OR "Life Cycle Optimization" OR "Life Cycle Thinking" OR "Low Carbon Agriculture"
OR "Low Carbon City Strategies" OR "Low Carbon Development" OR "Low Carbon
Ecological Mining" OR "Low Carbon Econom*" OR "Low Carbon Enterprise" OR "Low
Carbon Future Cit*" OR "Low Carbon Governance" OR "Low Carbon Hotel" OR "Low Carbon
Innovative System" OR "Low Carbon Management" OR "Low Carbon Office" OR "Low Carbon
Policy" OR "Low Carbon Scenario" OR "Low Carbon Technolog*" OR "Low Carbon
Transition" OR "Material Efficiency" OR "Material Flow Analysis" OR "Optimal Model
Circular" OR "Performance Econom*" OR "Product Life Cycle" OR ("Reduc*" AND "Reus*"
AND "Recycl*") OR "Refurbishment" OR "Regenerative Design" OR "Regenerative
Econom*" OR "Remanufacturing" OR "Renewable Energy" OR "Renewable Resource" OR
"Resource Efficiency" OR "Resource Recirculation" OR "Resource Recovery" OR
"Restorative Econom*" OR "Reverse Logistics" OR "Service Life Extension" OR
"Sharing Cit*" OR "Sharing Econom*" OR "Sharing Societ*" OR "Sharing Value System"
OR "Sustainable Agriculture" OR "Sustainable Business Model" OR "Sustainable Cit*"
OR "Sustainable Consumption" OR "Sustainable Industrial Development" OR
"Sustainable Logistics" OR "Sustainable Materials Management" OR "Sustainable
Resource Use" OR "Sustainable Supply Chain Network" OR "Sustainable Waste
Management" OR "Waste Prevention" OR "Waste Recovery" OR "Waste Reduction" OR
"Waste To Energy" OR "Waste To Materials" OR "Waste To Resource" OR "Waste To
Value" OR "Zero Emissions" OR "Zero Value Residue" OR "Zero Waste"
)
)
AND
("sustainability" OR "sustainable"))
OR
(
(
"Circular Econom*" OR
"Circular Agriculture" OR
"Circular Business Model" OR
"Circular Competence Indicator" OR
"Circular Corporation" OR
"Circular Ecology" OR
"Circular Industr*" OR
"Circular Management" OR
"Circular Product*" OR
"Circular Supply Chain" OR
"Circular Technology Innovation" OR
"Circular Transition Framework" OR
"Circular Value Chain*" OR
"Circulatory Econom*"
)
)
)
AND PUBYEAR > 2005 AND PUBYEAR < 2016
```

Appendix 2

Scopus Database query for big data and internet of things.

```
(TITLE-ABS-KEY(
  ("Big Data" OR "Bigdata") OR
  ("Internet of Things") OR
  (("Spark Streaming" OR "Mlib" OR "Spark R" OR
  "Machine Learning") AND "Apache") OR
  (("Hdfs" OR "Cfs") AND "File System") OR
  ("Mizan" AND "Kaust") OR
  ("Presto" AND "SQL") OR
  ("Apache Avro") OR ("Apache Cassandra") OR ("Apache Drill") OR
  ("Apache Flink") OR ("Apache Flume") OR ("Apache Giraph") OR
  ("Apache Hive") OR ("Apache Impala") OR ("Apache Kafka") OR
  ("Apache Mesos") OR ("Apache Mrql") OR ("Apache Pig") OR
  ("Apache S4") OR ("Apache Samza") OR ("Apache Spark") OR
  ("Apache Storm") OR ("Apache Tajo") OR ("Apache Tez") OR
  ("Apache Yarn") OR ("Cloudera") OR ("Google Bigquery") OR
  ("Google Pregel") OR ("Graphchi") OR ("Graphlab") OR
  ("Graphx") OR ("Hadoop") OR ("Hbase") OR ("Ibm Big Sql") OR
  ("Ibm Infosphere Streams") OR ("Infosphere Biginsights") OR
  ("Mapr") OR ("Mapreduce") OR ("Microsoft Graph Engine") OR
  ("Microsoft Trinity") OR ("Nosql") OR ("Pivotal Hawq") OR
  ("Platfora") OR ("Powergraph") OR ("Pregelix") OR
  ("Spark Sql") OR ("Trifcata") OR ("Turbograph")
)
)
AND PUBYEAR > 2005 AND PUBYEAR < 2016
```

Appendix 3

Complete list of institutions publishing on CE and big data/IoT (Table 5).

Table 5 Institutions with publications on CE and big data/IoT—2006–2015

Affiliated institute	Country	Pubs	Citations	CPP
Aalto University	Finland	2	36	18.00
Chinese Academy of Sciences	China	3	32	10.67
Huazhong University of Science and Technology	China	2	18	9.00
Tsinghua University	China	1	17	17.00
University of Bergamo	Italy	1	10	10.00
Jilin University	China	1	5	5.00
University of Florida	United States	1	4	4.00
Fraunhofer IPK	Germany	1	3	3.00
Hong Kong Polytechnic University	Hong Kong	1	3	3.00
Royal Institute of Technology	Sweden	1	3	3.00
Ohio State University	United States	1	2	2.00
Caterpillar	United States	1	1	1.00
Cheshire Henbury	UK	1	1	1.00

Table 5 continued

Affiliated institute	Country	Pubs	Citations	CPP
EIT ICT LABS	Italy	1	1	1.00
Outotec Oyj	Finland	1	1	1.00
Plymouth University	UK	1	1	1.00
Technological and Educational Institute of Piraeus	Greece	1	1	1.00
Unilever—Colworth Park	UK	1	1	1.00
Université Catholique de Louvain	Belgium	1	1	1.00
University of Alicante	Spain	1	1	1.00
Wuhan University	China	2	0	–
Chongqing University	China	1	0	–
Hewlett Packard—Bracknell	UK	1	0	–
IBM Thomas J. Watson Research Center	United States	1	0	–
Ingram School of Engineering	United States	1	0	–
International IT University, Almaty	Kazakhstan	1	0	–
Jinan University	China	1	0	–
McGill University	Canada	1	0	–
Mehran University of Engineering and Technology	Pakistan	1	0	–
Nanjing University	China	1	0	–
Northwest University of Politics	China	1	0	–
Pace University	India	1	0	–
Politecnico di Torino	Italy	1	0	–
Robert Gordon University	UK	1	0	–
Singapore Institute of Manufacturing Technology	Singapore	1	0	–
Singidunum University	Serbia	1	0	–
Sinhgad Institute of Technology	India	1	0	–
Technical University of Cluj-Napoca	Romania	1	0	–
Technische Universität Darmstadt	Germany	1	0	–
Tianjin University	China	1	0	–
Universidade de Trás-os-Montes e Alto Douro	Portugal	1	0	–
Università Politecnica Delle Marche	Italy	1	0	–
Universität Osnabrück	Germany	1	0	–
Universiti Teknikal Malaysia Melaka	Malaysia	1	0	–
University Malaysia Pahang	Malaysia	1	0	–
University of Bayreuth	Germany	1	0	–
University of Bremen	Germany	1	0	–
University of California—Berkeley	United States	1	0	–
University of Innsbruck	Austria	1	0	–
University of Minnesota	United States	1	0	–
University of Münster	Germany	1	0	–
University of Paris	France	1	0	–
University of Southampton	UK	1	0	–
N/A (Conference Reviews) ^a	N/A	12	0	–

CPP citations per publication

^a Conference reviews are not affiliated

Appendix 4

Content analysis filtered terms. Numbers, prepositions, adverbs, verbs, punctuation, letters, references, plurals URL's also removed from the list

abstract	enable	may	sustainability
according	et al	mean	system
all rights reserved	etc	methodology	table
allow	example	must	term
also	exist	need	therefore
although	existing	new	thus
among	fig	non	time
analysis	figure	number	total
article	first	per	type
article	generated	possible	ufij
based	ie	practice	unit
better	inform	presented	use
big data	information	proposed	used
can	init	provides	using
case	introduction	pt	various
cite	issu	related	vol
copyright	journal	required	way
current	key	research	well
data	large	see	will
detail	lead	set	within
discuss	level	several	work
download	link	show	year
due	main	specific	
e.g.	make	study	
eight	many	sustain	

Appendix 5

Basic concepts of circular economy (CE), big data and internet of things (IoT)

Circular economy (CE)

The circular economy (CE) term was conceived based on an industrial economy focused on producing zero pollution and zero waste, by intention or by design. According to this concept, material flows/cycles are supposed to be natural and of two types: biological, which enters back to the biosphere with no harm to the environment (e.g. biodegradable/green wastes) and technical, which should be designed to circulate back to manufactures (original ones or others) as new resources, making the whole model work as a living system, where waste is considered a nutrient. This model contrasts with our current

linear economy, based on the traditional “take, make, use, dispose/waste” model (Ellen MacArthur Foundation 2016). There are several approaches/terms that have been recently being used to identify initiatives on CE, such as the 3R (reduce, reuse, recycle), cradle to cradle, biomimicry, industrial ecology etc. (Pearce and Turner 1989). The concept of CE was originally coined in the 1970s with a vision of an economy in loops and the positive impact on many areas, including resource savings and waste prevention (Stahel and Reday 1981). The CE also defends the concept of performance economy, which shows the importance of selling services than products (use x ownership). In developed countries (more saturated markets), for example, consumer behavior is already changing in this direction (Planing 2014). That explains the success of companies such as Airbnb and Uber, both valuable businesses that use technology as an enabler to provide services in marketplaces that could not even be imagined two decades ago.

Big data

The term big data is essentially about huge and continuous data gathering, processing and analyzing. One more detailed definition encapsulates the expression as the 4V's (Paharia 2013; Marr 2015): Volume—massive amounts of data being generated continually in a volume never before observed, scaling to Brontobytes; Variety—distinct and unstructured formats, representing today about 80% of all available data (texting, imaging, videos, voice); Velocity—high data generation frequency (today it is possible to analyze data before being stored in a database; and Veracity—the quality of the data and its proven real world application.

Other definition adds the word “complexity” to the 4 V's, and refers not only to the contents but also to the challenges to obtain, process and store the data, which has led to studies such as shared and collaborative cloud processing (Kaisler et al. 2013).

Exemplifying the relevance and importance of big data nowadays: Eric Schmidt, former Google CEO, pointed that “There was 5 Exabytes of information created between the dawn of civilization through 2003, but that much information is now created every 2 days, and the pace is increasing.” (Upbin 2012).

Value generation with big data can be achieved by: creating transparency to organizations so accurate business analysis can be done; experimental analysis support for decision making processes; marketing segmentation based on customer and markets; automated and real-time analysis; product innovation with the use of sensors that monitor customer reactions etc. (Kaisler et al. 2013).

Internet of things (IoT)

Internet of things (IoT), also known as internet of objects, is about the connection of everyday objects, often equipped with intelligence, with each other and with people. It is expected that the omnipresence of Internet will be increased with the raising adoption of IoT, as it intends to integrate every object through embedded systems (Xia et al. 2012). Applications of IoT include: intelligent sensors on cars, better disease diagnosis, prevention and treatment, smart home appliances, smart supermarket shelves, real time stocks monitoring, environment monitoring (Bandyopadhyay and Sen 2011).

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