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Green IT and Sustainable Technology Development: Bibliometric Overview

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ABSTRACT
Green Information Technologies (GIT) constitute a field of research, whose objective is to reduce the environmental pollution caused by masses of people using and producing technology.
This paper describes the search for literature related to GIT and technology sustainability in Scopus database. No restriction was imposed on the time period when carrying out the search. The data gathered revealed that the journal with the highest number of publications is Computer, and the most prolific author is Tomoya Enokido, with 45 publications. A total of 53.12% of the documents found in Scopus were Conference Paper. Although no statistically significant differences were detected, countries in the group with less CO_2 kton emissions per inhabitant and less income per capita have a higher percentage of publications. The reduction of power consumption in the cloud data centers is a hot topic for future work, since the word 'cloud' appeared in nine out of the ten most frequently cited papers.

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Introduction

THE TREATMENT OF TOXIC WASTE, AND PARTICULARLY HAZARDOUS WASTE (E.G. BATTERIES), WHICH IS HARMFUL TO PLANTS, animals or humans, requires careful disposal processes. These procedures are, in many cases, not properly regulated (Maharaj and Ramnath 2007). Environmental problems have, therefore, become a crucial topic to be addressed by researchers (Bohas and Poussing 2016) and to promote for the engagement in waste recycling (Yung 2012). Electronic devices with reduced energy consumption are growing in popularity since they provide a more sustainable operation (Dell and Rand 2001). This is the case of mobile phones. Given the fact that there are more subscriptions to mobile devices than inhabitants around the globe (GSMA-Intelligence 2017), these devices must be energy efficient in order to extend the battery charge cycle (Sahin et al. 2016) (Hartmann and Bosch 2016), thus enabling a reduction in the pollution caused by producing energy from non-renewable sources (Longo et al. 2015). Many approaches with which to attain both lower energy costs and zero power consumption as regards computing device have consequently been proposed (Gammaitoni et al. 2015).

Although the environmental impact of Information and Communication Technologies (ICT) attracted the particular attention of researchers in the early 1990s (Salahuddin and Alam 2015), energy consumption has been considered to a much lesser extent. Technical and functional features have been more important in the market for a better user experience. However, sustainability has, over the last few years, acquired more relevance as regards electronic devices.

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The measurement of energy consumption can be managed at hardware (Damaševičius et al. 2013), instruction-level (Šimunić et al. 2000), operating system (Sagahyroon 2006), benchmarks (Wilke et al. 2013), algorithms, data, application software and user levels (Ravi et al. 2008). These data facilitate the study of the performance of technology devices according to their energy needs (Stemm and H 1997). One way in which to boost the reduction of energy consumption and increase consciousness of sustainability at the time of selecting efficient technology products is labeling. As the behavior of hardware is determined by the software installed (Erdélyi 2013), benchmarks related to energy consumption in mobile applications have been applied in different domains (e-mail clients and browsing). A label for these software applications was proposed (Wilke et al. 2013) in order to highlight the importance of software in technology sustainability. Another example related to power consumption in ICT is the Energy Star program for sustainability consciousness. This initiative was started by the US Environment Protection Agency in 1992 and the European Union (EU) agreed to take part in it in 2001 (European Commision 2001). This project also proposes the labeling of office equipment in order to enable potential clients to identify energy efficient products. GIT therefore emerged in order to make users aware of the consequences for the planet of a massive use of technology and to enhance their concern about how this vast utilization of technology influences the environment.

GIT is slowly becoming a topic of importance amongst academics (Brooks et al. 2010). It comprises a set of concepts that propose a more conscious use of technology from the point of view of sustainability, and not only the hardware side of the technology, but also the software is considered. There is a variety of definitions of GIT in literature (Calero and Piattini 2015), but a relationship between technology and the planet's resources is generally established. Some authors claim that the main goal of GIT is to produce as little waste as possible when using IT (Erdélyi 2013). Other authors (Lo and Qian 2010) propose referring to Green Computing as any use of technology with little or no impact on the environment.

The terminology of sustainability is commonly criticized as being blurred, fuzzy and ambiguous (Daniel et al. 2017). Moreover, some barriers to ensure sustainable behaviors, such as a lack of clarity in the concept and resistance to change, have been identified (Paiva Duarte 2015). However, the basic ideas required to understand the concept of sustainability when applied to technology are set out in the Karlskrona manifesto (Becker et al. 2015). This document states that sustainability has to be understood as regards a set of five dimensions: social, individual, environmental, economic and technical. The Green Code of Ethics (Moraga et al. 2017) takes the basis of the Karlskrona manifesto to propose professional practices in the field of software engineering and its objective is to encourage software practitioners to adopt Green in IT methodologies, although there are still many misconceptions and misunderstanding surrounding Software Sustainability (Calero and Piattini 2017).

In this study, we introduce a bibliometric study of GIT and technology sustainability in order to provide an overview of the past, present and future trends of these research topics, which may help promote future research in the field and propose alternatives to the conventional economic growth paradigm (Gabor et al. 2018). In order to discover which factors have an impact on sustainability research, the relationship between economic data, population and pollution produced by countries is compared with the number of publications that each country generates in this field.

This paper is organized as follows. The search string construction process used in Scopus is described in the Materials and Methods section, while the data gathered from this database, parameters related to institutions, countries, author production, journal productivity, author citation analysis, scientific collaborations and journal citation analysis are depicted in the Results section. The Discussion section contains an in-depth analysis of the results, together with present actions carried out to promote GIT throughout the world. Finally, the limitations and future work are introduced in the conclusion section.

Related Work

A bibliometric analysis exploring the trends in the engineering and technology management, and business management publications on green innovations, green investments and green venture capital from 1990 to 2009 was carried out by (Tekin and Kocaoglu 2011). These authors predicted a rapid development stage as regards the sustainability-related publications in the areas studied. Another bibliometric analysis of two scientific networks (transition literature and transformation literature) investigating socio-technical change in sustainability policies discovered that transformation literature focuses on technology (Chappin and Ligtvoet 2014). A bibliometric review of the innovation adoption publications revealed five clusters based on bibliographic coupling, which indicates the research trends

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(van Oorschot et al. 2018). Cluster two, in which there are 267 articles, explores the adoption of dominant designs and new technology standards related to sustainable technology. A bibliometric, network and survey analysis of the evolution of circular economy scientific knowledge in China and the EU-28 showed that Green Sustainable Science Technology is one of the most common science categories and bodies of knowledge (Türkeli et al. 2018).

Few studies have been conducted on technology greenability to date. A detailed analysis of 618 papers on green innovation from the Web of Science database (1971–2015 period) was carried out (Albort-Morant et al. 2017). In this work a bibliometric analysis was performed, revealing a chronological development of the discipline, the research trends and popular issues in this field, the antecedent variables acting as key drivers of green innovations in these studies, and the main outcomes of green innovations. A comprehensive review of the literature surrounding GIT produced by both practitioners and academics was also conducted (Brooks et al. 2010). The overlaps and differences between both perspectives were introduced with the goal of identifying noticeable gaps in the current literature. Another study carries out an in-depth exploration of matters related to sustainability in business (Wichaisri and Sopadang 2017). In this work, research clusters concerning sustainable development are identified by using a bibliometric analysis. These clusters are divided into bunches of knowledge that reveal the need for a greater amount of study on sustainability issues regarding the social dimension, in order to balance economic and environmental dimensions. These studies focus on the specific sustainability aspects of the software industry and business. In contrast, our paper conducts an comprehensive bibliometric analysis that is related to GIT and technology sustainability. Our work encompasses a wider field of research, which provides readers with a more extensive understanding of the current situation of GIT and technology sustainability (see Appendix A). This is, to the best of our knowledge, the first bibliometric analysis of GIT and technology sustainability.

Materials and Methods

Bibliometric analyses provide researchers with information on scientific output in a brief and comprehensible form (Diem and Wolter 2013), and is used to identify and study the publications in a scientific field of interest (Garousi 2015). The term bibliometrics is defined as the application of mathematics and statistical methods to books and other means of communication (Pritchard 1969).

The data required for this bibliometric analysis were collected by using Scopus, which is the largest bibliometric database, and one of the most commonly used sources for citation data in bibliometric analyses (Mongeon and Paul-Hus 2016). The data gathered allowed us to obtain the parameters for our bibliometric study. A search string was constructed with words that were expected to appear in the documents' title, abstract and keywords sections. Wildcard characters were included in order to cover variations in nouns. The use of literals was necessary in the search string to guarantee the appearance of words in a specific order and prevent other words from appearing among those selected. The words were alternated so as to achieve a more extensive result (for example, "green* software" and "software green*").

Moreover, in order to avoid unexpected results, the use of contractions with two letters, such as IT (Information Technology) and IS (Information System), was limited to those cases in which a preposition such as in, by, for, through and with appeared together with a noun (for example, "green* by IT" and "sustain* in IS"). These contractions were used without a preposition, or only together with a noun, when searching in the documents' keywords and title sections. Contractions with three letters, such as ICT, despite the fact that there was no preposition after the noun, were included in the search string owing to the low likelihood of confusion with other contractions (e.g. there are more letters) and the production of erroneous results.

Metadata were exported in order to analyze the data collected in a bibliometric manner. Scopus allows the results to be downloaded as text-files and csv files. A total of 4398 publications were retrieved on 20th of June 2017 (see the search string in Appendix A). No restriction on period of time was imposed in the search.

The terms used in the search string were selected on the basis of their relationship with GIT and technology sustainability. A sensibility analysis of the publications obtained from the Scopus database was carried out to evaluate the accuracy of the results with regard to the aforementioned topics. This evaluation was conducted by randomly selecting a subset of publications from the whole list of literature obtained from the Scopus database. The relationship of each publication with the field being studied was then reviewed. The number of documents selected in order to

DOI: 00.0000/sd

perform the validation step was determined by means of Cochran's sample size formula (1), which is as follows (Cochran 1977):

$$n = \frac{N \cdot Z^2 \cdot p \cdot (1-p)}{(N-1) \cdot e^2 + Z^2 \cdot p \cdot (1-p)} \quad (1)$$

where n is the number of documents to be randomly selected for the validation, *N* is the total number of publications obtained from the Scopus database using the search string, *Z* is the deviation of the mean value that is accepted for the level of confidence (a level of confidence of 90% implies that Z=1.645; a level of confidence of 95% implies that Z=1.96; a level of confidence of 99% implies that Z=2.575), *e* is the error margin and *p* is the proportion of results that is expected to be invalid.

With N=4398
Z=1.96 (level of confidence 95%)
e=0.05
p=0.08 (randomly selected, it is expected to be low)
a sample of 110 publications was required to carry out the validation.

In this case, of the 110 publications randomly selected, only 10 publications did not have any relationship with the GIT and technology sustainability technology fields, which is a proportion of 9% of invalid results (8% expected).

Another validation of the search string was performed by means of the keywords most frequently referred to in the publications retrieved from Scopus. Concepts such as Green Computing, Energy Efficiency, Sustainable Development, Energy Utilization, Green IT, Cloud Computing, Sustainability, Information Technology, Information Systems and Data Centers are narrowly related to Green IT and technology sustainability, which confirms the use of appropriate terms.

Several tools were employed in this work to study the data. The Excel tool was employed to manage the data collected in csv format, while the VOSviewer tool allowed us to represent clustered data in the Results section and the SPSS tool was used for the statistical analysis of the data presented in the Discussion section.

Results

The results of this bibliometric analysis are structured in six subsections (Andrés 2009): descriptive analysis, author production, journal productivity, scientific collaboration, author citation analysis and journal citation analysis.

Descriptive analysis

In this subsection, we present a descriptive analysis of the main characteristics of the studies. The parameters discussed are divided into four groups: (1) Temporal evolution with parameters such as Growth of publications, Annual growth rate (AGR) of the publications, Compound annual growth rate (CAGR) of the publications, Relative growth rate (RGR) and Doubling time (DT), and Trend analysis for the number of publications; (2) Institution and countries with Most prolific institutions, and Geographical distribution of the publications; (3) Language, in which the Languages used in publications are shown, and (4) Type of document, which consists of the bibliometric variables, such as Kind of publications and Common keywords in the publications.

Temporal evolution

- <u>Growth of publications</u>. The data gathered in this study reveal that there is a clear upward trend in the number of publications that are created from year to year. Table 1 and Figure 1 indicate that since 2009, when a significant number of studies were published, there has been an important growth in the production of literature on GIT, with a higher output since 2010. The total number of publications from 2010 to 2016 was 3138 (71.35%), and another 683 publications appeared in 2017, when this search was performed.

DOI: 00.0000/sd

Year	Publications	%
2017	683	15.53
2016	519	11.80
2015	495	11.26
2014	450	10.23
2013	481	10.94
2012	488	11.10
2011	392	8.91
2010	313	7.12
2009	174	3.96
2008	86	1.96
2007	55	1.25
< 2006	262	5.96
Total	4398	100

Table 1. Growth of publications

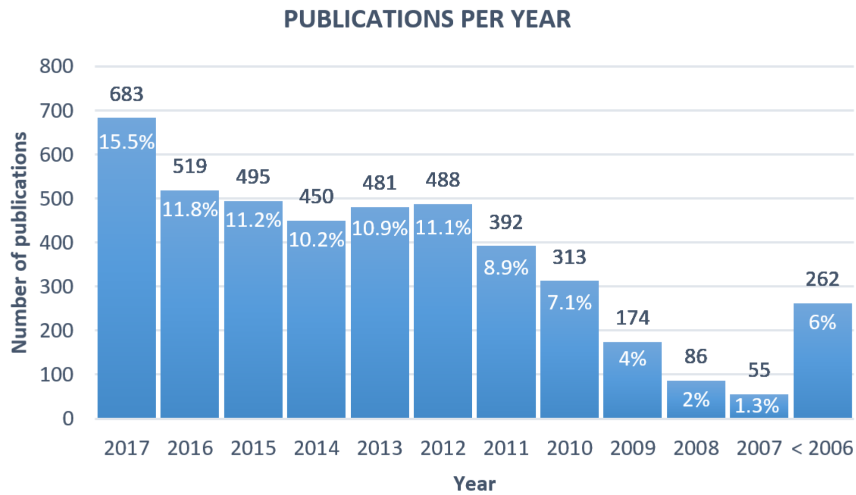

Figure 1. Growth of publications

- Annual growth rate (AGR) of the publications. The annual growth rate (AGR) indicates the total number of publications produced in comparison to the previous year (1). This factor is calculated by using the number of publications in one year and the number of publications from the previous year.

$$AGR(\%) = 100 \cdot \frac{NumberOfPublications_{year} - NumberOfPublications_{year-1}}{NumberOfPublications_{year-1}} \quad (1)$$

According to the results, a general decrease in this parameter, especially from 2010 to 2014, is presented in Table 2. A negative value was also attained in some years, which implies that fewer publications were produced in comparison with the previous year. These negative values appear in 2013 and 2014, but this value is positive in the other years, principally acquiring relevance (in descending order) in 2009, 2010, 2008 and 2017.

Year	%
2017	31.60
2016	4.85
2015	10.00
2014	-6.44
2013	-1.43
2012	24.49
2011	25.24
2010	79.89
2009	102.33
2008	56.36
2007	-

Table 2. Annual growth of the publications (AGR)

The AGR parameter had a value of 79.89% at the beginning of this decade, whilst in 2016 this value drastically decreased to 4.85. Moreover, the fluctuation observed in this factor indicates an unestablished annual growth rate, in spite of the increased number of publications produced throughout the decade. However, a remarkable difference

DOI: 00.0000/sd

appeared in the last year.

- Compound annual growth rate (CAGR) of the publications. The compound annual growth rate (CAGR) compares the annual growth rate of different periods of time (2). In order to obtain this parameter, the number of publications produced in a year, the cumulative number of publications from a year to a year of reference, and the number of years are considered.

$$CAGR(\%) = 100 \cdot \left[\left(\frac{CumulativeNumberOfPublications_{year}}{NumberOfPublications_{year}} \right)^{\frac{1}{year - referenceYear}} - 1 \right] \quad (2)$$

Table 3 and Figure 2 depict the CAGR parameter, taking 2007 as the year of reference, in which a relevant number of publications started to appear. A dramatic decrease took place in 2009, but no remarkable decreases in this factor have occurred again since that year. This variable has dwindled in small steps, from 30% to 20%, over the last decade, which reveals a stabilized downward trend in the CAGR.

Year	Cumulative	CAGR (%)
2017	4136	19.73
2016	3453	23.44
2015	2934	24.91
2014	2439	27.31
2013	1989	26.69
2012	1508	25.31
2011	1020	27.01
2010	628	26.13
2009	315	34.55
2008	141	63.95
2007	55	-

Table 3. Compound annual growth rate (CAGR)

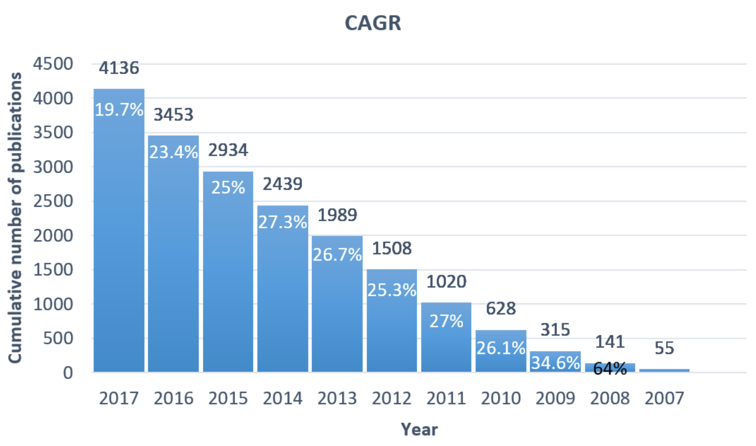

Figure 2. Compound annual growth rate (CAGR)

- Relative growth rate (RGR) and Doubling time (DT). The relative growth rate (RGR) shows hikes in literature related to the number of publications per unit of time. This factor is determined by using the Napierian logarithm of the cumulative publications in a set of units of time (W_2), the Napierian logarithm of the cumulative publications in the previous set of units of time (W_1) and the separation in units of time between W_2 and W_1. In this case, the unit of time was considered as a 1 year and the year of reference was 2007. The formula is the following (3).

$$RGR = \frac{Ln(W_2) - Ln(W_1)}{year - referenceYear} \quad (3)$$

This parameter also allows us to obtain the DT factor, which expresses the time required to attain double cumulative number of publications at the moment being studied. The formula is as follows (4).

$$DT = \frac{Ln(2)}{RGR} \quad (4)$$

As shown in Table 4 and Figure 3, we found that RGR factor as regards the GIT field decreased in the last decade, and a downward tendency can be observed from the beginning (0.94) to the end of this decade (0.18).

DT has increased each year. At the beginning of the decade, the parameter had a value of around 1, whilst in recent years it is around 4.

DOI: 00.0000/sd

Year	$Ln(W_1)$	$Ln(W_2)$	RGR	DT
2017	8.15	8.33	0.18	3.84
2016	7.98	8.15	0.16	4.26
2015	7.80	7.98	0.18	3.75
2014	7.60	7.80	0.20	3.40
2013	7.32	7.60	0.28	2.50
2012	6.93	7.32	0.39	1.77
2011	6.44	6.93	0.49	1.43
2010	5.75	6.44	0.69	1.00
2009	4.95	5.75	0.80	0.86
2008	4.01	4.95	0.94	0.74

Table 4. Relative growth rate (RGR) and Doubling time (DT)

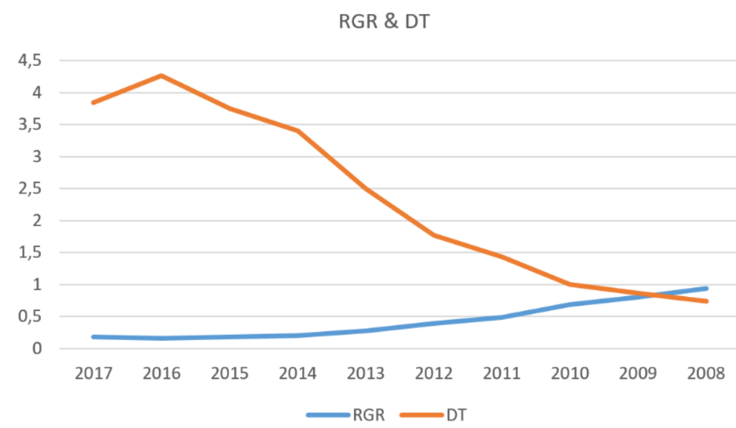

Figure 3. Compound annual growth rate (CAGR)

- Trend analysis for the number of publications. The least squares method was used as a basis on which to perform a trend analysis in order to estimate the number of publications that may appear in the future. A straight line was (5 left), therefore, calculated using the data concerning the last decade (from 2007 to 2016), resulting in the following equation (5 right):

$$Y = b \cdot X + a \Rightarrow Y = \frac{9019}{330} X + \frac{3453}{10} \; (5)$$

This formula was obtained by solving the following system of equations (6) and (7):

$$\sum Y = N \cdot a + b \cdot \sum X \; (6)$$

$$\sum X \cdot Y = a \cdot \sum X + b \cdot \sum X^2 \; (7)$$

where N is the number of years under consideration, Y is the estimated number of publications each year and X is an input of the equation conveniently selected. In order to make it easier to attain the coefficients, X values are selected so as to obtain zero when all their values are added up (8).

$$\sum_{n=2007}^{2016} X_n = 0 \; (8)$$

The straight line calculated (see Table 5) estimates that approximately 55 additional publications are produced each year in comparison with the previous year. Figure 4 shows the tendency of the number of publications per year versus the actual number of publications per year.

DOI: 00.0000/sd

Year	Actual number of publications (Y)	Input (X)	X·Y	X²	Number of publications trend	Difference
2021		19			864.58	54.66
2020		17			809.92	54.66
2019		15			755.25	54.66
2018		13			700.59	54.66
2017	683	11			645.93	-
2016	519	9	4671	81	591.27	24
2015	495	7	3465	49	536.61	45
2014	450	5	2250	25	481.95	-31
2013	481	3	1443	9	427.29	-7
2012	488	1	488	1	372.63	96
2011	392	-1	-392	1	317.97	79
2010	313	-3	-939	9	263.31	139
2009	174	-5	-870	25	208.65	88
2008	86	-7	-602	49	153.99	31
2007	55	-9	-495	81	99.33	-

Table 5. Computation of straight line trend using the least squares method

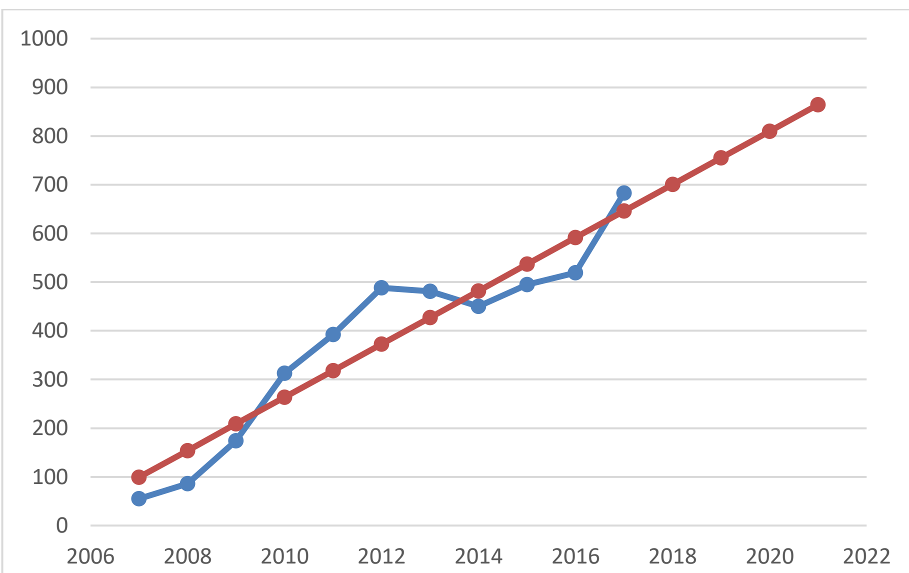

Figure 4. Tendency analysis graph of the number of publications per year

Institutions and countries

- Most prolific institutions. The institutions that produce most literature related to the GIT and technology sustainability topic are identified in Table 6. According to the results, the most prolific institutions are the Chinese Academy of Sciences, the RMIT University and the Rissho University, both with a percentage of around 1%. These institutions are followed by the Politecnico di Milano and Universität Göttingen, with between 38 and 36 publications respectively (0.86 and 0.82%). Beijing University of Posts and Telecommunications, Arizona State University, Tsinghua University, Seikei University and the Georgia Institute of Technology follow in the list, with between 32 and 26 publications.

DOI: 00.0000/sd

Pos.	Institution	Number of publications	%
1	Chinese Academy of Sciences	51	1.16
2	RMIT University	45	1.02
3	Rissho University	44	1.00
4	Politecnico di Milano	38	0.86
5	Universitat Gottingen	36	0.82
6	Beijing University of Posts and Telecommunications	32	0.73
7	Arizona State University	30	0.68
8	Tsinghua University	28	0.64
9	Seikei University	27	0.61
10	Georgia Institute of Technology	26	0.59

Table 6. Most prolific institutions

- Geographical distribution of the publications. Table 7 shows a list of countries as regards cooperation in literature production. The origin of the authors' institutions is considered in each document in order to add up the number of publications from each country. A percentage is obtained by dividing the number of publications from each country by the number of publications retrieved from the database. Figure 5 contains a world map in which the main contributing states are shown in colors in order to illustrate the current situation. The countries featured are the United States (22.44%) and China (12.78%). In a second rank are India (7.66%), Germany (7.44%), the United Kingdom (6.46%), Australia (5.25%) and Italy (4.93%). In another category, with a percentage of between 4% and 3%, are Canada, Japan, France, South Korea and Spain.

Pos.	Country	Number of publications	%
1	United States	987	22.44
2	China	562	12.78
3	India	337	7.66
4	Germany	327	7.44
5	United Kingdom	284	6.46
6	Australia	231	5.25
7	Italy	217	4.93
8	Canada	171	3.89
9	Japan	163	3.71
10	France	159	3.62
11	South Korea	139	3.16
12	Spain	133	3.02

Table 7. Geographical distribution of publications

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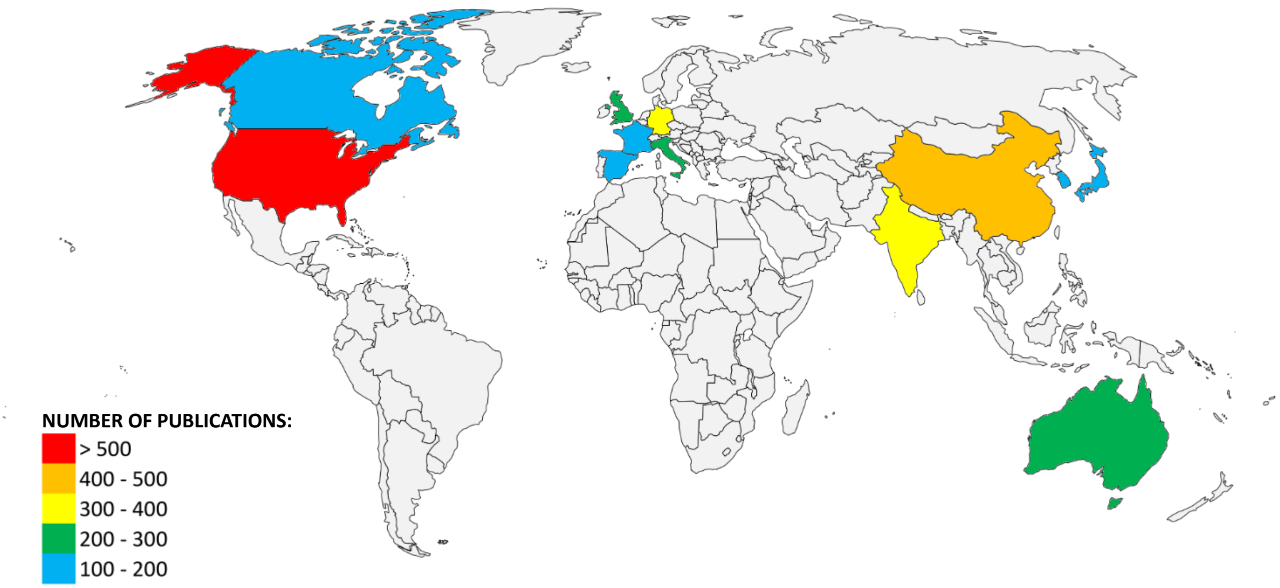

Figure 5. Map depicting the most productive countries

Languages

- <u>Language used in publications</u>. Table 8 indicates the languages used in the GIT literature. English is the most common, but a remarkable number of publications were found in other languages such as Chinese, German and French. At a lower level, with less than 10 publications, are Portuguese, Spanish, Italian and Russian.

Pos.	Language	Number of publications	%
1	English	4348	98.86
2	Chinese	85	1.93
3	German	28	0.64
4	French	16	0.36
5	Portuguese	9	0.20
6	Spanish	8	0.18
7	Italian	5	0.11
8	Russian	4	0.09
9	Bosnian	2	0.05
10	Croatian	2	0.05
11	Hungarian	2	0.05
12	Japanese	2	0.05
13	Slovenian	2	0.05
14	Greek	1	0.02
15	Korean	1	0.02
16	Polish	1	0.02
17	Turkish	1	0.02
18	Not indicated	3	0.07

Table 8. Distribution as regards languages used

DOI: 00.0000/sd

Type of document

- Kind of publications. Table 9 shows the most common means employed to publish in the area of GIT. More than half of the publications are in Conference Paper form (53.12%). Articles are also a common way in which to show the results of GIT, and comprise more than one third (33.11%), followed by Book Chapters which are used to a significantly lesser extent than the two previous forms (4.48%). These results show that the outputs of GIT research are more frequently found in the form of Conference Papers. The percentages were calculated with regard to the total number of publications retrieved from the database.

Pos.	Forms of publication	Publications	%
1	Conference Paper	2336	53.12
2	Article	1456	33.11
3	Book Chapter	197	4.48
4	Conference Review	120	2.73
5	Review	109	2.48
6	Article in Press	69	1.57
7	Editorial	43	0.98
8	Book	24	0.55
9	Note	14	0.32
10	Short Survey	14	0.32
11	Erratum	3	0.07
12	Letter	3	0.07
13	Report	2	0.05
14	Not indicated	8	0.18
	Total	4398	100

Table 9. Forms of publication

- Common keywords in the publications. Table 10 shows the most common keywords in GIT publications. These terms are: Green Computing, Energy Efficiency, Energy Utilization, Sustainable Development, Green IT, Cloud Computing and Sustainability, which are keywords that mention concepts related to the field being studied.

Pos.	Keyword	Number of publications
1	Green Computing	1289
2	Energy Efficiency	857
3	Energy Utilization	796
4	Sustainable Development	746
5	Green IT	576
6	Cloud Computing	511
7	Sustainability	418
8	Information Technology	352
9	Information Systems	325
10	Data Centers	307

Table 10. Keywords most frequently referred to (obtained from VOSviewer)

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Figure 6 depicts a label map of the main keywords that appeared in the Scopus database search. In this illustration, the more important a label is, the larger the text label and circle that surrounds the label is. These labels are distributed in clusters, with the same color, by means of the clustering technique (van Eck and Waltman 2010).

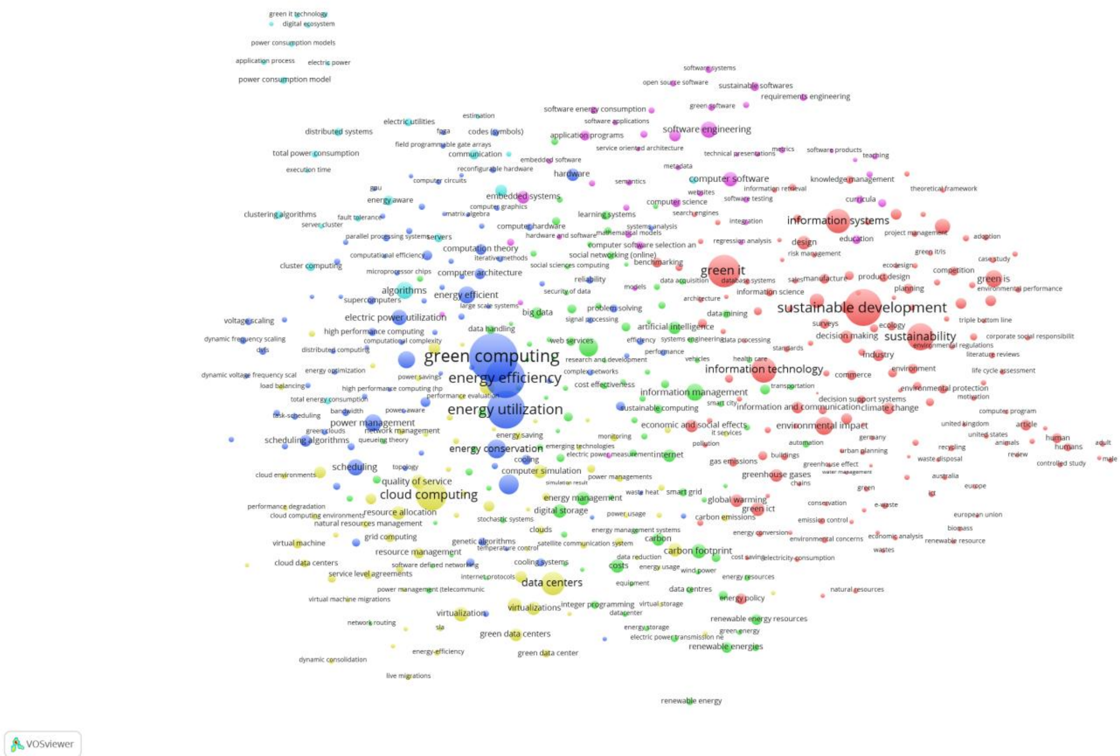

Figure 6. Network visualization map revealing the most frequently used keywords

Author production

In this subsection, the calculated parameters are divided into two groups: (1) Number of authors, in which parameters such as Author participants' productivity, Authorship trend analysis and Most prolific authors are studied, and (2) A second group, in which Lotka's law of regularity is evaluated with the goal of showing the inverse square law as regards author productivity (Andrés 2009)

Number of authors

- Author participants' productivity. An estimation of the mean author participants' productivity was calculated using the following formula (9):

$$AAPP = \overline{AuthorsPerPaper} = \frac{NumberOfAuthors}{NumberOfPapers} \quad (9)$$

Moreover, the inverse value provides the mean value of productivity per participant author (10):

$$PPP = \overline{ProductivityPerAuthors} = \frac{1}{\overline{AuthorsPerPaper}} \quad (10)$$

From 2007 to 2010, the number of authors per paper (AAPP) has a value of between 2 and 2.5, although a more collaborative literature scheme production has appeared since 2013 (see Table 11). The value is around three between

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2013 and 2016, reaching a value of almost four in the last year. This could be interpreted as a higher degree of maturity in the field, which has led to major cooperation among researchers. The mean value of productivity per author (PPP) has, however, decreased from 0.47 to 0.27 over the last decade.

Year	Papers	Authors	AAPP	PPP
2017	683	2542	3.72	0.27
2016	519	1647	3.17	0.32
2015	495	1501	3.03	0.33
2014	450	1435	3.19	0.31
2013	481	1454	3.02	0.33
2012	488	1419	2.91	0.34
2011	392	1163	2.97	0.34
2010	313	810	2.59	0.39
2009	174	454	2.61	0.38
2008	86	212	2.47	0.41
2007	55	118	2.15	0.47

Table 11. Author productivity

- Authorship trend analysis. The number of authors contributing to the publications over the years was analyzed. Anonymous publications were omitted when calculating the total output of single and multiple authorships over the years. The percentages were calculated with respect to the total research output obtained after adding up the publications that appeared from 2007 to 2017, considering anonymous, single and multiple authorship works. Table 12 indicates that multiple authors rather than single author contributed more to literature production from 2007 to 2017. The increase shown in multiple authors' patterns over the first five years (2007-2011) is lower than in the last lustrum (2016-2012). Furthermore, slight differences related to single author pattern productivity can be detected in the data over the years.

Year	Single author		Multiple authors		0 to N authors
	Total output	%	Total output	%	Total output
2017	32	0.77	647	15.64	683
2016	57	1.38	446	10.78	519
2015	66	1.60	410	9.91	495
2014	50	1.21	388	9.38	450
2013	68	1.64	390	9.43	481
2012	76	1.84	396	9.57	488
2011	59	1.43	318	7.69	392
2010	71	1.72	226	5.46	313
2009	58	1.40	107	2.59	174
2008	24	0.58	52	1.26	86
2007	16	0.39	35	0.85	55
TOTAL	577	13.95	3415	82.57	4136

Table 12. Authorship trend analysis

- Most prolific authors. As will be noted in Table 13, the most prolific authors as regards GIT are Tomoya Enokido, from the Faculty of Business Administration at Rissho University (Japan), with 45 publications; Makoto Takizawa, a

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professor from the Department of Advanced Sciences at Hosei University (Japan), with 45 publications and Alemayehu Molla, from the Business IT and Logistics Department at the RMIT University (Australia), with 36 publications. The percentages are calculated with regard to the total number of publications retrieved from the database.

Pos.	Author	Number of publications	%
1	Enokido T.	45	1.02
2	Takizawa M.	45	1.02
3	Molla A.	36	0.82
4	Wang Y.	27	0.61
5	Aikebaier A.	26	0.59
6	Wang L.	25	0.57
7	Zhang Y.	24	0.55
8	Khan S.U.	23	0.52
9	Li J.	23	0.52
10	Lolbe L.M.	21	0.48
11	Li X.	21	0.48
12	Liu X.	20	0.45
13	Wang X.	20	0.45
14	Lago P.	19	0.43
15	Li Y.	18	0.41
16	Penzenstadler B.	17	0.39

Table 13. Most prolific authors (obtained from VOSviewer)

Lotka's law

Lotka's law of scientific productivity is one of the main pillars of bibliometric analysis (Bailón-Moreno et al. 2005). Lotka's law predicts that the number of authors publishing *X* number of articles in any given field will be proportional (constant *c* depending on the specific discipline) to $1/X^n$, where *Y* is the number of authors publishing *X* articles, and *n* is an exponent, normally between 1.2 and 3.5 (11). This can be interpreted as meaning that there are a lot of authors who publish only one study, while a small group of prolific authors contribute with a large number of publications (Andrés 2009).

$$y = \frac{c}{x^n} \quad (11)$$

First, the values of the exponent *n* and the constant *c* were calculated by using equations (12) and (13):

$$n = \frac{N \sum XY - \sum X \sum Y}{N \sum X^2 - (\sum X)^2} \quad (12)$$

$$c = \frac{1}{\sum 1/X^n} \quad (13)$$

Table 14 shows the data used to determine *n* and *c*.

DOI: 00.0000/sd

x	*y*	*X=log x*	*Y=log y*	*XX*	*XY*	*y/(∑y)*	∑ *(y/(∑y))*	*Fe*	∑ *Fe*	*D*
1	7300	0.000	3.863	0.000	0.000	0.794	0.794	0.762	0.762	0.032
2	1166	0.301	3.067	0.091	0.923	0.127	0.921	0.129	0.890	0.030
3	335	0.477	2.525	0.228	1.205	0.036	0.957	0.045	0.936	0.021
4	129	0.602	2.111	0.362	1.271	0.014	0.971	0.022	0.957	0.014
5	77	0.699	1.886	0.489	1.319	0.008	0.980	0.012	0.970	0.010
6	45	0.778	1.653	0.606	1.286	0.005	0.984	0.008	0.977	0.007
7	33	0.845	1.519	0.714	1.283	0.004	0.988	0.005	0.982	0.006
8	24	0.903	1.380	0.816	1.246	0.003	0.991	0.004	0.986	0.005
9	17	0.954	1.230	0.911	1.174	0.002	0.992	0.003	0.989	0.004
10	18	1.000	1.255	1.000	1.255	0.002	0.994	0.002	0.991	0.004
11	12	1.041	1.079	1.084	1.124	0.001	0.996	0.002	0.992	0.003
12	6	1.079	0.778	1.165	0.840	0.001	0.996	0.001	0.994	0.003
13	6	1.114	0.778	1.241	0.867	0.001	0.997	0.001	0.995	0.002
14	4	1.146	0.602	1.314	0.690	0.000	0.997	0.001	0.996	0.002
15	3	1.176	0.477	1.383	0.561	0.000	0.998	0.001	0.996	0.001
16	4	1.204	0.602	1.450	0.725	0.000	0.998	0.001	0.997	0.001
17	1	1.230	0.000	1.514	0.000	0.000	0.998	0.001	0.998	0.001
18	2	1.255	0.301	1.576	0.378	0.000	0.999	0.000	0.998	0.001
19	1	1.279	0.000	1.635	0.000	0.000	0.999	0.000	0.998	0.000
20	1	1.301	0.000	1.693	0.000	0.000	0.999	0.000	0.999	0.000
21	3	1.322	0.477	1.748	0.631	0.000	0.999	0.000	0.999	0.000
23	1	1.362	0.000	1.854	0.000	0.000	0.999	0.000	0.999	0.000
24	1	1.380	0.000	1.905	0.000	0.000	0.999	0.000	1.000	0.000
25	2	1.398	0.301	1.954	0.421	0.000	1.000	0.000	1.000	0.000
26	1	1.415	0.000	2.002	0.000	0.000	1.000	0.000	1.000	0.000
36	1	1.556	0.000	2.422	0.000	0.000	1.000	0.000	1.000	0.000
45	2	1.653	0.301	2.733	0.498	0.000	1.000	0.000	1.000	0.000
	9195	28.473	26.187	33.889	17.697					

Table 14. Number of studies published by the authors in GIT (column *x*), number of authors publishing a given number of articles (column *y*), and observed (column *y/(∑y)*) and expected (column *Fe*) frequency of authors with *x* publications

The values of *n*=2.568 and *c*=0.762 were used to establish the power model. A logarithmic data plot (Figure 7) depicts the linearity between the number of authors and articles, with a high coefficient of determination ($R^2 = 0.9369$). The graph suggests that data on highly productive authors should be omitted to achieve good fit. A Kolmogorov-Smirnov goodness-of-fit test was conducted to determine whether there are significant differences between the observed and expected distributions. Since the critical value computed (0.016) is lower than the maximum difference between the cumulative distributions (0.032), the null hypothesis that the distribution is not different from the distribution predicted by Lotka's law must be rejected. Note that the vast majority (7300 authors, or 79%) participated in only one paper. This statistic also differ from Lotka's Law, which states that approximately 60% of authors contribute to just one paper (Tsay et al. 2000).

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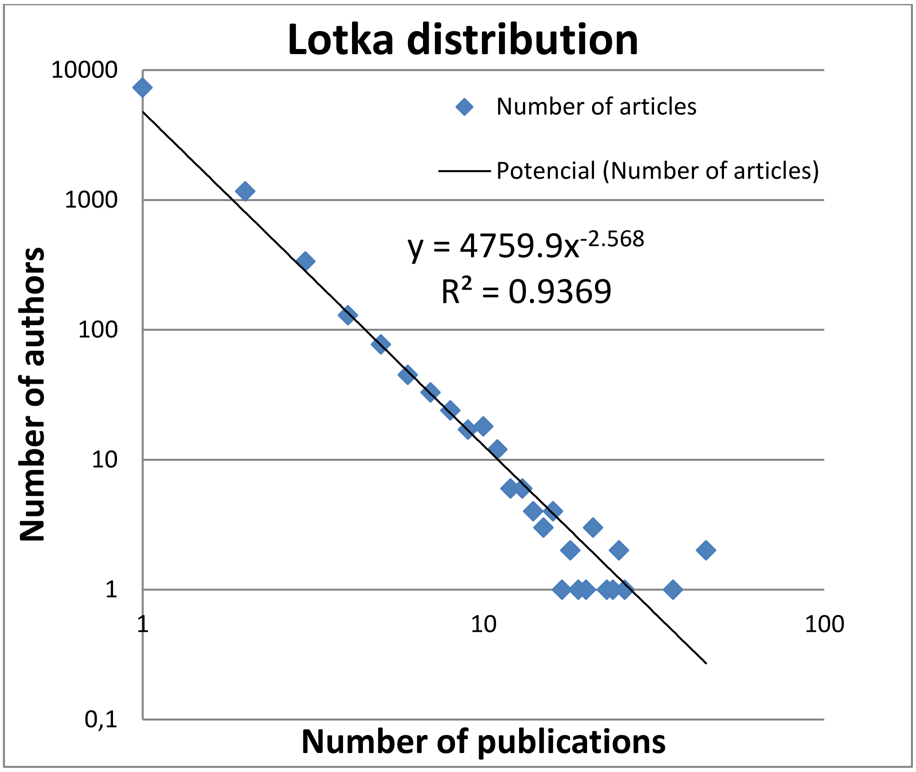

Figure 7. The curve fitting of relationship between number of articles and authors

Journal productivity

In this subsection, a more detailed analysis of the scatter of journal productivity will be carried out. First, Bradford's law, which is the main law applied to journal productivity, is studied (Andrés 2009). Second, the journals and conferences are ranked on the basis of the frequency of the documents published.

Bradford's law

Bradford's law is applied in order to study the distribution of literature among sources and identify a core group of sources containing a high proportion of articles on GIT. There are a total of 160 sources and conferences that published 4398 articles dealing with GIT. Figure 8 presents the Bradford plot, which is not the typical Bradford's S-shape. A droop at the tail end of the distribution indicates the incompleteness of the bibliography. This is the result of plotting the cumulative number of papers published by each source against the logarithm of their rank. The curve also fails to have the final droop in the Bradford plot. These findings suggest that the literature on GIT is spread across numerous different sources. Since the linear portion appears after the rank of approximately 90, the top 90 sources and conferences can be considered as the core in GIT literature.

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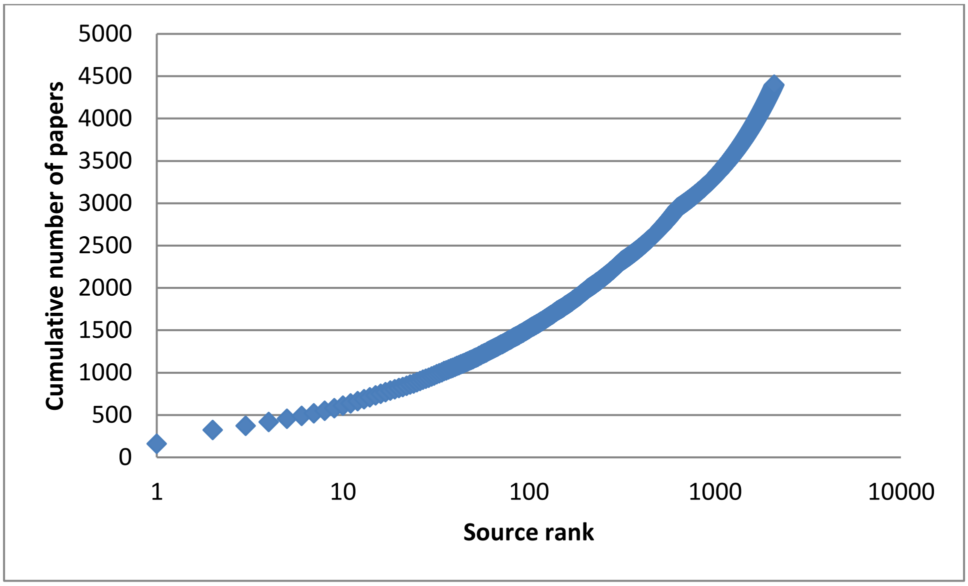

Figure 8. The Bradford plot

Bradford's Law states that the sources can be divided into three groups with the same number of publications, in which each group contains the number of sources in proportions of $1{:}k{;}k^2$. This regularity is called the inverse relationship. In the case of our study, 1466 records are included in each part. The value of Bradford's constant k is calculated by using the formula (14).

$$k = (e^{\gamma} \times Y_m)^{1/P} = (1.781 \times 162)^{1/3} = 6.594 \; (14)$$

Where γ is Euler's number (γ = 0.5772), Y_m is the maximal productivity of the source of rank one, and P is the number of Bradford groups. The numbers of sources in each of the three parts were 40:269:1774, representing approximate proportions of 1:6:36, so k = 6. Theoretically, the first 40 sources comprise approximately 33% of literature, while the remaining 67% is scattered among 2044 sources. The empirical data were calculated to confirm the data fit to Bradford's law. The empirical values in each of the three parts were 92:533:1551, with k = 5.793 for zone 1 and 4.105 for zone 2. This data reveals that the literature on GIT is clearly scattered. Observe that 1453 authors published only one article, and that the first two sources together cover approximately 7.276% of the literature.

Journal and conference ranks

- Most preferred sources. Table 15 indicates the percentage (column 4) that represents each source as regards the 4398 publications found in Scopus database, and considering the publications within the same source (column 5). The most preferred sources in which to publish can be divided into journals and conferences. The journals Computer (1.16%), Sustainable Computing Informatics and Systems (0.75%) and IT Professional (0.68%) are the most common sources in which it is possible to find publications related to this area. Furthermore, Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence And Lecture Notes in Bioinformatics (3.68%), Proceedings 2016 IEEE International Conference on Internet of Things IEEE Green Computing and Communications IEEE Cyber Physical and Social Computing (3.62%), and 2016 7th International Green and Sustainable Computing Conference IGSC 2016 (1.09%) were the conferences, some of them a specific edition of the conference, in which appeared the largest amount of literature related to this topic.

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Pos.	Source	Number of publications	%	%
1	Lecture Notes in Computer Science including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics	162	3.68	0.06
2	2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)	159	3.62	91.90
3	Computer	51	1.16	2.49
4	2016 7th International Green And Sustainable Computing Conference	48	1.09	44.85
5	CEUR Workshop Proceedings	39	0.89	0.12
6	ACM International Conference Proceeding Series	33	0.75	0.09
7	Sustainable Computing Informatics And Systems	33	0.75	16.58
8	Handbook of Research on Green ICT Technology Business and Social Perspectives	30	0.68	60.00
9	IT Professional	30	0.68	3.71
10	Communications in Computer and Information Science	28	0.64	0.62

Table 15. Most preferred sources

Scientific collaboration

In this subsection, we analyze the collective efforts of various researchers. Degree of collaboration, Collaboration index (CI), Co-authorship index and Research networks are subsequently obtained (Andrés 2009).

Collaboration index

- Degree of collaboration. The data collected in the database enabled us to discover the degree of collaboration among the authors, thus allowing us to discover the cooperation tendency. This parameter was calculated as follows (15).

$$C = \frac{NumberOfPublications_{multipleAuthors}}{NumberOfPublications_{multipleAuthors} + NumberOfPublications_{singleAuthor}} \quad (15)$$

Table 16 denotes that half of the publications have two or three authors. In both cases, this represents almost 25% of the literature produced. The following pattern of authorship is one and four authors, which is 15% of publications for each one. Most of the anonymous publications appeared in Conference Proceedings, and the degree of collaboration was 0.843, discarding the literature for which no author was mentioned.

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Pos.	Number of authors	Number of publications	%
0	Anonymous	156	3.46
1	Single author	666	14.77
2	Two authors	1095	24.28
3	Three authors	1024	22.71
4	Four authors	703	15.59
5	Five authors	386	8.56
6	Six authors	174	3.86
7	Seven authors	73	1.62
8	Eight authors	57	1.26
9	Nine authors	21	0.47
10	Ten authors	15	0.33

Table 16. Authorship pattern of publications

- Collaboration index (CI). Table 17 shows the collaboration index among the authors. This parameter is calculated as follows (16):

$$CI = \frac{NumberOfSignatoriesInMultiauthoredPublications}{NumberOfMultiauthoredPublications} \quad (16)$$

As shown in Table 17, this factor has a value near to three over the years and almost reaches the value of four in 2017. A high collaboration pattern among the authors is, therefore, observed. The increase in both multi-authored publications and total authors in multi-authored publications parameters also indicates a more collaborative environment.

Year	Multi-authored publications	Total signatories in multi-authored publications	CI
2017	647	2510	3.88
2016	446	1590	3.57
2015	410	1435	3.50
2014	388	1385	3.57
2013	390	1386	3.55
2012	396	1343	3.39
2011	318	1104	3.47
2010	226	739	3.27
2009	107	396	3.70
2008	52	188	3.62
2007	35	102	2.91

Table 17. Collaboration index

National and international collaborations

A collaboration profile can be obtained by calculating the papers involving researchers from different institutions or countries. The nature of these collaborations can be (1) international when authors are from different countries, (2) national when authors are from different institutions belonging to the same country, and (3) no collaboration in the remaining papers. A graphical representation of these collaborations is shown in Figure 9, which illustrates a growing interest in both national and international team work. Nevertheless, most of these collaborations were between authors from the same country.

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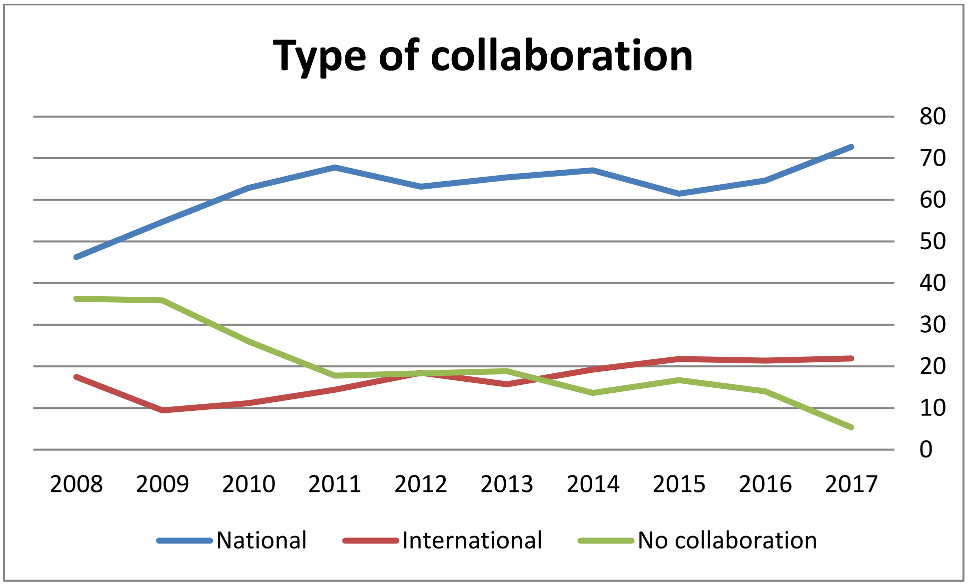

Figure 9. Collaboration pattern in international and intranational publications

Co-authorship index

In order to study whether the number of publications in a country corresponds to the average within a co-authorship pattern, the co-authorship index (CAI) is proposed. This index is obtained by calculating the number of single-, two-, three-, multi-authored papers from different nations of different subdisciplines in a proportional manner. The CAI formula for different countries is shown as follows (17):

$$CAI = ((N_{ca}/N_{ct})/\,(N_{ta}/N_{tt})) \times 100 \quad (17)$$

where N_{ca} represents the number of papers co-authored by *a* authors in the *c-th* country, N_{ct} represents the total number of papers in the *c-th* country, N_{ta} represents the number of papers co-authored by *a* authors in the total number of countries and N_{tt} represents the total number of papers in the total number of countries.

Figure 10 shows seven CAI values for the 10 countries with the highest number of publications. Spain achieves high CAI values for six-, seven- and eight-authored papers and China for six- and eight-authored papers, while Japan and Italy, with eight-authored papers each, also have a proportion of co-authored papers that is much higher than the average obtained for all the countries.

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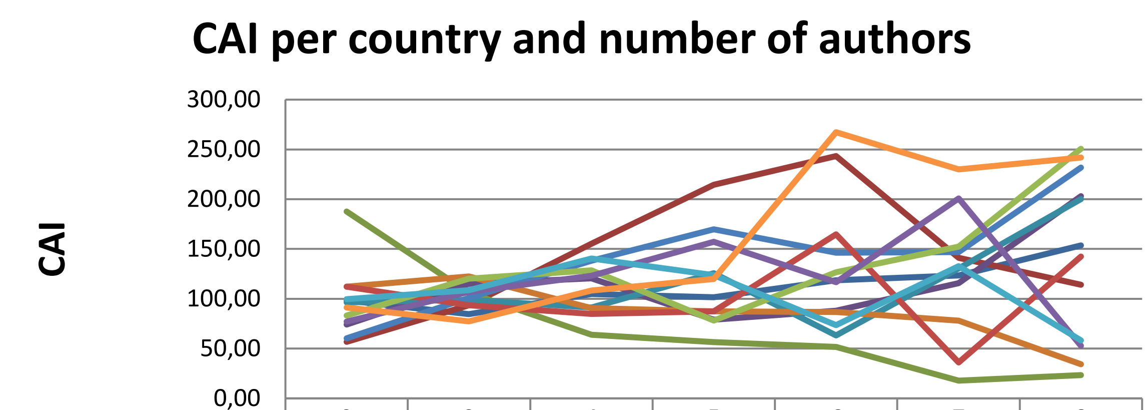

	2	3	4	5	6	7	8
United States	98,43	84,60	104,90	101,59	118,56	123,31	153,59
China	56,78	93,55	155,42	214,35	243,30	141,07	114,14
India	187,64	106,15	63,80	56,45	51,79	17,82	23,43
Germany	74,15	115,00	120,46	79,14	88,16	115,82	203,04
United Kingdom	96,48	99,05	91,20	125,60	63,19	130,45	200,11
Australia	112,24	122,43	90,69	87,45	86,60	78,21	34,28
Italy	60,32	100,90	138,26	169,72	146,38	146,89	231,76
Canada	112,26	93,52	84,86	87,37	164,71	36,06	142,25
Japan	83,31	120,22	128,69	78,14	126,61	152,47	250,59
France	77,12	106,94	123,23	157,12	116,69	200,75	52,79
South Korea	99,72	108,63	140,44	123,78	73,55	132,85	58,22
Spain	91,35	77,33	108,18	119,94	267,24	229,87	241,79

Figure 10. The co-authorship index plot

Research networks

Research networks can be assessed for author, institution or country dimension. The author dimension will be analyzed in this subsection. Groups of authors are related to whether they have published a given number of articles in co-authorship. Figure 11 shows a map that displays groups of authors working together in the same area, obtained after carrying out the clustering technique. The main authors in each cluster for the GIT and sustainability research fields and the intensity of the relationship between them are shown, based on the number of papers published in co-authorship (van Eck and Waltman 2010).

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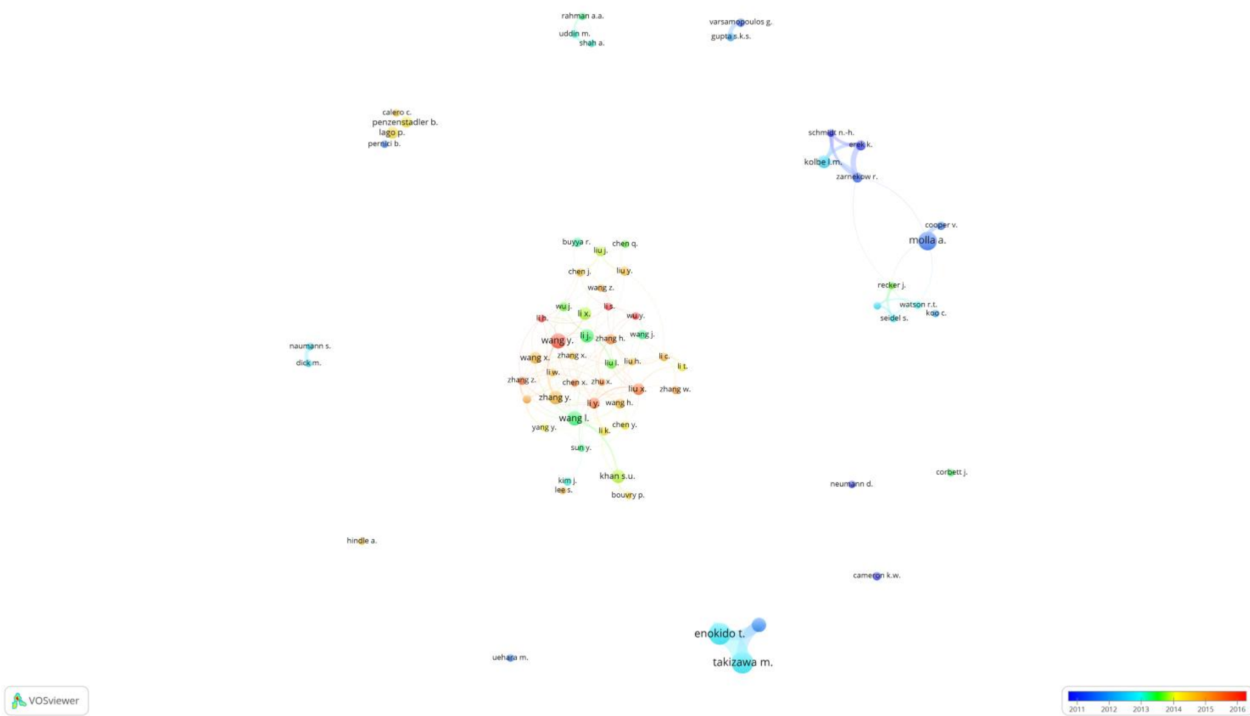

Figure 11. Overlay visualization revealing the most relevant authors in each cluster based on co-authorship

Author citation analysis

In this subsection, an author citation analysis will be developed to reveal connections between authors or groups of researchers. The most frequently cited publications and their authors will be identified, and a co-citation analysis will be performed in order to discover intellectually related authors.

Most cited publications

In Table 18, documents are sorted by number of citations in Scopus. The most frequently cited articles are "The case for energy-proportional computing", with 1184 citations, "Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing", with 819 citations and "Optimal online deterministic algorithms and adaptive heuristics for energy and performance efficient dynamic consolidation of virtual machines in Cloud data centers", with 418 citations.

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Pos.	Title	Authors	Source	Citations
1	The case for energy-proportional computing (2007)	Barroso, L.A., Hölzle, U.	Computer	1184
2	Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing (2012)	Beloglazov, A., Abawajy, J., Buyya, R.	Future Generation Computer Systems	819
3	Optimal online deterministic algorithms and adaptive heuristics for energy and performance efficient dynamic consolidation of virtual machines in Cloud data centers (2012)	Beloglazov, A., Buyya, R.	Concurrency Computation Practice and Experience	418
4	Harnessing green IT: Principles and practices (2008)	Murugesan, S.	IT Professional	406
5	Energy efficient resource management in virtualized cloud data centers (2010)	Beloglazov, A., Buyya, R.	CCGrid 2010 - 10th IEEE/ACM International Conference on Cluster, Cloud, and Grid Computing	315
6	Dynamic resource allocation using virtual machines for cloud computing environment (2013)	Xiao, Z., Song, W., Chen, Q.	IEEE Transactions on Parallel and Distributed Systems	238
7	Energy efficiency in telecom optical networks (2010)	Zhang, Y., Chowdhury, P., Tornatore, M., Mukherjee, B.	IEEE Communications Surveys and Tutorials	235
8	Greencloud: A new architecture for green data center (2009)	Liu, L., Wang, H., Liu, X., Jin, X., He, W., Wang, Q., Chen, Y.	Proceedings of the 6th International Conference Industry Session on Autonomic Computing and Communications Industry Session, ICAC-INDST'09	206
9	Energy efficient allocation of virtual machines in cloud data centers (2010)	Beloglazov, A., Buyya, R.	CCGrid 2010 - 10th IEEE/ACM International Conference on Cluster, Cloud, and Grid Computing	188
10	Environment-conscious scheduling of HPC applications on distributed Cloud-oriented data centers (2011)	Garg, S.K., Yeo, C.S., Anandasivam, A., Buyya, R.	Journal of Parallel and Distributed Computing	180

Table 18. Most cited publications

Co-citation analysis.

A co-citation implies that two authors are cited in the same document. Figure 12 depicts the intellectual structure of GIT based on an author co-citation analysis by using the mapping and clustering approach. A total of six clusters were identified as the most commonly co-cited groups of authors. Three of the groups stand out from the rest as having more co-citations in common, thus assuming that their work is related.

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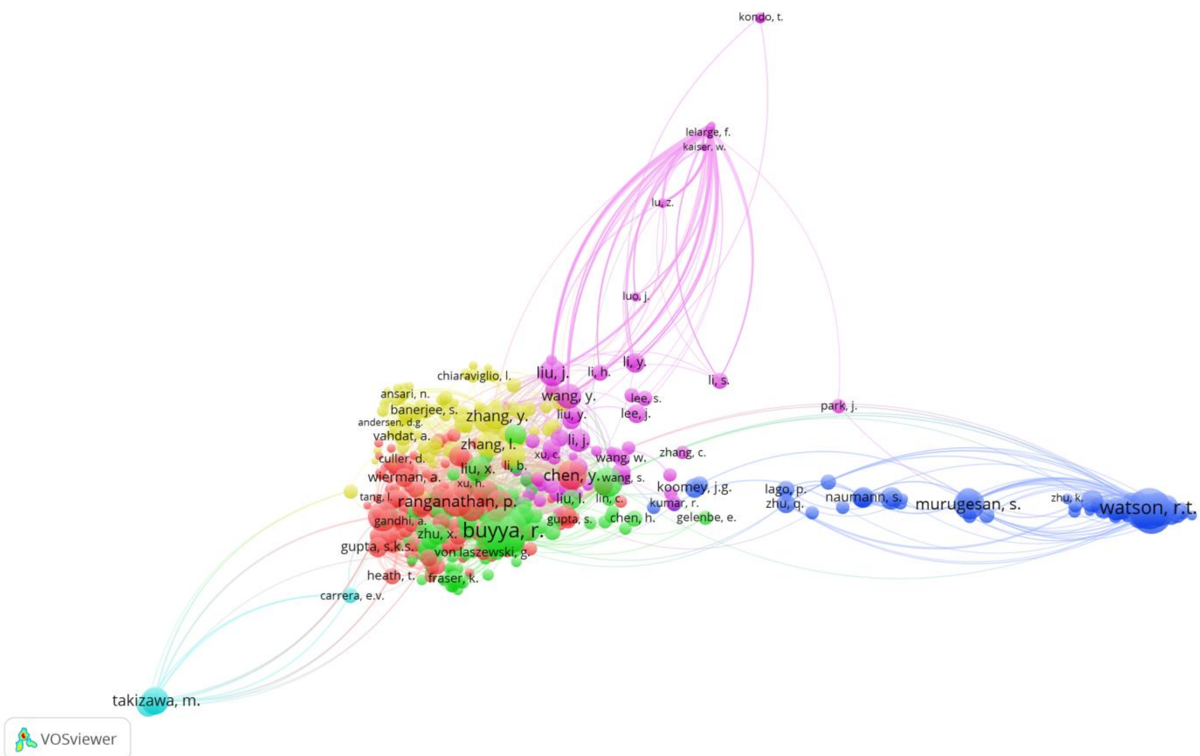

Figure 12. Network map revealing co-citation of authors

Journal citation analysis

In this subsection, the two-year and five-year impact factors of the journals included in the top ten considering the number of citations will be identified. Moreover, a journal co-citation analysis will be performed to discover connections between journals and conferences.

Journal impact factor

The two-year and five-year impact factors for the ten journals that have received the highest number of publications are shown in Table 19. Observe that 5 out of 10 journals are included in the JCR 2017 report, all of them in the first two quartiles.

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Quartile	Source	2-year IF	5-year IF
Q1	IEEE Computer	1.940	2.113
-	Sustainable Computing Informatics and Systems	-	-
Q2	IT Professional	1.618	1.561
-	Communications in Computer and Information Science	-	-
Q1	Journal of Cleaner Production	5.651	6.352
Q1	Future Generation Computer Systems	4.639	4.968
-	Applied Mechanics and Materials	-	-
Q2	Journal of Supercomputing	1.532	1.495
-	International Journal of Applied Engineering Research	-	-
-	Advanced Materials Research	-	-

Table 19. Two- and five-year impact factors (IF) in JCR 2017

Co-citation analysis

Another means of studying the relationships among journals is co-citation analysis. Figure 13 depicts a network by using co-citation analysis in journals, thus identifying the most commonly co-cited groups of journals. Based on the mapping and clustering approach performed, five clusters emerged automatically in the scientific literature landscape.

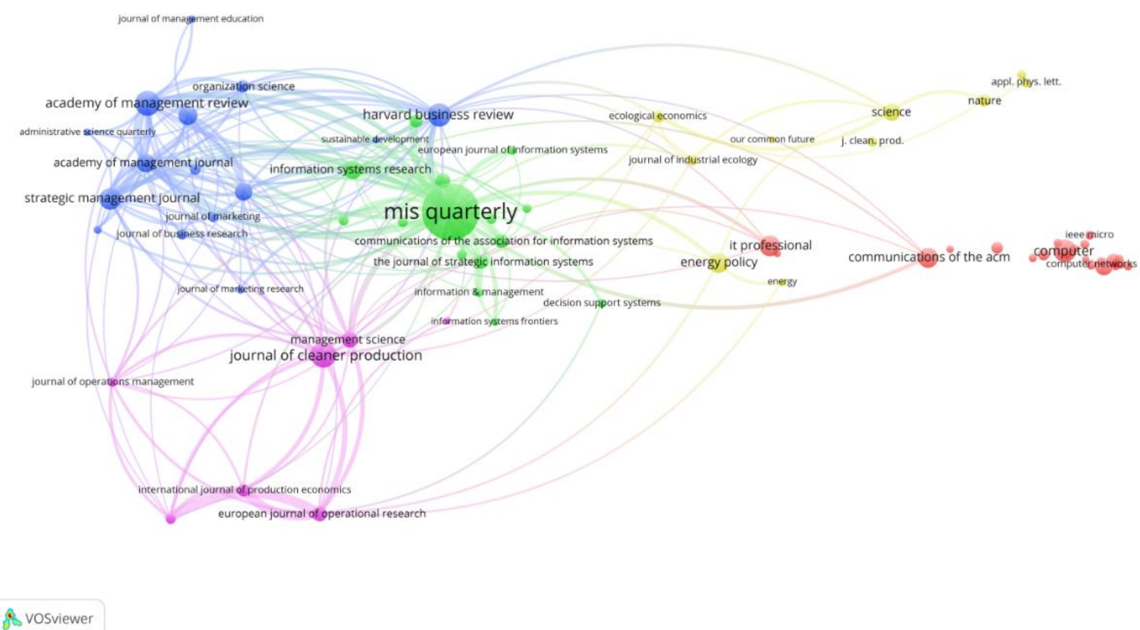

Figure 13. Network map revealing co-citation of publications

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Discussion

In this paper, data collected for a bibliometric study has allowed us to depict the current literature situation as regards technology sustainability in general and GIT in particular. The figures revealed that researchers were more productive during the last decade, with more than 150 publications per year since 2009, and reaching 519 publications in 2016. This can be explained by an increasing global concern about environmental damage to the planet, which is leading society to restore the living space on the planet (Andrae 2016). Moreover, people are becoming conscious of pollution actions such as e-waste dumping (11.7 millions of tons are expected to be generated by 2020 in China alone (Li et al. 2015)). As an example, many programs concerning sustainability are now found all over the world, such as Green Citizens from UNESCO with a budget of M$667 for the period 2016-2017 and Switch Africa Green, funded by an EU grant, with a budget of M€20.5. Both programs began in 2014 and have a duration of 4 years. Another example is the Global Green New Deal, which proposes a true green economy to drive human welfare without putting the planet under pressure that it is unable to withstand (Steiner 2009). The Climate Change Mitigation Technologies in Europe study, conducted by the European Patent Office (EPO) and the United Nations Environment Program (UNEP) and introduced in the Conference of the Parties (COP) 21 Paris France Sustainable Innovation Forum 2015, points out that inventions in climate change mitigation technologies (CCMTs) around the world has steadily increased since the Kyoto Protocol was signed in 1997. Around 80% of all European inventions as regards sustainable technology are from six European countries: Germany, which leads with almost half of Europe's CCMT inventions, followed by France, the UK, Italy, Sweden and Spain (European Patent Office 2015). Negotiations for the Paris Agreement took place in the COP 21 Forum and its applicability is expected to start after 2020, when the validity of the Kyoto Protocol expires. The tendency observed in this study is, therefore, that not only have the number of publications concerning GIT and technology sustainability increased each year, but also the actions to promote planet-care awareness.

The countries that produced most literature related to GIT and technology sustainability were the United States, with 987 publications (22.44%) and China, with 562 publications (12.78%). The Kyoto Protocol was signed but not ratified by the United States. On the contrary, China signed and ratified the Kyoto protocol but has no binding targets in its Annex B (United Nations 1997). A relevant number of publications appeared in other countries, such as India with 337 (7.66%), Germany with 327 (7.44%), the United Kingdom with 284 (6.46%), Australia with 231 (5.25%), Italy with 217 (4.93%), Canada with 171 (3.89%), Japan with 163 (3.71%), France with 159 (3.62%), South Korea with 139 (3.16%) and Spain with 133 (3.02%). Note that the countries that emitted the most CO_2 into the atmosphere in 2015, which were China with 10641788.99 ktons of CO_2 and the United States with 5172337.73 ktons of CO_2, as indicated in the Emissions Database for Global Atmospheric Research (European Commission - Joint Research Centre (JRC)/PBL Netherlands Environmental Assessment Agency 2015), are those most engaged in this topic. In this respect, the production of literature in all these countries reveals a global concern about how the massive use of technology affects the environment, and this awareness is not only present in the most populated countries. This scientific production can be also attributed to economic reasons, since a causal relationship between renewable energy consumption and economic growth has been demonstrated (Alper and Oguz 2016).

Table 20 shows absolute data for most prolific countries, including the number of inhabitants (variable INH), the gross domestic product (variable GDP) and the number of publications in Scopus (variable PUB). The Pearson correlation factor was calculated for the INH and PUB variables ($r=0.531$, $n=39$, $p=0.003$), and for GDP and PUB ($r=0.954$, $n=30$, $p>0.001$). This result reveals that the most populous countries and the richest countries have a higher number of publications on GIT and sustainability in comparison with the less populous countries and the poorest countries. This fact is bound to appear, since it is much easier to establish networks with researchers attached to other institutions in the same country (Xie et al. 2008).

The median of INH and GDP were calculated. Countries were grouped according to their INH and GDP values (i.e., higher and lower than or equal to the median). The mean values of PUB in the two resulting groups of countries are depicted in Table 21. Observe that the countries in the group with fewer inhabitants (variable INH) and less gross domestic product (variable GDP) have a lower percentage of publications on GIT and sustainability in Scopus (PUB). A statistical study based on the *Mann-Whitney U* test was carried out. Relevant differences were found between INH and PUB ($U=189.500$, $p=0.001$) and between GDP and PUB ($U=223$, $p<0.001$).

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Country	INH[1]	GDP[2]	PUB
United States	324459463	18561934	987
China	1409517397	11391619	562
India	1339180127	2250987	337
Germany	82114224	3494898	327
United Kingdom	66181585	2649893	284
Australia	24450561	1256640	231
Italy	59359900	1852499	217
Canada	36624199	1532343	171
Japan	127484450	4730300	163
France	64979548	2488284	159
South Korea	50982212	1404383	139
Spain	46354321	1252163	133
Netherlands	17035938	769930	99
Brazil	209288278	1769601	95
Sweden	9910701	517440	89
Malaysia	31624264	312433	88
Switzerland	8476005	662483	81
Taiwan	23626456	519149	74
Finland	5523231	256922	61
Belgium	11429336	470179	44
Ireland	4761657	217884	43
Greece	11159773	241796	42
Austria	8735453	415366	41
Singapore	5708844	295744	39
Denmark	5733551	330958	37
Pakistan	197015955	238737	35
Hong Kong	7364883	273658	33
Iran	81162788	366259	33
New Zealand	4705818	181330	30
Romania	19679306	189659	30

Table 20. Comparison of internal country data and literature production

	Countries with variables INH or GDP higher than the median	Countries with variables INH or GDP lower or equal than the median
PUB mean value in INH groups	248.670	64.930
PUB mean value in GDP groups	265.670	47.930

Table 21. Mean values of INH and GDP of the divided grouped countries

[1] Source: United Nations (July 2017) (source: https://esa.un.org/unpd/wpp/)
[2] Source: International Monetary Fund (April 2016) (source: http://www.imf.org/external/pubs/ft/weo/2017/01/weodata/index.aspx)

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In contrast, the situation is quite different in relative terms. Table 22 shows the data that were retrieved to perform the statistical analysis. The rows are sorted according to the number of publications. Relative data, such as CO_2 kton emissions per inhabitant (variable COE) and income per capita (variable IPC) of the main literature producing countries were compared to the percentage of publications on GIT and sustainability found in Scopus (variable PGIT). The aim was to find a relationship for a major output production. As the data concerning variables IPC and COE were not normally distributed, a Spearman correlation was obtained in order to reveal the relationship between the COE and PGIT variables ($r_s(28)=-0.028$, $p=0.884$), and between IPC and PGIT ($r_s(28)=-0.140$, $p=0.459$). Both results show a low negative correlation.

The medians of COE and IPC were then calculated. Countries were grouped according to their COE and IPC values (i.e., higher and lower than or equal to the median). The mean values of PGIT in the two resulting groups of countries are shown in Table 23. Note that countries in the group with less CO_2 kton emissions per inhabitant (COE) and less income per capita (IPC) have a higher percentage of publications on GIT and sustainability in Scopus (PGIT). However, a statistical study based on the *Mann-Whitney U* test did not find any significant differences between COE and PGIT ($U=118$, $p=0.803$) or between IPC and PGIT ($U=94$, $p=0.443$).

The most common form of publication in GIT was Conference Papers, and one out of every two papers (53.12%) was published in this form. This is not surprising, since changes occur in short periods of time in technology. There is, therefore, a widespread need for computing researchers to attend conferences in order to communicate their results as quickly as possible. Moreover, the degree of collaboration parameter ($C=0.843$) indicates that cooperation among authors is frequent. This can be explained by the fact that pollution and climate change are global problems which have no frontiers (Thatcher and Yeow 2016). The journals in which publications concerning GIT and technology sustainability are most frequently found are “Computer” (Journal Citation Ranking Q2 in 2016), “Sustainable Computing Informatics and Systems” (SCIS) (Q2 in 2016) and “IT Professional” (Q3 in 2016). These journals have published several special issues related to GIT, such as “Fostering Green IT” in 2013 and “Green Mobile Cloud Computing (Green MCC)” in 2016. Note that SCIS is a journal that specializes in publishing research findings related to the energy-aware management of computing resources and was launched in 2011. The most preferred conferences are, meanwhile, “Lecture Notes in Computer Science Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics” (3.68%), which consists of the proceedings of several conferences and is not ranked according to any CORE value, “2016 IEEE International Conference on Internet of Things (iThings) and IEEE Green Computing and Communications (GreenCom) and IEEE Cyber, Physical and Social Computing (CPSCom) and IEEE Smart Data (SmartData)” (3.62%), which has no core classifications, and “International Green And Sustainable Computing Conference 2016” (1.09%), also without a core classification.

Tomoya Enokido and Makoto Takizawa were the most prolific authors. There has been an extensive collaboration between these authors in GIT and technology sustainability since 2010, with a total of 45 joint publications and an average number of joint publications per year of six. These authors have focused their efforts on energy-efficient systems over the last ten years.

Future trends

Note that the word cloud is included in 9 out of the 10 most cited papers (Table 18). The shift to the cloud computing model has led to the consumption of enormous amounts of electrical energy. Cloud computing involves the establishment of Cloud Data Centers (CDC), with thousands of computing nodes. An average CDC can consume as much energy as 25000 households (Kaplan et al. 2008). Most computers operate at 10-50% of their full capacity (Barroso and Hölzle 2007). Moreover, even completely idle computers might still consume about 70% of their peak power (Fan et al. 2007). Computing service providers worldwide are, therefore, increasingly more interested in promoting energy efficiency for CDC and minimizing the environmental impact (Consortium 2011).

Several solutions with which to increase CDC’s energy efficiency have been proposed (Beloglazov et al. 2012): (1) architectural frameworks for energy-efficient cloud computing and (2) energy-efficient resource allocation policies and scheduling algorithms. Resource usage can be optimized by using the dynamic consolidation of virtual machines (VMs) and switching idle servers to power-saving modes. Different algorithms have been proposed to reduce energy consumption, while ensuring a high level of adherence to the service level agreements. Some open research challenges in Green Cloud Computing are which, how, when and where to reallocate VMs in order to: (1) optimize multiple system resources (CPU, RAM, and network Bandwidth); (2) reduce the energy consumed by the network infrastructure; (3) minimize the power drawn by the cooling system; and (4) identify common behaviors and patterns,

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and determine load forecasting approaches that can potentially lead to improved energy efficiency.

Energy-aware resource provisioning and allocation algorithms can be classified under the term green by software, which refers to IT when used as a tool to support sustainability goals (Calero and Piattini 2017), in the case of CDC, so as to reallocate VMs in order to reduce the power consumption. However, less attention has been paid to how to make software in a more sustainable manner (García-Mireles et al. 2017), also known as green in software. The practices used to develop software influence energy consumption. For example, the use of application development environments such as HIBERNATE can simplify developers' programming tasks, thus improving development process efficiency (Steffen and Narayan 2007). However, the energy consumption issues must be considered in order to write energy efficient code when using these tools. The use of this abstraction layer may cause extra work for the processor when a program is executed. An empirical study with 63 open source software applications showed that, for small to average sized applications, the use of application development environments, such as frameworks and external libraries, is associated with greater software energy efficiency (Capra et al. 2012). However, the code of larger applications created by using application development environments is less energy efficient than code developed from scratch. Software developers need practical guidelines to support sustainability during software development (García-Mireles et al. 2017).

Several methodologies considering how to make professionals aware of sustainability have been proposed to date. The Greensoft Model (Naumann et al. 2011) is a conceptual model for "Green and Sustainable Software". This model has the objective of supporting software developers, administrators and software users as regards creating, maintaining, and using software in a sustainable manner. Another example is the Random decision forests-based software energy consumption profiling (Beghoura et al. 2017). This work proposes an evaluation tool with which to describe green efficiency by considering energy consumption as the main aspect during the development stage.

Apart from software issues, it is essential to address improvements to hardware. The CPU and memory are the largest power consumers in a CDC server. Whereas modern CPUs are significantly better as regards energy efficiency (Barroso and Hölzle 2007), the new memory technology is not more significantly power-efficient than previous generations, thus making memory one of the biggest hot spots in power and energy usage optimization.

Another emerging threat and topic that has been heavily debated over the past few years is the Bitcoin mining process. This currency requires a huge amount of calculations to process financial transactions, signifying a high consumption of electricity. Observe that the Bitcoin network currently consumes at least 3 gigawatts of electricity, currently, which is comparable to the electricity consumption of medium-sized countries such as Denmark, Ireland or Bangladesh (between 3 and 6 gigawatts) (de Vries 2018) (Vranken 2017). Promising alternative mechanisms have been proposed to address the energy consumption of the algorithms required for bitcoin mining (Zheng et al. 2017) (Ateniese et al. 2014)

Mobile devices have particular activity patterns with high performance for short periods of time, followed by long idle intervals of seconds or minutes (Barroso and Hölzle 2007). Compared with other applications, mobile device applications require faster responses. Moreover, the new resource-intensive mobile applications, such as speech recognizers, natural language translators and gaming, demand a high computing speed and battery lifetime. The resource-constrained mobile devices can incorporate high performance multiple core processors into mobile devices to improve their computational algorithm efficiency. Another solution proposed in research literature to reduce the energy consumption of the mobile device CPU is that of offloading major processing tasks to a CDC (Ali et al. 2016). However, the use of available network communication channels and CDC also incur power consumption.

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Country	COE[3]	IPC[4]	Publications in Scopus	Publications on Green IT and Sustainability	PGIT
United States	0.016	0.057	14997687	987	0.006581015
China	0.008	0.008	4770307	562	0.011781212
India	0.002	0.002	1597829	337	0.000187755
Germany	0.009	0.043	3356605	327	0.009741986
United Kingdom	0.006	0.040	4136491	284	0.006865723
Australia	0.018	0.051	1431504	231	0.016136874
Italy	0.006	0.031	1873864	217	0.011580349
Canada	0.015	0.042	1984908	171	0.008615009
Japan	0.010	0.037	3366630	163	0.004841637
France	0.005	0.038	2386204	159	0.006663303
South Korea	0.012	0.028	975478	139	0.014249424
Spain	0.006	0.027	1327988	133	0.010015151
Netherlands	0.010	0.045	1077607	99	0.009187023
Brazil	0.002	0.008	845613	95	0.011234454
Sweden	0.004	0.052	771349	89	0.011538227
Malaysia	0.008	0.010	238879	88	0.036838734
Switzerland	0.005	0.078	782582	81	0.010350353
Taiwan	0.012	0.022	629884	74	0.011748195
Finland	0.009	0.047	362953	61	0.016806584
Belgium	0.008	0.041	569945	44	0.007720043
Ireland	0.008	0.046	203306	43	0.021150384
Greece	0.006	0.022	311266	42	0.013493282
Austria	0.008	0.048	417896	41	0.009811053
Singapore	0.009	0.052	264995	39	0.014717259
Denmark	0.006	0.058	432368	37	0.008557525
Pakistan	0.001	0.001	125280	35	0.279374202
Hong Kong	0.006	0.037	267148	33	0.012352703
Iran	0.008	0.005	427408	33	0.007720960
New Zealand	0.007	0.039	263715	30	0.011375917
Romania	0.004	0.010	167254	30	0.017936791

Table 22. Comparison of internal country data and literature production

	Countries with COE or IPC variables higher than the median	Countries with COE or IPC variables lower than or equal to the median
PGIT mean value in COE groups	0.013	0.029
PGIT mean value in IPC groups	0.011	0.030

Table 23. Mean values of COE and IPC of the divided grouped countries

[3] Source: Emission Database for Global Atmospheric Research (EDGAR) (January 2015) (source: http://edgar.jrc.ec.europa.eu/)
[4] Source: International Monetary Fund (April 2016) (source: http://www.imf.org/external/pubs/ft/weo/2017/01/weodata/index.aspx)

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Conclusion

In this study, a publication search related to GIT and technology sustainability was performed in Scopus without filtering the period of time. Data gathered from 4398 publications has allowed us to describe the present situation regarding literature production, thus revealing that the number of publications in this field increase every year, particularly in 2017, with an annual growth rate of 31.6% detected at the time of performing the search in the database.

This enabled us to discover that sustainability has gained popularity not only in the academic world. The existence of international programs regarding sustainability indicates an increasing concern about the current environmental situation and the need for a change in attitude as regards respect for the planet. One of the goals pursued by GIT and sustainability is the restoration of the environment, and policies are gradually being implanted by governments in order to guarantee environment care. As an example, the French government announced its intentions to finalize the sale of diesel and gasoline cars by 2040 (Chrisafis and Vaughan 2017).

One limitation of this study is the fact that only Scopus was used to perform the search. Although this database is the largest abstract and citation database of peer-reviewed literature (Mongeon and Paul-Hus 2016), some results related to the field of research might have been overlooked. Another limitation is related to the novelty of GIT. There is no clear tendency regarding how to name concepts that comprise GIT and the same concepts may have different names, depending on the authors. This variety of designations made it difficult to determine which words to include in the search string. Some words were, therefore, included in the search string in order to generate new results when seeking the proposed terms in the future. However, the sensibility analysis performed in this study validated that the results were those expected.

Future work could consist of extending the search already carried out in Scopus to other databases and analyzing the data retrieved. This could provide the opportunity to discover the differences among databases as regards GIT and technology sustainability. Another suggestion for future work would be to study the interdisciplinarity of journals (Zhang et al. 2016) as to the topics analyzed in this paper.

The publications studied in this analysis have been categorized according to the type of paper. Three classifications based on scientific literature have been used: study type (Petersen et al. 2008; Wieringa et al. 2006; Petersen et al. 2015), empirical study (Wohlin et al. 2012) and secondary studies (Nurdiani et al. 2016). Study type is the facet that reflects the research approach used in the papers. It consists of the following categories: evaluation research, validation research, solution proposal, philosophical paper, experience report, and opinion paper. An empirical study consists of the evaluation of a model proposed based on observation. Depending on the purpose of the evaluation and the conditions for the empirical investigation, an empirical study can be a case study, an experiment, or a survey. Secondary studies are reviews of relevant primary studies that are carried out to synthesize evidence related to a specific research question. The kind of secondary studies classified are; reviews of studies, systematic literature reviews, meta-analyses, and systematic mappings. Cochran's formula (1) was used to establish the sample size, by employing the parameters set out previously in the sensibility analysis. After reviewing 110 randomly selected papers, 35 were classified as evaluation research, 12 as validation research and 62 as solution proposals. With regard to empirical studies, eight papers were classified as case studies, 17 as experiments and three as surveys. Finally, as regards secondary studies, only five reviews of studies were found. Keeping these results in mind, there is a need to dedicate more effort to theoretical approaches, evaluation studies and systematic literature reviews. A technology takes about 15 to 20 years to attain sufficient maturity for it to be adopted by industry (Redwine Jr and Riddle 1985). According to Redwine and Riddle model, we can expect a future state–of–practice in which a wide coverage of GIT and sustainable technology development by real world will occur in 5 or 10 years. An increasing trend for experiments was observed in recent years. However, more work is required on evaluation research in real world (case studies) and systematic literature reviews.

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Appendix A

Search string introduced into the advanced search tab of the Scopus database.

OR TITLE-ABS-KEY ("green* software")
OR TITLE-ABS-KEY ("software green*")
OR TITLE-ABS-KEY ("green* information technolog*")
OR TITLE-ABS-KEY ("information technolog* green*")
OR TITLE-ABS-KEY ("green* in Information Technolog*")
OR TITLE-ABS-KEY ("green* in IT")
OR TITLE-ABS-KEY ("green* by Information Technolog*")
OR TITLE-ABS-KEY ("green* by IT")
OR TITLE-ABS-KEY ("green* with Information Technolog*")
OR TITLE-ABS-KEY ("green* with IT")
OR TITLE-ABS-KEY ("Information Technolog* for green*")
OR TITLE-ABS-KEY ("IT for green*")
OR TITLE-ABS-KEY ("green* for Information Technolog*")
OR TITLE-ABS-KEY ("green* for IT")
OR TITLE-ABS-KEY ("green* through Information Technolog*")
OR TITLE-ABS-KEY ("green* through IT")
OR TITLE-ABS-KEY ("green* Information and communications Technolog*")
OR TITLE-ABS-KEY ("green* Information communications Technolog*")
OR TITLE-ABS-KEY ("green* ICT")
OR TITLE-ABS-KEY ("Information and communications Technolog* green*")
OR TITLE-ABS-KEY ("ICT green*")
OR TITLE-ABS-KEY ("green* by Information and communications Technolog*")
OR TITLE-ABS-KEY ("green* by ICT")
OR TITLE-ABS-KEY ("Information and communications Technolog* for green*")
OR TITLE-ABS-KEY ("ICT for green*")
OR TITLE-ABS-KEY ("green* for Information and communications Technolog*")
OR TITLE-ABS-KEY ("green* for ICT")
OR TITLE-ABS-KEY ("Information System* for green*")
OR TITLE-ABS-KEY ("IS for green*")
OR TITLE-ABS-KEY ("green* for Information System*")
OR TITLE-ABS-KEY ("green* for IS")
OR TITLE-ABS-KEY ("green* Information System")
OR TITLE-ABS-KEY ("Information System green*")
OR TITLE-ABS-KEY ("green in software engineering")
OR TITLE-ABS-KEY ("green in SE")
OR TITLE-ABS-KEY ("green by software engineering")
OR TITLE-ABS-KEY ("green by SE")
OR TITLE-ABS-KEY ("green* comput*")
OR TITLE-ABS-KEY ("comput* green*")
OR TITLE-ABS-KEY ("green* ontolog*")
OR TITLE-ABS-KEY ("ontolog* green*")
OR TITLE-ABS-KEY ("green* hardware")
OR TITLE-ABS-KEY ("hardware green*")
OR TITLE-ABS-KEY ("green data center*")
OR TITLE-ABS-KEY ("data center* green*")
OR TITLE-ABS-KEY ("green requirement* engineer*")
OR TITLE-ABS-KEY ("engineer* green requirement*")

OR TITLE-ABS-KEY ("green* software develop*")
OR TITLE-ABS-KEY ("software develop* green*")
OR TITLE-ABS-KEY ("software energy consumption")
OR TITLE-ABS-KEY ("sustain* comput*")
OR TITLE-ABS-KEY ("comput* sustain*")
OR TITLE-ABS-KEY ("sustain* software")
OR TITLE-ABS-KEY ("software sustain*")
OR TITLE-ABS-KEY ("sustain* of software")
OR TITLE-ABS-KEY ("sustain* in software")
OR TITLE-ABS-KEY ("software for sustain*")
OR TITLE-ABS-KEY ("sustain* for software")
OR TITLE-ABS-KEY ("Information System Sustain*")
OR TITLE-ABS-KEY ("Sustain* Information System")
OR TITLE-ABS-KEY ("Information Technology Sustain*")
OR TITLE-ABS-KEY ("Sustain* Information Technology")
OR TITLE-ABS-KEY ("sustain* with Information Technology")
OR TITLE-ABS-KEY ("sustain* with IT")
OR TITLE-ABS-KEY ("sustain* through Information Technology")
OR TITLE-ABS-KEY ("sustain* through IT")
OR TITLE-ABS-KEY ("sustain* for Information Technology")
OR TITLE-ABS-KEY ("sustain* for IT")
OR TITLE-ABS-KEY ("sustain* in Information Technology")
OR TITLE-ABS-KEY ("sustain* in IT")
OR TITLE-ABS-KEY ("Information and Communication Technology Sustain*")
OR TITLE-ABS-KEY ("Sustain* Information Communication Technology")
OR TITLE-ABS-KEY ("Sustain* Information and Communication Technology")
OR TITLE-ABS-KEY ("Software Engineering for Sustain*")
OR TITLE-ABS-KEY ("sustain* in require* engineer*")
OR TITLE-ABS-KEY ("sustain* with software")
OR TITLE-ABS-KEY ("Sustain* in Open Source Software")
OR TITLE-ABS-KEY ("sustain* non-function* require*")
OR TITLE-ABS-KEY ("sustain* self-aware service* system*")
OR TITLE-ABS-KEY ("sustain* of business")
OR TITLE-ABS-KEY ("sustain* in business")
OR KEY ("green* IT")
OR KEY ("IT green*")
OR KEY ("green* IS")
OR KEY ("sustain* IT")
OR TITLE ("green IT")
OR TITLE-ABS-KEY ("sustain* requirements")
OR TITLE-ABS-KEY ("sustainability indicator software development")
OR TITLE-ABS-KEY ("IS green practices")
OR TITLE-ABS-KEY ("eco-comput*")
OR TITLE-ABS-KEY ("green informat*")
AND NOT TITLE-ABS-KEY ("Green's function")

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