

A bibliometric analysis-based review on Green IT

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ABSTRACT:

With the increasing global greenhouse gas emission (GHGE) from ICT usage, several research projects have been conducted in the areas for Green IT development (such as optimal resource allocation algorithms, deterministic heuristics approaches) and Green IT deployment (integrated framework approach). Although there was significant progress in Green IT research during the period of 2008-2013, it has declined gradually in recent years. The findings from all of these Green IT research play a vital role in improving the resource optimisation, which can result in GHGE from ICT usage. This book chapter presents the findings from bibliometric analysis, co-authorship and citation network analysis on Green IT articles. The findings show that the numbers of total related articles increased from 2008 to 2013 and gradually decreased in recent years. USA, Germany, India, Australia and England are the leading countries. The high average citations of articles from Australian scholars reflect their significant academic value in this Green IT research area, although the funding support from Australia research council on Green IT is comparatively low. There is a need to encourage more academic collaborations with co-authorship to share experiences, knowledge and skills for more innovative solutions. The citations among articles from worldwide are widely distributed and well linked among articles from various countries and academic institutions.

Keywords: Bibliometric Analysis, Green IT, Co-authorship Network Analysis, Citation Network Analysis

1. Introduction

Climate change has been adverse in recent decades, and environmental sustainability is the serious challenge that we need to address urgently. It is essential to reduce the global greenhouse gas emission (GHGE) as discussed in the Paris agreement. Nevertheless, there has been little attention to ICT as a significant contributor to total global greenhouse gas emission. Belkhir and Elmeligi (2018) estimated that GHGE from ICT usage would be increased from 1.2% (min estimate) in 2007 to 3% (min estimate) in 2020 of a total global footprint. It was estimated that GHGE from ICT usage has accounted for nearly 1,700 metric tons of carbon dioxide equivalent (Mt-CO₂-eq) (min estimate) and 2,000 Mt-CO₂-eq (max estimate). They also projected that GHGE from ICT usage would reach to 14% of the total global footprint in 2040.

With fast-growing GHGE rate from ICT usage, it is vital to understand which ICT categories will be contributing more to GHGE than others so that Green IT research will be able to focus more to tackle these issues. Belkhir and Elmeligi (2018) projected that there would be

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a dramatic increase in GHGE contribution from smartphone usage from 4% in 2010 to 11% in 2020. Another rising share of GHGE is also estimated from data centres, estimated from 33% in 2010 to 45% in 2020. Referring the online tool named as the Cambridge Bitcoin electricity consumption index, Baraniuk (2019) also states that in 2019, Bitcoin uses nearly the same amount of energy as the whole nation of Switzerland, and reaches to seven gigawatts of electricity (0.21% of the total electricity supply for the whole world). Therefore, it is essential, to increase the momentum of Green IT research to improve the computing resource allocation and performance efficiency which in turn reducing the GHGE from ICT usage.

Academically, many articles have been published in the Green IT-related research area since the 1980s. However, the electricity consumption from ICT usage has been dramatically increasing over the last few decades. As a result, its contribution to GHGE has been accelerating. It is crucial to understand how Green IT research has been progressing and identify the areas for improvements. This study is aimed to provide a holistic and quantitative overview of Green IT publications by applying the bibliometric analysis along with co-authorship and citation network analysis. One of the objectives of this study is to evaluate the current research progress on Green IT and the academic collaborations among academic institutions and countries. It also aims to discuss the potential research directions for further studies derived from findings from this study.

This book chapter is organised as below. After the introduction section, research methods and data collection process will be described in section 2. Then empirical findings from bibliometric analysis, co-authorship and citation networks analysis will be presented in section 3. In the last section 4, the research conclusion will be drawn to recommend further studies.

2. Methods and data

In this paper, bibliometric analysis, co-authorship and citation network analysis are applied to provide the overview of Green IT literature and current trends in its publication and collaboration. The detailed explanation on these data analysis methods and how Green IT publication data is collected from Web Of Science database will be provided in this section.

2.1 Methods

Pritchard (1969) defined the bibliometric analysis as applying the mathematics and statistical methods to conduct the literature review on previously published books and other media of communications. Before Pritchard, statistical bibliography analysis was used in health science, and Raisig (1962, pg.450) defined it as “*assembling and interpretation of statistics relating to books and periodicals; it may be used in a variety of situations for an almost unlimited number of measurements*”.

Citation analysis, along with network analysis of co-citation and content analysis, has been extensively used methods in bibliometric analysis. Pilkington and Meredith (2009), Chen and Ho (2015), Mao et al. (2015a), Mao et al. (2015b), Zhi et al. (2015), Zhou et al. (2007) state that citation analysis in accompany with network analysis of co-citation data can be used to identify the significant publications, its evolution overtimes, the core literatures, mostly researched countries, the primary knowledge groups, their evolutions in terms of their research popularity, the impacts of scholars and the relationship between citing and cited works in a particular studied area. On the other hand, content analysis can be used to

identify the current popular research topics or themes or trends or issues based on the frequency of keywords and other distributions, Gao et al. (2016). According to Gao et al. (2016), network analysis can be used to classify the network of publications (as nodes), and inter-relations among them and this publication/citation networks can be used to examine the importance and influences of a publication based on its centrality and connectivity with other publications (nodes). In this study, network analysis will be conducted as a citation network analysis which illustrates research articles, organisations and countries, and also co-authorship network analysis based on authors, organisations and countries. The findings from these network analysis will evaluate the influence and importance of a node; representing research articles, authors, organisations and countries, by measuring the centrality and connectivities of these nodes.

In this study, VOSviewer is used to visualise the results from co-authorship and citation network analysis. These co-authorship and citation network analysis are undertaken to evaluate the academic collaboration among various authors, organisations and countries. In these network analysis map, each node represents the author or organisations or country. A network link is a connection or relation between two nodes, and the strength of each link represents the number of publications two authors have co-authored (in co-authorship network analysis). Waltman et al. (2010) state that the weighted variant of modularity-based clustering method is applied in VSOviewer to group the nodes.

2.2 *Data collection and treatment*

In this study, the Web of Science database is used to extract the literature dataset because it provides a comprehensive and wide range of journals and other publications access. “Green IT”, “Green IS”, “Sustainable IS” and “Sustainable IT” are used as keywords to search the related publications from 1994 through 2019. The subject areas included in this search are computer science information systems, environmental sciences, computer science theory methods, management, environmental studies, computer science software engineering, green sustainable science technology, business, telecommunications, social sciences interdisciplinary, computer science interdisciplinary applications, computer science hardware architecture, multidisciplinary sciences, computer science cybernetics and computer science artificial intelligence in order to provide how Green IT has been discussed in the computing areas. The search was conducted in December 2019, and 909 publication results are listed during the period 1994-2019. Of all these retrieved documents, journal articles are accounted for 55%, followed by conference proceeding papers (39%) and editorial materials 4% as shown in Figure 1.

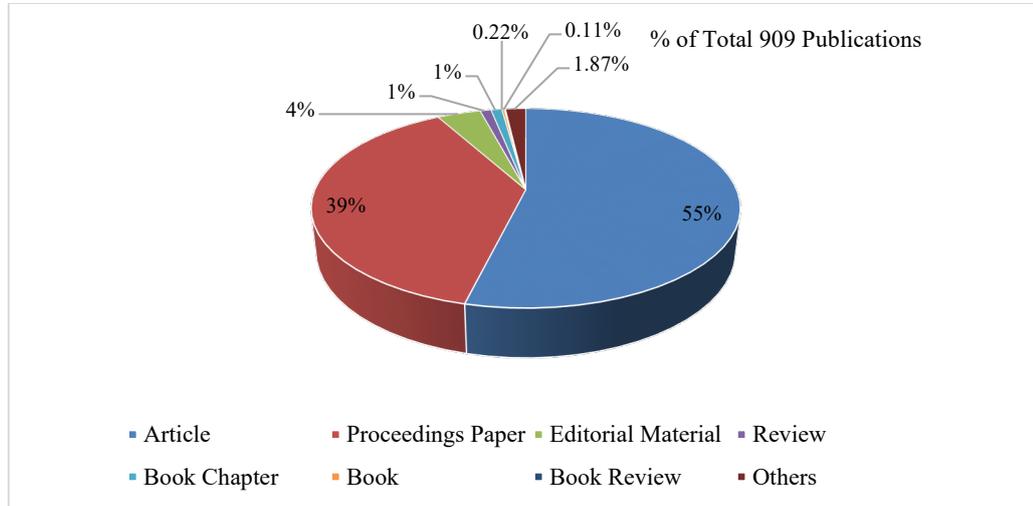


Figure 1: Numbers of publication by document types

Of these 909 publications, English 97.03% is the most frequently used language, followed by Portuguese, which accounted for 2.2%. Some articles are published in other European languages such as German, Italian and Spanish. All of these 909 publications are included in further analysis in order to provide an international perspective.

In regards to counting the national property of a paper, it depends on where its first author comes from when multiple authors could be from various countries. The full address of its first author is taken into consideration for identifying his/her country. There could be some various keywords for the same meaning, for example, “public transport” and “public transit”. Both “Green IT” and “Green IS” were used in the search and “Sustainable IT” and “Sustainable IS” because these keywords are interchangeable terminologies. In addition, digital object identifiers (DOI) are used to standardise the citations in various referencing styles.

3. Results and discussions

In this section, the findings from bibliometric analysis will be discussed first to provide the overview and trends in Green IT publications and to highlight the journals, articles and countries which are high performing in this Green IT research area. Then findings from coauthorship and citation network analysis will be explained to identify which academic institutions and countries are collaborating more than others, and also their citation performance.

3.1 The performance of related publications

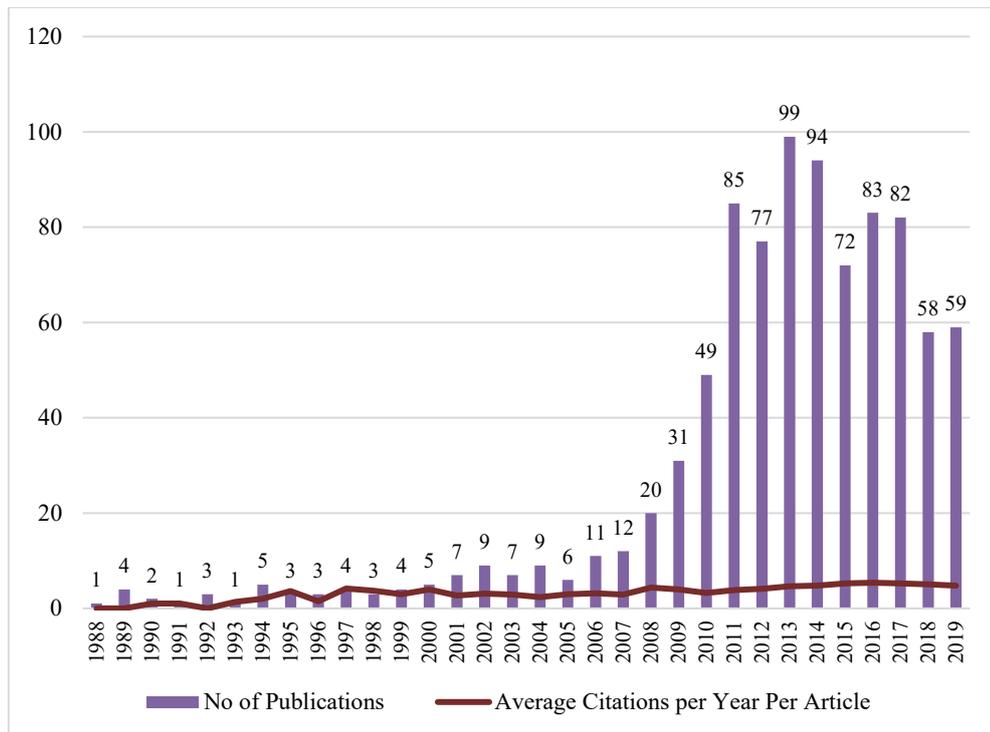


Figure 2: Numbers of publications and average citation per year per article during the period of 1988-2019

Figure 2 presents the total number of published articles and average citations per year per article between 1988 and 2019. Several publications for Green IT significantly increased since 2008, then experienced a significant increase in 2010 and 2011. In 2010, some researchers from Japan, such as Enokido et al. (2010) researched to develop the algorithm and models on power saving with peer to peer systems. At the same time, Dedrick (2010) also raised the awareness of Green IS in terms of its concepts and issues. In 2011, the highly cited agenda for Green IT and systems research was proposed by Tracy Jenkin and her colleagues.

Meanwhile, a research group led by Viet Dao also developed the highly cited from green to sustainability: information technology and sustainability framework. Then it reached its peak at ninety-nine publications in the year 2013. It is noticeable that there is a slight decrease in its publications in 2015, again in 2018 and 2019. Nevertheless, the average citation per year per article has remained stable since 1997.

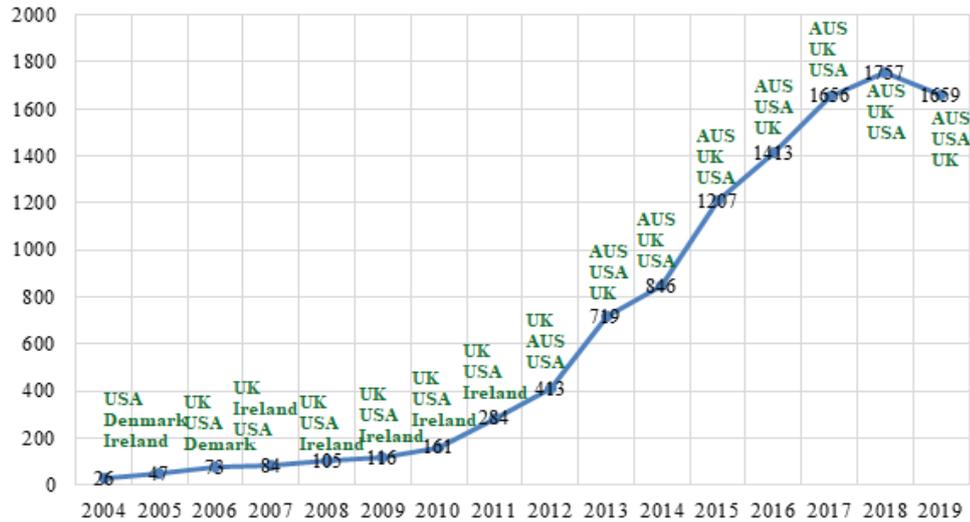


Figure 3: Numbers of citations and the top three cited countries

Figure 3 illustrates the numbers of citations and top three published countries from 2004 to 2019. An increase in the numbers of citations in Figure 3 also aligns with the increase in numbers of publications Figure 2 between 2010 and 2019. Nevertheless, there is a slight decrease in the number of citations in 2019. Since the highly cited deterministic algorithms and adaptive heuristics to improve the resource allocation and performance efficiency in cloud data centres were published by Beloglazov and Buyya (2012), Beloglazov et al. (2012), Australia has reached in the annual first highest cited country since 2013. It is noticeable that Australia, the United Kingdom and the United States of America have remained the status in the top three cited countries since 2012.

3.2 Journals' performances

The collected 909 articles were published in 696 various journals or conference proceedings indexed in Web of Science. It indicates the expanded nature in publication distributions and the broad interests of various journals and conferences. The number of articles published in top 15 sources contributes to 17.05% of total publications. Among all of these document sources, Sustainability is the most published journal with 26 (2.86%) articles. Among these document sources, Journal of Cleaner Production and Computer are the two influential journals with high H-index above 150. Some of the highly cited articles, proposing the algorithms and models to improve the resource allocations and performance and energy efficiency for high-performance cloud computing centres, were published in Future Generations Computer Systems: The International Journal of E-Science which has high H-index 93.

Source Titles	records	%	H-index
Sustainability	26	2.86	53
Journal of Cleaner Production	16	1.76	150
Australasian Journal of Information Systems	12	1.32	12
Communications in Computer and Information Science	12	1.32	40
New Scientist	12	1.32	17
Computer	11	1.21	153
Communications of the Association for Information Systems	10	1.1	38
Journal of Strategic Information Systems	8	0.88	76
Proceedings of the Annual Hawaii International Conference on System Sciences	8	0.88	72
Advanced Science Letters	7	0.77	24
Future Generation Computer Systems: the International Journal Of E-science	7	0.77	93
IFIP Advances in Information And Communication Technology	7	0.77	44
Information Systems Frontiers	7	0.77	55
IT Professional	7	0.77	42
Business Information Systems Engineering	5	0.55	37

Table 1: The top 15 journals or related conferences

3.3 *The most cited articles*

In this section, the top fourteen cited articles during the last decade 2009-2019 are explored. The total numbers of citations imply the academic values of each article. Sometimes, the number of citations can heavily rely on the number of researchers or groups working on a particular research topic.

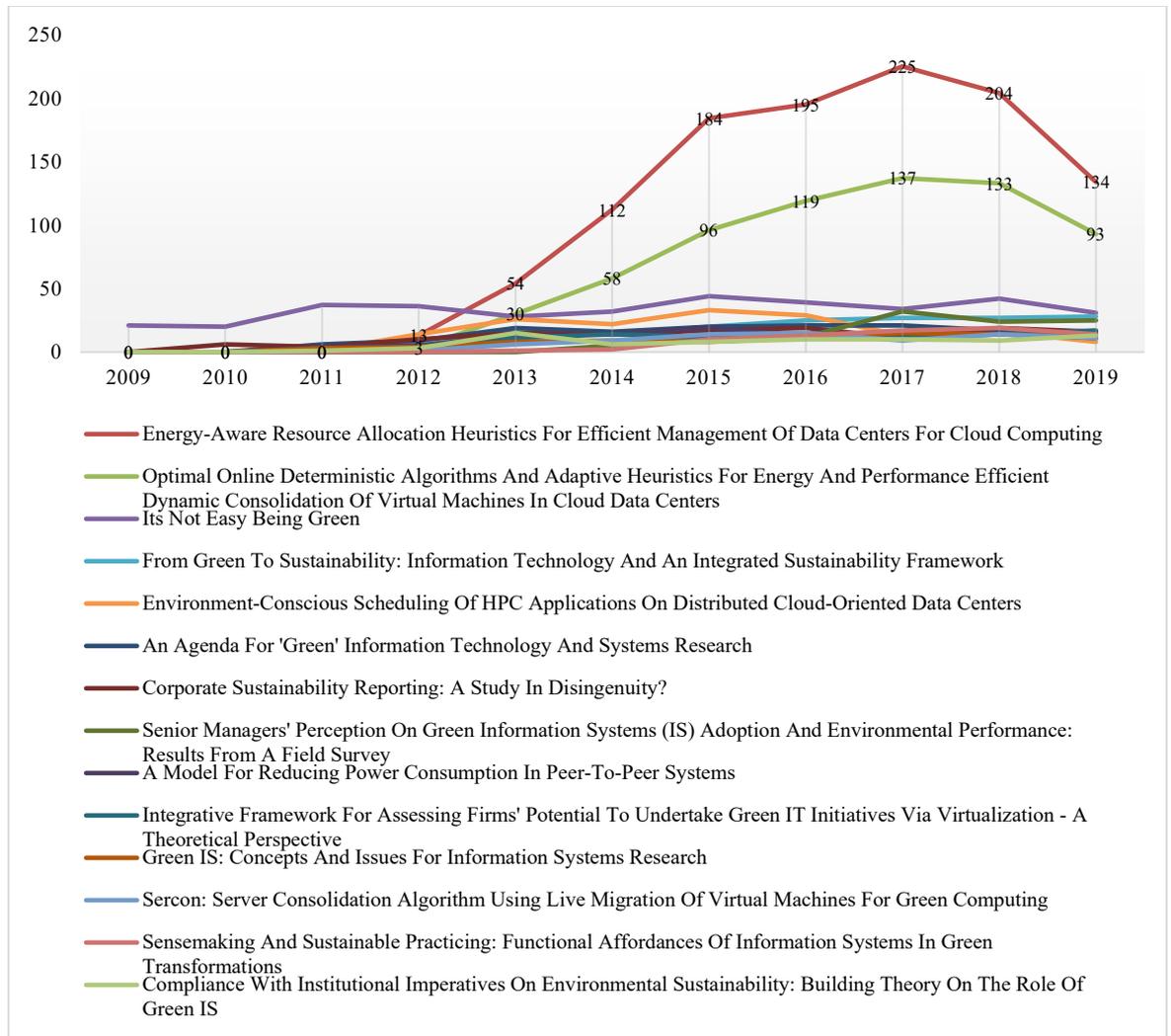


Figure 4: The most cited articles

Figure 4 shows two significant evolution trends of the first and second most cited articles after they were published, Beloglazov et al. (2012) and Beloglazov and Buyya (2012). Their deterministic algorithms and adaptive heuristics to improve the energy and performance efficiency have been highly cited till now even though there is a slight decrease in the number of their citations in last two years 2018 and 2019. Both of these articles significantly contributed to energy-saving and efficient performance in cloud data centres and added significant values in Green IT development area. They are followed by the articles describing the flow optimization-based framework to reduce the workload and carbon emissions from request-routing and traffic engineering, Gao et al. (2012). It is noticeable that not only the articles relating Green IT development but also the articles emphasising on its deployment are also significantly contributing to this Green IT research area. An article, proposing information technology and an integrated sustainability framework, was published by Dao et al. (2011). This paper suggests how IT can contribute to sustainability more than for reducing energy consumption from IT systems. This paper has been the fourth highly cited and the number of its citation has been steadily increasing since its publication.

3.4 Countries' performances

The number of publications from one country indicates the support and attention that this country has in the related research topics. Only the resided country of the first author at the time of publication is considered in this analysis.

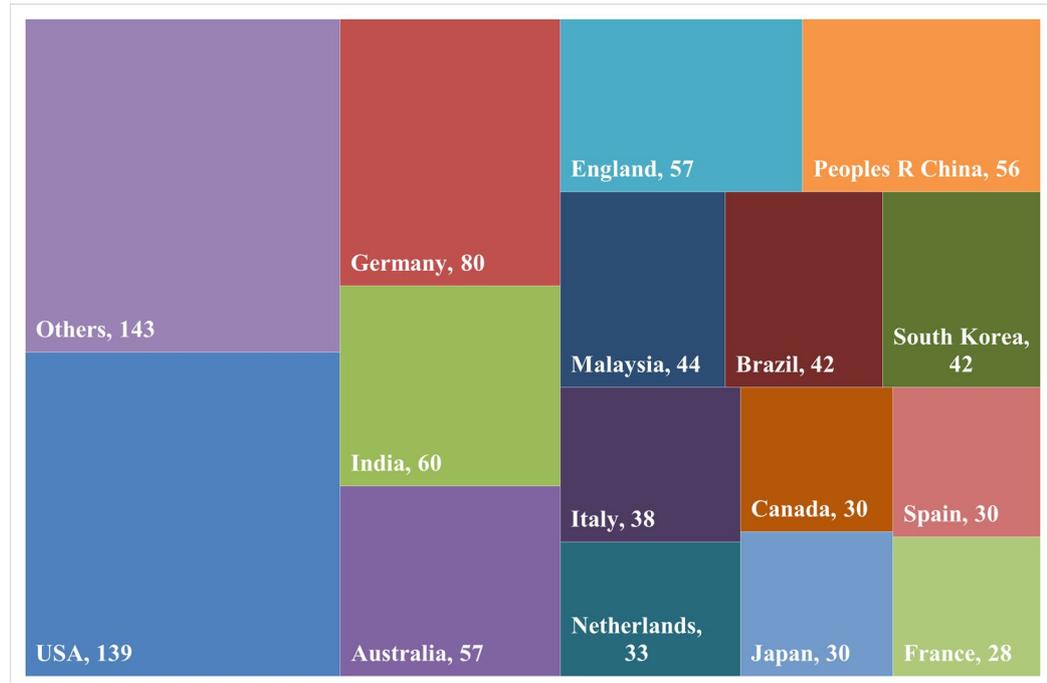


Figure 5: The top 15 most productive countries

Figure 5 shows the top 15 most productive countries, which have published significantly in Green IT research area. These top 15 countries published a total of 766 articles which accounted for 84% of the total searched articles, which includes USA (139 articles, 15.3%), Germany (80 articles, 8.8%), India (60 articles, 6.6%), Australia (57 articles, 6.3%) and England (57 articles, 6.3%). Among all the productive countries, USA is the most productive country and is leading the Green IT research area. European countries are also contributing significantly, and six out of the top 20 countries are from Europe. Furthermore, the Asia-Pacific countries (Australia, China, Malaysia, South Korea, Japan, Taiwan and Indonesia) are making a significant contribution to Green IT-related publications, accounted for 27.83% of the total articles included in this study.

3.6.3 Funding agencies

The number of publications supported by funding agencies shows how well the governments or regional agencies have the interest and encourage their scholars in a particular research area with their high research priority.

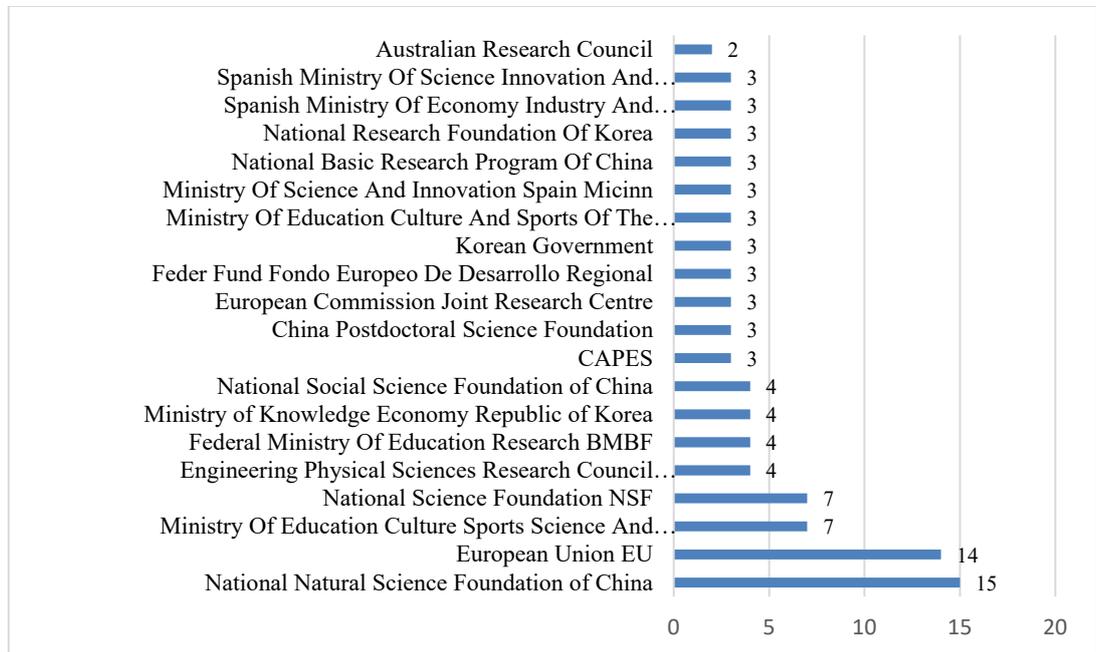


Figure 6: Top funding agencies during the period of 1988-2019

Figure 6 illustrates the top twenty funding agencies which supported to conduct research and publish the articles on Green IT from 1988 through 2019. Two hundred fifty-two funding agencies supported to publish 200 articles which are included in this study. Funding agencies information were not reported for others 709 (78%) articles. The most funded agency for the research on Green IT during the period 1988-2019 is National Natural Science Foundation of China, supported for 15 publications. Other funding agencies from China are the National Social Science Foundation of China, China Postdoctoral Science Foundation and National Basic Research Program of China and their contributions accounted for 4, 3 and 3 publications, respectively. Even though China is not the most published country, as shown in Figure 5 but funding agencies from China have been reported as the most contributed ones for the articles included in this study. European Union EU contributed to 14 publications and ranked the second among the most funded agencies. It is followed by the Ministry of Education Culture Sports Science and Technology Japan MEXT and National Science Foundation NSF where each of them supported seven publications, reflecting that MEXT and NSF need to make more efforts.

3.6 Co-authorship Network Analysis

In this section, the findings from the co-authorship network analysis will be discussed in terms of academic cooperation and collaboration among countries.

3.6.1 Academic Cooperation

The research collaboration among academic institutions is essential and valuable to accelerate the progress of a particular research topic or area.

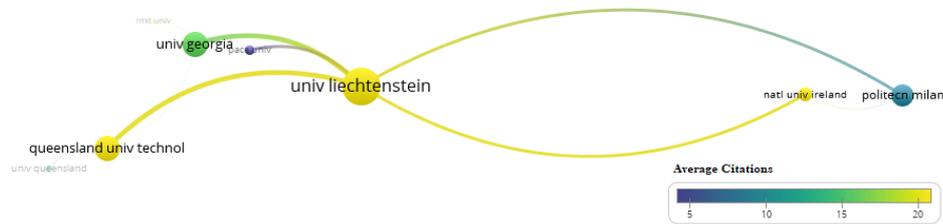


Figure 7: the highly collaborative academic institutions

Figure 7 illustrates the highly collaborative academic institutions for Green IT research area. It is clear that the University of Liechtenstein has the highest collaboration network links, compared to other academic institutions which published the Green IT related articles; 909 articles included in this study. However, the link of the University of Liechtenstein is only 5. According to Van Eck and Waltman (2009), the link of co-authorship means the number of co-authorship between the University of Liechtenstein and other academic institutions. Professor Stefan Seidel, the University of Liechtenstein, collaborated with other researchers from various academic institutions for the five highly cited Green IT related articles. These articles are a) Green IT: A Matter of Business And Information Systems Engineering?, (Loos et al. 2011), b) Sensemaking And Sustainable Practicing: Functional Affordances Of Information Systems In Green Transformations (Seidel et al. 2013), c) IT-Enabled Sustainability Transformation-The Case Of SAP, (Seidel et al. 2014), d) The Sustainability Imperative In Information Systems Research, (Seidel et al. 2017) and e) Design Principles for Sensemaking Support Systems In Environmental Sustainability Transformations, (Seidel et al. 2018). Among these articles, the second article is the highest cited one which proposed the theoretical framework identifying four important functional affordances. This framework highlights how an organisation and individual can imply more environmentally sustainable approach by using the information systems. Additionally, the University of Georgia and Queensland University of Technology are the second-highest collaborative academic institutions in Green IT research area with four co-authorship links.

3.6.2 Collaboration among Countries

The academic collaborations among various countries are essential to enhance the momentum in seeking an innovative solution and to improve the research progress. Figure 8 indicates the academic collaborations among various countries for Green IT publications from 1988 to 2019. The top ten most collaborative countries for Green IT research area are the USA, Germany, India, Australia, China, England, Malaysia, South Korea, Brazil and Italy. The researchers from the USA have most co-authored with their colleagues in Germany, China, India, South Korea, Australia, England, Italy and Netherland and its number of articles co-authored with others reached to 137 during 1988-2019. Among these academic collaborations, co-authored publications from Australia researchers have the highest citations accounted for 2584, followed by USA (2133), England (1489), Germany (598) and Canada (579), reflecting that these academic collaborations are contributing the high academic values for Green IT research areas.

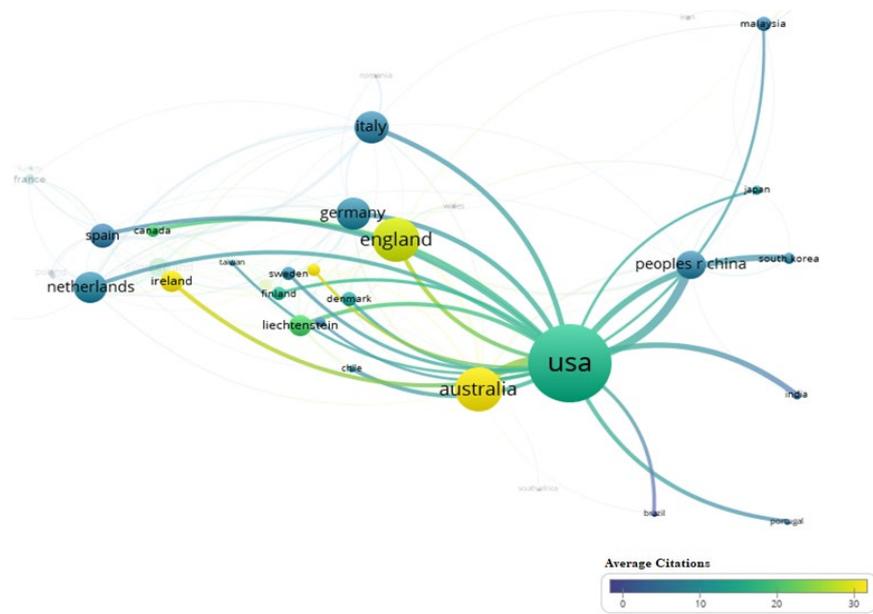


Figure 8: The academic collaborative relationships among 40 countries

3.7 Citation Network Analysis

In this section, the findings from citation network analysis will be discussed in terms of citations among documents, sources and countries.

3.7.1 By Documents

In this citation network analysis, all 909 Green IT related articles (collected for this study) are clustered by using the weighted variant of modularity-based clustering method first. Then citation links between each pair of articles are established.

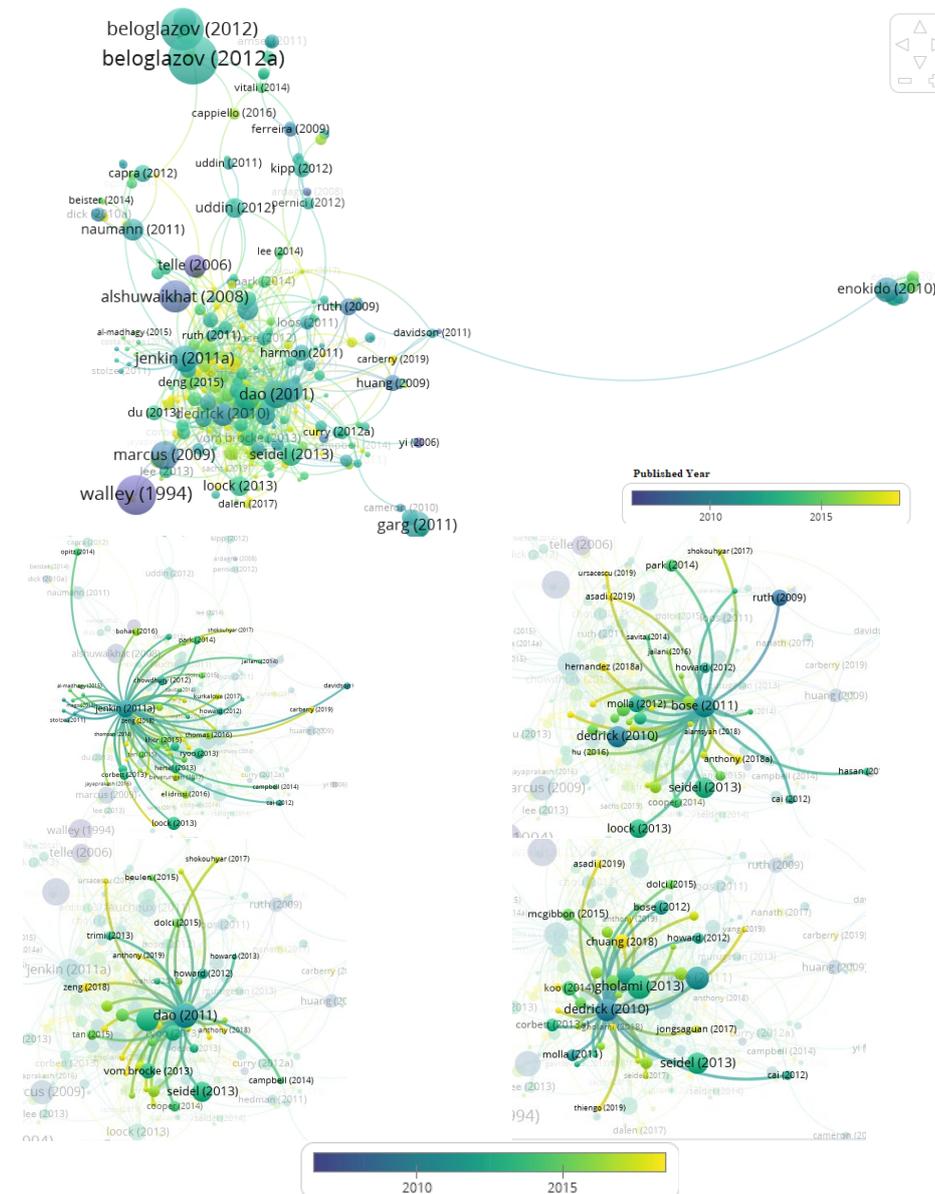


Figure 9: Citation network analysis by documents

Figure 9 shows how each Green IT related articles are citing each other. The size of circles in Figure 9 represents the number of a citation for an article, and the colour of the circle represents its published year according to the shown colour scale. Nearly at the end of the twentieth century, Walley and Whitehead (1994) highlighted the complexity and the urgent need to address the environmental challenges in the organisations by utilising the information systems to track and disseminate emissions data on the cross-functional basis for better decision making on the trade-off between cost and environmental control. Their article has been highly cited since its publication also in the strategic management research area, followed by a highly cited article from Telle (2006). He suggested that other important factors should also be considered rather than claiming the different effect of environmental performance on economic performance. In addition, Alshuwaikhat and Abubakar (2008) proposed a framework for campus sustainability by integrating Green technology, environmental management, public participation, social responsibility, teaching and research on sustainability and this framework has been well cited. At the end of the first decade in the 21st century, researchers start publishing the algorithm, methods, approaches to improve the resource allocation, performance efficiency and energy consumption for Green IT development. Enokido et al. (2010) published a model to reduce the power consumption in peer-to-peer systems. Even though their work has been highly cited, their focus is more specific for peer-to-peer systems and relative distance from the rest of Green IT related articles. Two articles on resource allocation heuristics and optimal deterministic algorithms were published by Beloglazov et al. (2012); (Beloglazov and Buyya 2012). These two articles are the two highest cited ones among 909 Green IT related articles, (1122 and 672 citations respectively) and contributed significantly to Green IT development for cloud data centers. These articles are highly cited in other computational research topics. At the same times, other researchers such as Jenkin et al. (2011), Dao et al. (2011), Gholami et al. (2013), Bose and Luo (2011) and Dedrick (2010) more emphasised on developing frameworks for Green IT implementation. These articles have been well in later Green IT related articles, as shown in Figure 9.

3.7.2 By Sources

It is also essential to understand what are the publication source that Green IT scholars are referring or citing more than others and also how this citation trends progress over time. The citation network analysis by the source is useful to provide this insight.

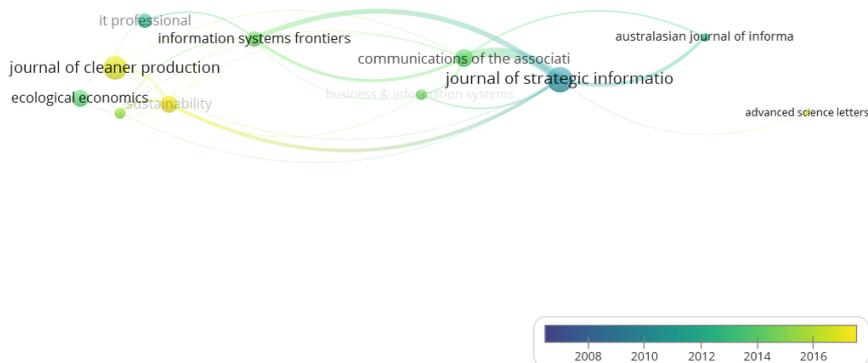


Figure 10: Citation network analysis by sources

In Figure 10, the size of circles represents the total number of citations from a particular source, and its average published year is illustrated as in the colour scale bar. In terms of citations by source, the Journal of Strategic Information has been highly cited by others such as the Information Systems Frontiers, the Communications of the Association for Information Systems, the Sustainability and the Australasian Journal of Information Systems at the early period of 21st century. In the midst of the 21st century, the number of citations shifts to the articles, published in the Information Systems Frontiers, the Communications of the Association for Information Systems and the Ecological Economics are the journals. Later, there have been more Green IT related articles published in and cited from the Journal of Cleaner Production and the Sustainability.

3.7.3 By countries

As another perspective, the citation network analysis by the countries is valuable to understand the publications from which countries are cited more and how they are connected or linked together.

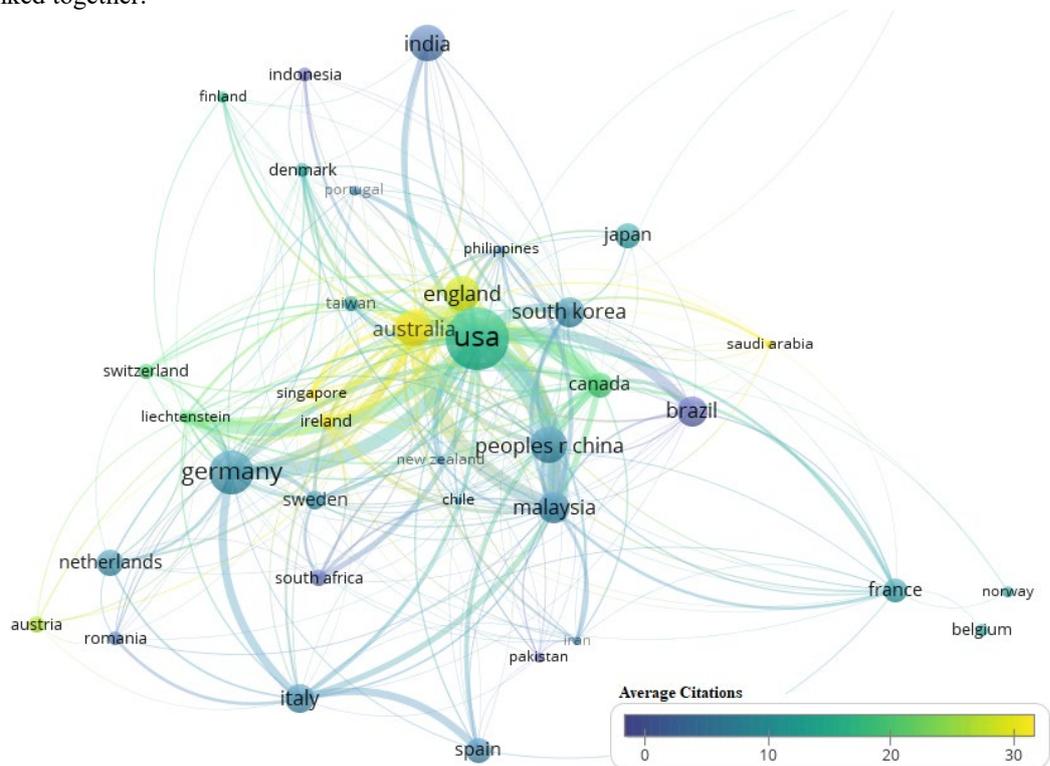


Figure 11: Citation network analysis by countries

The size of the circle represents the number of documents published by scholars in a particular country and the average citation for each country is shown as in the colour scale bar in Figure 11. Even though researchers from the USA have published most, the average citation for articles published by Australian scholars (as the first author) is significantly higher, followed by the ones from England.

Additionally, these three countries have been in the core of the Green IT-related citation network. It is interesting to note that the number of published articles is not comparatively high, but their average citations are significantly high for authors from Singapore, Ireland

and Saudi Arabia. The European Union is the second-highest funding agencies for Green IT research and its substantial contribution reflects on the high number of Green IT-related publications from Germany, Italy, Spain, Netherlands, Sweden, France, Romania, Switzerland and Liechtenstein. Although citations of articles from Germany is well linked with the articles from other European nations such as France, Netherlands, Italy, Spain, Sweden, Switzerland and Liechtenstein, the articles from Norway and Belgium are only linked with the ones from France. This citation network illustrates that countries from all continents are well linked with each other, except Wales, Norway, Belgium and Austria.

4. Conclusions and Future Research Directions

The Green IT research has made significant progress since the 1980s and accelerated from 2008 to 2013. Since then its progress has been gradually decreasing in the last few years. The supports of funding agencies from the USA, UK and Australia are relatively low compared to funding agencies from the EU and China, highlighting the needs of their more efforts. According to co-authorship network analysis, the academic collaboration links among academic institutions or countries are not strong, and it is necessary to encourage the co-authorship to share experiences, skills and ideas for more innovative solutions. From citation network analysis, two main research areas for Green IT is its development with improved algorithms for resource allocation and energy efficiency and its deployment with integrated framework or approach. It is also vital to enhance the awareness of sustainability, and Green IT and academic institutions play essential to the role to change the students' mindset by incorporating the sustainability and Green IT concepts in the curriculum (Issa and Issa 2017) and by paying more attention to research on Green IT awareness.

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