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ORIGINAL ARTICLE

State-of-the-art of scientific production about Green Information Technology

Estado da arte da produção científica sobre Tecnologia da Informação Verde

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Abstract: With the purpose of identifying the state-of-the-art in the literature, on the theme of Green Information Technology, or simply Green IT, this study presents a bibliometric review about it. Following a research protocol, 171 papers published between the years 2007 to 2020 were selected, providing an overview or are focused on a particular aspect of Green IT. As the main results of this theoretical production, research highlighted that most of the literature on Green IT is based on analyzes at the organizational level. The surveys and theoretical frameworks that consider the environmental aspects of Green IT stand out. Among the empirical studies, investigations related to organizational motivations and the role of corporate social responsibility in the adoption of Green IT prevail. Behavioral factors linked to cognitive aspects that provide a preliminary view on the diffusion status and maturity of the Green IT also emerge among field studies. It should be noted that most studies were conducted in developed countries, that is, countries where technology is more widespread. Among the main managerial implications of the research, it was evident that the need for greater energy efficiency and, consequently, cost savings in IT operations, are the main factors for the adoption of Green IT.

Keywords: Green Information Technology; Bibliometric review; State-of-the-art.

Resumo: Com o propósito de identificar o estado da arte da literatura, acerca da temática da Tecnologia de Informação Verde, ou simplesmente TI Verde, este estudo apresenta uma revisão bibliométrica sobre a referida temática. Seguindo um protocolo de pesquisa, selecionaram-se 171 artigos publicados entre os anos de 2007 a 2020, que fornecem uma visão geral ou são focados em um aspecto particular da TI Verde. Como principais resultados desta produção teórica, destaca-se que a maior parte da literatura sobre TI Verde se fundamenta em análises do nível organizacional. Sobressaem-se as *surveys* e os quadros teóricos que consideram os aspectos ambientais da TI Verde. Dentre os estudos empíricos, prevalecem as investigações relacionadas às motivações organizacionais e o papel de responsabilidade social corporativa na adoção da TI Verde. Fatores comportamentais, atrelados aos aspectos cognitivos que fornecem uma visão preliminar sobre o status da difusão e maturidade da TI Verde também despontam entre os estudos de campo. Ressalta-se que a maioria dos estudos foram conduzidos em países desenvolvidos, isto é, países onde a tecnologia é mais difundida. Dentre as principais implicações gerenciais da pesquisa, evidenciou-se que a necessidade de maior eficiência

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energética e, consequentemente, economia de custos nas operações de TI, são os principais fatores para adoção da TI verde.

Palavras-chave: Tecnologia da Informação Verde; Revisão bibliométrica; Estado da arte.

1 Introduction

In the current market scenario, information technology (IT) plays an important role in the industrial sector, as it is used as a management tool, supporting market analysis, increasing profitability and operational efficiency, helping companies to differentiate themselves in the global competitive market. Considering this context, the perception that IT cannot be dissociated from business activities is increasingly intense, as it serves as an instrument to support the incorporation of the knowledge as the main factor to increase value to the products, processes and services delivered to customers.

However, as companies become more dependent on IT services, factors related to service availability and continuity have increased, multiplying equipment requirements. Consequently, there is an increase in energy consumption, resulting in higher emissions of greenhouse gases, as the dependence on fossil fuels remains high in the global economy (Matsumura et al., 2014). Regarding electricity consumption, Uddin & Rahman (2012) indicate that despite the significant improvements in energy efficiency in devices and data centers, the demand for energy related to IT gradually increases.

In this way, as environmental problems become more evident, requiring a new positioning of managers, the concept of a new corporate social responsibility stands out, characterized by the concern to reduce pollution and energy costs in the development of products and services (Bohas & Poussing, 2016). In the IT area, this movement has been called Green IT. The concept was created by technology companies, with the objective of incorporating sustainability and economy policies within organizations, generating benefits both for the environment and for companies (Deng et al., 2017).

In the Brazilian research scenario, the search for the keywords “Green IT”, “Green Information Technology”, “Green IT” and “Green Information Technology” on the Scielo search platform, found only five articles, on the date of 15 June 2020. It is noteworthy that the search for words was carried out in the title field, without any filter in relation to the year of publication, according to the availability of that database. In a search on the SPELL portal, also on June 15, 2020, using the aforementioned keywords and without delimitation of the time of publication, twelve articles were found, in addition to those already found on the Scielo portal.

Based on the finding that few studies on the theme of Green IT have been carried out in Brazil, this research performed a bibliometric review on Green IT, with the aim of identifying the state-of-the-art of Green IT literature. In addition, this research seeks to investigate how the works are related to each other, in order to contribute to the understanding of the subject, providing guidance for future research. 171 articles were selected, which provide an overview or focus on a particular aspect of Green IT. After this introduction, the work consists of the methodological procedures used in the execution of this research, followed by the analysis and discussion of the results, and, finally, the considerations in relation to the analyzed articles are described, the possible contributions of the study, the limitations of the research and suggestion for future investigations.

2 Methodology

Bibliometric methodology makes it possible to observe the state-of-the-art of science and technology through scientific production registered in a data repository. It is a method that allows us to situate a country in relation to the world, an institution in relation to a country, and individual scientists in relation to the scientific communities themselves. It is based on the count of scientific articles, patents and citations. Depending on the purpose of the bibliometric study, the data can be either the text that makes up the publication or the elements present in records about publications, extracted from the bibliographic database, such as name of authors, title, source, language, keyword, classification and citations (Rao, 1986; Zhu et al., 1999). Furthermore, bibliometric analyzes contribute to expose the state-of-the-art in relation to the knowledge developed in a given area of science.

Machi & McEvoy (2016) emphasize that, in view of the accelerated growth of scientific information, due to the information technologies, it is necessary to develop an appropriate protocol for the selection of articles. In this sense, the systematic literature review process presented by Fink (2019) was adopted, which includes planning, conducting and documentation. Each step also includes specific activities which are: (1) Selecting research questions, (2) Selecting bibliographic or article databases, (3) Choosing search terms, (4) Applying practical selection criteria, (5) Apply the methodological selection criteria, (6) Do the review, and (7) Synthesize the results. These activities are presented in the following section.

2.1 Process steps

Based on the literature reviews, carried out by Jenkin et al. (2011), Malhotra et al. (2013), Asadi et al. (2017) and García-Berná (2019) it was found that the term “Green IT” was used for the first time in 2007, thus justifying the initial date for the selection of the bibliography on that topic. It should be noted that Jenkin et al. (2011) developed a research focused on management literature, environmental psychology and social marketing, that is, they used environmental research on individuals and organizations.

Malhotra et al. (2013) focused their research on studies that present solutions to mitigate climate change, excluding those that only conceptualize and analyze the theme of Green IT. Finally, Asadi et al. (2017) analyzed 131 articles in order to have a better understanding of the field of Green IT, presenting a roadmap to guide future studies and highlight the practices for implementing Green IT.

It should be noted that the authors mentioned above carried out their bibliographic review focusing on the portals of specific journals and conferences. Regarding the methodology adopted in this study, and that is different from previous studies, it is that the literature search was carried out in databases, in order to expand the research to interdisciplinary areas, considering that, according to Webster & Watson (2002), the IT area is an interdisciplinary field that fits into other disciplines. Another difference, in this research, is that the largest number of articles comes from journals and not from conferences.

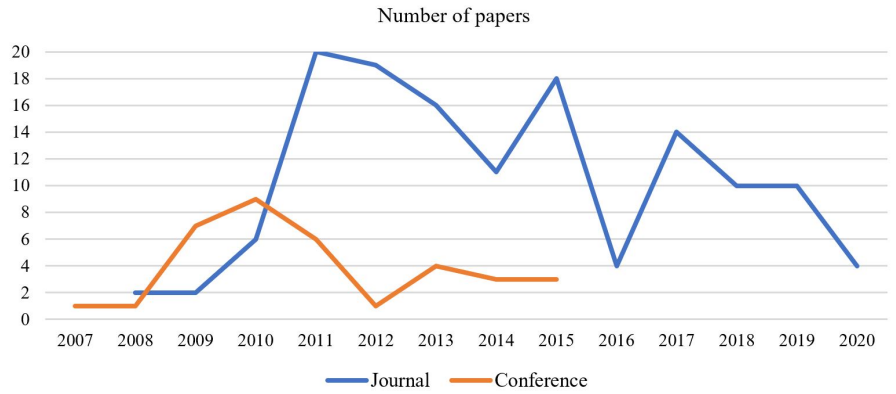
The following databases were used: ABI/INFORM Global, AIS Electronic Library, JSTOR Archival Journals, Science Direct, Scopus and Wiley Online Library. Search was carried out between June 18 and 22, 2020, using as keywords: “Green IT”, “Green IS”, “Green Computer”, “Green ICT”, “Green Information Technology” and “Green Computing”. The terms were typed using double quotation marks, so that the search

results presented only articles within the desired semantic context. Regarding the study areas, the filters used were: information technology management, computer science, business administration, management, sustainability, sustainable development and the environment.

However, the authors Webster & Watson (2002) suggest consulting articles published in annals of scientific events, in view of their contemporaneity, considered relevant in the referred area of knowledge, which is characterized by the fast pace of technological innovation. Therefore, articles published in conferences that are supported by the Information Systems Association (AIS) were selected. Thus, the procedures of the following conferences were reviewed: Hawaii International Conference on System Sciences (HICSS), Australian Conference on Information Systems (ACIS), International Conference on Information Systems (ICIS), American Conference on Information Systems (AMCIS), Pacific Asia Conference on Information Systems (PACIS) and European Conference on Information Systems (ECIS).

Regarding the practical criteria for bibliography selection, also called by Fink (2019) as inclusion and exclusion criteria, was considered: the year of publication, only scientific articles in the English language, and the approach on sustainability and information technology in organizational environment. The articles were selected by reading their titles, abstracts, keywords and objectives, in order to identify whether they met the criteria mentioned above. This process was carried out until the bibliographies started to be repeated, configuring the saturation principle presented by Eisenhardt (1989). Theoretical saturation is the point at which incremental learning is minimal, or, in the case of this study, when articles from search filters began to repeat themselves, bringing no new knowledge.

As a result of this research strategy, 171 articles were selected, which provide an overview or focused on a particular aspect of Green IT, which were considered for further analysis. The categorization regarding the means of disseminating the articles and their temporal aspect, can be seen in Graph 1. It should be noted that the Graph 1 shows to the reader that this study used more articles published in journals than conference, without intention to make a comparative research. EndNote X8 was used as a reference management tool, in order to avoid duplication in studies. It is noteworthy that this study did not intend to exhaust the review of the literature on Green IT, nor to address the whole theme, but to collect enough information to adequately answer the research problem and verify the originality of the theme.



Graph 1. Time view of studies related to Green IT from 2007 to 2020. Source: Research data.

The next step concerns the application of the methodological selection criteria, which, according to Fink (2019), consists of identifying the studies with the best quality. For this purpose, the citations tracking technique described by Webster & Watson (2002) was used, since this is an indicator of the impact and quality of studies. It is noteworthy that for this stage of the process, the Google Scholar search engine was used, with the articles most cited in journals shown in Table 1, below. It should be noted that the number of citations was verified on June 23, 2020.

Table 1. Most cited journal papers.

Title	Year	N^0 of citations (Google Scholar)
Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing	2012	1650
Information systems innovation for environmental sustainability	2010	1149
From green to sustainability: Information Technology and an integrated sustainability framework	2011	584
An agenda for Green information technology and systems research	2011	434
Information systems and ecological sustainability	2008	407
Greenwash and Green Trust: The Mediation Effects of Green Consumer Confusion and Green Perceived Risk	2012	403
Environment-conscious scheduling of HPC applications on distributed Cloud-oriented data centers	2011	369
Integrative framework for assessing firms' potential to undertake Green IT initiatives via virtualization – A theoretical perspective	2011	354
Senior Managers' Perception on Green Information Systems (Is) Adoption and Environmental Performance: Results from a field survey	2013	332
Compliance with institutional imperatives on environmental sustainability: Building theory on the role of Green IS	2011	272
Theory of reasoned action application for Green Information Technology acceptance	2014	251
The GREENSOFT Model: A reference model for green and sustainable software and its engineering	2011	245
The implications of new information and communication technologies for sustainability	2008	239
Spurring Impactful Research On Information Systems For Environmental Sustainability	2013	235
Motivating Energy-Efficient Behavior with Green Is: An Investigation of Goal Setting and the Role of Defaults	2013	219
Origins of green innovations: the differences between proactive and reactive green innovations	2012	168
IT for green and Green IT: A proposed typology of eco-innovation	2011	148

Table 1. Continued...

Title	Year	N⁰ of citations (Google Scholar)
Energy efficiency and low carbon enabler Green IT framework for data centers considering green metrics	2012	147
A Survey of Green Information-Centric Networking: Research Issues and Challenges	2015	142
An Institutional Perspective on the Adoption of Green IS & IT	2011	138
Organizational Green Motivations for Information Technology: Empirical Study	2012	122
Exploring the role of IT for environmental sustainability in China: An empirical analysis	2013	107
The greening of organizational IT: what makes a difference?	2010	98
Green IT Readiness: A Framework and Preliminary Proof of Concept	2010	95
Intended Belief and actual Behavior in Green Computing in Hong Kong	2009	97
Awareness of Green IT and its value model	2012	93
An International Comparison of Green IT Diffusion	2009	87
Green IT: A Matter of Business and Information Systems Engineering?	2011	82
Information Technology-Enabled Innovativeness and Green Capabilities	2010	75
Sector diversity in Green Information Technology practices: Technology Acceptance Model perspective	2015	73
Building environmentally sustainable information services: A green is research agenda	2011	69
Green information, green certification and consumer perceptions of remanufctured automobile parts	2018	46
Assessing the impact of intrinsic and extrinsic motivators on smart Green IT device use: Reference group perspectives	2015	44
Organizational research in the field of Green IT: A systematic literature review from 2007 to 2016	2017	39
Modelling upper echelons' behavioural drivers of Green IT/IS adoption using an integrated Interpretive Structural Modelling – Analytic Network Process approach	2017	35
Environmental regulations, staff quality, green technology, R&D efficiency, and profit in manufacturing	2018	35
A competitive multiperiod supply chain network model with freight carriers and green technology investment option	2018	33

Source: Research data.

For the initial analysis, only the articles most cited by Google Scholar were considered, reaching a result of 37 articles in journals. Then, the same procedure was carried out for conference articles, obtaining a total of 13 papers published in annals of scientific events, as shown in Table 2. However, during the initial analysis process, it was found that four papers most cited in conferences had been previously selected, as

they were among the most cited articles published in journals, so the number of articles in conferences in the final analysis was 9 articles.

Table 2. Most cited conference papers.

Title	Year	Conference	Nº of citations (Google Scholar)
GITAM: A Model for the Adoption of Green IT	2008	ACIS	144
Green Information Systems: Directives for the Is Discipline	2013	CAIS	131
Environmentally Sustainable ICT: A Critical Topic for IS Research?	2007	PACIS	124
Green IT Adoption: A Motivational Perspective	2011	PACIS	106
Green Information Technology, Energy Efficiency, and Pro ts: Evidence from an Emerging Economy	2010	CAIS	95
Managerial Attitudes Towards Green IT: An Explorative Study of Policy Driver	2009	PACIS	82
Unearthing the Value of Green IT	2010	ICIS	79
Unpacking Green IT: A Review of the Existing Literature	2010	AMCIS	76
Predictors of Green IT Adoption: Implications from an Empirical Investigation	2010	ACIS	74

Source: Research data.

However, it was observed that 44 of the selected articles were published in scientific journals in the last five years, so it is not expected that in the short term they will be able to reach a high number of citations. In order to consider them in the research, aiming to keep the data more updated as possible, the selection criteria was the new methodology for evaluating journals of the Coordination for the Improvement of Higher Education Personnel (CAPES) through Legal document nº 6/2019-CGAP/DAV/CAPES. Through this document, it was verified that the objective of the CAPES Evaluation Board is to seek more objective criteria that allow greater comparability between areas of evaluation.

The new Qualis Periodicals establishes a unified classification between the areas, divided into A1, A2, A3, A4, B1, B2, B3, B4 and is based on four criteria: (i) Each journal will receive only one classification, even if it has been informed by programs linked to more than one assessment area; (ii) The classification will be given by a single area, which refers to that where there is the largest number of publications in the evaluative reference years; (iii) Qualis' new methodology proposes a reference classification, which is given through the combined use of bibliometric indicators and a mathematical model; (iv) Bibliometric indicators are those that consider the number of citations of the journal within three bases: Scopus (CiteScore), Web of Science (Impact Factor) and Google Scholar (index h5). It is considered the category of area that each base assigns the journal and its relative position within it.

Thus, in order to maintain the quality of the selected articles, it was defined that the cutoff factor should be journals with strata in the new Qualis greater than A2. In this sense, 13 more studies were included in the final scope of the research, that can be seen in Table 3. Therefore, the final analysis was performed reviewing 59 papers.

Table 3. Papers published in journals with strata greater than A2.

Title	Year	Journal	Qualis	Number of citations Google Scholar)
Extending the TAM for Green IT: A normative perspective	2018	Computers in Human Behavior	A1	31
An empirical exploration of the role of strategic and responsive corporate social responsibility in the adoption of different Green IT strategies	2016	Journal of Cleaner Production	A1	27
Impacts of software and its engineering on the carbon footprint of ICT	2015	Environmental Impact Assessment	A1	24
Green IT in practice: virtual meetings in Swedish public agencies	2016	Journal of Cleaner Production	A1	20
Energy-Saving Transmission for Green Macrocell–Small Cell Systems: A System-Level Perspective	2017	IEEE	A1	18
Green information technologies practices and financial performance – The empirical evidence from German publicly traded companies	2018	Journal of Cleaner Production	A1	16
Sustainable production: Using simulation modeling to identify the benefits of green information systems	2017	Decision Support Systems	A1	14
A Green Information Technology governance model for large Mauritian companies	2018	Journal of Cleaner Production	A1	10
Toward green computing practices: A Malaysian study of green belief and attitude among Information Technology professionals	2019	Journal of Cleaner Production	A1	7
Green IT Governance and Management based on ISO/IEC 15504	2019	Computer Standards & Interfaces	A1	5
Students' green information technology behavior: Beliefs and personality traits	2020	Journal of Cleaner Production	A1	5
Green IT and sustainable technology development: Bibliometric overview	2019	Sustainable Development	A2	3
Efficiently managing green information and communication technologies, high-technology exports, and research and development expenditures: A case study	2019	Journal of Cleaner Production	A1	2

Source: Research data.

After the bibliometric review, the content analysis of the selected articles was carried out, which, according to Bardin (2016), refers to a set of analysis techniques that use systematic procedures that aim to evidence valid inferences, derived from the text, classifying words, phrases, or even paragraphs in content categories, in order to identify what is being discussed and the main concepts used by the authors.

In this sense, it was identified in each article: country of origin, objective of the study, type of methodological approach, theory employed, concept of Green IT, dimension of the most explored Green IT, method of data collection and analysis, sector analyzed and quantity references, understanding that these aspects represent the structure of the specific topic. The data analysis is presented next using the described methodological procedures.

3 Analysis of articles

Initially, it was verified that the United States and Australia have the largest number of publications, with a total of 11 and 10 articles respectively, followed by China and Germany, which have 5 and 4 articles, respectively. Next, with three works, are Malaysia, Taiwan and Spain. With 2 articles are France, Turkey, Canada and South Korea. With one selected article, Austria, Hong Kong, India, Ireland, Saudi Arabia, Iran, Switzerland emerge. It was observed that five studies were performed, based on data collection in different countries: Australia and the United States with two studies together; United Kingdom, Malaysia and Australia; Switzerland and Germany; Australia, New Zealand and the United States. Thus, it can be inferred that most studies were conducted in developed countries, that is, countries where technology is more widespread (Lee et al., 2013).

It was found that the literature about Green IT, predominantly, consists of surveys and theoretical models that configure 24 and 22 articles of the sample respectively. The final scope of the analysis also comprises 4 case studies, 4 literature reviews and 4 model simulations focused on data center energy efficiency (Uddin & Rahman, 2012; Fang et al., 2015; Chung, 2017; Kurkalova & Carter , 2017), to estimate profits from energy savings and reduction of greenhouse gas emissions and, a simulation of a multiperiod supply chain model that maximizes the net present value of investments in Green IT (Saberi et al., 2018). In addition, 39 of the studies report data at the organizational level, 13 concern the character of the individual using motivational, behavioral and socio-psychological theories, and 7 studies consider the level of analysis of the individual and organization together. Table 4 presents these data.

Table 4. Level of analysis of the papers.

Type of approach	Number of papers	Analysis level		
		Organizational and Individual	Organizational	Individual
Theoric model	23	4	17	2
Survey	24	2	13	9
Model simulation	5	1	4	
Review article	4		3	1
Case study	3		2	1

Source: Research data.

Regarding the data collection methodologies used in the surveys, it was found that most authors opted for the questionnaire with a Likert scale of five or seven points. Most of the data were analyzed using descriptive statistics (Arnfalk et al., 2016), multivariate analyzes (Benitez-Amado et al., 2010; Cai et al., 2013; Chen et al., 2011; Chow & Chen, 2009; Koo et al., 2015), cluster analysis (Bohas & Poussing, 2016), exploratory factor analysis (Molla & Abareshi, 2012), maximum likelihood estimators (Chen & Chang, 2013; Molla & Abareshi , 2011), correlations (Song et al., 2018), partial least squares (Dalvi-Esfahani et al., 2020), modeling of structural equations (Chen et al., 2012; Mishra et al., 2014; Wang, 2008; Ojo et al., 2019) and principal component analysis and confirmatory factor analysis (Hardin-Ramanan et al., 2018).

Theoretical models were elaborated using secondary data from the literature review, and the content analysis was performed, through the crossing of citations (Fuchs, 2008), description of concepts (Elliot, 2007; Molla, 2008; Chowdhury, 2012; Brocke et al., 2013; Chen et al., 2008; Chou & Chou, 2012; Dao et al., 2011; Kern et al., 2015; Loos et al., 2011), mathematical models (Beloglazov et al., 2012; Garg et al., 2011; Patón-Romero et al., 2018), integrative model (Corbett, 2010; Bose & Luo, 2011; Faucheux & Nicolaï, 2011; Fang et al., 2015), development of a reference model (Naumann et al., 2011; Yoon, 2018), bibliographic research (Jenkin et al., 2011; Brocke et al., 2013), Interpretive Structural Modeling (Dalvi-Esfahani et al., 2017) and cross-sectional analysis (Melville, 2010). It should be noted that theoretical models, as well as model simulations, use only data derived from the review of the literature, without validation through empirical tests, nor relation with a specific economic sector. Chart 1 presents more details about theoretical models presented in the 20 selected articles.

Chart 1. Theoretical models of the selected papers.

Paper	Authors	Theoric model
Energy-aware resource allocation heuristics for efficient management of data centers for Cloud computing	Beloglazov et al. (2012)	Architectural structure and principles for energy efficient cloud computing.
Information systems innovation for environmental sustainability	Melville (2010)	Demonstrates the role of IT forming beliefs about the environment.
From green to sustainability: Information Technology and an integrated sustainability framework	Dao et al. (2011)	Integration of human resources, supply chain and IT to enable companies to develop sustainability.
An agenda for Green information technology and systems research	Jenkin et al. (2011)	Multilevel research structure to guide future research.
Environment-conscious scheduling of HPC applications on distributed Cloud-oriented data centers	Garg et al. (2011)	Scheduling policies that explore heterogeneity in data centers, considering energy efficiency.
Information systems and ecological sustainability	Chen et al. (2008)	How IT can be leveraged to achieve the three milestones of ecological sustainability.
Integrative framework for assessing firms' potential to undertake Green IT initiatives via virtualization	Bose & Luo (2011)	Factors that contribute to assessing a company's readiness to go green through virtualization.

Chart 1. Continued...

Paper	Authors	Theoric model
The implications of new information and communication technologies for sustainability	Fuchs (2008)	Relationship of new technologies and sustainable development.
The GREENSOFT Model: A reference model for green and sustainable software and its engineering	Naumann et al. (2011)	Product life cycle model, for software design and development in a sustainable way.
IT for green and Green IT: A proposed typology of eco-innovation	Faucheux & Nicolaï (2011)	iDiscusses the growing use of Green IT and its applications.
Green IT_A Matter of Business and Information Systems Engineering?	Loos et al. (2011)	Impact of Green IT on information systems.
Building environmentally sustainable information services: A green is research agenda	Chowdhury (2012)	Shows that information systems and services generate massive emissions of greenhouse gases.
Awareness of Green IT and its value model	Chou & Chou (2012)	Identifies components that influence how organizations assess the value of Green IT.
A Survey of Green Information-Centric Networking: Research Issues and Challenges	Fang et al. (2015)	Proposals for information-centered network architectures (ICN) in order to improve energy efficiency.
Modelling upper echelons' behavioural drivers of Green IT/IS adoption using an integrated Interpretive Structural Modelling	Dalvi-Esfahani et al. (2017)	Identifies the psychological factors that motivate managers to adopt Green IT.
Impacts of software and its engineering on the carbon footprint of ICT	Kern et al. (2015)	Calculation method to quantify the carbon footprint of a software product over its life cycle.
Environmentally Sustainable ICT: A Critical Topic for IS Research?	Elliot (2007)	Defines the problems and scope of the ICT's environmental sustainability.
GITAM: A Model for the Adoption of Green IT	Molla (2008)	Defines the Green IT from four different but interrelated perspectives.
Green Information Systems: Directives for the Is Disciplin	Brocke et al. (2013)	Discuss future Green IT guidelines.
Unearthing the Value of Green IT	Corbett (2010)	Provide insights that justify and the choice of organizations by Green IT and how they value these investments.
Extending the TAM for Green IT: A normative perspective	Yoon (2018)	Proposes a technology acceptance model for Green IT.
Green IT Governance and Management based on ISO/IEC 15504	Patón-Romero et al. (2018)	Proposes a maturity model to help organizations implement governance and management of Green IT.

Source: Research data.

Among the sectors investigated by survey and case study research, most mentioned are the information technology (Butler, 2011), electrical (Fang et al., 2015; Loock et al., 2013), automobile (Wang et al., 2018), higher education (Cai et al., 2013;

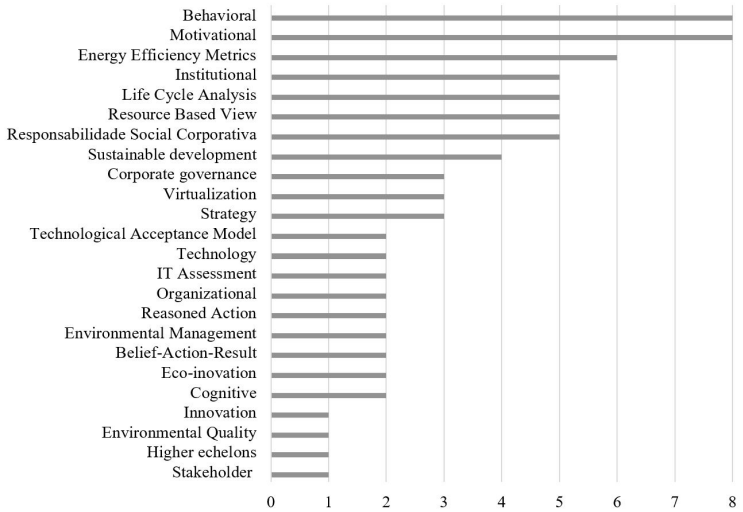
Chow & Chen, 2009; Chowdhury, 2012; Dalvi-Esfahani et al., 2020), manufacturing (Molla et al., 2009; Song et al., 2018), service provision (Gholami et al., 2013) and public companies (Akman & Mishra, 2015; Arnfalk et al., 2016; Mishra et al., 2014; Ojo et al., 2019). Only three papers analyzed sector data together: Benitez-Amado et al. (2010), that investigated companies in the wholesale, retail, construction, communication, chemical, mining, food, beverage and tobacco sectors; Chen et al. (2011), that focused on the manufacturing and service sectors; and Hardin-Ramanan et al. (2018) studied the financial, tourism, technology and textile sectors.

Research that addresses the level of individual analysis, deals with cognition (Jenkin et al., 2011), behaviors (Chow & Chen, 2009; Malhotra et al., 2013; Gholami et al., 2013; Akman & Mishra, 2015; Dalvi-Esfahani et al., 2020), motivational factors (Cai et al., 2013; Sarkar & Young, 2009) attitudes (Loock et al., 2013; Yoon, 2018; Ojo et al., 2019) and perception (Wang et al., 2018) in relation to the adoption of Green IT. It is noteworthy that the research performed by Chen & Chang (2013) analyzed consumer behavior in relation to the purchase of electronic products, concluding that companies that try to introduce environmental aspects into their products if they are not substantiated, lose consumer confidence.

In the aspects that relate with the organizational level, the theoretical models pointed out the collective cognitive changes, that may foster the integration of human resources, supply chain (Garg et al., 2011) and IT (Fang et al., 2015), in order to allow companies to develop their capacity for environmental sustainability (Bose & Luo, 2011) and maturity in relation to the management of Green IT (Patón-Romero et al., 2018) based on the reduction of gas emissions greenhouse effect (Kern et al., 2015) and energy efficiency (Beloglazov et al., 2012) throughout the life cycle of their products, from creating content to distributing, accessing, using and posting (Chowdhury, 2012).

In the same way of the individual level, it is possible to find surveys that address the motivational factors for adopting Green IT practices, also through organizational analysis. Among the most cited factors, stand out competitive and legal pressures (Kuo & Dick, 2010; Wang et al., 2018), institutional pressures (Chen et al., 2011), cost reduction (Koo et al., 2015) and the corporate social responsibility approach at the company's strategic level (Bohas & Poussing, 2016; Molla et al., 2009), noting that only the environmental benefits do not generate sufficient motivations for the implementation of Green IT (Molla & Abareshi, 2011). Thus, the referred research investigates the economic benefits arising from the implementation of Green IT (Chung, 2017; Mithas et al., 2010), as a way to motivate its adoption by companies.

Due to its multifaceted nature, several theories have been applied to understand the phenomena of Green IT. As shown in Graph 2, motivational and behavioral theories were the most widely used as conceptual bases. This result is due to the fact that 13 of the selected articles sought to understand the factors that influence the adoption of Green IT, and that, on the other hand, cause changes in organizational processes, stimulating cognitive and behavioral changes.



Graph 2. Theories most used in Green IT studies. Source: Research data.

In line with this research approach, we found the Grounded Action Theory, used by Mishra et al. (2014) to investigate the relationship between attitude and behavior based on the principles of compatibility and behavioral intention, seeking to predict individual actions according to certain criteria. The psychological factors, which influence the decision-making process of managers regarding the adoption of Green IT, are addressed by Dalvi-Esfahani et al. (2017) through the Theory of Higher Levels, which describes that strategic choices are based on the perceptions, values and knowledge of individuals in management positions. In turn, the authors Gholami et al. (2013) employ the theoretical Belief-Action-Result model, in order to assess how management beliefs and commitments lead to organizational action, which allows companies to develop sustainability capabilities based on Green IT.

Still with regard to aspects that touch the employee's level of awareness, Akman & Mishra (2015) used the Technology Acceptance Model to investigate the behavior of individuals regarding the use of IT, in order to evaluate potential of the reduction of environmental impacts, and Yoon (2018) proposes a technology acceptance model for Green IT, adding normative variables. In the perspective of cognitive changes, the authors Jenkin et al. (2011) used the Cognitive Theory to elucidate that, although a particular Green IT practice can be successfully designed, developed and implemented, to achieve the Green IT strategy the organization depends on the behavior of employees. In other words, success is determined by how Green IT is used in organizational processes.

From the point of view of the individual level, the most used theory was the behavioral one, used to clarify an individual's decision-making process. In this approach, Chow & Chen (2009) investigated the beliefs and behavior of IT users in relation to green computing. In addition, Mishra et al. (2014), conducted a survey among IT professionals from the public and private sectors, in order to understand their intentions in relation to the various Green IT practices. In turn, Dalvi-Esfahani et al. (2020) investigated the behavioral intention regarding the practice of Green IT in students. The results showed that the behavioral intention positively influences the real behavior, that is, the behavioral conceptions can explain, in great part, the enormous variation in the professionals' intentions regarding the adoption of the Green IT initiatives.

At the organizational level, to elucidate the collective cognitive changes that occur as the organization develops capacities in the use of IT aimed at environmental sustainability, the authors used institutional theory more frequently. Based on this theoretical model, Chen et al. (2011) clarify how institutional pressures affect the adoption of Green IT in organizations. Przychodzen et al. (2018) investigated the effect of implementing Green IT on various aspects of creating shareholder value and financial performance. In addition, Butler (2011) uses institutional theory to explain how the regulatory, normative, cultural and cognitive factors external to the institutional environment and the organizational field influence the decisions of IT manufacturers in the development and manufacture of environmentally sustainable products.

One of the IT business areas where environmental sustainability is becoming imperative is data centers. The growing demand for storage, networking and computing has driven the intensification of large data centers that run many of the Internet, financial, commercial and business applications (Garg et al., 2011). In this thematic chain, Beloglazov et al. (2012) propose algorithms for provisioning and allocating resources for efficient energy management in cloud computing environments. The results demonstrate that the cloud computing model has immense potential, as it offers significant cost savings and demonstrates high potential to improve energy efficiency in dynamic workload scenarios.

For Harmon & Auseklis (2009), datacenters are the driving force in the Green IT movement. Wang (2008) point out that although advances in processors have, in many cases, allowed for higher performance with less power consumption per processor, energy consumption per server continues to grow. Considering that the amount of information generated by a given organization gradually increases, requiring more storage space, there is a tendency to increase the number of servers installed, requiring a greater amount of physical space. Thus, with the increase in heat dissipation, there is a greater need for the reduction of the energy costs.

Among the Green IT practices available to improve energy efficiency, stand out the adoption of a green data center, by using airflow to reduce costs such as air conditioning, installing energy management software or adopting a sustainable infrastructure. Generally, companies achieve the best results when integrating energy and cooling changes with advanced technologies, such as energy efficient virtualization, hardware and software, as well as energy and workload management initiatives. It should be noted that there is no single way to structure a green datacenter, however, IT managers must carry out a systematic check-up in order to point out areas of higher energy consumption and perform an assessment of existing best practices, which allows the establishment of a plan of action on data center usage conditions (IBM Global Service, 2020).

Unhelkar (2011) points out that managers need to improve the energy efficiency of the organization through innovative management strategies, and these strategies need to combine operational costs with the carbon emissions spent by data centers. In order to monitor this Green IT practice, the author recommends the use of indicators, created specifically to assess the organization's carbon footprint as well as the financial impact, the latter considered the most relevant factor for adopting Green IT practices. In terms of IT infrastructure, the author mentions the use of data storage virtually, in order to reduce energy consumption.

Through virtualization, companies can reduce the number of physical servers by running multiple virtual machines on a single or few physical servers, reducing the number of equipment. The benefits are measured, not only in the reduction of energy consumption, but also in the reduction of depreciation and maintenance expenses.

Virtualization can also be used on clients' computers, so that the user works in a virtual environment that can be easily implemented and restored, in case of technical problems (Unhelkar, 2011).

Datacenters can provide highly flexible and responsive architectures, both hardware and software, whose customers share and demand as needed, via the internet. These structures are called cloud computing and, when using these services, companies do not need to build their own server facilities. Consequently, costs are reduced and CO_2 emissions decrease, due to a single structure shared by several companies instead of a structure for each company (Baroudi et al., 2009).

In terms of IT infrastructure, considering the workstations of each employee, companies have used client structures lean that are nothing more than structures consisting only of keyboard, mouse, monitor and a device that communicates with the main server that, in turn, is responsible for processing and storing the data. It is important to highlight that in this system, energy consumption is much lower when compared to conventional solutions. Another important characteristic is that due to fewer components it may be treated at the end of its life cycle, so generating less electronic waste (Bose & Luo, 2011).

Another practice of Green IT refers to the recycling and disposal of the equipment, when old electronic devices can be reused by other organizations. In addition to the increased use, the final disposal of these materials should be considered, such as: printer cartridges, cell phones and batteries, which can be easily recycled; but recycling should only be carried out when it is no longer possible to reuse the equipment (Fairweather, 2011).

Dick & Burns (2011) point out that saving on paper consumption is one of the most widespread Green IT practices among organizations. The computerization of some processes, through the electronic management of documents and Business Intelligence (BI) systems are fundamental for the reduction of paper consumption and, also, printing programs consolidating and reducing the amount of equipment. When printing is unavoidable, you can still reduce waste by setting your printers to print on both sides of the paper.

It is worth highlighting the conceptual model developed by Naumann et al. (2011), which aims to assist in the creation, maintenance and use of software in a more sustainable way. The model presents a product life cycle, which assesses the ecological, social, human and economic compatibility of a product throughout the life cycle. The findings obtained from these evaluations can be used to optimize the product or to compare a product with that of competitors.

In addition, Chowdhury (2012) points out the need to develop software to assess greenhouse gas emissions, taking into account the entire product life cycle. Therefore, information systems can favor the development of innovative environmental strategies, since they contribute to the improvement of sustainable processes and practices, which reduce potential environmental impacts in addition to improving economic performance (Melville, 2010). Thus, Faucheux & Nicolaï (2011) propose a typology of eco innovation aimed at reconciling IT development and green growth, explicitly addressing four types of changes for sustainable development: technological, social, institutional and organizational innovation.

The conceptual bases for sustainable development also emerge among the articles analyzed. This theory was used by Elliot (2007) in order to introduce the concept of Green IT in the academic field, to increase awareness and understanding of the role of information technologies in sustainable development. On the other hand, there is another theoretical approach presented by Fuchs (2008), who considers that science and technology, due to their unsustainable social design, contributed to environmental degradation, as they were

transformed into destructive forces by social forces. This perspective suggests that, in order to achieve a sustainable information society, organizations need to give up profit, investing in the future of human beings, society and nature.

Another theory that stands out is the Resource-Based View, which proposes that internal resources are the main sources of competitive advantage for the organization, as they include tangible and intangible attributes that enable the implementation of long-term strategies (Wernerfelt, 1984). The studies in this review have been carried out to describe how IT contributes to the creation of value and competitive differential (Corbett, 2010). For example, Dao et al. (2011) developed a sustainability framework, which illustrates the integration of human resources, supply chain and IT, enabling companies to develop competitive advantage capabilities based on sustainability. Using a simulation modeling approach, Kurkalova & Carter (2017) estimate the quantitative benefits of green technology, expressed in dollars saved and reductions in greenhouse gas emissions.

In summary, based on the analyzed articles, it can be inferred that most of the literature on Green IT is based on analyzes at the organizational level. The surveys and theoretical frameworks that consider the environmental dimension of the Green IT stand out. Due to the duality in the use of information technologies, on the one hand, each stage of the ICT life cycle has the potential to contribute to environmental damage, on the other, they can provide tools to measure and report greenhouse gas emissions, analyze energy efficiency and quantifying the use of water in production processes, among other applications, Table 5, provides more information on how the dimensions of Green IT were addressed in previous research. It is noteworthy that few papers consider more than one theory to analyze a particular characteristic of Green IT.

Table 5. Studies carried out in the different dimensions of the Green IT.

Green IT Dimension	Number of papers	Theories used
Environmental	18	Energy efficiency; Resource-based view; Sustainable development; Corporate governance; Institutional; Technology; Virtualization; Innovation; Life cycle; Strategy; Environmental management; Socio-psychological; Grounded action theory; Belief-action-result.
Environmental, social and economic	14	Comportamental; Motivação; Responsabilidade social; Governança corporativa; Estratégia; Sustentabilidade; Modelo de aceitação de tecnologia; Upper echelon; Ação Racional.
Environmental and economic	15	Belief-Action-Result; Life cycle; Behavioral; Eco-innovation; Motivational; Energy efficiency; Social responsability; Resource-based view.
Economic	4	Stakeholder; IT valuation; IT benefits; Resource-based view.
Environmental and social	6	Behavioral; Cognitive; Institutional; Resource-based view; Green innovation; Environmental management; Technology acceptance model.
Social	2	Behavioral; Motivational.

Source: Research data.

It was found that only thirteen empirical studies addressed the three dimensions of the Green IT, two of which are multiple case studies. In the other studies, investigations were found related to the organizational motivations of sustainability (Molla & Abareshi, 2011), the role of corporate social responsibility (Bohas & Poussing, 2016) of IT governance (Hardin-Ramanan et al., 2018) and environmental regulations (Song, Wang and Sun, 2018) in the adoption of Green IT. Behavioral factors (Mishra et al., 2014; Akman & Mishra, 2015; Dalvi-Esfahani et al., 2020), linked to the cognitive aspects that provide a preliminary view on the diffusion status and maturity of the Green IT (Molla et al., 2009; Wang et al., 2018) also stand out among field studies.

4 Future research

It was found that most studies have been carried out in developed countries and suggest that the growing business opportunities with the use of IT have brought with it increased pressure to become IT environmentally friendly. However, Hanne (2011) points out that this field of research is of great interest to developing countries, as it offers new business opportunities with economic, social and environmental benefits. Thus, it is essential to expand research on Green IT in these regions, where imminent industrialization increases global environmental costs.

It should be noted that the need for greater energy efficiency and, consequently, savings in tangible costs in IT operations, are the main factors for the adoption of Green IT. In this sense, a potential research area concerns the collection of more accurate data on consumption, standardizing the data collection process; development of broader and more detailed guidelines for reducing energy consumption, and validation and quantitative characterization of the effect of these guidelines. In addition, the bibliometrics carried out suggests for the development of a cost model that highlights the relationship between the Green IT initiatives and the possible cost savings in the short and long term, in relation to energy consumption, carbon printing and the waste of IT resources.

Still in terms of motivation, it was found that the long-term continued economic value influences the engagement of Green IT practices at the organizational level. In this perspective, the organizational context of Green IT should be better investigated, since actors from different sectors are involved. An ideal reference model that defines processes, tasks, functions and responsibilities within the scope of Green IT for the entire company seems useful. In addition, future research needs to examine the dynamics of environmental guidance at the group level, since the selection and implementation of technologies and systems generally fall within the domain of the IT department; power supply, cooling, general energy cost management and corporate sustainability initiatives generally fall within the domain of Facility Management.

Although the domains of IT departments and facilities are interdependent, the organization's structure generally does not reflect this interdependence, resulting in misalignment of organizational goals and, in particular, goals based on sustainability. While it is important that the organizational structure (for example, reporting, decision-making rights, incentives) changes to align the IT and Facilities goals with the organization's environmental sustainability goals, it is also crucial that each group's cognitions are changed, in order to shape and implement new environmental sustainability practices.

In addition, empirical research is needed to understand how to increase individuals' environmental awareness, as well as a sense of responsibility towards the

environment, change their attitude towards Green IT and promote the moral obligation to practice Green IT initiatives. In addition, cultural, social, geographical and economic factors deserve a more detailed analysis in terms of their impact on organizational and personal perspectives in the practice of managing Green IT.

Although several studies have been carried out, in terms of energy conservation (Chung, 2017; Fang et al., 2015; Uddin & Rahman, 2012) and cost reduction (Jongsaguan & Ghoneim, 2017; Kurkalova & Carter, 2017) arising from implementation of Green IT practices, they are restricted to theoretical models. Therefore, based on the results of this study, it was found that empirical research that measures the cost reduction resulting from green IT initiatives, the operational performance or the market value of companies, are scarce in the current literature. In this sense, these topics serve as a guide for exploratory research, which can be characterized by case studies, single and multiple, as well as field research.

It should be noted that Bose & Luo (2011) recognize that it is difficult to obtain this type of information through field research, due to the difficulty in conducting data collection with companies. Thus, it is suggested that universities and public bodies work together in order to mobilize companies to make their information available, in a confidential manner, for the production of new knowledge. Government involvement can also provide further studies at the level of society, as investigations into the social benefits of implementing Green IT are rare.

In addition, it would be relevant in future research to create performance indicators for each dimension of the Green IT in order to assist in the management process. These indicators would facilitate the development of research that analyzes the company after the implementation of Green IT practices, since this is a topic little explored in the literature and would require a longitudinal study. Another challenge, in terms of measurement, concerns how to quantify the environmental impacts of information technology. In addition, there was a lack of awareness of the impacts of IT on the environmental footprints of organizations, as research that focused on the environmental dimension of Green IT analyzed a particular impact.

Another possibility for future research is related to the alignment of Green IT with technologies within the scope of industry 4.0. The technologies underlying this process are many and are at different stages of maturation. More than one or another technological development, the disruptive character that Industry 4.0 brings is, above all, the result of the articulation and convergence of technologies such as Cyber-Physical Systems (CPS), Internet of Things (IoT), Additive Manufacturing (3D printing), Big Data, Cloud Computing, Advanced Robotics, Artificial Intelligence (AI), virtual and augmented reality, to promote sustainability.

Finally, it is emphasized that the generic nature of Green IT initiatives is a consequence of the conceptual stage of current technologies and management practices: academics and professionals try to visualize processes, products and services enabled for information systems that will shape the future. However, so far, few examples of implementation and best practices can be found in this field.

5 Final considerations

This paper provided a bibliometric review about Green IT, in order to identify the state of the art in the literature on that subject. Following a research protocol, 171 articles published between 2007 and 2020 were selected. After applying the practical criteria for article selection, 59 articles remained for final analysis, and the remaining

articles were not included in this review because they did not match the inclusion criteria: language, citation number and impact factor of the journal.

With regard to the methodological implications, the article aims to identify the magazines and conferences that give more space to the theme of Green IT, in addition to presenting the countries where the theme is most studied and the most used methodological paths. In addition, it is believed that research may be considered valuable for researchers and professionals, due to the insertion of the Green IT in the environmental management debate, turning possible to visualize better the central role of IT in corporate environmental initiatives and, in general, how IT can be introduced into corporate social responsibility programs. In addition, this bibliometric study brings an initial contribution to the discussion of the subject and the suggestions of future works, indicating possible research questions to be worked on in the field.

Although this research has achieved the proposed objectives and the methodological rigor has been pursued, the existence of limitations cannot be exempted. The first one concerns the authors' interpretation bias during the analysis process. The limitation of operational process is also noteworthy, because, when searching for articles in specific research portals, the proposed results are relevant to the databases consulted. It should be noted that, when using the number of citations as criteria for selecting articles for analysis, further studies will not find the same results as the ranking presented in this theoretical investigation.

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