Universitat Oberta de Catalunya

uoc.edu

Evolution and current state of the art of Green IT, a literature review

Jose Pertierra das Neves
Máster Universitario en Ingeniería Computacional y Matemática
Computación de Altas Prestaciones

Belen Bermejo Gonzalez
Joseph Jorba Esteve

Junio 2022

Licencias alternativas (elegir alguna de las siguientes y sustituir la de la página anterior)

A) Creative Commons:

Esta obra está sujeta a una licencia de Reconocimiento-NoComercial-SinObraDerivada 3.0 España de Creative Commons

Esta obra está sujeta a una licencia de Reconocimiento-NoComercial-CompartirIgual 3.0 España de Creative Commons

Esta obra está sujeta a una licencia de Reconocimiento-NoComercial 3.0 España de Creative Commons

Esta obra está sujeta a una licencia de Reconocimiento-SinObraDerivada 3.0 España de Creative Commons

Esta obra está sujeta a una licencia de Reconocimiento-CompartirIgual 3.0 España de Creative Commons

Esta obra está sujeta a una licencia de Reconocimiento 3.0 España de Creative Commons

B) GNU Free Documentation License (GNU FDL)

C) Copyright

FICHA DEL TRABAJO FINAL

Título del trabajo:	*Evolution and current state of art of Green IT, a literature review*
Nombre del autor:	*Jose Pertierra das Neves*
Nombre del consultor/a:	*Belén Bermejo González*
Nombre del PRA:	*Joseph Jorba Esteve*
Fecha de entrega (mm/aaaa):	06/2022
Titulación:	*Máster en Ingeniería Computacional y Matemática*
Área del Trabajo Final:	*Computación de Altas Prestaciones*
Idioma del trabajo:	*Ingles*
Palabras clave	*Green IT/IS, Technology Sustainability, Systematic Literature Review*

Resumen del Trabajo (máximo 250 palabras): *Con la finalidad, contexto de aplicación, metodología, resultados i conclusiones del trabajo.*

La Green IT tiene como objetivo ayuda a alcanzar las mejoras en un ámbito más concreto dentro de la sostenibilidad de las TI. A diferencia de otras áreas, como puede ser la Green IS que cubre la parte de aplicación y software de las tecnologías para abordar los problemas ambientales, la Green IT se centra en el impacto directo de los equipamientos o hardware y sus procesos. Los centros de datos son una pieza vital de nuestra infraestructura actual, para preservar las comunicaciones y la transmisión de datos. Sin embargo, su impacto en las emisiones globales de CO2 no es nada despreciable. Representan casi el 2% del total de CO2, y los gobiernos ya están presionando para reducir al máximo estas contribuciones negativas. Para ello, muchos investigadores tratan de analizar desde diferentes perspectivas cuál es la forma más efectiva de implementar prácticas que minimicen el consumo de energía y su impacto en el planeta. Desde técnicas que ayuden a equilibrar las cargas de procesamiento o a programar el uso de la energía, hasta marcos de gobernanza de alto nivel para adoptar normas y supervisar los avances.

Sin embargo, aún no está claro que las GIT hayan cobrado suficiente impulso en su aplicación y que muestren resultados que orienten a la comunidad mundial hacia un camino claro. Para el futuro a corto y medio plazo, la Green IT debe estar en el centro de todos los proyectos tecnológicos. Ya que tiene una tremenda repercusión en muchas otras áreas de aplicación que traerán una disrupción significativa en el mundo de los centros de datos como: IoT, blockchain, o la digitalización de las industrias.

Abstract (in English, 250 words or less):

Green IT helps to achieve sustainable goals in the bigger spectrum of the IT Sustainability. Unlike other differentiated areas, such as Green IS that covers the application and Software side of technologies to tackle environmental issues, Green IT focuses on direct impact from equipment or hardware and its processes. Data Centers are a vital piece of our current infrastructure, preserving communications and transmission of data. However, their impact in CO2 global emissions is not negligible at all. They account for almost 2% of the total GHG, and governments are already pressuring to reduce to the minimum these negative contributions. For this, many researchers try to analyze from different perspectives what is the most effective way to implement practices that minimize energy consumption and impact on the planet. Either techniques that help balancing the processing loads, or scheduling energy usage, to high level governance frameworks to adopt standards and monitor progress.

However, it is not clear yet that GIT gained sufficient momentum in implementation and showing results that guide the global community towards a clear path. For the short-term and medium-term future, Green IT needs to be in the center of every IT project. As it has tremendous repercussion in many other areas of application that will bring significant disruption in the world of data centers such as: IoT, blockchain, or digitalization of industries.

Index

1. Introduction 1
1.1 Context and work justification 1
1.2 Objectives 1
1.3 Methodology 2
1.4 Planning 2
1.5 Summary of final deliverables 3
1.6 Structure of the Thesis 3
2. Background: Green IT 4
2.1. Technical terms definitions 4
2.2. What is Green IT? 8
2.3. Previous Systematic Literature Review 10
2.4. Wrap up with key conclusions 19
3. Systematic literature review 21
2.1. Research Questions 21
2.2. Keyword Selection 22
2.4. Topic distribution of the papers obtained 24
2.5. Filtering 27
2.6. Preliminary observations 29
4. SLR Findings and discussion 31
4.1. Research Questions 31
4.2. Discussion 35
5. Study Conclusions 37
5.1. Results Summary 37
5.2. Conclusions 37
5.3. Study Limitations and future work 38
6. Glossary 40
7. Bibliography 41
8. Appendix 44

List of Figures

Figure 1 Calendar planning for workstreams 2
Figure 2 % of market share in global market by type of service (IDC 2020) 5
Figure 3 Pool of resources in virtualization (Red Hat 2022) 6
Figure 4 Power Utilization Effectiveness metric for European data centers (Paolo Bertoldi 2017) 7
Figure 5 Number of articles published addressing Green IT vs. Green IS between 2007 and 2016 13
Figure 6 From data demand to Green IT (Dewatcher 2020) 18
Figure 7 Keywords extracted from titles for query 1 24
Figure 8 Keywords extracted from abstracts for query 1 24
Figure 9 Word cloud generated from titles of publications obtained (via monkeylearn.com) 25
Figure 10 Relation between topics in publications 26
Figure 11 Representation of existing relationship topics (adapted from matrix of occurrences) 26
Figure 12 Identification of trends in publications through 2018 to 2021 in selected topics 27
Figure 13 Sequential steps to filter publications (with Green IT in title) 28
Figure 14 Sequential steps to filter publications (no Green IT or similar) 29
Figure 15 Frequency "Green" concepts in articles obtained 30
Figure 16 Representation of the analysis in the effectiveness and implementation of Green IT 36
Figure 17 The implementation of Green IT can be analyzed considering the nature of sectors, individuals participating in, or other demographic factors. ... 34

1. Introduction

1.1 Context and work justification

According to the European Commission, the Information and Communication Technology (ICT) sector accounts for 2% of the global greenhouse gas (GHG) emissions, a similar share as the one generated by the global aviation industry. Breaking down the different implicit business activities we can find, it is observed that the impact from data centers represent the fastest growing carbon footprint within the industry. This is primarily due to a drastic evolution in the accessibility to devices connected to the internet which increased cloud-based products to service the new demand. This behavior was not unexpected and is aligned with the Jevons Paradox on technology innovation and efficiency formulated in the 19th century.

Policy-makers from different geographies were forced to issue guidelines on how to address the energy-efficiency equilibrium targeting the environmental uncontrollable impact it will represent in the very near future. The most recent analyses provide a diverse range of perspectives, including a broad spectrum of recommendations, but there is potential profit from compiling them and inferring a common scheme.

What are the Green IT principles that companies should follow? What techniques need to be implemented in their regular operating processes? How can government agencies identify and deploy a range of regulatory frameworks to analyze and measure the impact of the cloud data centers during the following decade?

1.2 Objectives

The development of this study is constructed around a set of main objectives to be covered during the following months:

1. Review the existing literature, case studies and best practices on Green IT.
2. Identify a common framework with focus on current regulatory restrictions.
3. Understand the current mechanisms and methodologies for efficiency optimization (a concrete look to data centers management).
4. Generate a holistic approach on how data centers are defined and categorized.

5. The final product is the SLR conducted analyzing the different areas of research during the period selected.

1.3 Methodology

Based on the guidelines for systematic literature review (SLR) proposed by Kitchenham (B. Kitchenham 2009) and adaptations from Okoli (Okoli 2015), the following 3 main phases compose the methodology to be followed during the study:

- Planning and detail of the research questions.
- Screening and selection defining inclusion and exclusion criteria.
- Extraction and analysis assessing the quality of each individual unit of content.

The process allows iteration for flexibility in case a deviation from this protocol is needed, e.g. new research questions are introduced for deeper analysis.

1.4 Planning

During the 8 months, the study has been developed in 3 different work streams: literature research, analysis, and final document. A calendar planning has been estimated and presented in Figure 1. Following Universitat Oberta de Catalunya (UOC) requirements, 4 deliverables have been produced as part of the evaluation process, with key dates represented explicitly.

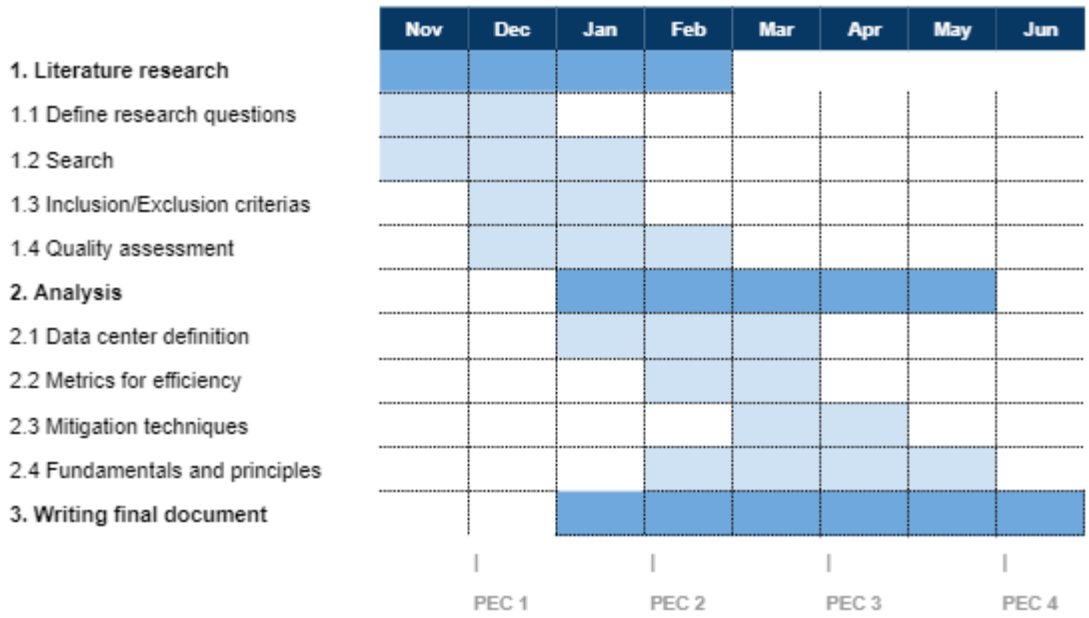

Figure 1 Calendar planning for workstreams

1.5 Summary of final deliverables

This study pursues the obtention of an exhaustive analysis of the state of art in the research of Green IT from 2018 to 2021. This analysis sketches the main trends in the subareas of Information Technologies, from a global perspective, that are affected by the energy utilization of Data Centers. Additionally, the reader would be able to understand what past gaps in literature are and the future trends.

1.6 Structure of the Thesis

In the following chapter (2), the procedure used for the Systematic Literature Review over Green IT is described in detail. Including sources, searching methodology, and quantitative results. After (section 3), presents the main findings and conclusions driven by the review performed over the documents obtained.

2. Background: Green IT

This chapter introduces the concepts and definitions needed to address the analysis of the Green IT research. From what is the cause behind the creation of Green IT, to the current definition extended among experts.

2.1. Technical terms definitions

- **What is a Data center?**

  Data centers are (Cisco 2022) physical facilities that contain a network hardware such as routers, servers, or storage systems, that provide with the critical infrastructure to manage data and run applications. In essence, the technical grid of computers that processes emails, virtual desktops, communications, productivity applications, file sharing, … among others, for organizations. Not all of them are centralized data centers. An edge data center (Gillis 2021) is the one that splits the network architecture to facilitate a quicker delivery of the information, usually as a bridge between two networks.

  Some of the most desired attributes of data centers for the well-functioning are specified and certified by agencies of standards. For instance, one of the most extended is the ANSI/TIA-942 (Borgini 2020) that covers any-size or modular data center product assesing 4 levels of rating: 1 – Basic Site Infrastructure; 2 – Some redundant components and protection against physical events; 3 – Concurrently Maintainable with capacity components that can be replaced or serviced according to planning; and 4 – Faults in any part does not impact the end user.

- **What is Cloud Computing?**

  As it is intuitively indicated by its name, it constitutes the delivery on demand of Information Technology capabilities or resources instead of buying, owning, and maintaining physical devices mainly, data centers (Amazon 2022). The application of Cloud Computing introduces several benefits for institutions, organizations and end consumers (Won Kim 2009):

  - Avoid intense capital requirements to cover upfront investment, space, utilities, and staff with higher flexibility.
  - Flexibility on resource allocation, increasing or decreasing easily.
  - Pay only for the computing and services that are used and planning for specific peaks.
  - Universal access and constant availability.

Depending on the architecture used and the accessibility from different networks (external or internal to the business) several methods of deployment can be found (Microsoft 2022): public cloud, private cloud on-premises, or hybrid cloud composed of the two previously mentioned.

- **What type of services can be offered?**

There are 3 common offers that can be encountered nowadays in the market of Cloud Computing. The classification reflects the trade-off in terms of management responsibility between the Cloud provider and the client as follows (Amazon 2022):

- Infrastructure as a Service (IaaS) provides access to the lowest level of IT resources: network deployment, data storage, and computational power.

- Platform as a Service (SaaS) enables an efficient and effective management of the organization's applications facilitating the underlying hardware and systems.

- Software as a Service (SaaS) are usually seen as the end-user application and the highest level of abstraction in the hierarchy.

In terms of global market share driven by the revenues generated contracting each one of these types of services, SaaS is the leader with more than 60% (IDC 2020).

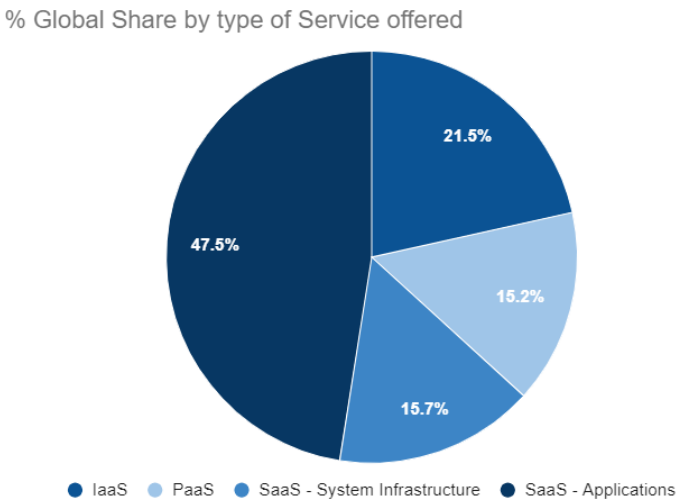

Figure 2 % of market share in global market by type of service (IDC 2020)

- **Virtualization**

Virtualization (Red Hat 2022) is a technology that consolidates many independent physical hardware systems into delivering a one customizable environment or even split into different secure environment

known as Virtual Machines. They use resources from the environment as if they were part of a pool of resources for computing, memory, or storage, and they could be relocated easily.

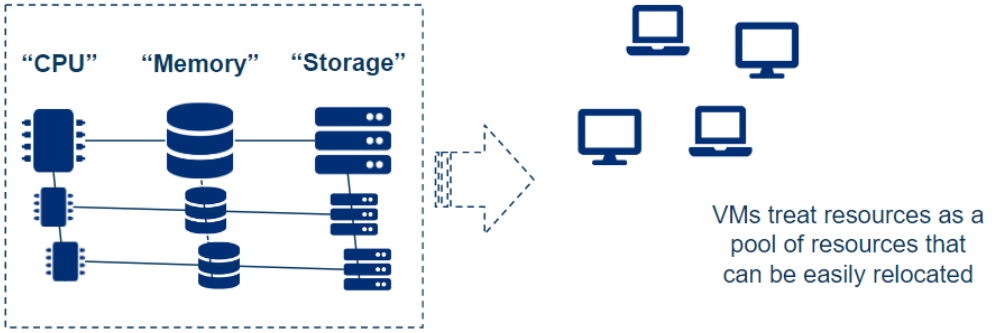

Figure 3 Pool of resources in virtualization (Red Hat 2022)

The usage of Virtualization goes along with some key benefits from its implementation (Marta Chinnici et al. 2021): consolidation reducing number of servers, containment helping to manage the life cycle of applications, and availability and data recoverability. In contrast, some disadvantages are found as well: upfront cost, limited support of applications, and relatively long-time investment to understand the virtualization environment.

- **Energy consumption at data centers**

  The energy consumed by any device is measured by the electrical input needed for the correct performance and the total time in operation. Standard measure for this is Watts per hour (Wh). For instance, in 2020, the global data center electricity use was 205 TWh (Eric Masanet 2020) similar to the domestic energy consumption in South Africa.

  Study made by expert agencies in energy (International Energy Agency 2021) identified that during the last decade (from 2010 to 2020) the energy consumption by data centers has increased only by a 10%. On the other hand, total internet traffic was at the end of the period almost 17 times than in 2010, and 40% year-over-year in 2020 (when the COVID-19 pandemic impacted to most developed countries and technologies were leveraged to sustain online communication). All these while the specific data center workload increased by a factor of 9.5.

  However, the energy demanded by data centers is yet significant, ~1-2% of the global energy demand, and a constant issue to control minimizing while maintaining effective performance.

  Some other factors could facilitate to balance workloads and energy consumption. An extended practice in the management of networks of data centers in Multi Regions.

- **Energy efficiency**

Only using the energy consumption, we cannot answer to the question: is it low and acceptable or high and we should put in place initiatives to reduce it? To do this, and also as a common benchmark against the different existing data centers, the Power Utilization Effectiveness (PUE) (Paolo Bertoldi 2017) metric is widely used. For instance, it is included in the European Code of Conduct for data centers. PUE helps representing the ratio of input power to the IT load power. Normal values range from 1.25 to 1.75. As can be seen in Figure 4, the efficiency in European data centers has increased since 2009 and a long-term trend is expected due to several factors. Moore's Law and the density of transistors make possible higher computation capabilities using less physical space and energy resources. On the other hand, as stated previously, total energy consumption will tend to increase due to the additional networks that will be built in the future.

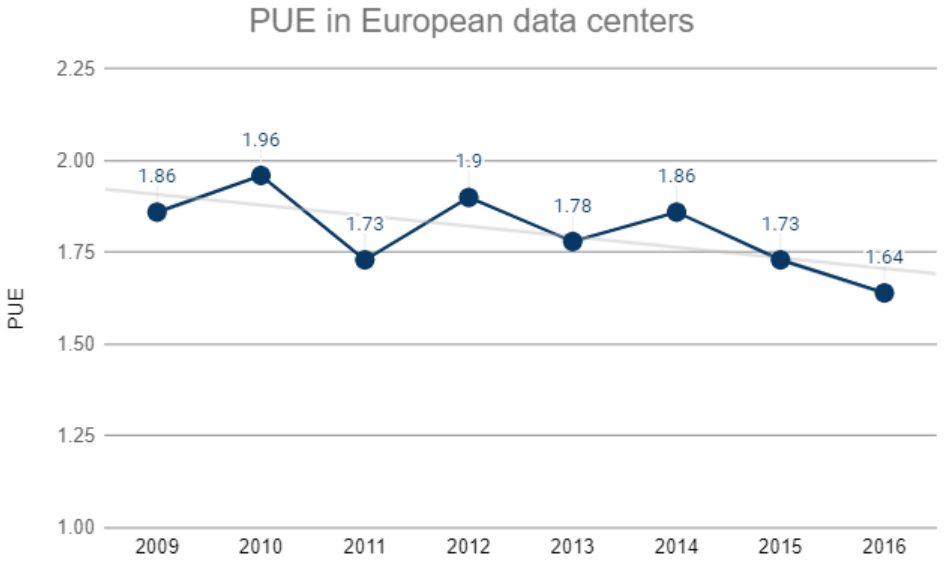

Figure 4 Power Utilization Effectiveness metric for European data centers (Paolo Bertoldi 2017)

2.2. What is Green IT?

In this section the concept of Green Information Technology is addressed. Firstly, in order to understand the origins of the term, we need to observe the evolution of technology during the late 1900s and sketch the big picture of how Information Technologies were, at some point, increasing energy consumption by offering much more services without specific controls and long-term consciousness. For this, let's review first the evolution of the concept of sustainability in the world of IT/ICT into the scope of GIT.

2.2.1. From sustainability to Green IT

The specific moment of origin of the term Green IT is not yet clearly defined. Some experts indicate (TechTarget 2022) the creation of the Energy Star program in 1992 (backed by the US government), one of the first standards that tackles the energy efficiency of electronic devices, PCs and servers. It is as well considered as one of the cornerstones of the ICT transformation in sustainability practices. Although, there are authors that sustain that the green practices in Data centers could have been initiated back in the 1970s, such as some examples of heat reuse with the objective of reducing CO2 emissions in Sweden (Taro Lennerfors 2018).

In respective to Green IT, the term raised great interest and was widely spread after some key publications in 2007 (Bokolo 2020) and reports from Gartner (research and consulting firm). There exist multiple definitions of Green IT. One of the broadest ones that can be encountered is provided by (Elliot, 2011, Erek et al., 2011): "The systematic application of practices that enable the minimization of the environmental impact of IT, maximize efficiency and allow for company-wide emission reductions based on technology innovations".

Some authors even have elaborated an exhaustive study on the definitions built around Green IT and its relationship with sustainability concepts of Information Technologies: "Green IT is the practice of designing, manufacturing, using and disposing of computer, servers and associated subsystems efficiently and effectively with minimal or no impact on the environment" (Shun Caia, 2013) . In contrast, IT for Green is:" use of information systems to enhance sustainability across the economy, with a focus on IT as a solution" (Shun Caia, 2013).

Looking backwards, Green IT experienced a peak in 2010, in contrast with the relative decrease in interest compared to origination of a Green IS trend afterwards. The differentiation and definition of both concepts remains vague for many (Loeser 2013), although it has been found that typically initiatives in Green IT are more linked to hardware and operations, while Green IS works closely to the environmental management systems, business and production processes, or even tracking emissions and reporting.

2.2.2. Data center sustainability

Regulation on Sustainability

The analysis of how sustainable companies are nowadays, is commonly analyzed by extended frameworks. One of the most popularized is ESG, that dives into three different factors: Environment, Social, and Corporate Governance. ESG gained influence in the finance world after being used to promote sustainability across portfolio investments to ensure long term activities. Although it regained more traction after the publication of the “Triple bottom line” (Elkington 2018). On a more technical scale, ISO standards ensure the correct implementation of best practices in processes or EPEAT which serves as a registry of electronic products and its environmental assessment. On the other hand, regulators are reacting to sustainability in ICT companies:

- In the European Union, data centers would be measured according to a Code of Conduct (CoC) that stipulates common ground for companies across the continent. The CoC also defines the PUE as a central metric for efficiency.

- The European Green Deal establishes zero greenhouse emissions by 2050 (Commission 2019). In 2018, energy consumption from data centers in the European union was 76.8 TWh. Accounting for the 2.7% of total energy consumption in the EU. Recent studies forecasted that it will potentially reach ~100TWh by 2030 (representing a 3.2% by that same year). The biggest data centers are located in the Northern and Western part of the continent (representing 82% of the total consumption of the European sector).

- The United Nations Paris agreement searches for a global effort towards net-zero. Puts on the focus as well, developing countries that will need financing help in order to contribute to the long-term goals (United Nations - Paris Agreement 2015).

- The US houses ~30% of the data centers but, compared to Europe, they represent in 2018 the 0.5% of the total CO2 emissions in the country (Md Abu Bakar Siddik 2021) regulated by the EPA (Environmental Protection Agency) and the Clean Air Act. Although some individual states did increase the level of focus and enhanced initiatives from federal government, such as California that created the CARB (California Air Resources Board). The most recent Energy Act (from 2020) defines a clear path around the supervision of data centers efficiency. Although the majority of the guidelines presented tackle energy dependency on carbon sources, access to minerals, and the development of new financing programs (US-Senate 2015).

2.3. Previous Systematic Literature Review

With the goal of extracting the existing literature during the last years in the topic of Green IT, based on the search engine Google Scholar, over the period 2018 to 2021, a total of 16 articles SLR related have been reviewed. They can be classified in 3 different groups depending on the area of scope (see Table 1): GIT generalist (3), Green IT adoption (8) and Geographical specific analysis (6). One observation can be made regarding the category of the newest articles reviewed that are focused on specific areas (Malaysia, Belgium, Indonesia and Ecuador).

1. GIT/GIS General	
Year	**Title**
2018	The Role of Data Centers in Advancing Green IT: A literature review
2019	Green IT and sustainable technology development: Bibliometric overview
2020	IT Governance and Green IT: a systematic review
2. Green IT adoption	
2.1. Organization adoption	
Year	**Title**
2018	Green IT/IS Adoption within Organizations: A Systematic literature review
2019	Influence of Organizational Culture on Green IT Adoption: Study Literature
2019	Organizational Green Information Technology (it) adoption theoretical frameworks: a systematic literature review
2020	Towards adoption of Green IS: a literature review using classification methodology
2020	Adoption of Green IT in the university environment: systematic review of sustainability practices in educational institutions
2020	Evaluating Green IT in local administration
2.2. Consumer Adoption	
Year	**Title**
2020	Social gamification affordances in the green IT services: perspectives from recognition and social overload
2020	How to change household behaviour with Green IT
3. Geography specific	
Year	**Title**
2019	Investigating factors influencing decision makers' intention to adopt Green IT in Malaysian manufacturing industry
2020	A generic study on Green IT/IS practice development in collaborative enterprise: Insights from a developing country
2020	Examining the role of green IT/IS innovation in collaborative enterprise
2021	Critical Analysis of Green IT in Belgian data centres
2021	Green InformationTechnology in Indonesia – A systematic Literature review
2021	Analisis bibliometrico de green it en el ecuador

Table 1 Classification of Literature Review related articles analyzed from 2018 to 2021

A. GIT/GIS General

2018 - The Role of Data Centers in Advancing Green IT: A literature review

The author observed that literature reviews on green IT had covered very specific topics, and there is still a gap:

- Practitioners versus academic literature
- Corporate social responsibility, sustainability, stakeholders, environment, green IS and green IT
- Existing research and gaps
- Categories of Green IT publications
- Adoption
- Organizational Green IT

Thus, decided to perform a review of to address the research question of why data centers are important in the context of green it (631 articles reviewed) classified into: 1) Power savings, 2) cost savings, 3) sustainability and green energy, 4) information technology for greening DC, 5) aligning business requirements with resource utilization. These topics provide a taxonomy from research on the role of data centers in the Green IT field advances.

Limitation and gaps: more research is needed in areas of sustainable software engineering and space management in data centers. The literature review has not covered the subcategory of utilization in the data center. More areas to explore: space as a subcategory within cost savings, influence of business alignment with IT.
Potential future work: relationship between various categories and subcategories quantitively to determine priorities and dependencies when it comes to implementing GIT in a DC.

2019 - Green IT and sustainable technology development: Bibliometric overview

A total of 4,398 publications have been analyzed from a quantitative perspective. Classification by study type (evaluation research, solution proposal, experience report, …), empirical study (case study, experiment, …) and secondary studies (literature reviews, meta-analysis, …).
Limitations: using Scopus only, using the designation of GIT to search.

2020 – IT Governance and Green IT: a systematic review

The author frames the issue of Green IT over the connection between organization initiatives and internal alignment. “Every day, a greater number of

organizations around the world are implementing new practices about Green IT; however, these are not connected with organizational management and governance" (D. Cordero 2020) through 100 articles that are classified a map that relates Practices applying Frameworks or Models. Other dimension to classificate articles is based on governance process oriented (COBIT, ITIL, VALIT, ISO) or behavior oriented.

B. Green IT adoption

The objective of this category is to create awareness of the issues associated with the Green IS/IT adoption research area.

i. Organization adoption

2018 - Green IT/IS Adoption within Organizations: A Systematic literature review

323 relevant articles out of 556 obtained from the search performed from 2007 to 2016. Classification into different categories by the focus of the study: 1) Benefits (cost and environment), 2) Initiation, 3) Adoption framework, 4) Approaches and strategies. The author presents key insights highlighting most present Regions, Organizational-Level Theories, and Individual-Level Theories in research (see Table 2).

Mostly used	
Regions	Oceania/Pacific, North America, East Asia, Europe
Organization-Level Theories	Institution Theory, Natural-Resource-Based View, Technology-Organization-Environment
Individual-Level Theories	Theory of Planned Behavior, Belief-Action-Outcome, Theory of Reasoned Action
Green IT	
Rarely used	
Regions	South America, Southeast Asia, South Asia, North Asia, Middle-East, Africa
Organization-Level Theories	Belief-Action-Outcome, Transaction-Cost Theory, Stakeholder Theory, Corporate Ecological Responsiveness
Individual-Level Theories	Diffusion of Innovation Theory, Norm-Activation Model, Elaboration Likelihood Model, Motivation Ability Theory, Motivation Ability Theory, Technology Acceptance Model

Green IS

Table 2 Classification of research Regions, Organizational-Level Theories, and Individual-Level Theories according to presence in research

Other important contribution the article provides is the comparison between GIT and GIS during recent years. “Green IS topic has gained more emphasis in research from the period 2010/2011”, as can be seen in Figure 5.

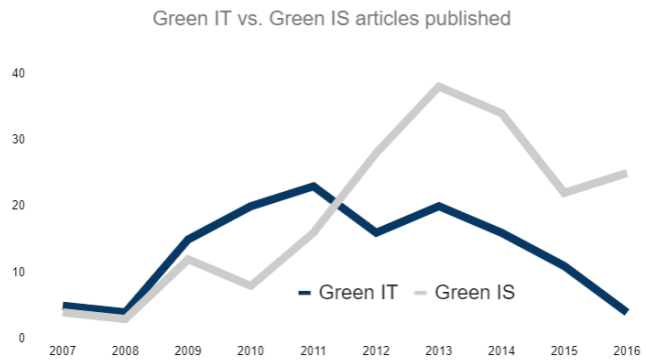

Figure 5 Number of articles published addressing Green IT vs. Green IS between 2007 and 2016

2019 - Influence of Organizational Culture on Green IT Adoption: Study Literature

Reviews literature focus on the Green IT readiness to infer a conceptual model of the Organization Culture based on Green IT Readiness:

- Green IT Attitude
- Green IT Policy
- Green IT Practice
- Green IT Technology
- Green IT Governance

2019 - ORGANIZATIONAL GREEN INFORMATION TECHNOLOGY (IT) ADOPTION THEORETICAL FRAMEWORKS: A SYSTEMATIC LITERATURE REVIEW

After reviewing papers related to the Green Information Technology adoption, there is a clear evolution in the academic research about the theories utilized to the adoption of GIT. A total of 33 theories are identified. Key takeaways:

- Missing some sectors such as the high education sector in which a lot of devices and energy consumption are present.

- Very focus on America and Europe. We need more research in Green IT adoption studies are needed in developing nations, particularly in Africa.

2020 - Towards adoption of Green IS: a literature review using classification methodology

“The area of Green IS and its adoption is in its nascent stage” (M. Singh 2020)

Literature review performed in a cascade: Need of Green IS -> Green IS Planning and Development -> Green IS adoption -> Green IS Measures -> Green IS Initiatives Upshots
The research areas can be classified in 5 different areas:

- **Global context**: develop, developing, underdeveloped countries. Conclusion: fill the research gap of countries

- **Understanding of Green IS:** Evolution, definitions and concepts, dimensions. Conclusion: need more research to provide unequivocal definitions and concepts for Green IS.

- **Green IS adoption:** Success factors, technology HW SW. Conclusion: need more focused study on technological, motivational and ecological CSFs

- **Impact of Green IS initiatives:** industries, government, society. Conclusion: more study on post-adoption

- **Measures and policies:** technology, government regulatory and policies adapted to measure Green IT adoption. Conclusions: important to study and develop measures, practices and universal standards.

Limitations: low availability of research in developing and underdeveloped countries. Limited research in the area of post-adoption of Green IS in private or government organization.

2020 - Adoption of Green IT in the university environment: systematic review of sustainability practices in educational institutions

9 papers were found relative to the implementation of Green IT projects in educational institutions during the last 10 years. As a conclusion, author extracted:

- How to start a Green IT project at the university

- Used Technologies to implementing Green IT

- Difficulties you can face during a Green IT project

- Benefits of Adopting Green IT

Author references future lines of work around how Green IT practices and technologies as solutions for problems and improvements with the concrete example in universities in Latin American. Specifically, institutions in southern Brazil.

2020 - Evaluating Green IT in local administration

How to evaluate the alignment of the Green IT initiative in Local Administration (LA), several dimensions are presented:

- IT valences: hardware, software, IS, security, governance
- Financial valences: direct and/or indirect costs of IT
- Environmental valences: CO2, recycling, contribution to global warming
- Social valences: satisfaction of the citizen, speed of response, number of trips, …

As an observation from the author, Industry 4.0 will increasingly be focused on sustainability.

ii. Consumer Adoption

2020 – Social gamification affordances in the green IT services: perspectives from recognition and social overload

Research questions to identify how could recognition and social overload affect gamified green IT services use? Based on Interactivity, Cooperation, and Competition could establish Recognition but also social overload to impulse Green IT Services Use. Topic in line with how to persuade households to change and showcase *"Ant Forest"*, an example of gamification to incentive users of transport platforms to walk, use bikes, …

2020 – How to change household behavior with Green IT

27 relevant papers out of the 243 found. Focus on behavior of households and green technology energy. Covers different issues in this scope of analysis, some of the most important are:

- Knowledge and anchoring
- Adoption of new things – Roger's theory of diffusion of innovation
- Kahneman's theory of system 1 and system 2
- The hassle factors
- Changing energy consumption
- The theory of persuasion
- Nudging
- Six principles that can be used to make something stick

C. Geography specific

2019 - Investigating factors influencing decision-makers' intention to adopt Green IT in Malaysian manufacturing industry

Malaysian manufacturing industry is in emerging stage (2015) and the study tries to explore an adoption model which considers micro-level factors that could influence decision-makers withing organizations and intention towards the adoption of Green IT. At the moment, organizations were in the initial phase of awareness and adoption and few findings from real implementation were seen. On the other hand, since the benefits of Green IT are not yet realized they cannot be measured. Thus, researchers tend to focus on the adoption part.

2020 - A generic study on Green IT/IS practice development in collaborative enterprise: Insights from a developing country

Some of the key contributions that this article has are the following:

- Description of the Perceived Organizational e-readiness theory
- Definition of Process Virtualization Theory
- History of Malaysia and Green IT
- Initiatives to be adopted by collaborative enterprises.

The final purpose of the paper is to provide with questionnaire to validate those theories in Malaysia. Several restrictions in the sample (133) of professionals interviewed. Some researchers maintained that "Green IT has a limited scope of technical related issues whereas Green IS is more systemic and includes humans, procedures, and know-hows that address sustainability issues"

2020 – Examining the role of green IT/IS innovation in collaborative enterprise-implication in an emerging economy

This paper overlaps with the previous one, but more centered in the reasons behind Collaborative Enterprises and sustainability initiatives.
As conclusions, businesses are motivated by social, internal, and external pressure that determines how they conduct business in relation to Green IT/IS innovation

2021 – Green Information Technology in Indonesia – A systematic Literature review

Inspired by Anthony Jr Bokolo et al. addressing Green IT in Malaysia, research methodology to be applied for Indonesia. 44 articles from 2011 to 2020. Limited to publications in Indonesia. Research themes classified in: adoption, benefits, initiation, and strategy.

2021 – Critical Analysis of Green IT in Belgian data centres

This article is a Master Thesis with strong focus on the tech industry and the evolution of data centers in Belgium with the support of interviews done to professionals of the sector. The author presents how the necessity of Green IT was generated caused by the negative impacts (economic repercussion in profits), environmental (for the planet) of an endless growing demand of data (serviced through the 4Vs: Volume, Variety, Velocity, and Veracity) as represented in Figure 6.

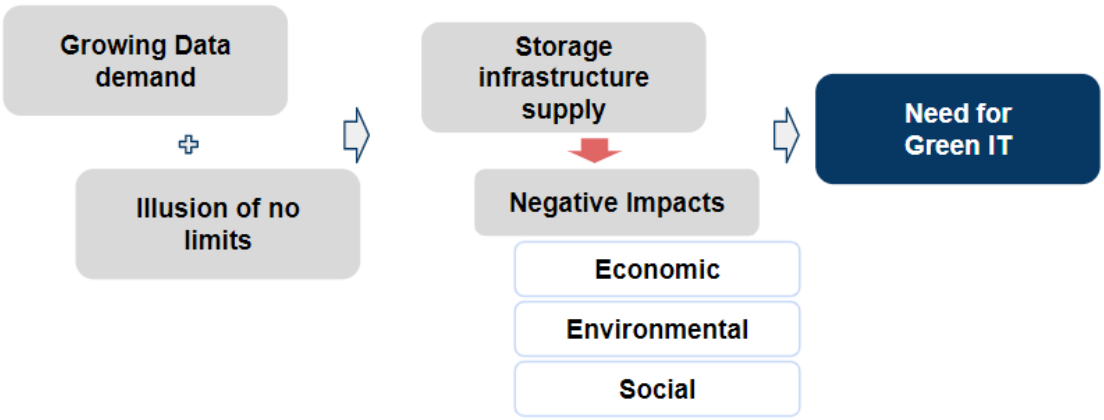

Figure 6 From data demand to Green IT (Dewatcher 2020)

Also extensively explored are the mechanisms that can be put in place to increase sustainability in different components that contribute to the activities of data centers. Some of them are presented below:

- **Hardware:** reducing energy consumption pursuing the efficiency of equipment on one side applying Dynamic Power Management, and the cooling process on the other (also reusing the heat in colder countries).

- **Software:** an important concept is reviewed: Environment Opportunistic Computing (EOC), which processes the available information of: cooling, lowest energy cost location, zone where heat is needed, … to optimize workloads in geographically distributed systems.

2021 – Analisis bibliometrico de green it en el Ecuador

Review of 131 articles related to the application of Green IT from 2007 to 2016
Similar to the previous systematic reviews, this one is restricted to Ecuador. A very basic classification was performed: social and politic, entrepreneurship, social and economic, environmental, social, social and tech.

2.4. Wrap up with key conclusions

The review of past SLRs provides a very good understanding of past trends and previous difficulties that authors have encountered along the way of analysis the research areas under Green IT and their evolution. Some key findings that these SLR highlight:

- There is a blurred line that separates each one of the definitions given to sustainability in Information Technologies. Some authors expressed the difficulty to define search terms to locate specific papers (J. A. Garcia-Berna et al., 2019).

- Different regions look at the problem differently. Depending on the economy of the country (whether public sector or private sector maintain high relative importance) or the stage of local regulation in sustainability. However, we can observe that there is a common procedure in the expansion in literature analysis that impulses research such as the focus on adoption (authors put focus on the need of this for developing countries) due to the lack of examples in the industry in which Green IT practices already implemented and results measurable (S.Asadi et al., 2019).

- There is no clear trend on the trend of research in the Green IT field. Some authors observed the downwards trend vis-à-vis an increasing interest for Green IS (B. A. Jr, M.A. Majid, A. Romli, 2020) due to a broader scope and a more systemic impact. Others identify a strong difference in Green IT being much more covered than Green IS which will require an impulse in future research work (M.D. Esfahani et al., 2018).

- As stated already above, researchers tend to focus on adaptation of Green IT as not much implementation has been realized. Additionally, authors observe a potential gap in the management side to ease this implementation. Some see potential on emphasizing the alignment between organizational management and governance during the implementation of Green IT in the industry (J. A. Garcia-Berna et al., 2019), or covering the cost savings aligment with IT defining priorities and dependencies when deploying Green IT in Data Centers. Also exploring Sustainable Software topics and space management in Data Centers (A. Santhanam, C. Keller, 2018).

- Results from literature reviews describes the benefit from promoting the adoption of GIT and research in the education sector (A. A. Muslim et al., 2019), some more concretely in universities (M. R. da Rosa, 2020). Others try to motivate the analysis of post adoption of Green IS in private or governmental organizations (M. Singh, 2020). There is also some expectation that local administration will be impacted from Industry 4.0, as it will increasingly be focused on sustainability (M. Landum, M. Moura, L. Reis, 2020).

- Following the recommendations of authors about the importance to introduce Green IT practices in developing countries we observe some key regions that have not seen significant research in these topics (M.D. Esfahani et al., 2018). These can be: South America, Southeast Asia, South Asia, North Asia, Middle East, or Africa.

Having seen many different articles that already address the evolution of research in the dimensions of sustainability and Green IT then: what causes the need for performing a new SLR? Several key reasons can be found to justify this:

- Existence of gaps during previous years. Looking at the least analyzed sectors and geographies identified as a need to improve, has it changed in most recent periods?

- Some of the SLRs only cover until 2018, while others (very few) touch until 2020. However, there is the need to perform an SLR including one of the periods with more digital push in history due to the COVID-19 pandemic situation. Covid Pandemic impacted positively in CO2 emissions reduction in transportation and building energy utilization due to lockdowns. On the opposite side of the coin, how did it affect enterprises that required more virtualization and data centers efficiency if any relevant study has been developed?

- New trends in the technology landscape are suddenly disruptive the performance and logistics of Data Centers. For instance, unknown efficiency profiles of smaller chips, the downsizing limit of these chips or the migration of data centers closer to the users. The latter is a trend predicting the digital transformation, growing urbanization and mass migrations will push data centers closer to the user for better and faster connectivity (edge computing). Or even massive deployment of connected devices such as the Internet of Things and Industry 4.0.

3. Systematic literature review

In the second chapter, the idea of Green IT was explored. The main concepts related to the implementation of Green Information Technologies were presented. During this section, the main focus will be to answer the research questions obtained from gaps in previous SLRs. The Systematic Literature Review (SLR) aims to standardize the methodologies used to identify and process the existing literature on a specific topic of research with a broad lens first and a formal filtering process. Based on the model developed by Kitchenham (B. Kitchenham 2009) we can find 3 main phases:

1. Plan Review to address the current State of the Problem Research

    a) Specify Research questions and locate related Systematic Reviews

    b) Develop a review protocol with inclusion and exclusion criteria, and selection of data bases or journals

2. Conduct the Review.

    a) Selection of primary studies, quality assessment, data extraction and monitoring

3. Document the Review Report and Validate.

During the following subsections, the SLR applied to the Green IT area of research will be extensively detailed. First, producing the research questions that will serve as an objective for the study, and later the extraction of the universe of articles that will be analyzed in detail to address those questions.

2.1. Research Questions

The purpose of this literature review is to analyze the evolution of contributions to how Green IT and its implementation in the different agents of our society. In this sense, 4 research questions have been used as anchor to the final discussion on the state of art of this topic.

RQ 1.- How much Green IT contribution has there been since 2018?

Is there an existing trend in terms of increase or decrease of the total number publications tackling the topic in general? Are there any specific subareas that have taken key roles in the contributions? During this exercise we will try to challenge the unclear evolution of contributions to Green IT research indicated by different authors.

RQ 2.- What research topics have been addressed?

Main areas and subareas that have been focus of the contributions and present relevance in the research area of Green IT. Is there any prominent topic that

evolved to significant importance? As seen from other SLRs we could expects new technologies (such as the industry 4.0) or different areas (such as software sustainability) to gain momentum towards future application. Other sub-issues that may arise from this RQ are related to the gap in management alignment with IT and whether the needs of organizations and individuals for adoption are covered extensively during this period of analysis.

RQ 3.- Who are the main agents boosting the evolution of Green IT?

It is needed to understand if there is a change in what the incentives for the divulgation of Green IT are. Is it an issue only addressed by specific sectors? By academia only or organizations also participate? Did any of the regions that was listed in the bucket of lower contributors to the Green IT research (such as Africa) or sectors (such as education and local administration)?

RQ 4.- What are the limitations and gaps of the existing research?

From a high-level perspective observing the existing studies as a whole, and transversal to other industries, what are the potential research opportunities that have not been addressed.

2.2. Keyword Selection

A preliminary analysis of the existing studies has been executed following the plan below. It helped to identify the most significant keywords to be used in the final query:

Iteration 1: “Green IT”.

> As a broad approach, the question is directly defined with the keyword: “Green IT”. As can be observed in Table 3, there is a slight increase in the number of publications identified in 2020 for the “Green IT” keyword although experiments a correction during the following year. There is no clear sign of a decrease or increase in publications.

Terms	2018	2019	2020	2021
“Green IT”	~3,980	~3,980	~4,190	~3,960
"green it principles and practices"	153	146	117	103
“Green IT Governance”	15	24	18	22
“Green IT principles”	162	158	120	109
“Green IT” “ISO”	433	389	432	433

Table 3 Number of publications by search term: “Green IT” performed on 27th Dec 2021

In Table 2, an example of what are the mechanisms to compare the number of publications retrieved from GS for different sub areas under Green IT. This

technique has been used again in a cumulative manner adding new keywords to the “Green IT” query until a manageable volume was reached (see Table 3). Notice that these terms have been included using the expression logic *AND*, consequently, the last row identifies the minimum number of articles.

Terms	2018	2019	2020	2021
“green it” “data center”	328	274	266	294
“green it” “data center” “performance”	276	237	226	266
"green it" "data center" "performance" "energy"	259	222	203	246
"green it" "data center" "performance" "energy" “principles”	126	115	106	118
"Green IT" "data center" "performance" "energy" "principles" "ISO"	25	30	21	23
"Green IT" "data center" "performance" "energy" "principles" "ISO" "governance"	16	19	12	12

Table 4 Number of publications by search term: “Green IT” plus other keywords, performed on 29th Dec 2021

Iteration 2: adding keywords.

As a critical observation from the preliminary analysis, logic expression AND to be used with searching keywords could not be sufficient to gather the wider spectrum of publications. Hence, the definition of the query has been revisited in order to implement an inclusive approach. As an example, we will proceed to evaluate the following query (also identified as “query 1”):

"Green" AND ("technologies" OR "computing" OR "ICT"OR "datacenter" OR "IT")

As the volume of articles increases, some more analytical procedures were applied collecting keywords, from both title and abstract over ~950 publications (see Figure 7 and Figure 8), that could potentially have been left behind.

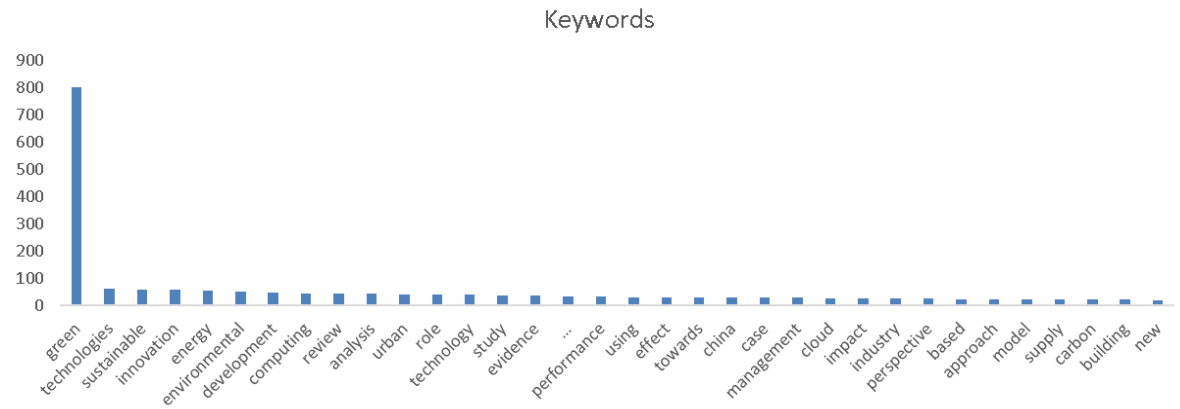

Figure 7 Keywords extracted from titles for query 1

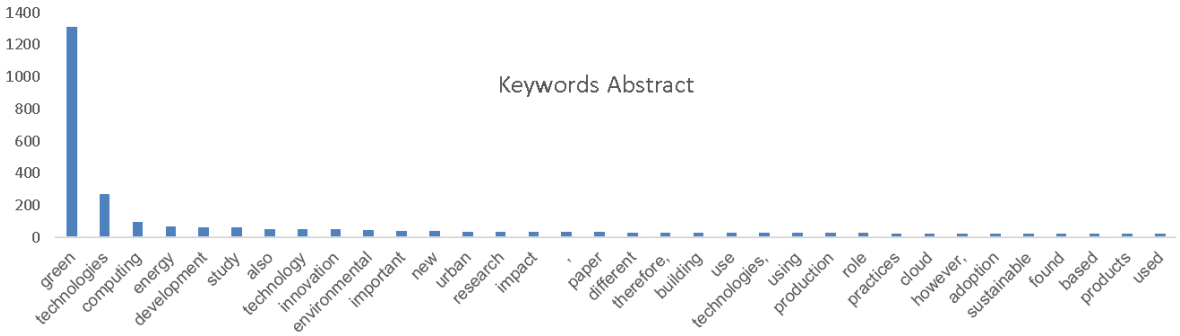

Figure 8 Keywords extracted from abstracts for query 1

Iteration 3: Final Query

Considering previous iteration, some adjustments have been made to the query mainly including additional terms. The following one will be used for the purpose of retrieving publications from GS:

"Green IT" AND "Green Information Technologies" OR "Green technologies" OR "energy" OR "computing" OR "sever" OR "innovation" OR "performance"

Performing the search using this query, a total of 3,759 papers results have been extracted from Google Scholar (see Table 5).

	2.018	2.019	2.020	2.021	Total
Intitle: "Green IT"	55	46	43	39	183
No Green IT in title	865	903	917	891	3576
Total	**920**	**949**	**960**	**930**	**3759**

Table 5 Results for final query

2.4. Topic distribution of the papers obtained

In this section, an initial analysis and classification of the papers obtained using the query built is presented. The titles are analyzed with natural language processors to get an overview of the different topics that are covered. The main ones over the 3,759 documents can be found in a Word cloud visualization at Figure 9.

Figure 9 Word cloud generated from titles of publications obtained (via monkeylearn.com)

As can be seen, there are some terms that gained more presence than others (as an example, energy or sustainability are more relevant than human resources management or smart city based on the number of occurrences). Once an intuitive map of the results is obtained, it has been joined with the terms used within the query to get a deeper view (also based on a keywords analysis performed over the titles extracted). A matrix of 1 to 1 occurrence is presented (see Figure 10) highlighting some of the key relations and representing them using a bubble map (considering the most important interactions based on the number of shared titles) (see Figure 11).

	Green IT	data center	performance	energy	principles	ISO	governance	computing	server	innovation	sustainab
Green IT	183	3	5	7	0	4	11	5	0	1	22
data center		105	6	68	0	1	0	14	5	1	8
performance			279	18	2	2	5	7	4	21	39
energy				516	1	4	3	48	13	2	39
principles					13	0	0	0	0	0	5
ISO						44	2	1	0	1	4
governance							49	1	0	2	8
computing								379	0	1	30
server									21	0	1
innovation										137	30
sustainab											514

Figure 10 Relation between topics in publications

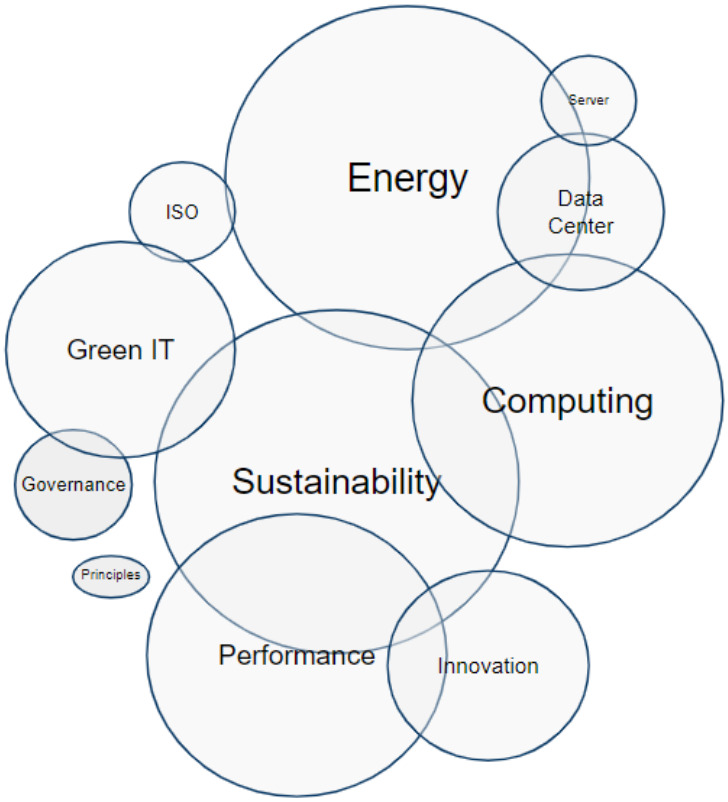

Figure 11 Representation of existing relationship topics (adapted from matrix of occurrences)

Other aspect in the analysis of the most relevant areas defined by the keywords is the presence of trends in number of contributions by subarea. Again, applying the process of the titles in the documents obtained matching these terms, we can see 3 different categories of evolution (see Figure 12). First category, a

positive increase in the number of publications (this is the case for innovation, performance, and sustainability). Secondly decrease in the number of contributions (Green IT, data center, energy, or computing) against prior expectations before the analysis. Lastly, the weak presence of some terms (although very relevant, perhaps quite concrete) such as: principles governance, server, or ISO (which decreases).

Keyword distribution	2.018	2.019	2.020	2.021	Total
Green IT	55	46	43	39	183
data center	34	23	23	25	105
performance	45	57	86	91	279
energy	142	119	126	129	516
principles	2	5	4	2	13
ISO	12	15	8	9	44
governance	9	16	14	10	49
computing	111	96	80	92	379
server	7	4	5	5	21
innovation	22	24	41	50	137
sustainab	123	117	143	131	514

1) **Significant increase in publications:**
- innovation
- performance
- sustainab

2) **A clear increase was expected:**
- Green IT
- data center
- energy
- computing

3) **Not a significant number of publications:**
- principles
- ISO
- governance
- server

Figure 12 Identification of trends in publications through 2018 to 2021 in selected topics

From the existing selection, there are multiples areas or research that make complex the understanding of Green IT. In the following section, a number of articles will be selected depending on their fit with the goals of this SLR and will be analyzed in more details.

2.5. Filtering

Under this segment, the total 3,759 number of documents obtained will be further narrow down following standard methodology of the SLR. Papers will be divided into two groups:

1. The first one provides a more direct interaction with the topic analyzed and thus documents are filtered based on the appearance of “Green IT” in their title or similar terms (“Green Information Technology”, “Green Information Technologies”, “Green IS”). Finally, abstracts are processed and filtered depending on their availability and fit with the research questions stated as guidance for the SLR (see Figure 13). Out of a total number of 267 papers that contain “Green IT" (or similar terms above specified) are considered for the following step of reading the abstract and superficial review. A total of 70 articles are moved forward for a deeper understanding of the content and results.

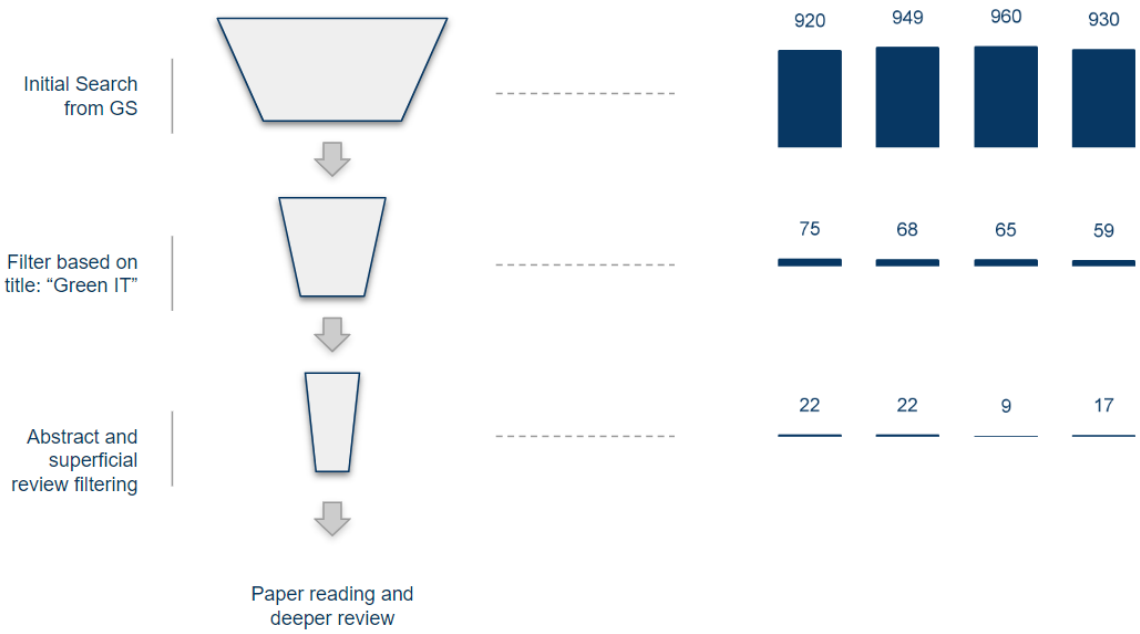

Figure 13 Sequential steps to filter publications (with Green IT in title)

2. Documents that do not include "Green IT" (or similar terms described above) are excluded from the previous processing and will be tackled by this second batch (3,492 publications). For these documents, an intermediate step analyzing the fit based on the title is performed based on expert criteria (and the removal of existing duplicates), again trying to align the scope with the one covered by the RQ of the SLR. A total of 494 publications were moved forward to the stage of abstract reading and superficial review (similarly the previous process). Finally, 192 articles have been introduced in the final phase of deeper understanding of content and results (see Figure 14).

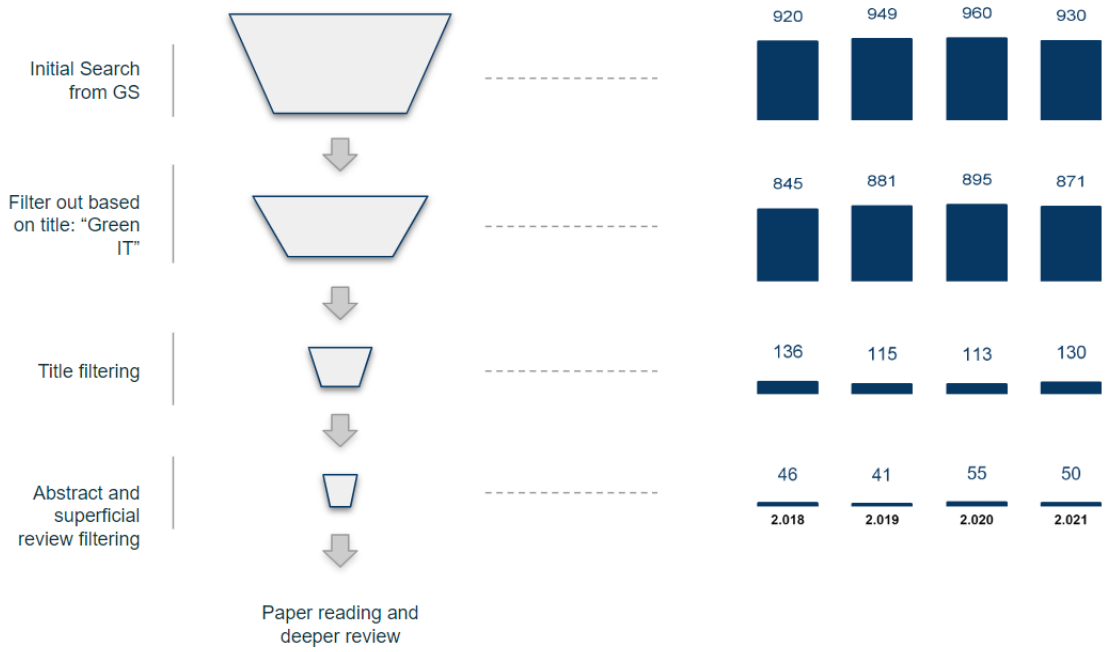

Figure 14 Sequential steps to filter publications (no Green IT or similar)

2.6. Preliminary observations

From the articles excluded from the last phase of the funnel, and more exhaustive one, some observations can be made regarding the content and focus of the research:

- There are multiple "Green" terms from the obtained titles of articles obtained. "Green Computing" (see Figure 15) is the most frequent (150 occurrences), followed by "Green Cloud" with one third frequency than the top one (52). "Green Tech" (that includes "Green IT" and similar) is found in the fifth position after "Green Human Resources", "Green Marketing", and "Green Supply Chain" that gained interest during this period but are not related directly related to the application of technologies.

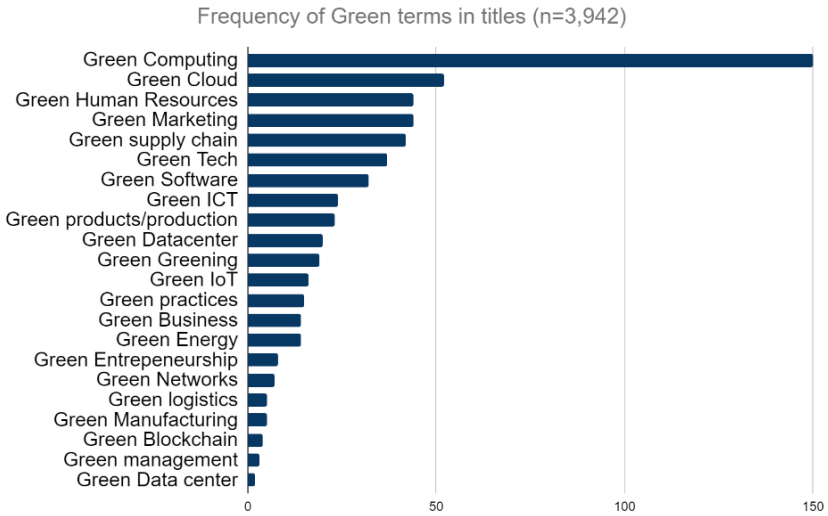

Figure 15 Frequency "Green" concepts in articles obtained

- Internet of Things appears as a topic in significant number of studies retrieved (either from a Green IT perspective or not). Internet of Things is usually backed up by intensive cloud computing capabilities to process all the data (sometimes in real time) received (A. Ullah et al., 2020). This new paradigm called “CloudIoT” has intimate relation with the data centers that support it as a perfect ally for many Big Data applications.

- Other growing topics are related with Software Sustainability, underneath which many issues have been researched from how to make developers aware and accountable for the environmental impact of inefficient implementation (I. Starxin, 2019) analyzed on several dimensions: code, performance, functional, or safety attributes. Or even benchmarking against energy efficiency considering different algorithms such as Machine Learning methodologies (G. D. Silva, 2021) or even programming languages (I. Hamizi et al., 2021).

In the followin chapter, the main take aways from this SLR are presented in line with the Research Questions initially proposed.

4. SLR Findings and discussion

Through this chapter, the main conclusions drawn from the SLR are presented. As a first step, an evaluation of the status on the Research Questions (whether these have been answered). Following, a discussion on the key findings and details on the state of art of Green IT on academic publications are discussed.

4.1. Research Questions

RQ 1.- How much Green IT contribution has there been since 2018?

As stated in previous section, the evolution of new publications under the scope of Green IT does not reflect a significant trend. The number of articles with title Green IT decreased from 2018 (55) to 2021 (39). Data center is another topic that showcases a downward trend from 2018 (34) to 2021 (25). Nevertheless, there has been significant increase in topics related with sustainability in general, innovation and performance.

Overall, Green IT is still a very relevant topic, although gains presence articles that tackle Green IS and software to enhance environmental goals. Green IT encapsules a vast variety of research topics, but, as researchers interpret this area as directly related with hardware, we encountered many publications tackling the adoption by the different industries (different surveys addressing similar strategies but changing context), e-waste (how to control de life cycle of electronic devices, e.g. with legislation and standards), or the transition to renewable energies. Despite of the subarea of virtualization (which helps to mitigate significant issues from the current utilization of technologies), this scope seems to much more limited (currently) than the potential software and Information Systems in General.

RQ 2.- What research topics have been addressed?

From the literature review we have located several topics have been covered by different authors across the globe. Some of the most important are described below:

a) A total of 121 articles have been reviewed under the scope of Data Centers and Green IT. Some key areas that have been target of the research during this period include:

- Architecture, infrastructure (including networks), and cooling systems. A traditional scheme of consumption for DCs utilizes 40% of the total energy consumption for refrigeration purposes, similar to the power used for servers (L. Hernandez et al., 2020).

- Scheduling, migration and server consolidation, Virtual Machine and resource allocation algorithms, demand response prediction and strategies.

- Smart energy grids and renewable resources: solar, hydrogen, water usage… Besides, several articles have been found covering the

- Efficiency, as a benchmark over the different measures and empirical data. Researchers tend to compare metrics to indicate possible gaps in assessments.

- Carbon control and minimization of emissions (to zero).

- It is also relevant the fact that some authors also claim that datacenters have sufficient power to induce to global benefits and challenge current issues from technological industry such as the obsolescence of devices (F. A. Schulze, H. Arndt, H. Feuersenger , 2021).

b) Application topics around how Sustainable Software and Green IT/IS, which are mostly the leverage of technology to achieve environmental goals. For example, implementing the digitalization of processes in key industries (healthcare, food manufacturing, among others).

c) Studies covering IoT or IoE are other area originated from the disruption of new technologies. This topic touches on multiple applications (from mobility and transport to healthcare) and impacts (balance of performance for data centers and networks such as 5G).

d) Security represents an important concern related to Green IT. There is not a direct impact on emissions, but energy and efficiency leaks Green security: ciphers. Requirements to be green IT.

e) Green AI: Energy efficiency in algorithms. There are a lot of articles illustrating the differences in performance and resource utilization by algorithms. For instance, Machine Learning is covered: Decision Trees, Fast Decision Trees, SDN Neural Networks

f) From a management perspective there have been several studies covering the methodologies to evaluate the different dimensions that management needs to address to evaluate the Green IT compliance and maturity of an organization or processes. Some of them via Scorecard Models (see Table 6). Other authors reflect on the existing standards and evolution (mainly ISO) that regulate organizations in regards of their sustainable IT practices (see Table 7).

Organizational responsibility with Green approach	Does the organization evaluate models and alternatives to assign responsibilities oriented to Green IT?	0 - 4
	Does the organization evaluate the competencies of those responsibles with focus on Green IT?	
	Does the organization ensure the compliance of IT plans towards an environmentalist approach?	
IT acquisition with focus on Green	Does the organization analyze costs and risks derived from Green IT?	
	Does the organization apply formal procedures for Green IT assets purchase?	
Human Factor behind IT with scope in Green	Does the organization measure human factors within the activities under Green IT?	
	Does the organization guarantee the consistency of Green IT activities aligned with the Human component?	
...	...	

Table 6 Sample factors to evaluate the maturity of Green IT practices in organizations

	Description
ISO 14000	Environmental responsibility
ISO 15504	Software process improvement capability determination
ISO 17021	Conformity assessment for bodies providing audit and certification of management systems
ISO 19011	Guidelines for auditing management systems
ISO 30132	Guidelines for the end-to-end evaluation of energy effectiveness of a reference computing model and suggestions for determining the energy effectiveness of a computing model
ISO 33000	Revises the ISO 15504 for the evaluation and improve of process capability and maturity
ISO 38500	Sets out six principles for good corporate governance of IT: Responsibility, Strategy, Acquisition, Performance, Conformance, and Human behavior

Table 7 Sample of key ISO rules addressing Green IT Standard

RQ 3.- Who are the main agents boosting the evolution of Green IT?

Across several of publications, a common view of non-effective implementation of Green IT is shared. Hence, these studies target to find the best strategies to enhance the adoption in real practice. Some sectors are specifically covered. This is the case of healthcare, for example, in which new trends in telemedicine and the constant requirement to reduce costs in electricity and equipment are leading to the implementation of virtualization of systems. Green IT has a potential application to this. On the other hand, studies and concrete surveys have been deployed to understand what the actions of employees are and how are they aligned with the Green IT implementation of organizations. All these conveying a disconnection between the sustainability goals of

companies and the limited training/knowledge of application in a day-to-day basis. Is this an issue in the way society teaches about sustainability? Figure 16 exemplifies the quest for finding factors that would indicate what is the weakest link in the transmission of the importance of GIT. Some papers address the non-existence of concrete education on this matter.

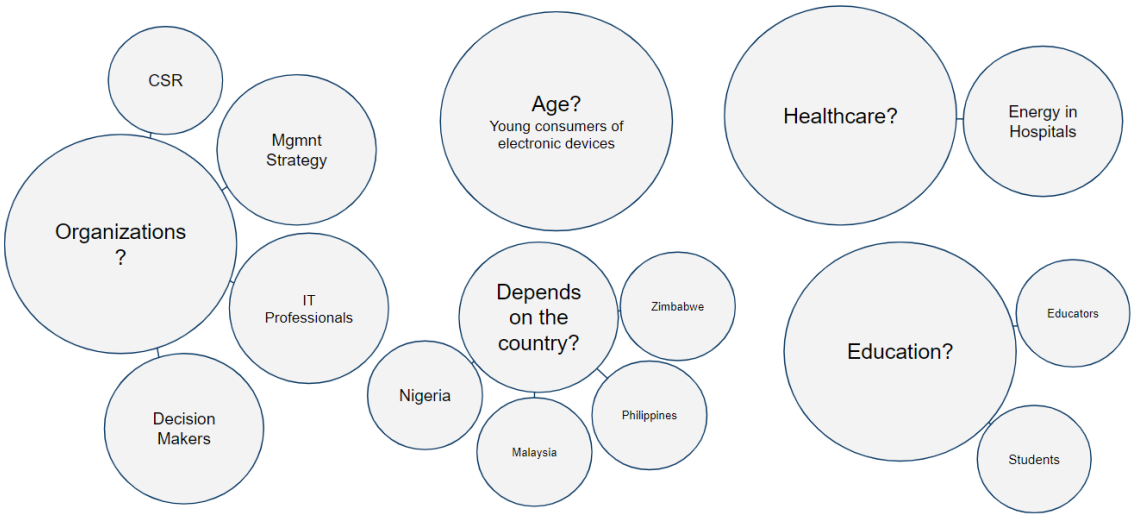

Figure 16 The implementation of Green IT can be analyzed considering the nature of sectors, individuals participating in, or other demographic factors.

Governmental organizations are also aware of the need for impulse to implement Green IT practices. In specific regions in the globe such as Malaysia, there has been a strong (although declining in number of contributions) interest on the Green IT area as it was promoted by government rules declared in 2009. Others such as in GCC countries, there is a lack of plans for sustainability and a first standard step of gathering information via surveys and reports is advised (Albahlal, 2019).

Majority of sectors are covered directly or indirectly through the literature. Including: Oil&Gas, auto industry, food manufacturing, transport, healthcare, tourism, finance, telecommunication, even websites. There is special focus on the education sector and universities (as it is an easier environment for transparency and testing purposes).

RQ 4.- What are the limitations and gaps of the existing research?

From the universe of literature obtained and analyzed we still see that the area of post-implementation is still in short supply. There is a vast amount of articles analyzing surveys and audit processes to retrieve information towards a much stronger adoption of Green IT. The vision is global, yet the depth of analysis is shallow and represents a very initial stage towards the maturity of Green IT.

Authors point out that future lines of work will focus on the integration of the multi region, load balance energy depending on the availability of

energy and access to data, but overall renewal energy to greening data centers.

From the list of disruptive technologies that cannot be captured yet but will be a potential source of investigation we can find the relationship between DCs and Smart cities. As an example, Catalyst project (2020) tried to establish, with the EU, a roadmap for greener Data Centers transforming them into “flexible multi-energy hubs” (European Union, 2020). Additionally, blockchain has been touched by studies from a cost saving perspective but not really from a Green IT or direct impact in data center consumption explicitly. Even though it is estimated that consumes more than 100TWh a year (Columbia Climate School, 2022).

Lastly, only two articles were found to cover the direct impact of the COVID-19 pandemic on data centers and virtualization, both from 2020. Authors emphasize research amidst the pandemic is unexplored even though digitalization has been a competitive advantage for enterprises to survive (A. Jr. Bokolo, S. A. Petersen, 2021).

4.2. Discussion

The research questions helped us to understand better what the current state of art in the Green IT research is. Contrary to what was indicated from previous SLR, research in regions that lacked promotion are now being covered, such as: Africa, South America, or South and South-East Asia.

On the other hand, notable number of articles tackle the adoption of Green IT, which is in line with what was already seen in past SLRs. Perhaps, we could see these contributions through the lens of a competence vs. confidence relationship (Dunning Kruger) in which experts and regulators mandate the immediate requirement to act conforming the rules of Green IT (see Figure 17). Afterwards, realizing there are multiple causes behind its limited implementation which has not been as effective as required, similar to the reasoning behind the origin of Green IT by Dewatcher (Dewatcher, 2020). Consequently, leading to research the connection between beliefs and actions performed by individuals (belief-action-outcome theory).

There is a sensation of overuse in surveys, that measure the consciousness on the Green IT and incentives for people to assume responsibility over the sustainability issue. It is seen as an entry mechanism in the process of adoption (A. T. Farghaly, A. M. Mazlina, 2019). Nevertheless, it seems very superficial due to, perhaps, the lack in transparency from private companies. Other topic that appears to be over-covered is the measurement of efficiency. It is not clear whether the elaboration of more articles would contribute to better management of Data Centers.

New technologies (such as IoT or IoE, blockchain) are disruptors for data centers and energy consumptions control in this new era. Even with the successful transition from carbon-source energy to renewable resources, the exponential generation of data oblies governments and private organizations to elaborate transparent rules to not lose the track of only a 2% of CO2 emissions.

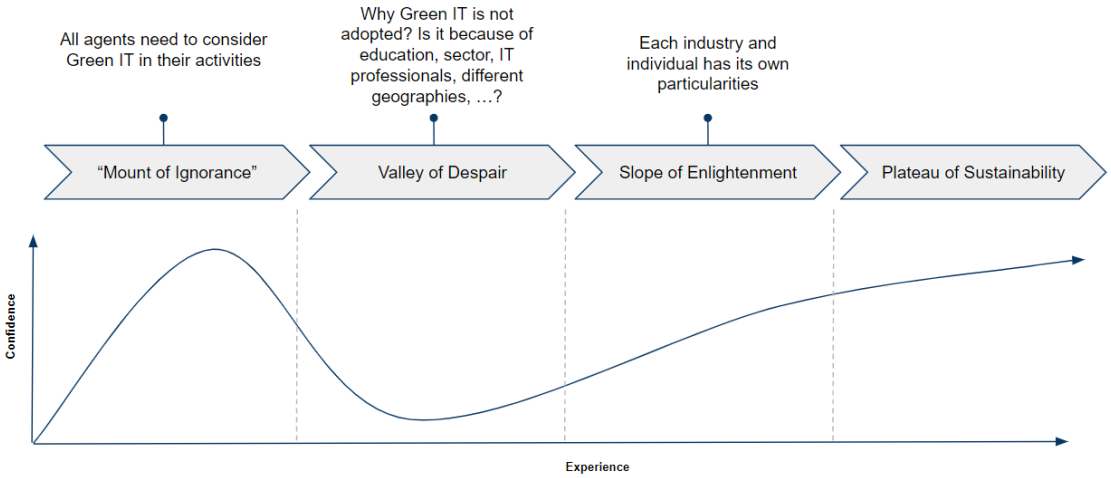

Figure 17 Representation of the analysis in the effectiveness and implementation of Green IT

5. Study Conclusions

The study contributed with an overview about Green IT in terms of sustainability practices mainly focus on data centers and helped to understand the universe of sustainability in ICT world in general.

5.1. Results Summary

This study served different purposes:

- Firstly, the role of Green IT in holistic perspective understanding the main stakeholders and agents of change in a world towards new and demanding sustainable goals.

- Secondly, the SLR established a methodological approach to assess the current state of art of Green IT following the Research Questions defined and answered them with the review of 3,942 articles.

- Lastly, how Data Centers are a key agent in the journey to sustainability of technologies that we use in our day-to-day life. During recent years they have been the target of efficiency measures including hardware and equipment (such as energy sourcing), or software and processes (such as load balance).

5.2. Conclusions

This thesis has been of significant relevancy to understand the role of the Systematic Literature Reviews. They not only serve as a fundamental element to aggregate the existing research of an area from produced articles, but also stimulate the future works identifying topics of future interest and gaps.

As defined before, Green IT has emerged as the set of tools to offset the current trends on exponential digital growth that can damage the long term sustainability of technologies. This includes higher volume of data obtain from many different sources. Some of them, such as the new Industry 4.0 and the IoT, are key for the future of technologies and its application in projects to improve the sustainability in other areas. It has been demonstrated how critical is to look for the practical integration not only the definition of theoretical frameworks.

Regarding planning, initial schedule was successfully followed with a total of 6 months dedicated to the project (since November 2022) to develop the three workstreams initially defined: first a Literature Search, secondly an Analysis focused on Data Centers, and lastly producing the final document of the project. However, some activities were less explored than expected due to time and complexity restrictions. In the case of the “Literature Review” workstream it involved much more iterations than the initial planning. Besides, the quality assessment was an objective informally performed without a quantitative criterion to follow and compare among the different articles available. Other adjustments were considered during the definition of Research Questions, as the initial thought was to include a detailed section for energy efficiency

management in Data Centers. Eventually this was removed due to the complexity of the problem and extensive literature.

5.3. Study Limitations and future work

On one side, during the process of this study, some scope limitations have been found. Particularly in the depth of analysis relative to the understanding of power utilization in datacenters. For instance, some articles published in a foreign language (such as Arabic or German) were found. Since some Spanish written publications were processed, it would be interesting to also have considered other papers in foreign language. Those will presumably cover the specific situation of a region.

- Definition of SLR. It is clear when the title says Literature Review, but some publications performed SLRs even when this was not the main goal, i.e., as a required exercise before any analysis.

- As already mentioned by authors of past SLRs, there is still some perceived unclear path from researchers on how to contribute to either Green IT or Green IS or Green ICT, versus very specific areas of research. This has been an obstacle in classifying articles. For instance, we have found two typical cases when filtering publications:

    - Articles that contribute to very specific area of improvement in technical methodologies for data centers but are not explicitly recognized by the author as Green IT contribution.

    - Contributions that want to address the development of Green IT in title and abstract. Although, the final conclusion of the paper derails from it covering a non-technology related topic (e.g. building construction).

- Developed countries establish rules and standards, like the European Commission does a great job serving as a common supervisor for the activity across different countries in the continent. The existence of many studies addressing the future of energy demand of data centers is quite detailed in this context. However, underdeveloped countries will suffer huge change in the next 20 years. Integrate forecasts related to potential networks in countries with high growth rate is more than needed as it would change our current perception of the adoption of GIT.

Lastly, after all the results obtained as the output of the SLR and the discussion, there are some potential work lines for future study:

- We have observed the recent evolution of new concepts and paradigms in the world of cloud computing that would be interesting to catch and analyze from the perspective of energetic efficiency: increase of IoT and impact on data centers, or decentralized data centers to seize energy available and be closer to users (Edge computing).

- Research will continue to explore the specificities of different geographies. Future re-assessment of the literature would be needed once the implementation of current GIT measures in developing countries start producing results.

- There are some trends of alternative methodologies to assess the Systematic Literature Review from a meta and network analysis that represents the citation network and co-occurrences with the evolution of main themes of GIT and emerging topics. (P. Murugaiyan, R. Venkatesakumar, 2018).

- As seen, Green IS has been gaining momentum during last years. It would be interesting to analyze if there are any gaps in the research perform in this field.

6. Glossary

CMS – Carbon Management System

CSFs – Critical Success Factors

ESG – Environmental, Social, and Corporate Governance

EMS – Environmental Management System

EU – European Union

IaaS – Infrastructure as a Service

ISO – International Organization for Standardization

IT – Information Technologies

IoE – Internet of Everything

IoT – Internet of Things

ICT – Information and Communication Technologies

IS – Information Systems

GIT – Green IT

GIS – Green IS

PaaS – Platform as a Service

RQ – Research Question

SaaS – Software as a Service

SLR – Systematic Literature Review

GHG – Greenhouse Gases

PUE – Power Usage Effectiveness

SLR – Systematic Literature Review

VM – Virtual Machine

7. Bibliography

A. A. Muslim et al. (2019). *Organizational Green Information Technology (IT) adoption theoretical frameworks: a Systematic Literature Review.*

A. Santhanam, C. Keller. (2018). *The Role of Data Centers in Advancing Green IT: A literature review.*

A. T. Farghaly, A. M. Mazlina. (2019). *A study on Green IT awareness among University Malaysia Pahang Students.*

A. Ullah et al. (2020). *Rise of Big Data Due to Hybrid Platform of Cloud Computing and Internet of Thing.*

Amazon, W. S. (2022). *Amazon - What is cloud computing?* Retrieved from https://aws.amazon.com/what-is-cloud-computing/

B. A. Jr, M.A. Majid, A. Romli. (2020). *A generic study on Green IT/IS practice development in collaborative enterprise: Insights from a developing country.*

B. Kitchenham, O. B. (2009). Systematic literature reviews in software engineering – A systematic literature review.

Bokolo, A. J. (2020). *Examining the role of green IT/IS innovation in collaborative enterprise-implication in an emerging economy.*

Borgini, J. (2020). *Tech Target*. Retrieved from https://www.techtarget.com/searchdatacenter/tip/A-quick-primer-on-the-ANSI-TIA-942-standard

Cisco. (2022). *What is a Data Center?* Retrieved from https://www.cisco.com/c/en/us/solutions/data-center-virtualization/what-is-a-data-center.html

D. Cordero, V. B. (2020). IT Governance and Green IT: a systematic review.

Dewatcher, N. (2020). *Critical Analysis of Green IT in Belgian data centres.* Thesis.

Elkington, J. (2018, June). 25 Years Ago I Coined the Phrase “Triple Bottom Line.” Here’s Why It’s Time to Rethink It. *Harvard Business Review*. Retrieved from https://hbr.org/2018/06/25-years-ago-i-coined-the-phrase-triple-bottom-line-heres-why-im-giving-up-on-it

Eric Masanet, A. S. (2020). Recalibrating global data center energy-use estimates. *Science*.

European Commision - Delivering the European Green Deal. (2022). Retrieved from https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/delivering-european-green-deal_en#key-steps

F. A. Schulze, H. Arndt, H. Feuersenger . (2021). *Obsolescence as a Future Key Challenge for Data Centers.*

G. D. Silva. (2021). *Performance and Energy efficiency Analysis of Machine Learning algorithms Towards Green AI: a case study of decision tree algorithms.*

Gillis, A. S. (2021, August). *Tech Target*. Retrieved from https://www.techtarget.com/searchdatacenter/definition/edge-data-center

I. Hamizi et al. (2021). *A Meta-analytical Comparison of Energy Consumed by Two Different Programming Languages.*

I. Starxin. (2019). *Sustainable Software Development - Criteria from theory and their use in practice.*

IDC. (2020). *Worldwide Semiannual Public Cloud Services Tracker.*

International Energy Agency. (2021, Nov). Retrieved from https://www.iea.org/reports/data-centres-and-data-transmission-networks

J. A. Garcia-Berna et al. (2019). *Green IT and sustainable technology development: Bibliometric overview.*

L. Hernandez et al. (2020). *Measurement of Energy Efficiency Metrics of Data Centers. Case Study: Higher Education Institution of Barranquilla.*

Loeser, F. (2013). *Green IT and Green IS: Definition of Constructs and.*

M. Landum, M. Moura, L. Reis. (2020). *Evaluating Green IT in local administration.*

M. R. da Rosa. (2020). *Adoption of Green IT in the university environment: systematic review of sustainability practices in educational institutions.*

M. Singh, G. P. (2020). Towards adoption of Green IS: a literature review using classification methodology.

M. Singh, G. P. Sahu. (2020). *Towards adoption of Green IS: A literature review using classification methodology.*

M.D. Esfahani et al. (2018). *Green IT/IS Adoption within Organizations: A Systematic literature review.*

Marta Chinnici et al. (2021). *SNMP for Cloud Environment Energy Efficiency.*

Md Abu Bakar Siddik, A. S. (2021). *The environmental footprint of data centers in the United States.*

Microsoft. (2022). *Azure - What is the Cloud?* Retrieved from https://azure.microsoft.com/en-us/overview/what-is-the-cloud/

Murugaiyan Pachayappan, R. V. (2020). *A Graph Theory Based Systematic Literature Network Analysis .*

Okoli, C. (2015). *A Guide to Conducting a Standalone Systematic.*

P. Murugaiyan, R. Venkatesakumar. (2018). *A Graph Theory Based Systematic Literature Network Analysis.*

Paolo Bertoldi, M. A. (2017). *Trends in data centre energy consumption under the European code of conduct for data centre energy efficiency.* Retrieved from Joint Research centre (European Commission).

Red Hat. (2022). Retrieved from https://www.redhat.com/en/topics/virtualization

S.Asadi et al. (2019). *Investigating factors influencing decision-makers' intention to adopt Green IT in Malaysian manufacturing industry.*

Senate, U. (2020). *Energy Act of 2020.*

Shun Caia, X. C. (2013). *Exploring the role of IT for environmental sustainability in China: An empirical analysis.*

T. Velásquez et al. (2019). *The role of green it in the non-functional software development requirements: Perspectives for functional design.*

Taro Lennerfors, T. (2018). *"We Started Building Green IT Back in the 1970s": Making Sense of.*

TechTarget. (2022). *Tech Target - Energy Star*. Retrieved from https://www.techtarget.com/searchdatacenter/definition/Energy-Star

US-Senate. (2015). *United Nations - Paris Agreement.* Retrieved from https://www.un.org/en/climatechange/paris-agreement

Won Kim, S. U. (2009). Cloud Computing: Today and Tomorrow.

8. Appendix

8.1. **Annex I.** Google Scholar processing of papers