

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

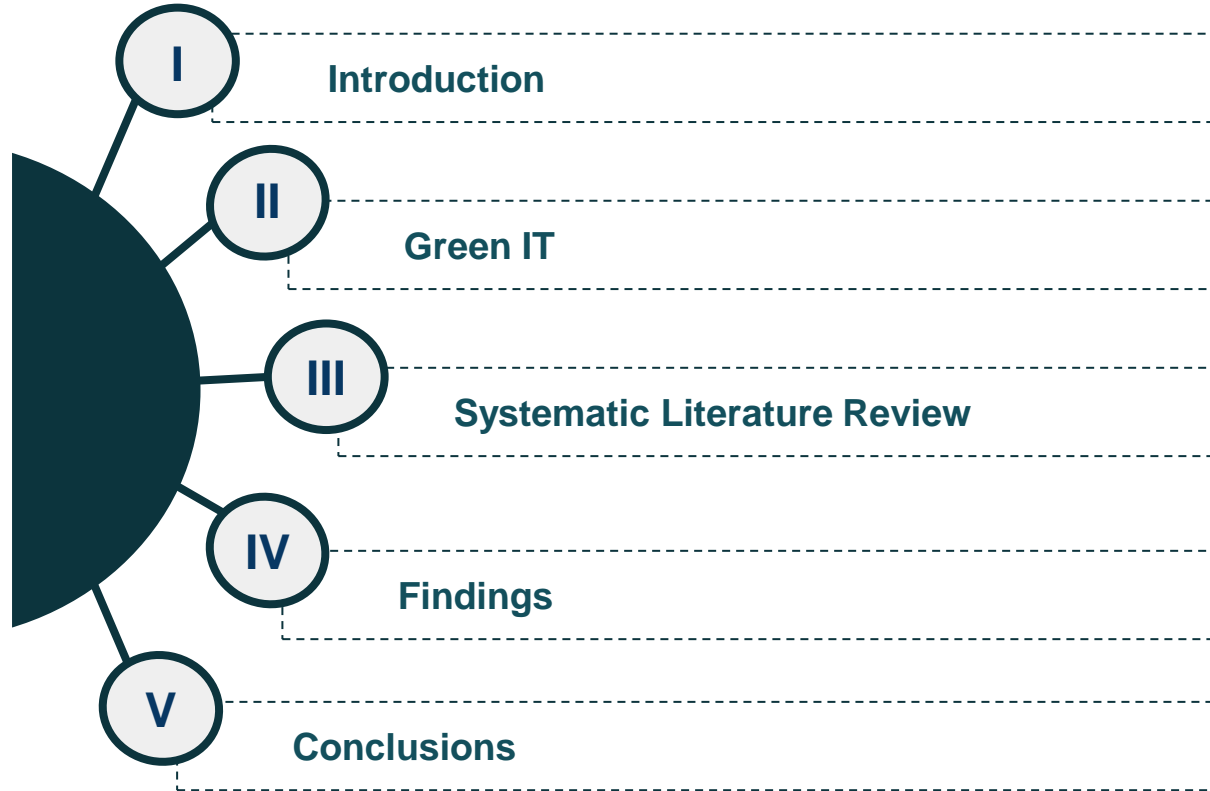
June 2022

Jose Pertierra das Neves

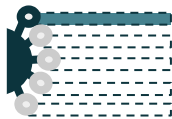
Master's Degree

Computational and Mathematical Engineering

Agenda



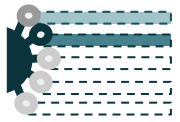
I. Introduction



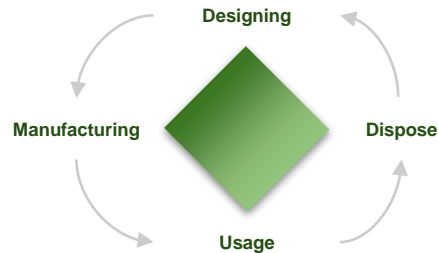
Sustainability on Information Technologies focuses on direct impact from equipment or hardware and its processes. Data Centers are a vital piece of our current infrastructure, preserving communications and transmission of data. However, their impact in CO2 global emissions is not negligible at all. They account for almost 2% of the total GHG (similar to the commercial air transportation industry), and governments are already pressuring to reduce to the minimum these negative contributions. During the COVID pandemic companies and individuals increased their digital footprint and so did the technological infrastructure.

1. Review the existing literature, case studies and best practices on Green IT.
2. Review the existence of common frameworks with focus on current regulatory restrictions.
3. Understand the current mechanisms and methodologies for efficiency optimization (a concrete look to data centers management).
4. Obtain a holistic approach on how data centers are defined and categorized.
5. Generate a SLR conducted analyzing the different areas of research during the period selected.

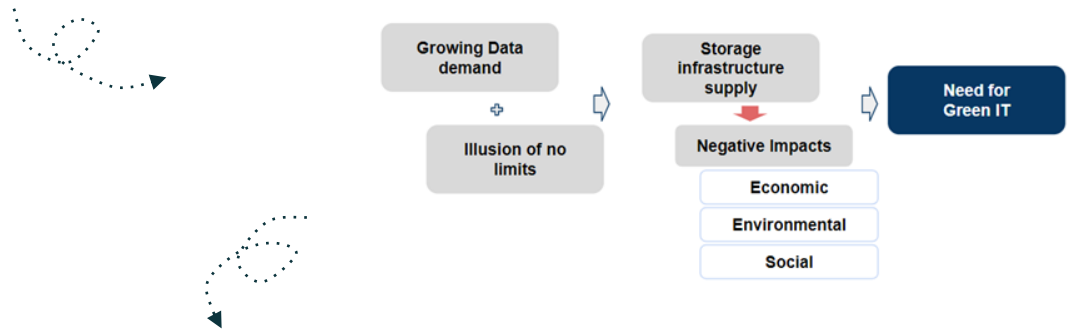
II. Green IT (1/2): What is GIT?



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. Other researchers sustain that Green IT emerged long time ago, as a natural result of the evolution of technology in the 70s (Taro Lennerfors 2018).

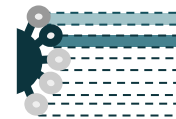


It definitely gained huge importance after key publications in the 2000s aligned with the beginnings of extensive regulation on CO2 emissions with a broader scope covering much more industries.



“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” - (Elliot, 2011, Erek et al., 2011)

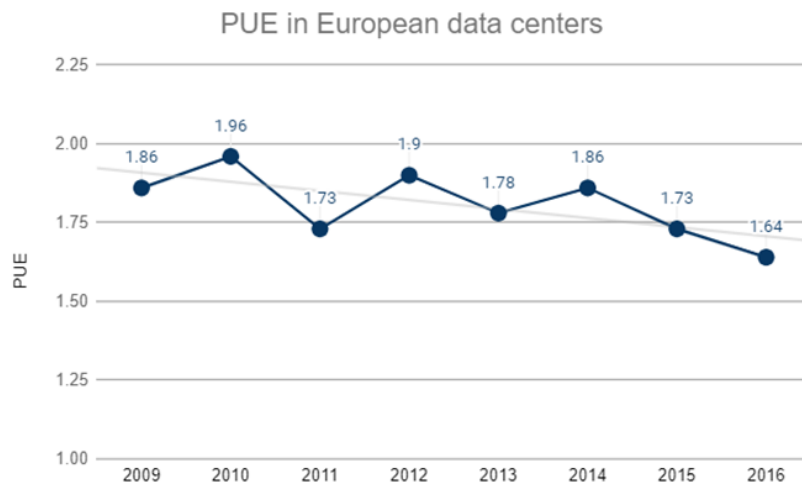
II. Green IT (2/2): Data Centers & Efficiency



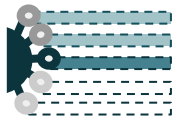
Inside the universe of technologies and the risks of harming the environment, we find data centers as an easily identifiable agent that serves as intermediary and suffers from the exponential growth in digitalization nowadays.

Some governmental agencies dedicate efforts on supervising the activities of Data Centers. In Europe, energy consumption from data centers was 76.8 TWh during 2018. Accounting for the 2.7% of total energy consumption in the EU. Recent studies forecasted that it will potentially reach ~100TWh by 2030. Nevertheless, data centers are successfully implementing practices to increase the efficiency of their operations (measured by the Power Usage Effectiveness for example in the case of the European Code of Conduct).

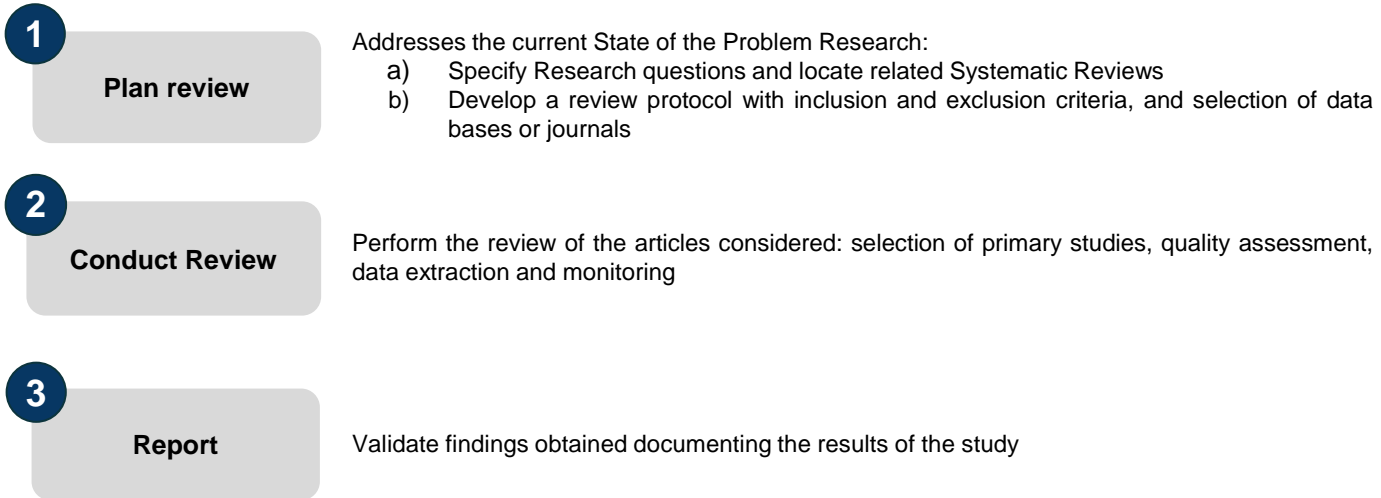
US also offers high transparency and regulation such as the EPA (Environmental Protection Agency) and the Energy Act that targets directly good practices to be implemented by data centers and energetic transition



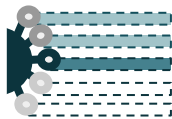
III. SLR (1/5): What is an SLR?



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:



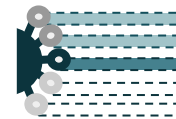
III. SLR (2/5): Why an SLR?



In order to understand the current state of art of the research lines of Green IT, a total of 17 SLRs have been reviewed and analyzed in depth to understand limitations and potential gaps:

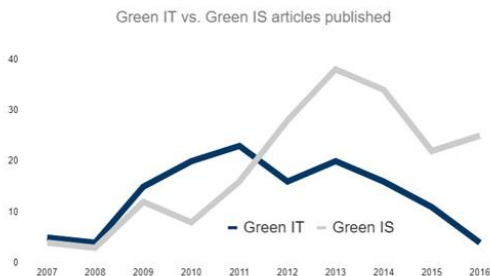
1. GIT/GIS General	
Year	Title
2018	The Role of Data Centers in Advancing Green IT: A literature review
2019	Green IT and sustainable technology development: Bibliometric overview
2020	IT Governance and Green IT: a systematic review
2. Green IT adoption	
2.1. Organization adoption	
Year	Title
2018	Green 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 Information Technology in Indonesia – A systematic Literature review
2021	Análisis bibliométrico de green it en el ecuador

III. SLR (2/5): Why an SLR?



Apart from providing a better understanding of the evolution in research over a specific area during the period of 2018 to 2021, the review of previous SLRs inspired the need to fill some of the open questions they had when the studies were performed.

- 1 Is Green IT in declining interest measured by published articles?



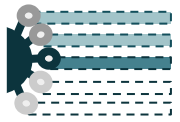
- 3 Missing key sectors such as high education

- 2 There are regions that rarely produce contributions to this topic. Need more in developing countries

Rarely used	
Regions	South America, Southeast Asia, South Asia, North Asia, Middle-East, Africa

- 4 The impact of newest technologies and events such as COVID pandemic

III. SLR (3/5): approaching the SLR



1

Plan review

2

Conduct Review

3

Report

a) Research questions

- RQ 1.-** How much Green IT contribution has there been since 2018?
RQ 2.- What research topics have been addressed?
RQ 3.- Who are the main agents boosting the evolution of Green IT?
RQ 4.- What are the limitations and gaps of the existing research?

b) Keyword selection

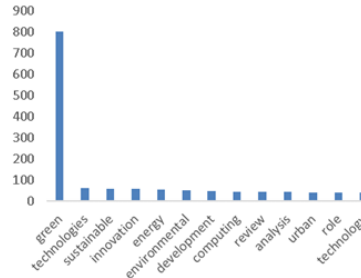
Phase 1

Preliminary analysis of Green IT occurrences

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

Phase 2

Inclusive approach and analysis of terms in titles and abstracts



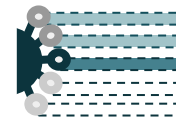
Phase 3

Final query including additional key terms for specific filtering:

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

	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

III. SLR (4/5): conducting search and review



1

Plan review

2

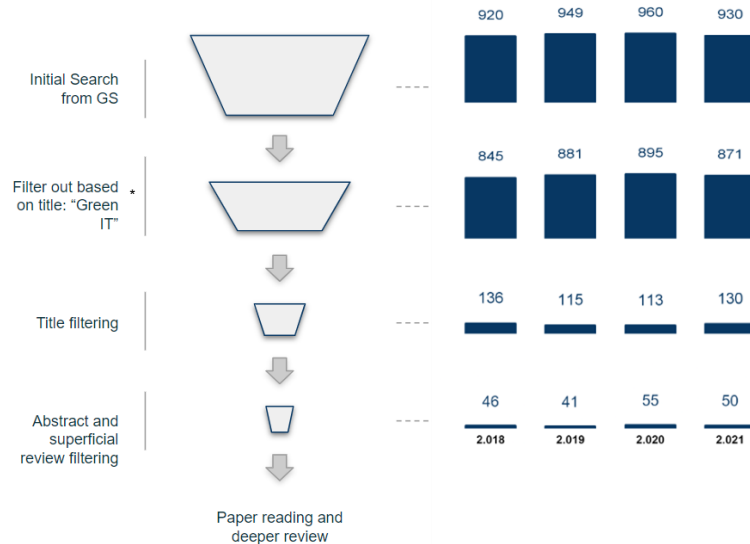
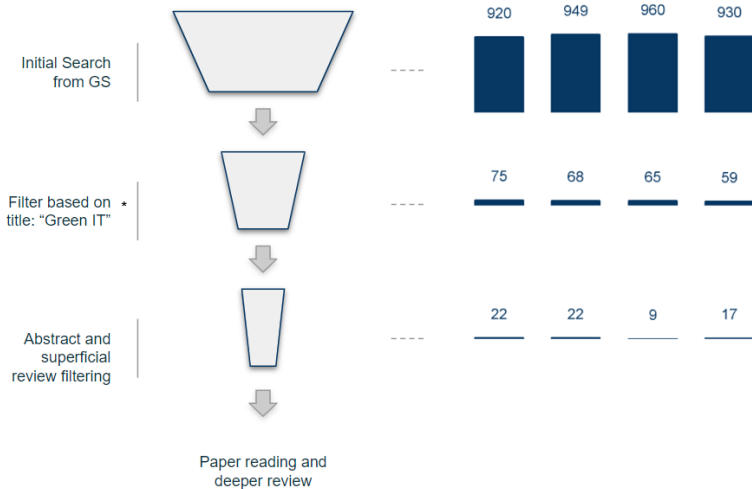
Conduct Review

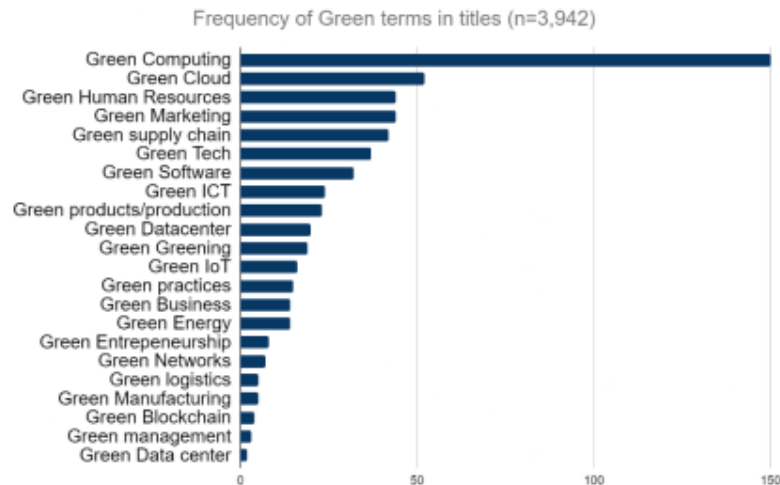
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Report

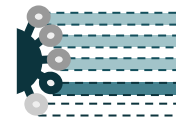
Green IT in title

Green IT not in title





III. SLR (5/5): Preliminary results



1

Plan review

2

Conduct Review

3

Report...

Applying the process of analyzing the terms from the titles in the documents obtained we can infer quantitatively 3 different categories of evolution:

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

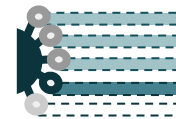
2) **A clear increase was expected:**

- Green IT
- data center
- energy
- computing

3) **Not a significant number of publications:**

- principles
- ISO
- governance
- server

III. SLR (5/5): Preliminary results



1

Plan review

2

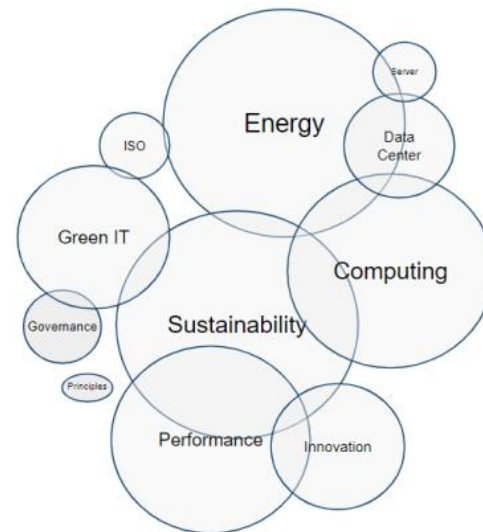
Conduct Review

3

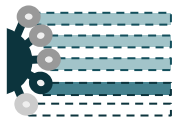
Report...

With the terms used within the query to get a deeper view if we present them in a matrix of 1 to 1 occurrence 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)

	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



III. SLR (5/5): Preliminary results



1

Plan review

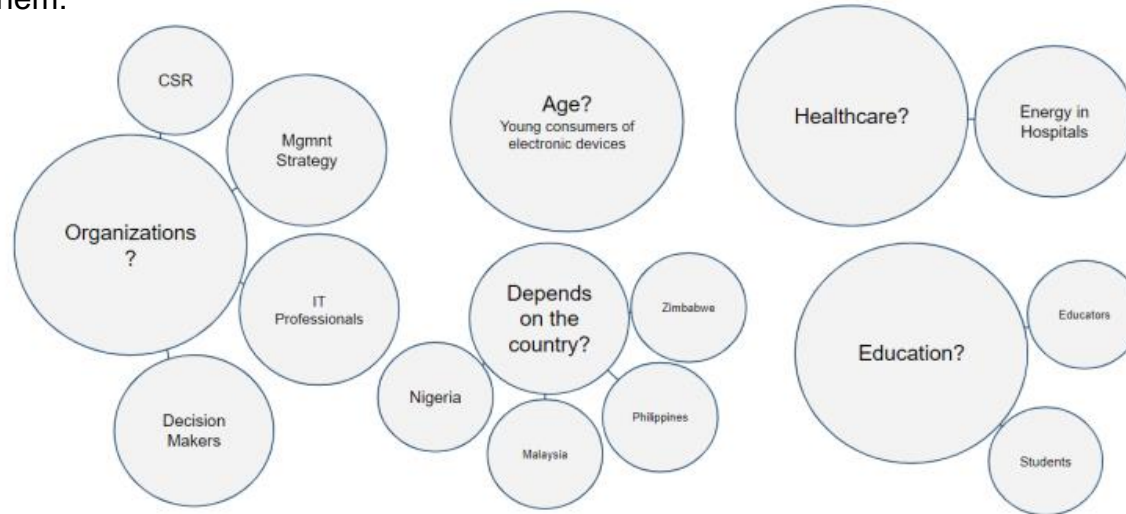
2

Conduct Review

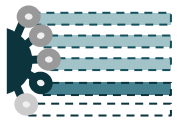
3

Report...

Across several number 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, as well as regions or type of organizations. Below we can see a sample of them:



IV. Findings



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

- Green IT does not reflect a significant trend.
- Other topics such as sustainability, performance and innovation grow.
- Authors consider Green IT also covering hardware management: e-waste, different industries, or the transition to renewable energies. And this scope is much more limited than Green IS.

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

- Majority of sectors are covered: Oil&Gas, auto, food manufacturing, transport, healthcare, finance, tourism, even websites. Education and Universities gained special focus.
- Contributions covering developing countries have been found: Africa, South America, Southeast Asia.
- Governments also participate in promoting Green IT.

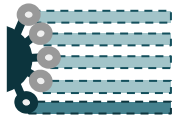
2 What research topics have been addressed?

- Data Centers: infrastructure and cooling systems, scheduling, migration, VM and resource allocation algorithms with focus on response prediction and demand strategies, smart grids and renewable resources (carbon control and zero emissions), or benchmarking and metrics.
- Applications and Sustainable Software.
- IoT and IoE.
- Security and energy leaks.
- Green AI: efficient algorithms.
- Management frameworks (maturity models based on scorecards) and standards (ISO)

4 What are the limitations and gaps of the existing research?

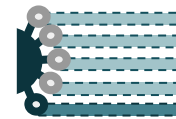
- Analyses on post-implementing is still in short supply. Many articles about adoption, yet this results into a very initial stage towards the maturity of Green IT.
- Some disruptive technologies are emerging but not fully covered yet, such as smart cities, or blockchain.
- Only two articles were found covering the impact of the COVID-19 pandemic.

V. Conclusions (1/3): Summary



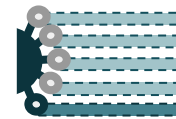
Green IT	Holistic perspective understanding the main stakeholders and agents of change in a world towards new and demanding sustainable goals.	
SLR	Established a methodological approach to assess the current state of art of Green IT following the Research Questions defined and answered them with the review of almost 4k articles.	
Data Centers	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).	




V. Conclusions (2/3): Limitations



Identify SLRs	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.	
Boundaries	Unclear path from researchers on how to contribute to either Green IT or Green IS or Green ICT, versus very specific areas of research.	
VUCA world	Underdeveloped countries will suffer huge change in the next 20 years due to the deployment of new networks and faster access to data	

V. Conclusions (3/3): Future work lines

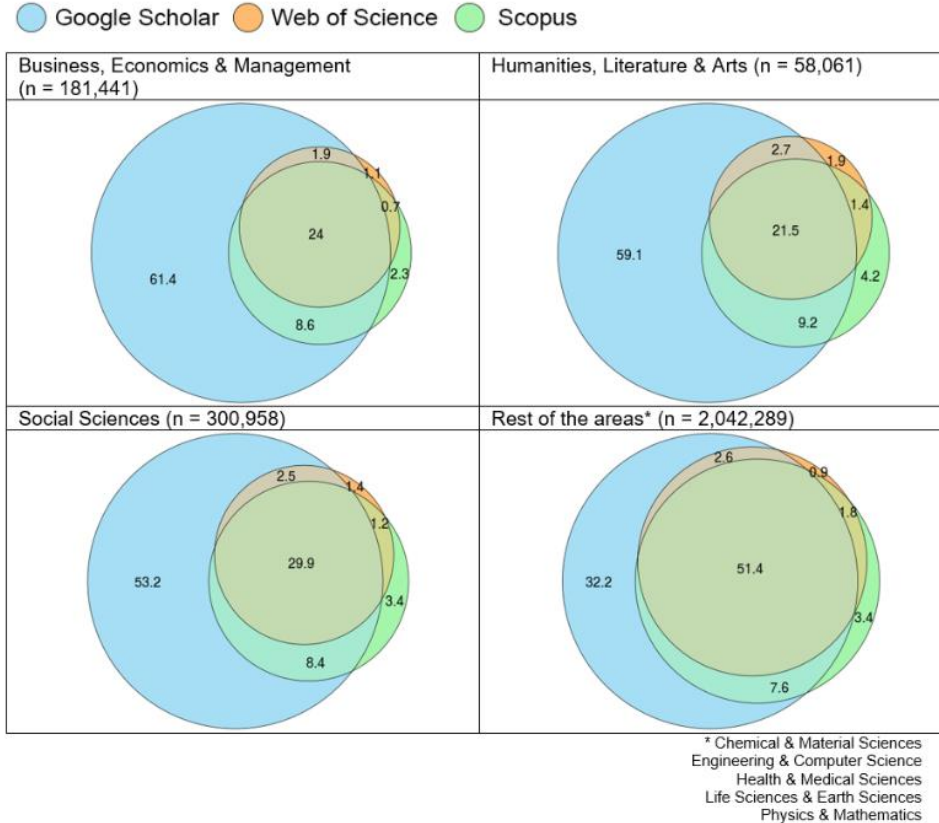


New areas	Interesting to catch and analyze from the perspective of energetic efficiency: increase of IoT and impact on data centers, or decentralized data centers to seize energy available and be closer to users. Others gained traction and significant relevance such as Green IS	
SLR	Future re-assessment of the literature would be needed once the implementation of current GIT measures in developing countries start producing results.	
Other SLR methods	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	

Thank you!

Annexes

I. Databases for scientific articles



II. Articles extraction from GS (titles and abstracts)

1

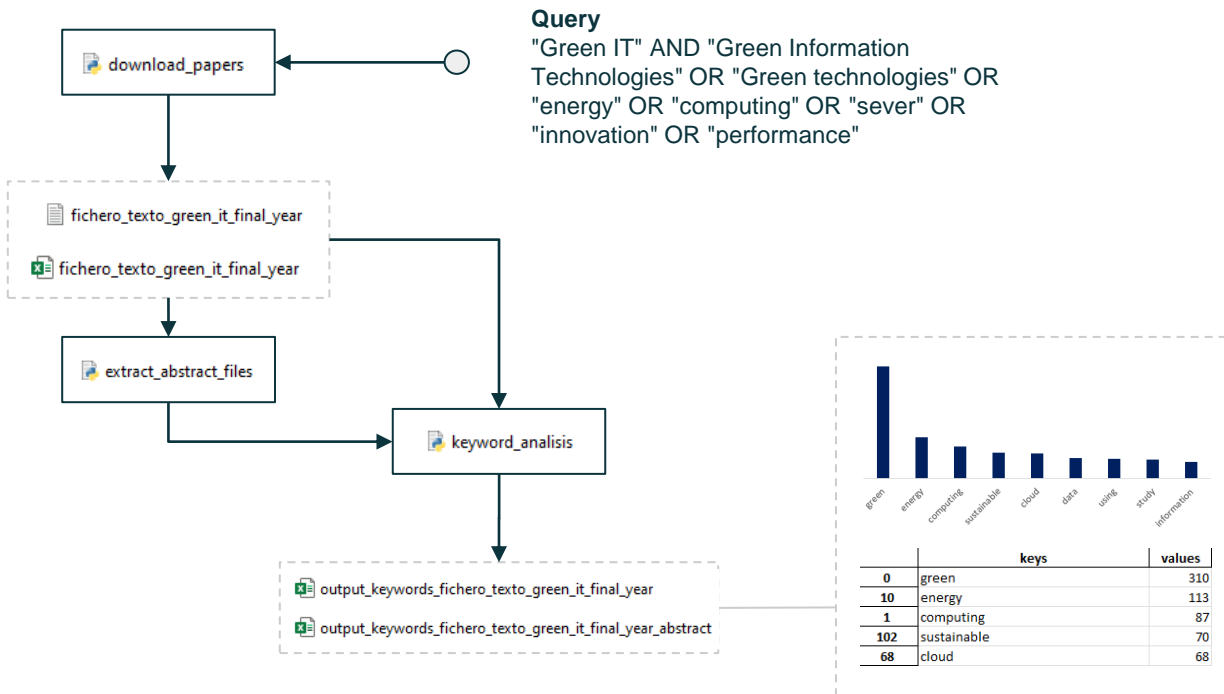
Download from
GS

2

Title and abstract
processing

3

Keyword extraction
and frequency
analysis



III. Interpreting the evolution of Green IT

