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A Bibliometric Network Analysis of Green Information Technology and Green Information Systems Research

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Abstract

Background: In recent years, the concepts of Green Information Technology and Green Information Systems (Green IT/IS) have attracted the attention of many researchers. Several environmental and sustainability studies have suggested that smart usage of Green IT/IS is one of the most important enablers for sustainable development in organizations and plays an essential role in greening the planet. **Objectives:** This paper aims to examine the development of the Green IT/IS field based on the published works. The focus is on analysing the keywords of related papers obtained from the Web of Science database. **Methods/Approach:** Based on the two-mode network of papers and keywords, the analysis of co-occurrence of keywords is provided. The most frequent keywords discovered by the temporal network analysis are presented from the perspective of the most prominent journals. **Results:** The main pillars of knowledge in Green IT/IS research are highlighted, and a chronological map of the field is provided. **Conclusions:** Green IT/IS's studied field shows constant growth in the last decades, and the results indicate the trends of future development in the field. The paper is one of the first studies that apply the bibliographic network analysis approach to the field of Green IT/IS.

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Introduction

In the last two decades, organizations have strived to achieve higher levels of sustainable development to contribute to the greening of the planet, primarily through the advanced use of information technology (IT) and information systems (IS) (Melville, 2010; Watson et al., 2008). The role of smart use of IT/IS in contributing to environmentally responsible human activities has become an attractive field of research and is therefore highly discussed in the literature. Consequently, aligned with the practical use in organizations, the discussions and research on these topics, two main concepts, Green Information Technology (Green IT) and Green Information Systems (Green IS), have become notable terms in professional and academic publications.

Due to the growing interest in the Green IT/IS research field, several studies have been published in recent years that deal with the related research topics. Esfahani et al. (2015) noted that the earliest study in this area was published back in 2007. Initially, the studies focused on Green IT, where the term Green IS was first introduced by Melville (2010). This work described the concept of information systems innovation for environmental sustainability and was included in the 20 most cited studies on green innovation (Albort-Morant et al., 2017). Later, Brooks et al. (2012) identified the main streams of Green IT/IS-related studies and provided a review of the literature from practitioners and academics. The authors reveal that most of the research focused on the concepts of Green IT, probably due to its popularity among practitioners. In addition, Loeser (2013) extended the literature search to the AIS electronic library using the keywords green IS and green IT and related terms such as sustain*, green or environmental. It was found that professional studies were ahead of academic ones, as most Green IT/IS papers were published in conference proceedings, while publications in top IS journals were rare.

On the other hand, Wang et al. (2015) significantly expanded the list of search terms (i.e., keywords). They classified Green IT/IS-related papers into four categories: initiation, enterprise strategies and practices, adoption framework, and outcomes. Further, Singh et al. (2020) examine five segments in the Green IS research area: Green IS concept, innovation and technology, the impact of green initiatives, measures and policies, and global context. Moreover, Esfahani et al. (2015) provided a review of research questions already addressed and the current state of research, while Bokolo (2016) used a set of search terms related to the concepts of Green IT/IS and retrieved 137 papers published in journals as well as conference proceedings. Based on this literature review, the authors provided a set of determinants that encourage/discourage organizations from incorporating Green IT/IS practices. One of the systematic literature reviews was provided by Muhammad et al. (2017), who used different search terms to retrieve Green IT/IS-related publications from various databases. The authors found that good search strings are difficult to formulate; they applied the snowballing method to complement the database search.

All these studies provide high-level research agendas and have opened new possibilities for future Green IT/IS research. One of the most important findings from the systematic Green IT/IS literature reviews concludes that the terms Green IT/IS have been vague concepts for several years. Both fundamental terms have often been used interchangeably without recognizing the differences, leading to confusion in professional and academic societies. While several authors attempted to present a clear distinction between the two terms (Brooks et al., 2012; Deng et al., 2015; Muhammad et al., 2017), Loeser (2013) distinguishes the terms based on the differences in the scopes. Following Loeser (2013), it is now clearly defined that the term "Green IT refers to measures and initiatives which decrease the negative

environmental impact of manufacturing, operations, and disposal of Information Technology (IT) equipment and infrastructure", while the term Green IS refers to "practices which determine the investment in, deployment, use and management of information systems (IS) in order to minimize the negative environmental impacts of IS, business operations, and IS-enabled products and services".

Besides the academic contribution, the research outcomes in Green IT/IS are also essential from the managerial implications point of view. Namely, Green IT/IS that are oriented to minimize the negative environmental impact is one of the key enablers of sustainable digital transformation in any contemporary organization (Gils et al., 2020). To assure organizations the valuable information for decision making for aligning the digital transformation activities with the sustainable development goals, up-to-date direction for proper use of Green IT/IS is needed. Therefore, the findings of already mentioned reviews on Green IT/IS literature are more than valuable. However, to gain a comprehensive overview of development directions, it would be worthwhile to supplement the qualitative literature research techniques with an appropriate quantitative attempt.

This paper aims to provide a comprehensive literature review on Green IT/IS to examine the development of the research field of Green IT/IS based on the published papers. Aligned this objective, the following research question was formulated: RQ: How have scientific publications on Green IT /IS research evolved over the past decades?

In addition to conventional search engines for literature analysis, advanced social network analysis (SNA) methods are applied. Our investigation will be based on Green IT/IS-related papers published in the Web of Science (WoS) database until 2020. When searching for the papers, the basic keywords Green information technology and Green information systems are expanded with various queries such as: "green information system*", "sustain* information system", "environment* information system*", "environmental informatics", "energy informatics", "green software", "green computing", "green information communication technology*", and "information system* for sustainable development". The justification for selecting the listed keywords is presented under Methodology Section.

From the obtained set of works in WoS, the complete descriptions were extracted considering the authors, the keyword list, and the work titles. Together with the initial hits, their citing articles were also obtained. Details on the data collection phase, converting raw data to network format, and analyses are presented in the Methodology section.

The paper is organized as follows; first, the process of bibliometric data collection and the preparation of the working set of keywords is presented, followed by the description of the derived networks, the normalized networks, and the temporal networks. The results start with the analyses of a two-mode network of works and keywords, followed by analyses of the keyword co-occurrence network. Furthermore, the selected journals that publish Green IT/IS topics were identified, and networks of emerging keywords within these journals were constructed and analysed. The Analysis employed enables the representation of the most frequently used keywords in the Green IT/IS research area through the lens of the most prominent journals. Moreover, the results provide a chronological mapping of the research field and show its future development trends. In the conclusions, an overview of the main findings is given, and our contribution to this research field and gaps for future research are identified.

Methodology

In the research design and data analyses we followed similar bibliographic research (e.g., Batagelj et al. 2013, 2014, 2019, 2020). For the analyses of publication practices on Green IT/IS, we analysed works included in WoS. We used the computer program WoS2Pajek to transform data into a network format to analyse the obtained data. The computer program Pajek for network analyses and Python libraries `Nets` and `TQ` for analyses of temporal networks.

Data collection

Data was collected from WoS Core Collection until 2020 using the following queries: *"green information system*", "sustain* information system", "environment* information system*", "environmental informatics", "energy informatics", "green software", "green information technology*"; "green computing", "green information communication technology*", "information system* for sustainable development"*. The justification of the ten selected queries is presented below.

- ***green information system**** *(and the* abbreviation ***Green IS****)*
- ***green information technology**** *(and* abbreviation ***green IT****)*
- **sustain* information system*:** Diverse functionalities can characterize IS as Green. According to Chowdhury (2012), one of the characteristics is the change in software development life-cycle, which aims to reduce the potential negative environmental impacts of the system. Aligned with this definition, the term sustainable information system has to be classified as a type of Green IS, whereas it is often used interchangeably.
- **environment* information system***, also known as an environmental management information system, is used to track, measure, and monitor the environmental variables: emission, waste, toxicity, and carbon footprint (Sanita et al., 2017).
- **environmental informatics:** In the 1990s, the new concept of Environmental informatics emerged, focused on the techniques of effective collection, storage, retrieval, and processing of complex environmental data (Avouris et al., 1995), which was later classified as Green IS.
- **energy informatics:** The concept of energy informatics was introduced by (Watson et al., 2010), describing the discipline dealing with the role of IS in the reduction of energy consumption.
- talking about **green computing** or rather **green information communication technology** (**Green ICT**) mainly sets the focus on hardware issues while software issues are directly named **green software** (Kern, 2018).
- **information system* for sustainable development**: The term Information system for sustainable development (Hilty et al., 2015) was used to describe various information systems supporting green initiatives.

Based on the search queries listed, the original hits and additional articles citing those hits were obtained.

Construction of network data

Using the computer program `WoS2Pajek 1.5` (Batagelj, 2017), we converted the raw text WoS file into a collection of different networks. The program `WoS2Pajek 1.5` transforms phrases from the raw WoS file into individual words when constructing networks (e.g., the phrase green information system is split into three keywords Green, information, and system). The obtained works include papers in scientific journals, papers in conference proceedings, reports, books, etc. We obtained one-mode

citation network $Cite$ of works and three two-mode networks: the authorship network on `works × authors` (WA), the journal network on `works × journals` (WJ), and the keywords network on `works × keywords` (WK). The authors were identified from the *AU* field in the WoS entry, the journals from the field CR or J9, the keywords from the fields of Author Keywords (DE field), Keywords Plus (given by ID field), and the document title from the field TI. Two types of works were extracted from WoS: works with full descriptions (referred as *hits*) and with partial description (referred as *terminal*). In the case of terminal works the journal name, the first author, the year of publication, the issue of the journal, and the first-page number were available. Keywords, abstract, and citations are missing in the case of terminal works.

Loops and multiple lines were removed from all networks, and we obtained the basic networks labelled as $Cite$, WA, WJ, and WK. Sizes of the networks are presented in *Table 1*. Since all terminal works (320 586) contain only partial information (without keywords and citations), we excluded them from the analyses. Since we aim to analyse the keywords of the works from the WoS on selected queries, we also removed all 9 530 citing articles. The resulting reduced networks (of hits) without citing articles are as follows: $CiteR$, WAr, WJr, and WKr. Sizes of the sets of these networks are presented in Table 1.

Table 1
Number of vertices in obtained and reduced networks

	Networks	
Business Performance	**Basic from WoS**	**Reduced to hits**
Number of works	332 047	1 931
Number of keywords	13 635	4 017
Number of authors	148 348	4 342
Number of journals	26 806	669

Source: Author's work

Derived networks

A rectangular two-mode matrix is usually used to represent the two-mode network. Using matrix multiplication of two matrices of compatible dimensions a new network can be constructed. More precisely, two rectangular matrices can be multiplied if the number of columns of the first matrix corresponds to the number of rows of the second matrix. Details on construction of networks can be found in Batagelj et al. (2013, 2014). Following this procedure two derived networks, described below were constructed.

First, the network of co-occurrence of keywords (keywords times keywords (KKr))

$$KKr = WKr^T * WKr \qquad (1)$$

The weight of an edge in KKr between two nodes $w[k1; k2]$ represents the number of works in which the selected keywords $k1$ and $k2$ were mentioned together.

Second, the network of journals and keywords was obtained with the following multiplication:

$$JKr = WJr^T * WKr \qquad (2)$$

The edge in a JKr network indicates how many times the journal j contained the keyword k. In the following sections, the detailed descriptions of the calculated networks as well as the result of the analyses are presented.

Normalization of derived networks

Derived networks may have some disadvantages, as, for example, works with a large number of authors or keywords may be overrated in terms of the contribution of such a work. To overcome this issue, we used the fractional approach in our analyses (Batagelj et al., 2013; 2019; Gauffriau et al., 2007). The importance of these works was normalized so that the sum of all weights in the calculating network is equal to 1.

We can illustrate this situation with the following example. In the (rectangular) two-mode network *of* `works × keywords` (WKr) an out-degree of a particular work is equal to the number of work's keywords, and an indegree of a selected keyword is equal to the number of works which included that word among the listed keyword. If the normalization is employed for the WK network, the weight of each arc is divided by the out-degree of a selected node which is equal to the sum of the weights of all the arcs pointing from that node. The contribution of each paper is normalized and the nWK is calculated as follows:

$$nWK[w,k] = \frac{WKr[w,k]}{\max(1, outdeg(w))} \qquad (3)$$

where w is work and k is a keyword.

The proposed normalization approach can be applied to different two-mode networks. In addition, for the normalization of the JK network, the term frequency-inverse document frequency (TF–IDF) approach was used (Robertson, 2004). Using this approach, the importance of a word to a document in a corpus of documents can be considered.

Temporal networks

Temporal networks have time quantities in their description specifying which links (or/and nodes) are active at certain points in time. Based on the WKr network with combined time quantities, temporal networks were constructed (Batagelj et al., 2016, 2020) using the Python libraries (Batagelj et al., 2014). Two types of temporal networks can be constructed – instantaneous (where values are given for each year) WKins, and cumulative (where cumulative values over the years are calculated) $WKcum$. With multiplication and normalization procedures employed on temporal networks described above, we can calculate various new temporal networks.

Results

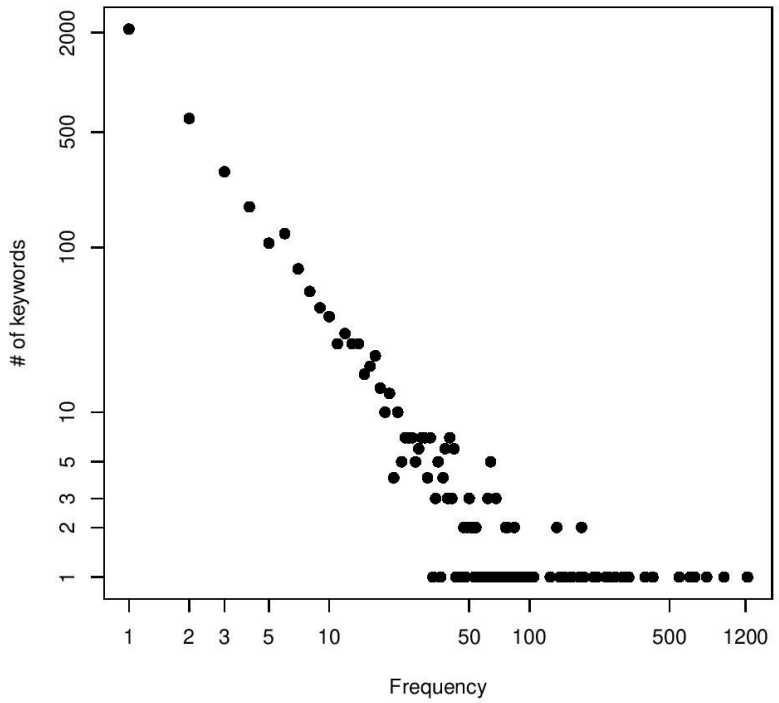
This section presents the results of different analyses performed to reach the research objective. First, with the analysis of the WK network, we identify the most frequent keywords and their distribution over the years. Second, the most important journals where Green IT/IS topics are published are identified, and subtopics published inside those journals are investigated.

Analyses of the WK network

The works cited only (also known as terminal) do not have any keywords. In our case, the WK network consists of 96,5% of such works. Therefore, we will focus on analysing the reduced network of hits WKr.

In the works with complete description (WKr network) the number of keywords ranges from 2 to 57. The distribution of keywords is presented in *Figure 1*. Works contain 4 017 different keywords, and more than half of them (2 105) are mentioned only once, while 604 keywords are mentioned twice.

Figure 1
Frequency distribution of the keywords



Source: Author's illustration

Eight of the most frequent vertices in the WKr network are *green, system, information, technology, energy, computing, environmental,* and *management* (*Table* 2). The word *green* occurs 1 226 times. This is expected since we use these words in phrases of the search query. Based on the most frequent keywords, the research field of Green IT/IS could be mapped. As expected, the research field consists of informatics or technically oriented keywords such as *data* (in tables and figures, the singular form of the noun is used - *datum*), *compute, cloud, base, communication, software, network, center, algorithm, application,* while also environmental aspects *sustainability, consumption, sustainable, environment,* etc. and organization performance *efficiency, performance, optimization, process*, etc. are also covered. Several words are closely related to research: *analysis*, *study, approach, framework*, etc.

Some words also have a different meaning related to the context, e.g., *center, issue, column,* etc. At the same time, their identification within a particular journal might reveal the specific scope or specialization of the journal.

Table 2
The frequencies of the most used keywords in the *nWKr* network

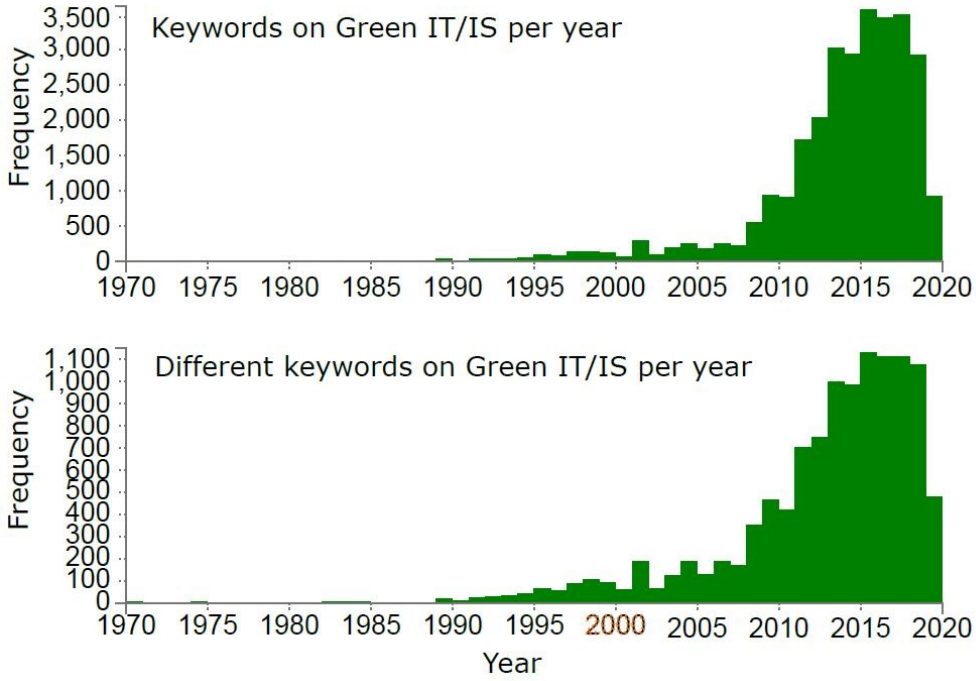
Rank	Value	Keyword	Rank	Value	Keyword	Rank	Value	Keyword
1	1 226	green	35	105	approach	68	62	assessment
2	936	information	36	103	study	69	60	adoption
3	767	system	37	102	virtual	70	59	behavior
4	668	energy	38	96	framework	71	57	save
5	633	technology	39	92	impact	72	56	sensor
6	559	computing	40	90	machine	73	54	carbon
7	413	environmental	41	86	optimization	74	54	integrate
8	378	management	42	84	scheduling	75	53	monitoring
9	313	datum[a]	43	84	process	76	52	social
10	299	compute	44	82	server	77	52	infrastructure
11	298	cloud	45	81	strategy	78	51	challenge
12	291	model	46	78	dynamic	79	51	cluster
13	267	power	47	78	architecture	80	50	simulation
14	248	sustainability	48	77	smart	81	50	policy
15	245	base	49	76	virtualization	82	50	control
16	241	efficiency	50	76	case	83	49	gi
17	217	performance	51	75	decision	84	49	method
18	213	communication	52	74	research	85	48	multi
19	209	consumption	53	72	support	86	47	waste
20	187	sustainable	54	71	practice	87	47	grid
21	184	software	55	70	perspective	88	46	informatics
22	182	network	56	68	innovation	89	45	issue
23	182	environment	57	68	distribute	90	44	scale
24	177	efficient	58	68	web	91	43	computer
25	163	center	59	66	business	92	42	emission
26	162	use	60	64	time	93	42	industry
27	161	resource	61	64	internet	94	42	eco
28	149	aware	62	64	theory	95	42	quality
29	147	algorithm	63	64	allocation	96	42	change
30	143	development	64	64	implementation	97	42	migration
31	142	design	65	63	engineering	98	41	user
32	137	analysis	66	62	evaluation	99	41	factor
33	137	service	67	62	mobile	100	41	consolidation
34	127	application						

Note: [a] As a keyword in works, a plural form data is used
Source: Author's work

Temporal analysis of the keywords

We looked at the temporal distributions of the number of all keywords and unique (*different*) keywords used in Green IT/IS (*Figure 12*). Keywords on Green IT/IS first appeared in the 1990s, while the number of publications started increasing in 2010. During the last few years, there have been around 3 000 publications in WoS on that topic. From 2013, around 1 000 unique keywords on IT/IS are published per year.

Figure 2
Distributions of keywords on Green IT/IS



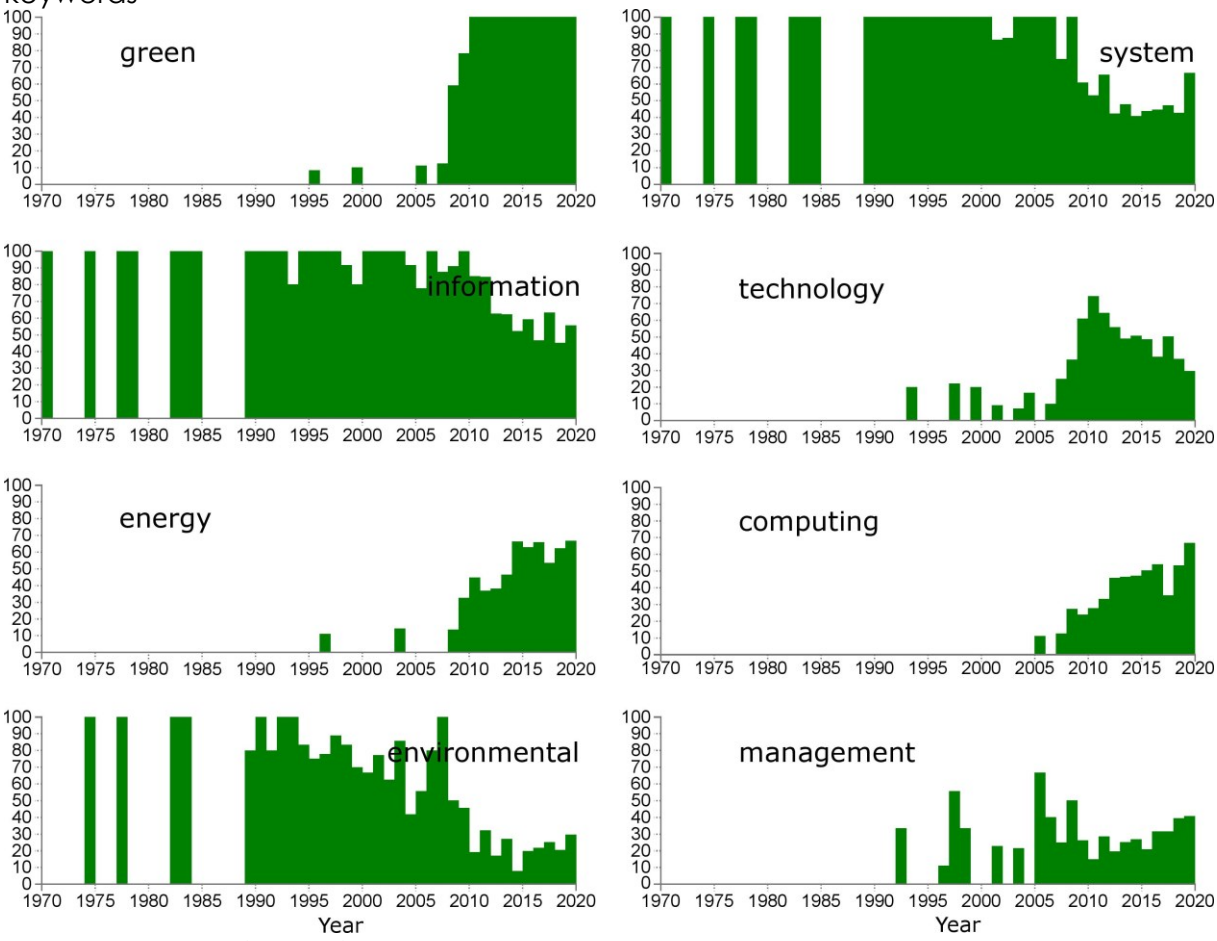
Source: Author's illustration

To determine the importance of a particular keyword over time, we calculated a proportion (ranging from 0% to 100%) of a particular keyword occurrence according to the keyword with the highest occurrence for each year based on the $WKins$ network (Figure 3). We created green, system, information, technology, energy, computing, environmental, and management pictures.

Some of the keywords shown in Figure 3 have been used for a long time, as their first appearance dates back to the 1970s (e.g., system, information, and environmental). Some words appear around 1995 (energy, technology, and management), while Green becomes popular after 2005.

It is quite reasonable to expect the keywords system and information to reach the maximal level of usage (or importance) in almost all years after their introduction, with a small decline after 2010, probably due to the more sophisticated subdomains of usage and the broader set of keywords used, as shown in Figure 2. Other information systems keywords appear from 2000, and their usage (or importance) is the most extensive around 2015 (e.g., computing). The keyword environmental has been used since 1975, and it became extremely popular in 1990. There is a small drop in 2010, but its occurrence is still around 30% of the most popular words each year. The keyword green is a newly developed concept related to IS and IT, which appeared in 2009.

Figure 3
Distribution of keyword appearance proportion considering the eight most frequent keywords



Source: Author's illustration

Keywords co-occurrence network

By column projection of the normalized hits $nWKr$ network, the normalized one-mode network $nKKr$ was calculated as follows:

$$nKKr = \mathrm{n}WKr^{T} * nWKr \qquad (4)$$

After the deletion of loops and the transformation of bidirectional arcs to edges, the calculated network $nKKr$ consists of 4 017 nodes and 126 639 edges. In this new calculated network, the weight on the edges between the keywords is equal to the fractional co-occurrence of keywords i and j in the same works. According to Batagelj *et al.* (2019) the $nKKr$ network is symmetric:

$$nKKr[i;\ j] = nKKr[\,j;\ i] \qquad (5)$$

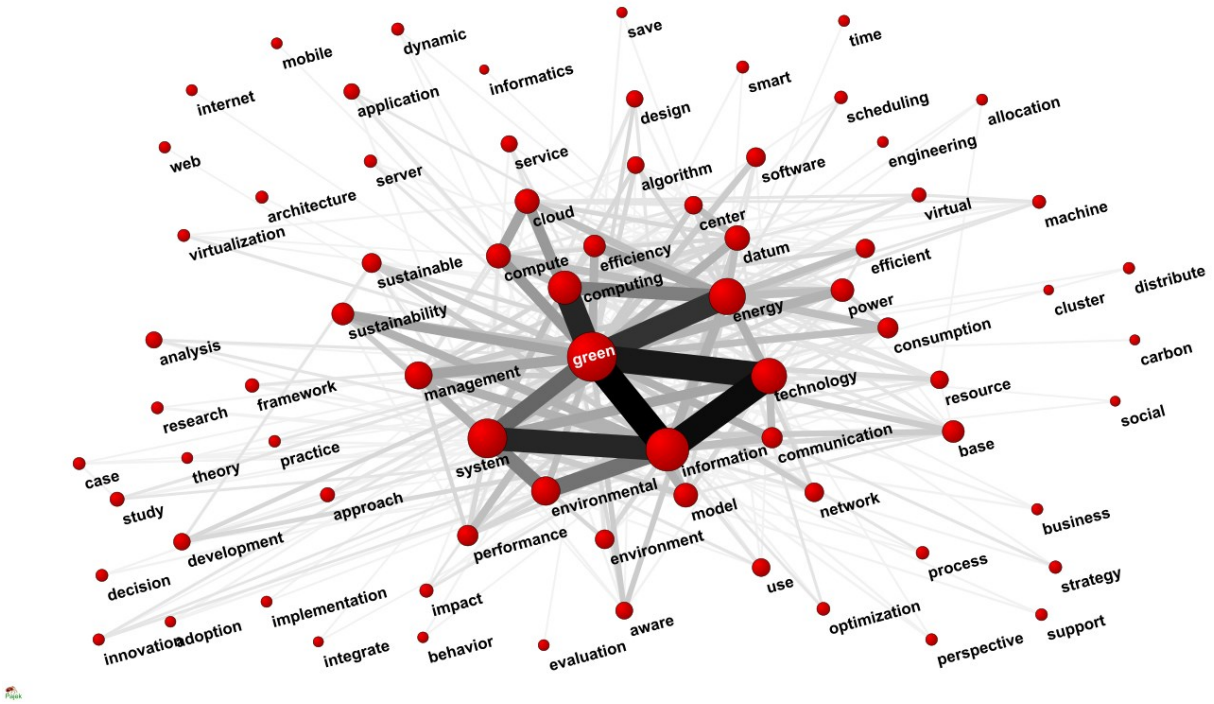
Furthermore, value 1 of a particular work is redistributed over the keywords:

$$\sum_{1,j} nKKr[i;\ j] = |W| \qquad (6)$$

Since $nKKh$ is a valued network, we employed the Line Island approach (Batagelj et al., 2014) and searched for the islands of sizes 2 to 75. We obtained 13 islands, 10 of

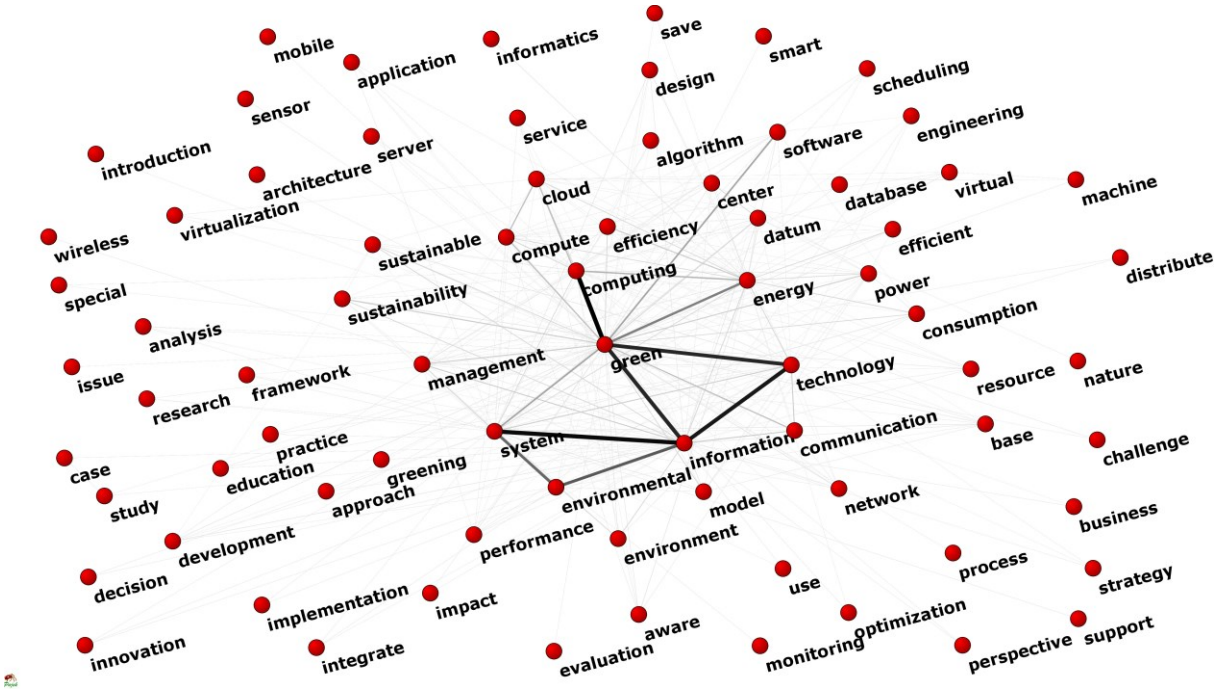
which consist of only one pair of vertices. Figure 4 represents the largest island with 75 vertices. The width and greyscale are proportional to the line weight, calculated based on the *fractional* co-occurrence approach described in the following subsection. Strongly associated (with the largest line weights) are *green - computing*, *green - technology*, *green - information*, *system - information*, and *environmental - information*. This was expected since these words are included in our search queries. Therefore, we removed the first 8 most frequent keywords from the network and repeated the Line Island approach. We obtained 73 islands ranging in size from 2 to 50 vertices, 78% of which consist of only one pair of vertices. The largest island is represented in Figure 6 and is described below. When we compare the island with 75 vertices obtained from the $nKKr$ network (Figure 5) instead of its non-normalized version (KKr) (Figure 4) the following words appeared to be more important: *nature, education, challenge, sensor, monitoring, database, special, issue, wireless, greening, introduction*, while some others were not included in this island (e.g., *adoption, behavior, social, theory, time*).

Figure 4
Line Island of KKr network on 75 vertices



Source: Author's illustration

Figure 5
Line Island of $nKKr$ network on 75 vertices



Source: Author's illustration

The above exploratory analysis results show that 8 of the most frequent keywords (*green, system, information, technology, energy, computing, environmental, management*) are connected to many other vertices. We excluded them from the network to obtain connection patterns between other keywords and again applied the Line Island approach. Figure 6 represents the largest island with 50 vertices. The most central part of the network is a pair of keywords *compute* and *cloud*, and both vertices are connected to the *datum* and *center*. Other vertices are *efficiency, scheduling, application, resource, allocation, algorithm, virtual, machine*... Other keywords that came up are *virtual - machine*, *sustainable - development*, and *power - consumption*. Around *sustainability* and *development,* the keywords *software, communication,* and *sustainability also* stand out.

Figure 6
The largest line island (size 50) of $nKKr$ network with removed 8 vertices

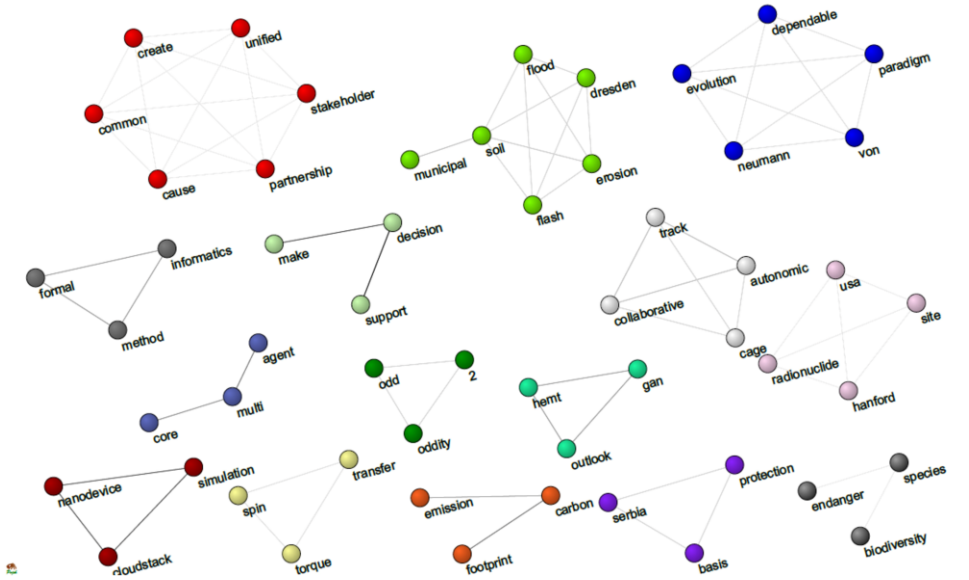


Source: Author's illustration

Smaller islands (Figure 7) identify some concepts related to the information systems domain (*core - multy - agent, cloudstack - simulation - nanodevice*), others are enterprise-oriented (*make - decision - support, cause - partnership - stakeholder - unified - create - common*) or environmentally oriented (*biodiversity - endanger - species, emission - footprint - carbon*).

Further analyses of the 2-vertices islands show that some common phrases with limited value appeared in the information systems domain, e.g., *publish-subscribe, special-issue, column-response, real-time, e-waste*, etc. To get a deeper insight into those keywords, we will present them in the context of the most popular journals from the field (see the next section).

Figure 7
Line islands of size 3 to 6 of $nKKr$ network with removed 8 vertices



Source: Author's illustration

Keywords and journals

First, the analysis of WJr shows the most important journals in which Green IT/IS topics are published (Table 3).

Table 3
Journals with the highest number of works on Green IT/IS

Rank	Title	Abbreviated title & ISSN	# of works	JIF	SNIP
1	**Lecture Notes in Computer Science**	**LECT NOTES COMPUT SC** 0302-9743	48		√
2	**IFIP Advances in Information and Communication Technology**	**IFIP ADV INF COMM** 1868-4238	35		√
3	**Sustainable Computing-Informatics & Systems**	**SUSTAIN COMPUT-INFOR** 2210-5379	29	√	√
4	**Studies in Systems, Decision, and Control**	**STUD SYST DECIS CONT** 2198-4182	23		√
5	Advanced Intelligent Systems	ADV INTELL SYST 2640-4567	21		
6	Communications in Computer and Information Science	COMM COM INF SC 1865-0929	20		√
7	**Environmental Modelling & Software**	**ENVIRON MODELL SOFTW** 1364-8152	19	√	√
8	**Future Generation Computer Systems**	**FUTURE GENER COMP SY** 0167-739X	19	√	√
9	**Computer**	**COMPUTER** 0018-9162	15	√	√
10	Sustainability	SUSTAINABILITY-BASEL 2071-1050	15	√	√
11	It Professional	IT PROF 1520-9202	12		√
12	Procedia Computer Science	PROCEDIA COMPUT SCI 1877-0509	12		√
13	Cluster Computing	CLUSTER COMPUT 1386-7857	11	√	√
14	Journal of Supercomputing	J SUPERCOMPUT 0920-8542	11	√	√
15	**Information Systems Frontiers**	**INFORM SYST FRONT** 1387-3326	10	√	√
16	**Journal of Cleaner Production**	**J CLEAN PROD** 0959-6526	10	√	√
17	Advanced Science Letters	ADV SCI LETT 1936-6612	8		√
18	Computer Networks	COMPUT NETW 1389-1286	8	√	√
19	Journal of Strategic Information Systems	J STRATEGIC INF SYST 0963-8687	8	√	√
20	Fujitsu Scientific & Technical Journal	FUJITSU SCI TECH J 0016-2523	8	√	√
21	Proceedings of the Hawaii International Conference on System Sciences	P ANN HICSS N/A[¤]	8		
22	Concurrency Computation Practice and Experience	CONCURR COMP-PRACT E 1532-0626	8	√	√
23	Advanced Materials Research	ADV MATER RES-SWITZ 1662-8985	8		
24	**Advances in Computer Science Research**	ACSR ADV COMPUT 2352-538X	8		

Note: [¤] ISSN is not-applicable. Book series, different ISSN for each volume
Source: Author's work

Table 3 presents 24 journals with the highest number of published papers among our hits along with the information whether they have the Journal Impact Factor (JIF) (Clavrivate, 2019) or the Source Normalized Impact per Paper (SNIP) factor (Elsevier B.V., 2019) to reveal publishing culture among the authors. There were 48 papers published in the journal *Lecture notes in computer science* (LECT NOTES COMPUT SC), followed by 35 papers in the journal *IFIP Advances in Information and Communication Technology* (IFIP ADV INF COMM) and 29 papers in the journal *Sustainable Computing-Informatics & Systems* (SUSTAIN COMPUT-INFOR).

The construction of KJ network and its normalization is presented below. First, the derived network of `journals × keywords` was obtained by multiplying two two-mode networks

$$JK = WJ^T * WK \quad (7)$$

To analyse keywords inside journals, two types of normalization were used: fractional approach and term frequency-inverse document frequency (TF-IDF).

Fractional normalization

The normalized reduced networks $nWJr$ and $nWKr$ were used to calculate a new normalized network of journals and keywords JK *as follows:*

$$nJK = nWJ^T * nWK \quad (8)$$

In the new network nJK, the weight on the edges between the nodes j and k is equal to the fractional contribution of a journal j for a given keyword k; or of a group of journals C:

$$JK[C,k] = \sum_{j \in C} JK[j,k] \quad (9)$$

Term frequency-inverse document frequency (TF-IDF)

$TF - IDF$ approach, proposed by Robertson (2004), was employed to the JKr network. In the normalization procedure the importance of a keyword for within a journal is considered. We used reduced networks WJr and WKr for JKr network construction, TF and IDF were defined (and calculated) as follows. TF represents the number of times a keyword appears in a selected journal, divided by the total number of (all different) keywords in the journal. IDF is defined as the logarithm of the number of the journals in the corpus divided by the number of journals in which the specific keyword occurs.

We calculated $TF - IDF$ indices for the keywords were calculated in the following way:

$$TF - IDF[k,J] = TF[k,j] * IDF[k] \quad (10)$$

$$TF[k,j] = \frac{\#\text{ times } k \text{ appeared in } J}{\text{total } \#\ K \text{ in } j} \quad (11)$$

$$IDF[k] = log \frac{\#\ J}{\#\ J \text{ with } k} \quad (12)$$

where k is a keyword, K – all the keywords, j – a journal, and J – all the journals.

Keywords in the selected journals

To analyse the most frequent or important keywords on Green IT/IS, we selected nine top journals (denoted with bold in *Table 3*) according to the number of papers received and their influence measured by JIF or SNIP.

Three journals with the highest number of published works are Lecture Notes in Computer Science (LECT NOTES COMPUT SC), IFIP Advances in Information and Communication Technology (IFIP ADV INF COMM), and Sustainable Computing-Informatics & Systems (SUSTAIN COMPUT-INFOR). All three journals are indexed in Scopus, and the third one is also indexed in JIF. In companion to these three journals, we selected five other prestigious journals with the highest JIF among the received journals: *Information Systems Frontiers* (INFORM SYST FRONT), Future *Generation Computer Systems* (FUTURE GENER COMP SY), *Environmental modeling & software* (ENVIRON MODELL SOFTW), *Journal of Cleaner Production* (J CLEAN PROD), and *Computer* (COMPUTER). The analysis of the co-occurrence of keywords in the selected journals is presented below.

TF-IDF indices approach for keywords in selected journals

We employed the TF-IDF approach for nine selected journals. According to TF-IDF, the most important keywords are presented in Table 4 - Table 6.

Table 4

The most important keywords according to TF-IDF indices (journals LECT NOTES COMPUT SC, INFORM SYST FRONT, FUTURE GENER COMP SY)

	LECT NOTES COMPUT SC		INFORM SYST FRONT		FUTURE GENER COMP SY	
Rank	**Value**	**Keyword**	**Value**	**Keyword**	**Value**	**Keyword**
1	0,063	energy	0,176	business	0,128	compute
2	0,059	compute	0,094	modernization	0,103	efficiency
3	0,056	design	0,088	supply	0,101	aware
4	0,053	technology	0,087	chain	0,091	distribute
5	0,052	cloud	0,077	value	0,089	energy
6	0,052	spatio	0,072	performance	0,083	cloud
7	0,051	science	0,072	sustainability	0,079	center
8	0,051	aware	0,069	technology	0,070	computing
9	0,049	computing	0,069	organization	0,069	exploit
10	0,049	service	0,064	alignment	0,067	scheduling
11	0,047	temporal	0,061	environmental	0,064	management
12	0,047	datum	0,060	determinant	0,063	performance
13	0,046	base	0,058	innovation	0,062	power
14	0,046	efficiency	0,057	small	0,060	resource
15	0,046	green	0,056	theory	0,056	datum
16	0,045	application	0,056	strategic	0,054	hardware
17	0,043	system	0,054	management	0,053	optimal
18	0,043	research	0,050	ecological	0,051	hpc
19	0,043	consumption	0,047	pea	0,050	heuristic
20	0,042	information	0,047	carrot	0,049	consumption
21	0,040	community	0,047	just	0,048	green
22	0,037	performance	0,047	complementarity	0,047	parallel
23	0,037	sustainability	0,047	doi	0,044	application
24	0,037	provision	0,047	pvt	0,043	indicator
25	0,036	management	0,047	midlands	0,043	cost
26	0,035	platform	0,047	gratification	0,042[a]	protein
27	0,035	environmental	0,046	eco		routine
28	0,035	smart	0,046	informatics		fip
29	0,034	conservation	0,046	make		backtracking
30	0,034	process	0,045	firm		datacentre

Note: [a] Several keywords have the same value; not all are listed here.
Source: Author's work

The keyword *green* is the most important keyword in 6 out of 9 journals, while in the other three journals, the first place belongs to the keyword *information*. Most of the

most important keywords within the journals are related to information systems, while in two journals, specificity is shown in the publication culture. Two important keywords within the Computer (COMPUTER) journals are *column* and *response,* indicating that the authors write replies to the initial columns (papers). Similarly, four of the most important keywords in the journal Sustainable Computing-Informatics & Systems (SUSTAIN COMPUT-INFOR) are related to publishing: *special - issue, conference - paper*. The connections between the keywords specific to the journal are presented in the following subsection.

Table 5
The most important keywords according to TF-IDF indices (journals ENIVORN MODELL SOFTW, J CLEAN PROD, IFIP ADV INF COMM TE)

	ENVIRON MODELL SOFTW		J CLEAN PROD		IFIP ADV INF COMM TE	
Rank	**Value**	**Keyword**	**Value**	**Keyword**	**Value**	**Keyword**
1	0,118	environmental	0,070	travel	0,125	environmental
2	0,117	integrate	0,070	meeting	0,112	semantic
3	0,112	integration	0,064	corporate	0,094	portal
4	0,110	ei	0,062	eco	0,085	semantics
5	0,105	support	0,056	financial	0,077	search
6	0,101	decision	0,055	environmental	0,074	web
7	0,084	service	0,053	company	0,071	information
8	0,076	ogc	0,052	collaboration	0,071	architecture
9	0,074	web	0,052	innovation	0,063	system
10	0,074	system	0,050	program	0,056	infotercio
11	0,071	design	0,050	technology	0,056	sise
12	0,065	information	0,048	management	0,056	ho
13	0,060	interface	0,048	practice	0,056	diagram
14	0,058	example	0,046	communication	0,056	subsystem
15	0,057	management	0,044	empirical	0,056	link
16	0,055	open	0,043	public	0,055	open
17	0,053	architecture	0,042[a]	appraisal	0,052	infrastructure
18	0,052	software		hide	0,050	discovery
19	0,050	use		ema	0,050	datum
20	0,047	datum		willing	0,048	sustainable
21	0,047	component		logit	0,047	rest
22	0,046	spatial		valuation	0,047	czech
23	0,045	application		contingent	0,046	technology
24	0,045	access		premium	0,044	balance
25	0,043[a]	navigator		videoconference	0,043	life
26		uwedat		swedish	0,042	microservice
27		abatement		responsive	0,042	user
28		enviroinfo		publicly	0,041	series
29		spread		circular	0,041	office
30		maintain		ghanaian	0,041	generic

Note: [a] Several keywords have the same value, not all are listed here.
Source: Author's work

Table 6
The most important keywords according to TF-IDF indices (journals SUSTAIN COMPUT-INFOR, COMPUTER, STUD SYST DECIS CONT)

	SUSTAIN COMPUT-INFOR		COMPUTER		STUD SYST DECIS CONT	
Rank	**Value**	**Keyword**	**Value**	**Keyword**	**Value**	**Keyword**
1	0,172	special	0,145	column	0,206	engineering
2	0,148	issue	0,106	technology	0,115	concept
3	0,126	conference	0,089	response	0,082	technology
4	0,124	papers	0,074	green	0,074	complex
5	0,122	computing	0,073	computing	0,069	development
6	0,118	introduction	0,072	accountability	0,062	preface
7	0,118	international	0,072	generalize	0,061	implementation
8	0,104	igcc	0,072	fear	0,058	thing
9	0,095	select	0,072	wild	0,052	fpga
10	0,076	reduction	0,072	shine	0,052	taxonomy
11	0,075	software	0,072	let	0,051	network
12	0,075	energy	0,072	sun	0,051	model
13	0,069	power	0,072	showcase	0,051	green
14	0,066	green	0,072	joule	0,049	logic
15	0,059	server	0,072	hurdle	0,048	physical
16	0,058	agile	0,072	modularity	0,047	information
17	0,057	efficiency	0,072	bloat	0,047	internet
18	0,054	compute	0,072	1680	0,046	function
19	0,052	ieee	0,072	odd	0,045	operation
20	0,049	renewable	0,072	oddity	0,044	computing
21	0,045	aspect	0,072	design	0,043	classification
22	0,044	allocation	0,069	computer	0,042	fuzzy
23	0,040	consumption	0,065	information	0,041	component
24	0,039	datum	0,065	fi	0,041	optimization
25	0,039	platform	0,065	wi	0,038	adaptive
26	0,038	optimization	0,065	speedup	0,037[¤]	energy
27	0,037	improve	0,065	creative		meronymous
28	0,037	enterprise	0,060	amdahl		spiral
29	0,037	technique	0,060	modular		specialized
30	0,172	special	0,145	column		engineering

Note: [¤] Several keywords have the same value; not all are listed here.
Source: Author's work

Important keywords in the normalized nJK networks of selected journals
Before applying the Line Island approach to the obtained normalized networks with the fractional approach nJK, we removed the 8 most frequent keywords (*green, system, information, technology, energy, computing, environmental,* and *management)*. We want to investigate the connection patterns among other keywords within the selected journal and thus reveal the differences in subfields of the journals' scope.

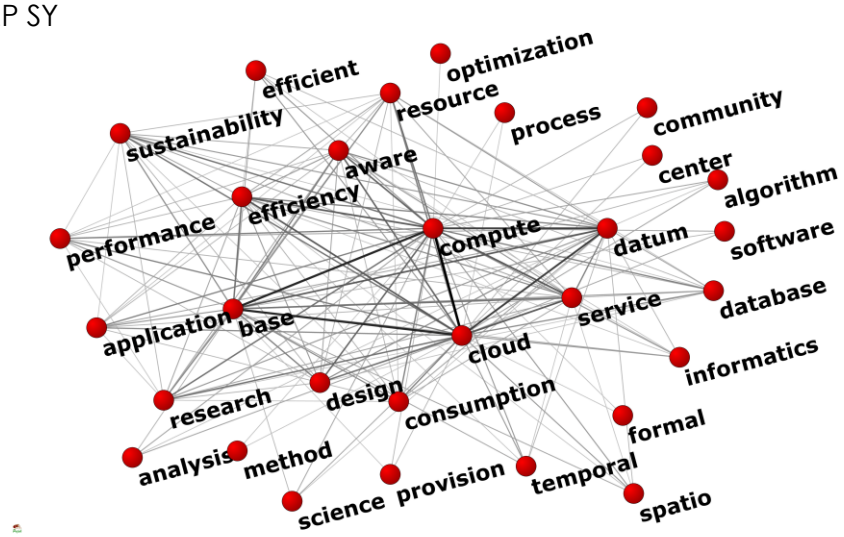
The keywords most frequently associated with the corresponding journals are shown in the Appendices, Figure 9 and Figure 10. The keywords reflecting the LECT NOTES COMPUT SC (Figure 8a) is related to energy, compute, design, technology, cloud, spatial, science, aware, computing, etc. A closer look at this publishing outlet reveals several conference proceedings series related merely to technological aspects of green sustainability. For instance, the main topics identified in this publication outlet are green and cloud computing, data analytics, renewable energy, energy informatics, and similar topics. We can highlight similarities by comparing this set of keywords with another book series (i.e., IFIP ADV INF COMM TE). Both publication outlets are primarily concerned with IT. However, some studies aim to bridge IT and green aspects, particularly addressing the potential of IT to reduce the negative impact on the environment.

Given the keywords in SUSTAIN COMPUT-INFOR (Figure 10a), one can identify the technological dimensions of Green IT/IS (such as computing, software, server,

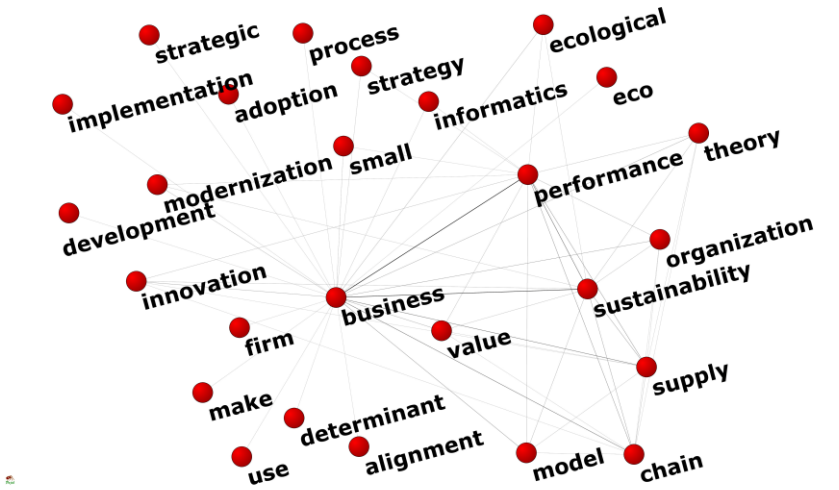
platform), the environmental dimension (reduction, energy, power, efficiency, renewable, allocation, consumption, improvement, etc.) and the organizational dimension (such as enterprise, technique, aware). Several works in this journal are related to green and sustainable computing, green high-performance computing (green HPC), and green IT. This journal is dedicated to scientific work related to the interplay between computer science and engineering and sustainability. In addition, this journal has several special issues devoted to green computing. Regarding the ENVIRON MODELL SOFTW (Figure 9a), the keywords such as environment, integration, support, decision, information, interface, management, architecture, and software can be emphasized. Examining the papers within this journal, we can outline the green infrastructure as one of the streamlined topics.

Furthermore, contrary to the publications mentioned above, the journal COMPUTER (Figure 10b) focuses predominantly on green energy and smart grid as far as green aspects are concerned. The keywords do not show a similar pattern compared to other publication outlets included in our study. Considering the FUTURE GENER COMP SY (Figure 8c), we can emphasize some similarities with other publication outlets such as LECT NOTES COMPUT SC and SUSTAIN COMPUT-INFOR. Green renewable energy, green computing, green data centers, and green IT are among the most notable research areas identified in FUTURE GENER COMP SY (Figure 8c). INFORM SYST FRONT (Figure 8b) also publishes the papers associated with Green IS practices and other non-technological aspects of Green IT/IS, such as attitudes towards Green IT, sustainability performance, etc. The keywords such as business, performance, sustainability, organization, innovation, strategy, and management also support the notation mentioned earlier on Green IS. While the scope of J CLEAN PROD (Figure 9b) is not related to IT or IS, there are also some papers on green technology in this journal, especially related to Green IT. The keywords indicate that attention is given to corporate/organizational sustainability and green technology, either information or energy, building, and other technologies.

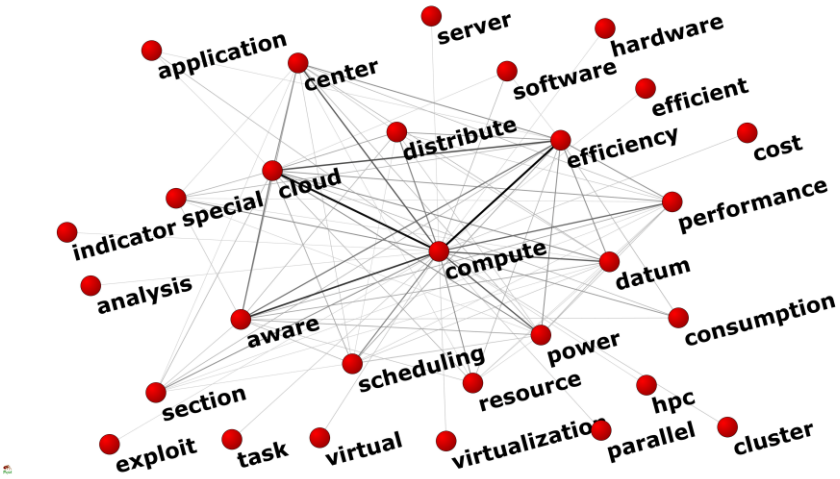
Figure 8
Keywords inside the journals LECT NOTES COMPUT SC, INFORM SYST FRONT, FUTURE GENER COMP SY



(a) LECT-NOTES-COMPUT-SC



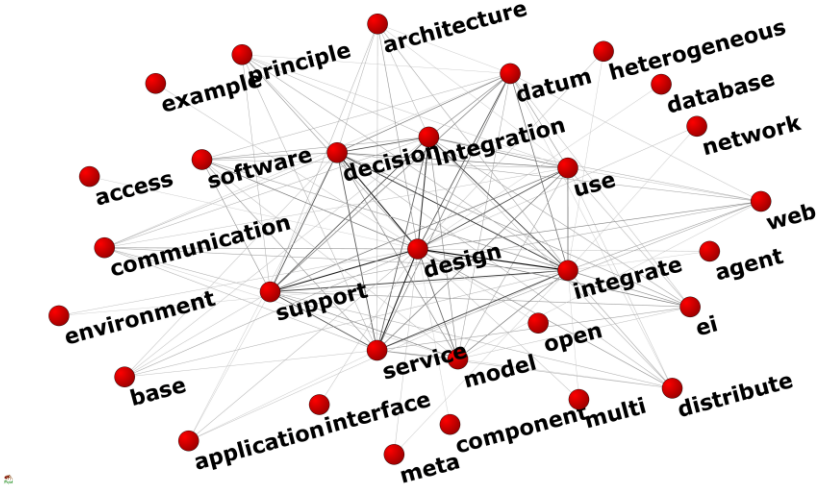
(b) INFORM-SYST-FRONT



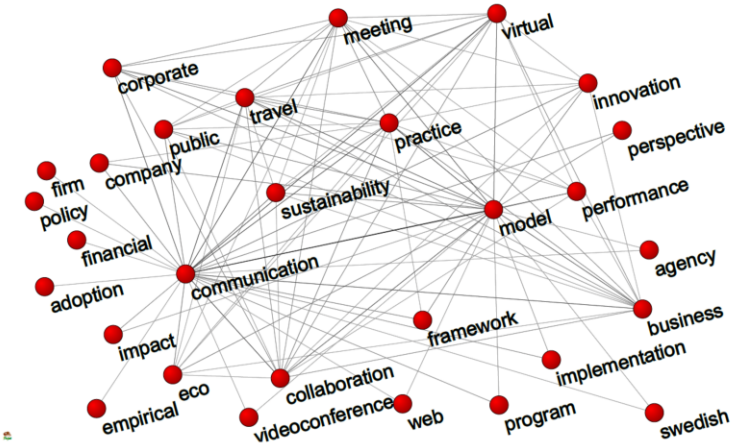
(c) FUTURE-GENER-COMP-SY

Source: Author's illustration

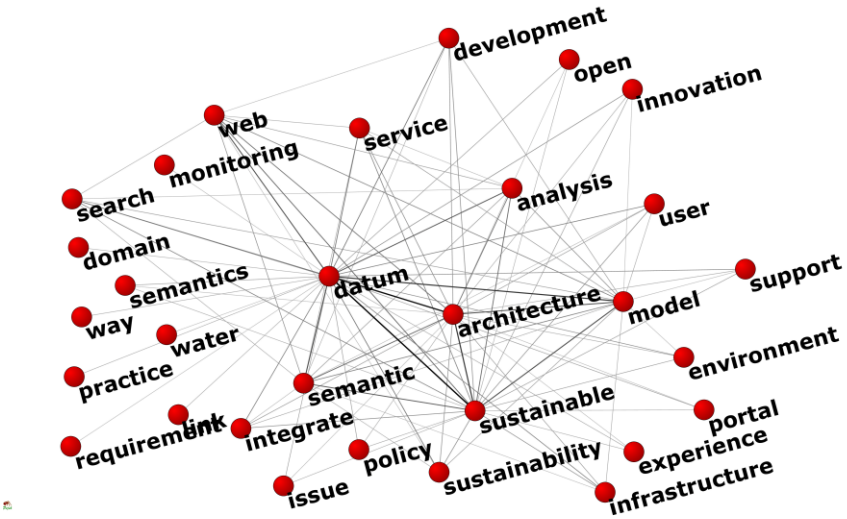
Figure 9
Keywords inside journals ENIVORN MODELL SOFTW, J CLEAN PROD, IFIP ADV INF COMM TE



(a) ENVIRON-MODELL-SOFTW



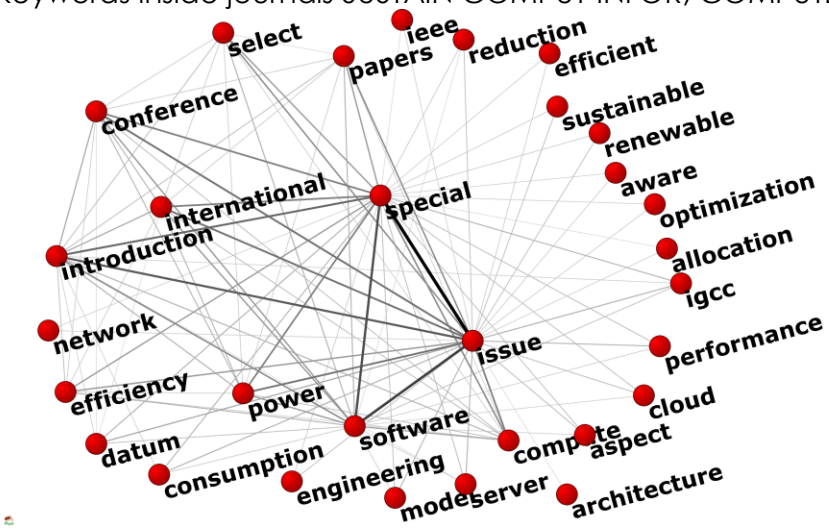
(b) J-CLEAN-PROD



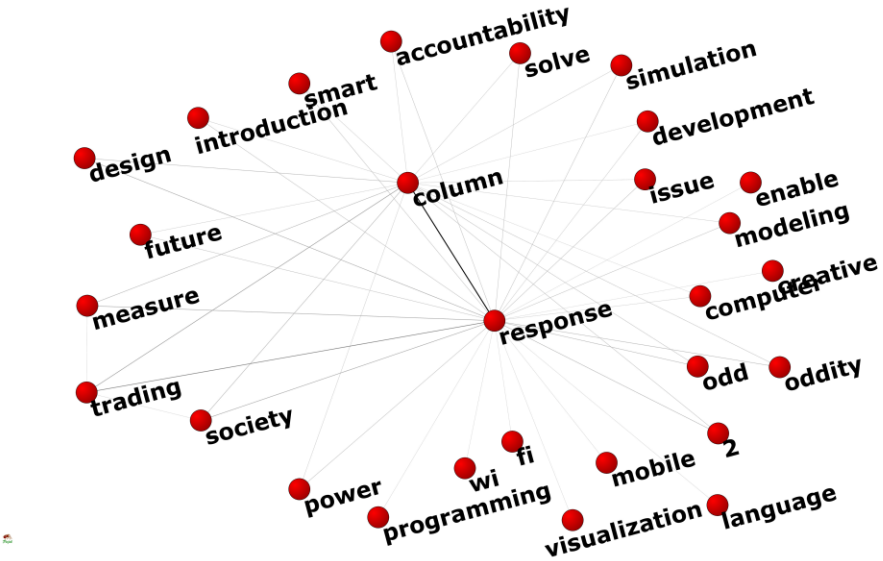
(c) IFIP-ADV-INF-COMM-TE

Source: Author's illustration

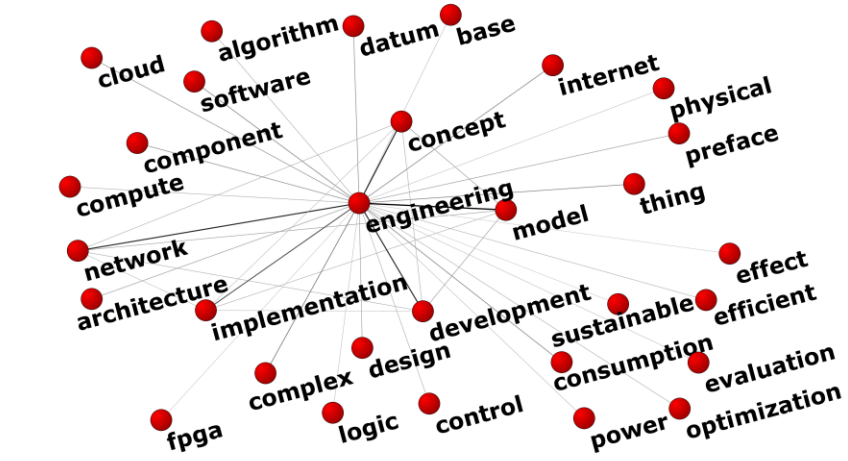
Figure 10
Keywords inside journals SUSTAIN COMPUT-INFOR, COMPUTER, STUD SYST DECIS CONT



(a) SUSTAIN-COMPUT-INFOR



(b) COMPUTER



(c) STUD-SYST-DECI-CONT

Source: Author's illustration

Discussion and Conclusions

Despite various barriers organizations face in implementing green operations (Alves et al., 2020), there are significant literature on Green IS/IT, its adoption, and practices. We aimed to identify the topics of Green IT/IS research published in scientific journals. This study makes an important contribution to the Green IT/IS literature and provides valuable information for policymakers in public administration and organizations about the advances and orientation of the Green IT/IS research topic to follow the sustainable goals of digital transformation. Our main contribution is to outline the Green IT/IS research area development from 1975. It should be noted that our research goes beyond the traditional qualitative review. A quantitative approach to SNA, which we undertook by applying keyword analysis, provides a more objective overview of the research area and its development. Therefore, the main contribution of this quantitative approach to literature review can be conceived to understand better the scientific discipline of Green IT/IS and open future research avenues. We portrayed the development of the Green IT/IS research area and emphasized how the greening of this emerging field has been incorporated into the IT/IS literature. We have highlighted the main knowledge pillars on which the Green IT/IS research streams are built (e.g., green computing, green infrastructure, green energy, green data centers, etc.). Temporal analysis of the words associated with the Green IT/IS revealed the rapid increase of Green IT-related keywords from 2000 onwards. Indeed, the interdisciplinary field of Green IT/IS has also developed accordingly.

Interestingly, not all journals publishing Green IT/IS topics are IS-oriented, showing the importance and widespread interest in the topic. The scope of journals publishing Green IT/IS-related scholarly work extends beyond the information systems research field. J CLEAN PROD, one of the most eminent journals publishing research on sustainable development, has also published many Green IT/IS-related works. This is a clear signal that Green IT/IS has become interested in a wider research audience. The journal with the highest number of works related to Green IT/IS, LECT NOTES COMPUT SC, publishes many conference proceedings series. These research works focus more on technological aspects of green sustainability and less on academic discussions, which shows that there are still opportunities for academic research on Green IT/IS.

The main contributions of this paper can be summarized as follows:

(1) Successful implementation of quantitative methodology that can be applied to different research fields;
(2) Comprehensive overview of the literature on the Green IT/IS topic;
(3) Identification of the trends in the advancement of publications related to Green IT/IS over the past decades.

The research provides an exhaustive overview of the keywords used in Green IT/IS research, their evolution, and orientation. It provides IT management in companies' guidelines for their future activities and strategical decisions on IT investments related to sustainable development. This unbiased Green IT/IS literature review guides companies in preparing a solid background for their digital transformation process aligned with the sustainable development goals. From a management perspective, there are many innovative solutions to Green IT/IS challenges, and there is growing momentum to develop more Green IT /IS solutions that can be successfully marketed.

Further on, the opportunities for future research that can be outlined are related to the Green IT/IS investigation in more depth. Focusing more on non-technological aspects of Green IT/IS is bound to become even more significant in light of the evolution of this literature stream. For example, the investigation of the factors influencing the internalization of Green IT/IS is currently not sufficiently grounded in theories of Green IT/IS. This could entail the investigation of Green IT/IS's underlying

practices by integrating Green IT/IS into the management system of organizations, the development of Green IT/IS policies, objectives, procedures, etc. Moreover, the domains of the firm's resource-based view (RBV) and knowledge-based theory (KBV) of the firm are considered theoretical lenses that could shape the future development of Green IT/IS research.

The Green IT /IS field is still in its infancy stage. Nevertheless, there is a growing scientific interest in the Green IT/IS phenomenon. In this sense, based on the results of our study, we argue that rigorous theory development should be the focus of research on Green IT/IS. Our study showed that Green IT/IS is not narrowly specialized but is rather an interdisciplinary-oriented research stream. We anticipate that the research field will gradually mature as more multidisciplinary and interdisciplinary studies are conducted.

In addition, studies that focus on different contexts would enrich this line of research. For example, IT/IS research could be linked to the circular economy research, or future studies could expand the green perspective to a broader sustainability perspective with a balanced focus on sustainability dimensions. Besides, future research could delve into which specific aspects of Green IT/IS offer significant benefits in terms of improved business value.

While this study contributes to the Green IT/IS literature in several ways, certain limitations need further attention. The analysis is based on the data derived from the WoS, and incorporating additional bibliographic sources could further increase the generalizability of the results. In addition, it would be interesting to conduct a bibliometric analysis of Green IT/IS by including only the most prestigious journals and then comparing the results with less prestigious journals to determine possible similarities and differences between the two. A possible limitation of the study could be that citation, and co-citation data and trends are usually dynamic and are likely to change over time.

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Appendices

Table A1

Vertices within the selected journals (I.)

	LECT NOTES COMPUT SC		INFORM SYST FRONT		FUTURE GENER COMP SY	
Rank	Value	Keyword	Value	Keyword	Value	Keyword
1	2.429	green	0.445	information	1.254	green
2	1.780	energy	0.445	green	0.921	energy
3	1.737	information	0.445	technology	0.846	computing
4	1.692	system	0.386	system	0.743	compute
5	1.255	technology	0.337	business	0.539	efficiency
6	1.114	computing	0.284	environmental	0.530	cloud
7	0.907	compute	0.274	management	0.453	management
8	0.893	cloud	0.271	performance	0.432	aware
9	0.779	base	0.248	sustainability	0.353	technology
10	0.758	environmental	0.184	supply	0.352	datum
11	0.681	datum	0.184	chain	0.352	center
12	0.627	management	0.147	model	0.350	power
13	0.608	service	0.134	organization	0.336	performance
14	0.597	efficiency	0.133	theory	0.298	information
15	0.564	aware	0.133	innovation	0.294	distribute
16	0.536	design	0.131	value	0.291	system
17	0.510	research	0.108	ecological	0.286	scheduling
18	0.498	sustainability	0.108	modernization	0.250	resource
19	0.491	resource	0.095	small	0.250	special
20	0.466	consumption	0.091	strategy	0.250	section
21	0.452	performance	0.090	energy	0.234	consumption
22	0.448	application	0.090	informatics	0.167	software
23	0.444	database	0.079	make	0.166	application
24	0.383	informatics	0.077	strategic	0.150	virtual
25	0.377	efficient	0.077	process	0.148	cluster
26	0.370	spatio	0.076	alignment	0.138	cost
27	0.370	temporal	0.074[a]	determinant	0.136	parallel
28	0.347	analysis		firm	0.136	task
29	0.335	algorithm		adoption	0.133	virtualization
30	0.319	science		development	0.130	hpc

[a]*Several keywords have the same value, not all are listed here.*

Source: Author's work

Table A2
Vertices within the selected journals (II.)

	ENVIRON MODELL SOFTW		J CLEAN PROD		IFIP ADV INF COMM TE	
Rank	Value	Keyword	Value	Keyword	Value	Keyword
1	1.254	green	0.484	information	2.402	information
2	0.921	energy	0.379	green	2.065	environmental
3	0.846	computing	0.379	technology	1.850	system
4	0.743	compute	0.288	environmental	0.918	technology
5	0.539	efficiency	0.273	management	0.722	green
6	0.530	cloud	0.235	system	0.630	datum
7	0.453	management	0.193	communication	0.559	sustainable
8	0.432	aware	0.182	model	0.532	architecture
9	0.353	technology	0.134	practice	0.463	model
10	0.352	datum	0.130	travel	0.439	management
11	0.352	center	0.130	business	0.411	semantic
12	0.350	power	0.130	collaboration	0.390	web
13	0.336	performance	0.130	meeting	0.375	analysis
14	0.298	information	0.130	virtual	0.321	service
15	0.294	distribute	0.123	corporate	0.320	search
16	0.291	system	0.101	innovation	0.306	sustainability
17	0.286	scheduling	0.101	performance	0.305	development
18	0.250	resource	0.101	sustainability	0.294	integrate
19	0.250	special	0.101	eco	0.283	user
20	0.250	section	0.100	public	0.283	infrastructure
21	0.234	consumption	0.099	company	0.260	support
22	0.167	software	0.097	framework	0.254	innovation
23	0.166	application	0.091	perspective	0.250	environment
24	0.150	virtual	0.083	impact	0.234	policy
25	0.148	cluster	0.083	implementation	0.227	open
26	0.138	cost	0.081	program	0.226	issue
27	0.136	parallel	0.071	videoconference	0.224	portal
28	0.136	task	0.071	swedish	0.223	semantics
29	0.133	virtualization	0.071	agency	0.220	experience
30	0.130	hpc	0.071	web	0.205	way

Source: Author's work

Table A3
Vertices within the selected journals (III.)

	SUSTAIN COMPUT-INFOR		COMPUTER		STUD SYST DECIS CONT	
Rank	Value	Keyword	Value	Keyword	Value	Keyword
1	2.368	green	2.644	green	1.546	green
2	1.728	computing	1.255	information	1.131	technology
3	1.063	energy	1.255	technology	1.040	information
4	0.946	issue	1.238	computing	0.985	engineering
5	0.869	special	0.533	response	0.747	system
6	0.688	software	0.450	column	0.531	computing
7	0.576	introduction	0.405	energy	0.478	energy
8	0.504	international	0.250	trading	0.478	model
9	0.504	conference	0.200	accountability	0.419	concept
10	0.485	power	0.200	solve	0.411	development
11	0.461	technology	0.200	measure	0.411	network
12	0.461	compute	0.200	issue	0.353	implementation
13	0.393	papers	0.200	society	0.261	complex
14	0.393	select	0.200	future	0.245	consumption
15	0.378	efficiency	0.188	design	0.245	software
16	0.375	system	0.167	odd	0.238	thing
17	0.344	information	0.167	oddity	0.238	internet
18	0.308	datum	0.167	2.000	0.236	component
19	0.293	igcc	0.143	simulation	0.227	datum
20	0.288	management	0.143	system	0.217	cloud
21	0.288	consumption	0.143	introduction	0.211	preface
22	0.270	server	0.143	power	0.211	architecture
23	0.265	performance	0.143	smart	0.199	design
24	0.260	model	0.143	modeling	0.177	control
25	0.254	aspect	0.121	development	0.176	compute
26	0.243	cloud	0.117	computer	0.170	optimization
27	0.228	reduction	0.091[a]	visualization	0.170	algorithm
28	0.222	engineering		language	0.168	efficient
29	0.219	sustainable		fi	0.156	base
30	0.219	renewable		wi	0.154	power

[a]*Several keywords have the same value, not all are listed here*
Source: Author's work

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