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Information ecology research: past, present, and future

Xiwei Wang · Yu Guo · Mengqing Yang · Yong Chen · Wenxiao Zhang

Abstract This paper examines the status of information ecology research through studying the published papers on the topic of information ecology included in Social Sciences Citation Index and Science Citation Index database from 1992 to 2013. It applies bibliometrics and knowledge mapping to analyze the changes in the number of published papers as time goes on, in terms of country and geographic area, research topics, research methods, funding sources, hot research spots, and research trends. In addition, this paper summarizes the origin and the evolution of information ecology research and introduces institutions that conduct information ecology research. The results indicate that information ecology is an emerging field with vigorous development in recent years, and information ecology research is a multi-disciplinary subject. The research also reveals that information ecology research mainly focuses on information ecosystems, information ecology in e-commerce, and information ecology in a network. This paper calls for wider and deeper research on information ecology, in order to explore information ecology issues caused by the rapid development of new technologies.

Keywords Information ecology · Information ecosystem · Bibliometrics · Knowledge mapping

X. Wang (✉) · Y. Guo (✉) · M. Yang · W. Zhang
School of Management, Jilin University, Renmin Street, Changchun, People's Republic of China
e-mail: wxw_mail@163.com

Y. Guo
e-mail: happygy@gmail.com

Y. Chen
Old Dominion University, Norfolk, VA, USA

1 Introduction

Balancing an economic recovery and sustainable development is a key challenge that most countries are facing right now. The recent global economic crisis urgently requires new patterns of world economic growth [73]. A green economy, as an economy growth pattern, can not only improve people's life and promote economic growth, but it can also significantly reduce environmental risks and ecological damages [33]. In the process of creating a green economy, the information and communication technology (ICT) is identified as one of the key driving forces; it has been growing at an astonishing speed, in recent years.

Both green economy and ICT have attracted scholars' attention recently. Many theories have been applied to explore how ICT promotes a green economy. This paper, in particular, studies information ecology, a field that studies how human beings, ICT, and the social environment can develop together in a harmonious fashion. According to Miyazaki et al. [45], information ecology can provide new frameworks for interpreting the complex relationships among organizations, information technologies, and information objects in the context of information. At present, studies about information ecology have gradually extended to many application fields, such as information ecosystems, network environments, e-commerce/e-business, and digital libraries. But how information ecology originated as a research field and what status information ecology research has now remain unclear.

In order to better understand the research trends of information ecology, this paper applies bibliometrics and knowledge mapping to analyze 138 publications collected by SSCI and SCI in the Web of Science database, in terms of the changes in the number of published papers as time goes on, based on country and geographical area

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distribution, research topics, research methods, founding sources, hot research spots, and research trends. The goal of this paper is to help researchers and practitioners better understand which issues and topics have been addressed in information ecology studies and what the trends are in information ecology research. This paper applies the principles of ecology and combines methods from management and computer science to study ecology issues at different levels in the ICT field from the perspective of harmonious development among human beings, information technologies, and information environment. As such, this paper provides a new research perspective on information technology research and management. It further promotes the integration of theories and methods from diverse disciplines and pushes forward theory innovation and method innovation in information technology research and management.

The rest of this paper is organized as follows: In Sect. 2, research methodology and a data selection method are introduced. Section 3 applies bibliometrics and knowledge mapping to analyze selected papers from a diverse perspective. In Sect. 4, the origin and development of information ecology research are summarized and famous institutions that conduct information ecology research are outlined. At the end, Sect. 5 outlines the findings of the literature reviews, provides suggestions for future information ecology research, and points out the limitations of this study.

2 Methodology and data selection

Bibliometrics is an application that applies mathematics and statistical methods to the study of books and other media [5]. It has been primarily used by information scientists to study the growth and distribution of scientific publications. Furthermore, bibliometrics is used for evaluating the influence of a specific author and for describing the differences between two or more authors' publications. As such, with proper design and guide, bibliometrics can be applied as a powerful tool for peer review [47, 66].

Since the time when Lotka's Law, an empirical regularity of the scientific productivity, was first proposed by Lotka [42], researchers have been modifying and improving it. For example, Price points out that of the number of scientific publications on one specific subject, half of them are written by a group of authors who have high productive power [53]. Moreover, the number of these authors is approximately equal to the square root of the number of all authors writing on the subject.

In addition, for given publications about a certain subject, their distribution in journals that publish them follows a pattern, as well, called Bradford's Law [4]. According to Bradford's Law, if the huge number of publications about a specific subject is listed by the quantity of authors' publications in descending order, the list can be segmented into three areas, each of which has one-third of the total amount of publications. The first area is the core zone that includes a small number of high-quality journals. The middle zone includes a relatively large number of mid-level quality journals, whereas the outer zone has a huge number of low-quality journals. If the number of journals is set as n_1, n_2, and n_3 for these zones respectively, their distribution can be described by the formula: $n_1:n_2:n_3 = 1:\alpha:\alpha^2$ and α is a constant [68].

2.1 Knowledge mapping

Knowledge mapping, a tool that can clearly visualize knowledge and the relationship among knowledge points, is able to display the characteristics of knowledge [15, 40]. It consists of methods, models, algorithms, and techniques, through which researchers can study accumulated knowledge and further disclose hot topics, distribution areas, creators and any developing trend of knowledge [11].

Among the many knowledge mapping software, Citespace is a visualization tool that can find and display developing trends and the latest updates in a discipline by analyzing publications in that specific domain. It can be used for checking the research status and the current research hot spots in a discipline. In particular, the features of text analysis and citation analysis in Citespace can create snapshots of the current research status in a discipline and then can connect these snapshots. These features are very helpful for understanding the nature of leading research, for identifying research areas, for catching research trends, for discerning mutations in research, and for displaying the evolving process of leading research [31].

2.2 Data collection

This study chooses "information ecology", "ecology of information", and "information ecosystem" as keywords and searches published papers collected by the SSCI and SCI databases. The results show that the earliest paper related to information ecology was published in 1978 and that the number of papers published in the following several years is small. Therefore, the time period for this study is set from 1992 to 2013. Altogether, 114 papers were found, but 6 of them are review articles. So after these six articles were removed, this study has 138 papers as samples.

In addition, a review of the titles and abstracts of these selected 138 papers indicates that they mainly focus on information ecology, the ecology of information, and the

information ecosystem. Due to the limitations of the search engine adopted in this study, not all of the related papers were found. However, this paper assumes that all papers related to information ecology collected by SSCI and SCI database are selected in this study.

It should be noted that conducting a thorough reading and analysis for each selected paper is not feasible. Instead, browsing through them can convey the outline of the development process of these papers. Therefore, this paper conducts a statistical analysis on these selected papers from the perspectives of time, the country and geographic area the authors are from, the research method, and the research institution. Furthermore, this paper undertakes discussions of papers and of scientific communities in the domain of information ecology.

By applying the aforementioned research methods, this paper aims (1) to improve the understanding of the milestones in the development of information ecology and (2) to propose recommendations for future information ecology research.

3 Sample categories

3.1 Time

The selected published papers collected by the SSCI and SCI databases are listed by time, first. Figure 1 shows the number of publications on information ecology in each year from 1992 to 2013. Next, these publications are grouped by the country and the geographic area where authors are from. Table 1 shows the number of yearly publications on information ecology from 1992 to 2013 based on the authors' countries or geographic areas.

In order to check whether the number of selected publications during the time period from 1992 to 2013 increased relatively or absolutely, the number of published

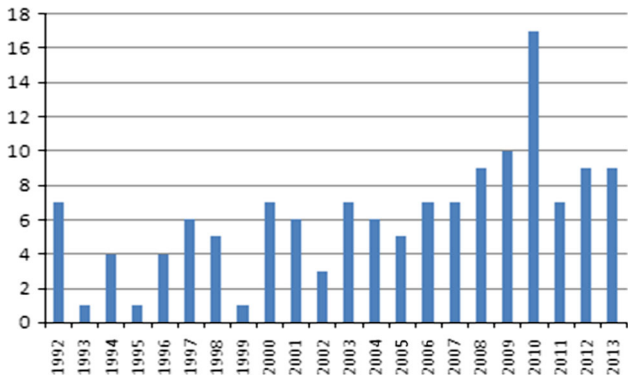

Fig. 1 The numbers of published papers on information ecology from 1992 to 2013

Table 1 The number of published papers on information ecology from 1992 to 2013 based on authors' countries or geographic areas

Country	1992–1993	1994–1995	1996–1997	1998–1999	2000–2001	2002–2003	2004–2005	2006–2007	2008–2009	2010–2011	2012–2013	Total
USA	3	4	5	6	5	2	2	4	6	6	3	50
England	1		1				1		3	2	2	9
Canada		1			2				1	3	1	7
France			2						2	2	1	7
Germany						1	3	1				5
Netherlands						2		2				4
China							1	1	1	2	2	7
Russia					1							1
Spain			1								2	3
Others	4		1		5	5	4	6	6	9	7	45
Sub-TTL	8	5	10	6	13	10	11	14	19	24	18	138

papers included in the Web of Science each year in the same time period was examined. The result shows that there was a peak of publications on information ecology in 1992, as seven papers were published. From 2006 to 2013, information ecology was gradually accepted by the public and the number of research on information ecology gradually increased, as well.

The average citation rate for selected papers is 13.20 and their *h* index is 22. These statistical data indicate that information ecology is a new field that is still growing. Figure 2 shows the number of citations of selected papers in each year during the period. The overall citation rate of papers on information ecology is relatively high. In addition, the number of citations increased each year. The changes in citations indicate that the quality of papers on information ecology is relative high, as these papers are well-recognized by academia, and their impact is growing. To a certain extent, these citation data prove that information ecology is becoming a hot topic in social science research.

Next, the selected 138 papers were loaded into Citespace, which generates the sequential network knowledge map for information ecology. The result is shown in Fig. 3. The visualized interface displays the changes in publications about information ecology from 1992 to 2013, the interaction among these publications, and the changes of the structure relationship among the nodes in the co-citation net, as time goes on.

The status of information ecology research from 1992 to 2013 can be seen as well. The square nodes represent unexpected frequencies, whereas the round ones represent keywords. The size of the nodes reflects their life cycle and influence. The color of the rings corresponds to the time zones at the top right corner of Fig. 3.

On the right side of Fig. 3, there are numbers that begin with #. As the order numbers for clusters, they are the results of clustering, ordering, and computing performed by Citespace on citations. The very top one, #1, represents the hotspots of research on information ecology at different times. It can be seen that Burnham and Anderson [6] was cited for five times. Their paper impacts significantly on information ecology research. Figure 3 also shows that ecosystem management, the ecosystem model, and the ecosystem approach are hot topics at different time periods of information ecology research.

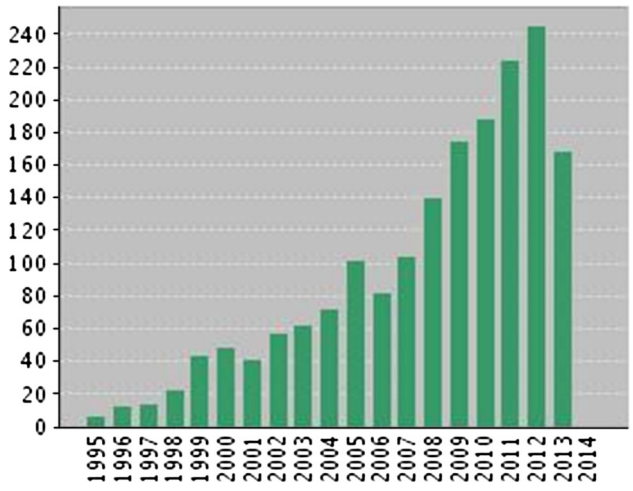

Fig. 2 The number of citations of selected papers from 1995 to 2013

When Citespace analyzes data, Centrality is often used to measure the degree of connection between nodes in the network map. In a literature co-citation network map, those pieces of literature that have large centrality values are the key pieces of literature which play vital roles in the process of the knowledge development in a field. Therefore, analyzing the evolution of the literature at the key nodes is an effective way to find how the key theories develop in a field. After the title, the keyword, the abstract, and the reference sections of the selected 138 papers were imported into Citespace, the network node was set as "Cited Reference", and the time period from 1992 to 2013 was divided into 22 time zones, Citespace generated a co-citation network knowledge map for information ecology. The result is shown in Fig. 4. There are 53 nodes and 45 connection lines altogether. These nodes and lines reflect the co-citations among the pieces of information ecology literature. Among the nodes, those with pink outer circles have centrality values >0.1. The highest centrality value is 0.27 in Fig. 4. This node represents Schmidt et al. [59], a paper cited 26 times on the Web of Science, which introduces the basic terminologies in information ecology, analyzes the impact factors of information ecology by using ecology theories and statistical decision theories, and explores the countermeasures for improving research on information ecology. The other node, which has a centrality value of 0.22, represents Diniz-Filho et al. [14]. Cited 93 times on the Web of Science, this paper analyzes the species mode of mammals in South America and develops models and methods based on Akaike information criteria for the purpose of building better region ecosystems.

3.2 Country or geographic area

Table 1 lists the number of publications on information ecology based on country or geographic area for each year from 1992 to 2013. The percentages of publications from some countries, such as the US, UK, Canada, France, Germany, Netherlands, China, Russia, and Spain, are shown in Fig. 5. It can be seen that the percentage of publications from the US is 36 %, more than one-third of the total number of publications. In contrast, publications from Asian countries were very limited during this time period. For example, publications from China only show

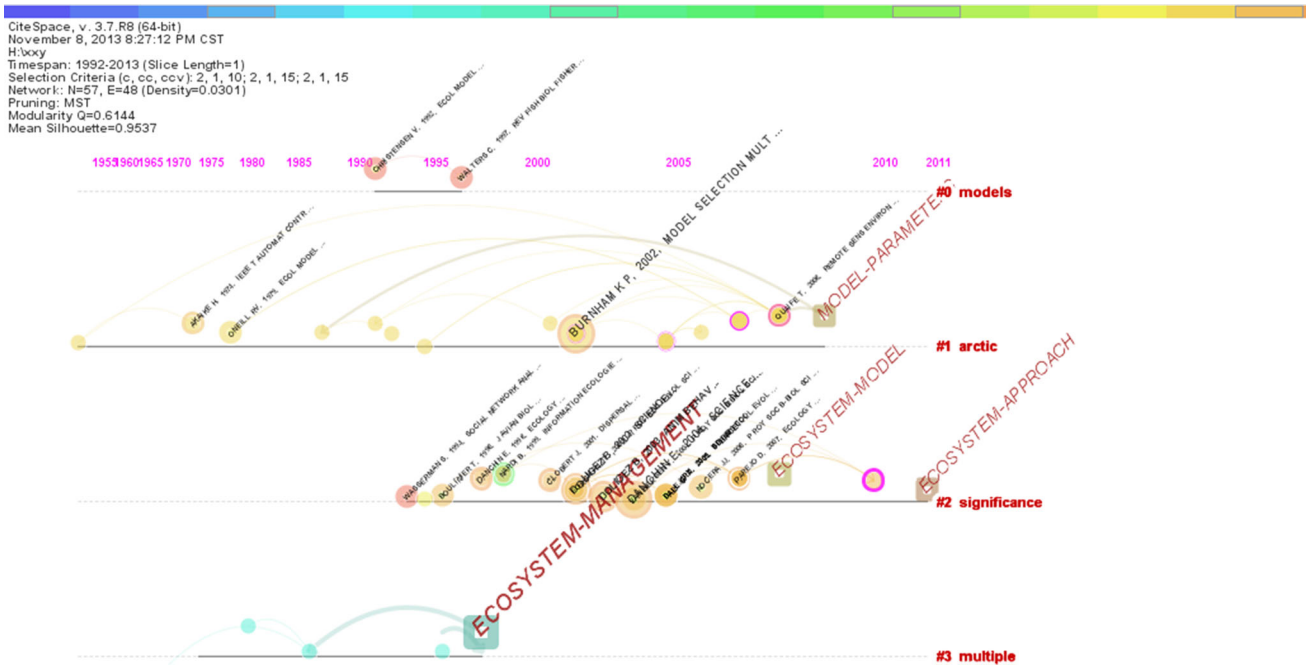

Fig. 3 Knowledge mapping of research process of information ecology, ordered by time

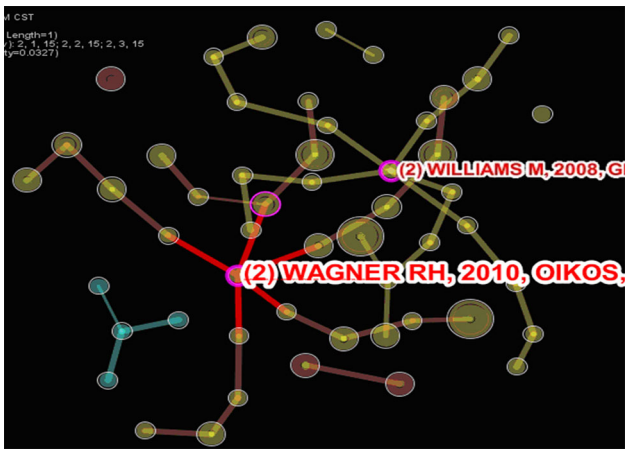

Fig. 4 Network map of literature co-citation in information ecology

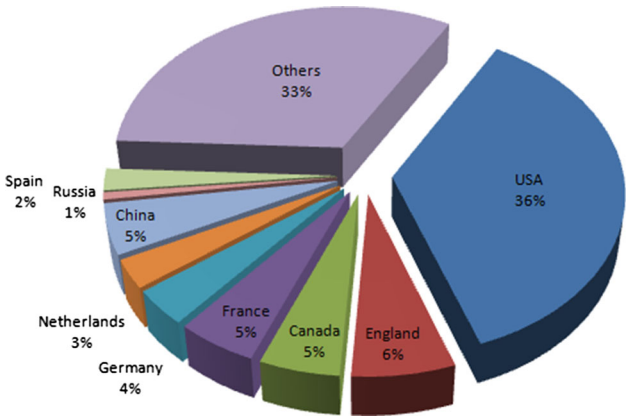

Fig. 5 Information ecology papers classified by country or territory

5 % of the total number. This distribution indicates that developed countries, which are represented by the US, lead information ecology research. Developing countries lag far behind developed countries in information ecology study.

According to Price's law [53], given a specific subject, half of the total papers are written by high-producing authors and the number of these authors is equal to the square root of the number of total authors. In other words, the lowest number of publications by key authors is equal to the number of publications by those authors who write the largest number of papers. Among information ecology researchers, R.C. Szaro is the one who publishes the largest number of papers. He has published three papers so far. Based on Price's law, the lowest number of publications by key authors in the field of information ecology is two. The number of authors who publish more than two papers is eight. Altogether, these authors published 17 papers, which account for 12.3 %, far less than the half, of the total number of publications. This proportion indicates that key authors in information ecology research have not yet played strong leading role; that a stable key author community has not formed; that the field of information ecology is not yet mature; and that information ecology research is still at the developmental stage.

Figure 6 shows the ranking of institutions where authors of information ecology papers come from. The top two institutions, actually at the bottom of Fig. 6, are both in the US.

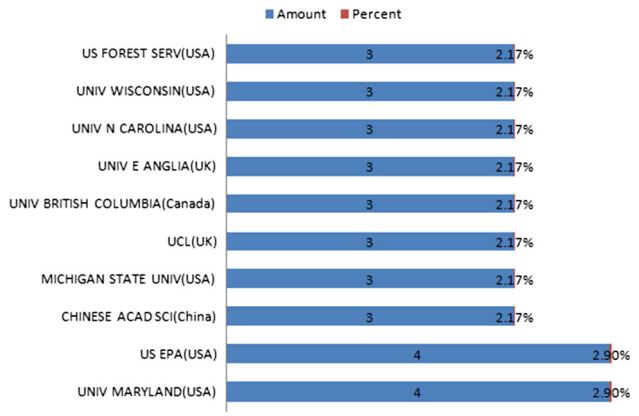

Fig. 6 Top ten institutions where authors of information ecology papers come from

Again, this ranking proves that developed countries lead information ecology research. Papers from institutions in developed countries account for high proportions in the ranking. Among the top ten institutions, six are in the US. Two are in the UK. One is in Canada and one is in China. The Chinese Academy of Social Sciences is the only institution from a developing country in the ranking list. Obviously, US universities are in the leading position in information ecology research.

3.3 Disciplines

According to the analysis of discipline distribution of selected papers (Fig. 7), it can be seen that disciplines of environment and ecology count for a large proportion of the total. This is because ecology provides the theory base for information ecology, which is the transplantation and ramification of ecology in information management. Meanwhile, the number of papers from some disciplines, such as geography, economics, information/library science, anthropology, and computer science, is large as well. This indicates that information ecology has attributes of the humanities and of social science and that information ecology has attracted attention from diverse disciplines. Thus, there are notable characteristics of multi-discipline integration in the development of information ecology.

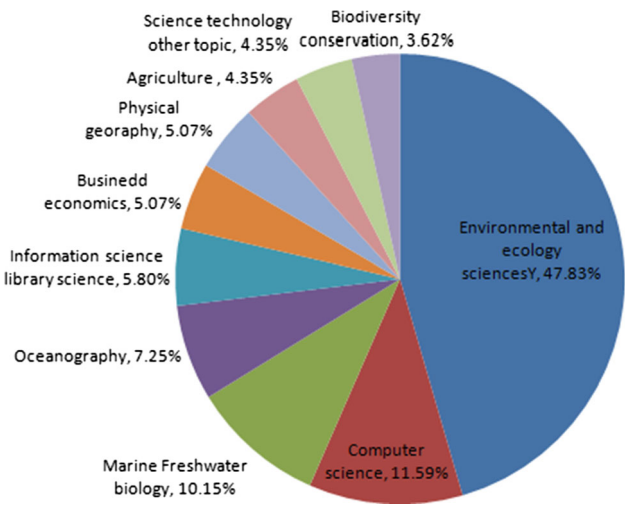

Fig. 7 Discipline distribution (top ten) among selected papers

Bradford's Law points out that journals, which publish 33 % of the total papers in a specific field, are key journals. Lists of the journals that publish the selected papers in a descending order and the top ten are shown in Fig. 8. Overall, these journals cover many related disciplines. This, to a certain degree, reflects that the trend of multi-discipline integrating and blending exists in information ecology research. The top ten journals published 33 papers on information ecology. This number accounts for 23.9 % of the total number of selected papers. This percentage indicates that there are no stable key journals in information ecology research. Because the selected papers are scattered widely throughout many journals, it can be determined that the field of information ecology is not mature yet and that research on information ecology needs to move forward.

3.4 Research method

Figure 9 shows the research methods adopted in the selected papers. Research methods are classified into four groups, namely empirical research, qualitative research, conceptual research, and formal model research. Table 2 provides the breakdown of these four groups into four time periods, each of which lasts 4 or 5 years. The data show that empirical research, qualitative research, conceptual research, and formal model research account for 45.65, 23.91, 18.84, and 11.59 % respectively in the total number of selected papers. The change in the proportions of these research methods indicates that information ecology researchers focused on theory research from 1992 to 2003 and that they switched to using an empirical research method to analyze social and natural issues from 2004 to 2013. Next, this paper will choose some typical papers as examples to explain these research methods.

As a typical example of empirical research, Zhu and Thatcher [74] explored the impacts of national information ecology on global e-commerce from 2003 to 2007 based on secondary data from the Global E-readiness Rankings of the Economist Intelligence Unit by applying multiple regression models. Another example is Hoehn et al. [28], which examines the effects of alternative information formats on stated choice outcomes, including the tabular information format and the text mode, by questionnaires and conducts choice experiments on wetland ecosystems by using the econometric model of Random Effect Probit.

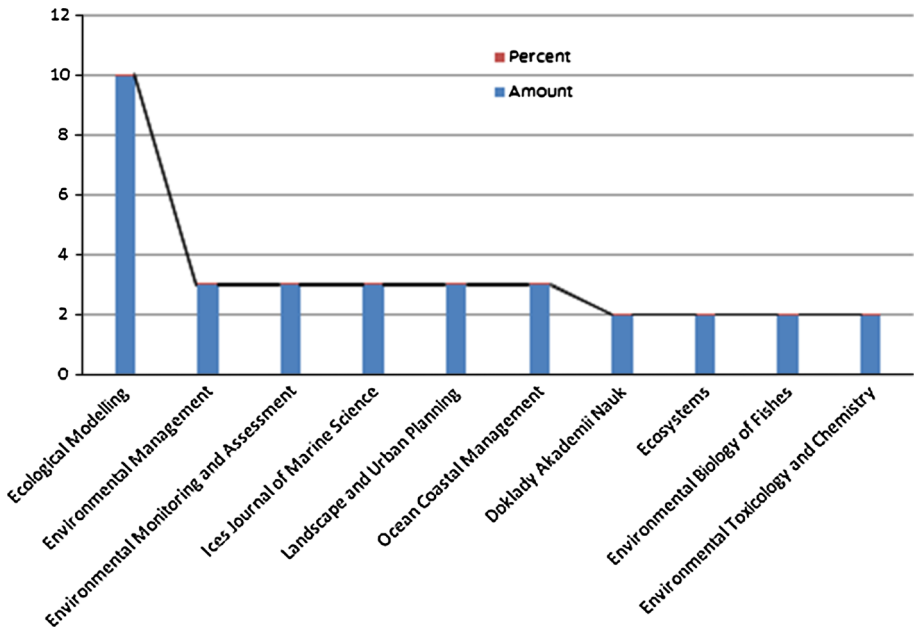

Fig. 8 The top ten journals that publish information ecology papers

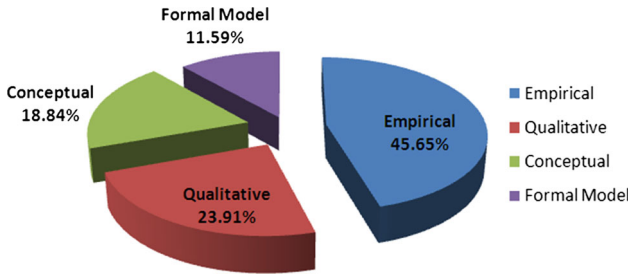

Fig. 9 Percentage of research methods adopted in selected papers

In term of qualitative research, as a high-quality paper that combines qualitative methods and quantitative methods, Treré adopts a qualitative method to explore participants' experiences and practices; it further explains the movement of anomalous waves by applying information ecology frameworks [65]. Mathew uses information ecology methods to analyze fishery-dependent industries and how to make fishermen's knowledge benefit fishery management [43]. He further explores how to integrate fishermen's knowledge into fishery management systems. This study applies qualitative methods to analyze fishermen in developing countries.

The formal model method is found in the selected papers as well. For example, Hogeweg conducts comparative analysis on hyper cycle models in space (CA model) and the well-mixed model (ODE model) [29]. Furthermore, he describes multilevel information processing models in ecosystems. In addition, Bianconi et al. [3] introduce a stochastic model for information selection in information ecology.

Among those papers that apply conceptual method, Canavese et al. [8] and Smith and Jenks [63] are two typical examples, which introduce information ecology theory, information ecological environment, and information ecology systems from diverse perspectives.

3.5 Support funding

Information ecology research gets funding from certain institutions in many countries. Table 3 lists four institutions ordered by the number of information ecology papers that they provide funding for. These top four institutions are all in developed countries and geographic areas, such as the US and Europe. Among these institutions, National Science Foundation in the US supports five papers, which

Table 2 Percentages of research methods adopted in selected papers in four time periods

Types	1992–1997	1998–2003	2004–2008	2009–2013	Total	Rate (%)
Empirical	5	15	21	23	63	45.65
Qualitative	6	6	6	15	33	23.91
Conceptual	8	6	4	8	26	18.84
Formal model	4	2	3	6	16	11.59
Sub-Tal	23	29	34	52	138	

Table 3 Top four institutions that provide the largest support for information ecology research

Foundation name (country/region)	Number of articles	%
National Science Foundation (USA)	5	3.623
European Commission (EU)	2	1.449
Natural Environment Research Council	2	1.449
University of Edinburgh (UK)	2	1.449

account for 3.623 % of the total number of selected papers in this study. The other three are the European Commission, the Natural Environment Research Council, and the University of Edinburgh. Each supports three papers, which account for 1.449 % of the total number of selected papers. These data indicate that institutions value information ecology research. The number of papers that were supported by European Commission ranks in the second place. This reflects that the European countries paid close attention to information ecology research. Table 3 shows that the number of published information ecology papers is directly proportional to the amount of funding in developed countries. Therefore, the output of high-level research counts on the support of the national research foundation. In addition, the National Natural Science Foundation of China ranks in fourth place among the institutions. The number of papers supported by it is larger in the SSCI than that in the SCI. The difference shows that the attention to research achievement about information ecology in China mainly comes from the field of social science.

4 Findings

4.1 Origin and development of information ecology

The concept of information ecology was first proposed by US researchers back in 1960s. Later, Horton introduced the flows of information inside organizations and the mapping of information [30]. Harris covered the same topics [23]. The method proposed by Harris was accepted by scholars later, and they further applied it to study the ICT on the flow of information in organizations [12, 24]. According to Davenport and Prusak, it is more modest, behavioral, and practical to manage information via ecological approaches compared with the perspectives of complex information system design and mechanical engineering. Information ecologists can construct better information environments by applying structural design and information technologies as well as by adjusting information strategies, politics, behavior, and workflow. In addition, Nardi [49] argues that culture, society, and the process of social mind in information ecology approaches are more important than the process of technology, in practice. He also tries to apply his argument to the management of complex information and document systems.

In contrast, Capurro [9] proposes the concept of information ecology from the perspective of macro systems. His proposal supplements the micro perspective held by previous researchers. The method proposed by Capurro focuses more on the logicality of the information flow inside organizations. Capurro further argues that information ecology must pay close attention to the question: what is the challenge in the societies in which more and more information technologies form knowledge, and in which communications rely more on information technologies? Nardi and O'Day [50] propose a new information ecology theory which notes that an information ecology system is a system that consists of human beings, work, value, and technology in certain environments; and that the focus of an information ecology system is the behavior of the people supported by technologies, not technologies themselves.

In recent years, the volume of research on information ecology has increased gradually. The development of information ecology drives the evolution of the worldwide web, digital libraries, electric governments, and social communication and social media based on the Internet [17, 20, 21, 41, 51, 58]. In addition, information ecology has an impact on information behavior as well [56]. The demands for a complex and open information environment become the drive for the application of ecology concepts [1]. Definitions provided in the next section will be helpful in understanding the information environment. According to Shi et al. [60], the concept of an information environment is proposed based on the evolution of information ecology structure property. Contextual factors are helpful for integrating concepts related to creation, such as cognition, language, and social patterns. These concepts are the basic principles in the information ecology framework.

4.2 Hot spots topics in information ecology research

Papers selected in this study were not limited to those that choose information ecology and information ecological characters as their subjects in the domain of information. In addition, papers about how to apply information ecology system or knowledge ecology in companies or firms were chosen as well. Given the characteristics of information ecology, the ecological characters of information, and information ecology systems, the hot subjects of information ecology research in the past 5 years can be classified into three categories: information ecology systems, information ecology in electronic businesses, and information ecology in networks.

The information ecology system is one of the main hot spots in information ecology research. Scholars have made some progress on this subject. For example, Walker used evolution computing to improve the accuracy and the recall mechanism of existing information retrieval systems in popular search engines [67]. His research provides an effective mechanism for knowledge sharing. Pérez-Quinones et al. [52] propose the concept of personal information ecology and explore how a user-device ecology system can provide designers and researchers with a language that can describe and discuss cross-device application design based on ubiquitous network equipments. Moccozet proposes a personal information ecology (PIE) framework which can be used for constructing user-centered ICT education and training environment. According to him, the PIE can be used for teaching technologies, and furthermore it can transmit course content and train students as active users for Web 2.0 communication devices [46]. Hussain et al. [32] propose to set up a digital information ecology system for the purpose of dealing with the change in global climate. The proposed system is able to capture multi-area digital ecology system that has impacts on global warming. It aims to capture the factors that impact global warming in different areas first and then connect these factors together to support adjustments of macro policies. Zhu et al. [75] apply the theory of an information ecology system to analyze an education ecology system and the three key factors of that education ecology system. They describe the interactions among these three key factors in detail. They further construct an education information ecology system framework about a 3D information chain resource network and knowledge domain based on the inactions among the three key factors.

With the development of the Internet and e-commerce, information ecology in e-commerce becomes a hot research subject. Some scholars have conducted research on this subject. For instance, based on the model proposed by Davenport and Prusak [12], Detlor [13] used case study to explore the impacts of organization information ecology and external environments on specific e-commerce activities. In addition, Javalgi et al. [34] construct a model for e-commerce by considering the characteristics of organization ecology dynamics about classic models in the Internet ecology system in the context of global e-commerce. Zhu and Thatcher [74] examine how e-commerce is adopted in the national information ecology environment and how the national information ecology environment influences e-commerce in 60 countries by using an empirical research method based on the secondary data from the Global E-readiness Rankings of the Economist Intelligence Unit.

Among the papers written about information ecology in network, Treré [65] applies an information ecology framework to explore the coevolution of Internet technologies for activism and examines the interrelationships among the actors who impact the diversity of systems, practice, and technologies. McKeon [44] proposes to apply a social data analysis to presenting and organizing data from multiple sources and to be more involved in network information ecology by providing real time data. Lastly, Nam et al. [48] use a social science hyperlink analysis to examine the network ecology of the 2010 local elections in South Korea.

4.3 Institutions conducting information ecology research

On the whole, information ecology research started early in developed countries. Right now, information ecology researchers and institutions are mainly located in developed countries, such as the US, UK, Canada, Australia, Japan, Netherlands, South Africa, Spain, and Switzerland. As the information ecology theory system is getting more complete and as information ecology continuously integrates itself with other disciplines, some well-known institutions that conduct information ecology research are appearing. These institutions are represented by the Media Lab at the Massachusetts Institute of Technology (MIT) in the US, by Queensland University of Technology (QUT) in Australia, and by Tokyo City University (TCU) in Japan. Research projects conducted by these institutions promote the formation of representative research findings and the in-depth and diversiform development of information ecology theory system to a certain extent.

Founded in 1980, the Media Lab at MIT is the leader in the multimedia industry in the world. It insists that communication and information technology will eventually converge. Led by Henry Holtzman, the research group in this lab mainly explores how to effectively connect physical environments and information resources. They aim to create and promote interaction between human beings and information by using low-cost sensors and ubiquitous technologies. Right now, they are working on ways to create better information ecology environments via electronic devices and sensing units in consumers' hands, in order to form effective information transfer and interaction between business environments and humans' sense organs. This media lab is known for choosing information and communication technologies as the breakthrough point in the research of information ecology theory and application.

QUT usually applies survey and modeling to investigate how to improve, share, and utilize effectively structured and unstructured information between human beings and firms. The main research projects conducted by QUT include: (1) building an information literacy model for social health and information institutions in order to deal with the

issue of the aging population in Australia based on quantitative methods; (2) examining human's reactions for natural disasters, including details about when, where, why, and how, through interviews and observations by using social media; (3) investing Twitter users' social networking experiences with Twitter, the most popular social networking platform in the world, at the present time; and (4) performing modeling to explore the complexity of information interaction among diverse environmental systems in social development. QUT is known for choosing social issues as the breakthrough point in the research of information ecology theory and application.

Tokyo City University (TCU) has a cross-discipline research team consisting of experts from computer science and social science. Their information ecology research mainly focuses on designing for cooperative development between ICT and social networks. They have three research directions: (1) an information system focus, in which, from the users' perspective, they study audio, image processing, graphics, web interface, wireless network systems, and digital processing, including information security, e-commerce systems and environment monitoring systems; (2) an information design focus, in which, through files, diagrams, symbols, TV programs, and website design, they carry out interface design, information image design, easy-to-use design, and property of participation design; and (3) a media and communication focus, in which they analyze and evaluate hot spots in the development of contemporary societies, including diverse social issues related to ICT, such as information security, intellectual property, the aging population, cultural diversity, and the aggravating climate and environment. TCU is known for combining computer technologies and the social sciences together and using the combination as the breakthrough point in the research of information ecology theory and application.

5 Discussion and conclusion

5.1 Insights of this study

The analysis of selected papers published between 1992 and 2013 and collected by SSCI and SCI database generates the following results:

First, the number of published papers on information ecology collected by the SSCI and SCI database and their citations increase as time goes on. Particularly in the past 5 years, information ecology has become a hot topic in academia, because the quality and the depth of information ecology research papers have increased remarkably and because empirical research methods are applied much more often than before. This change, to some extent, reflects that information ecology is a new interdisciplinary field. Second, developed countries are leading information ecology research because research results mainly come from these countries. In addition, universities and research institutions in the US, Australia, and Japan are forming new science communities regarding information ecology research. However, a stable key journal group in information ecology research does not exist, to date. Third, disciplines that conduct information ecology research are mainly from environmental science and ecological science. They include geography, economics, information library science, anthropology, and computer science. In terms of funding, information ecology research gets more in the US and other European developed countries than in developing countries. Fourth, regarding research methods, scholars who study information ecology from the perspective of technology prefer to use modeling and quantitative reasoning (including algorithms), whereas scholars who study information ecology from the perspective of the social sciences apply not only quantitative methods, but also empirical methods and case studies, in recent years.

In terms of hot topics in information ecology research, the main subjects focus on analyzing the harmonic development of human beings, the information environment, and information technology in terms of information ecology from the perspective of social science. In the science community of information ecology research, cooperation among scholars from diverse fields should be strengthened, so that the research perspective of information ecology can cover each aspect of social development. Future information ecology research should explore ways to apply ICT to promote the resolution of problems in the development of human society, such as aging population, firms' social responsibilities, social networking, social media, cultural diversity, environment monitoring, a low-carbon economy, green sustainable development, and natural disasters.

According to the statistical data in this study, the number of information ecology research papers published in developing countries is far less than that published in developed countries, specifically the US and European countries. Furthermore, few key authors of information ecology research papers come from developing countries. Therefore, developing countries have opportunities to promote international cooperation, through which they can improve their research levels, standardize their research methods, deepen their research depth, and move forward the interaction and integration among diverse disciplines in information ecology research. In this way, researchers can generate more high-quality research and can publish more papers in high-level international journals. As a result, researchers in developing countries are more likely to catch up to the leading levels in information ecology research.

5.2 Future research direction

This paper examines the status of information ecology research focusing on the changes in the number of published papers as time goes on, based on country and geographic distribution, research topics, research methods, founding sources, hot research spots, and research trends by analyzing published papers. It aims to investigate the contributions of typical researchers and the developing venation of theory in information ecology. Moreover, this papers aims to provide inspiration and reference for the direction and methodological innovation for future information ecology research. Based on the analysis, this paper proposes to improve information ecology research from the following aspects:

First, at the theory level, scholars should extend the breadth and depth of information ecology research. They should analyze information ecology and its characteristics in more industries, explore more methods for information ecology research, and enrich information ecology theories. The analysis also shows that information ecology theories and ecology methods should be applied to resolve problems in information technology and management in the following ways: (1) by analyzing the mechanisms about information communication, information diffusion, and information sharing, which can be accomplished by applying the concepts of information ecology factors, the information ecology chain, the information ecosystem, and the balance of information ecosystem from the perspective of the components of information ecology system (e.g., [10, 19, 64]); (2) by constructing an information ecosystem evaluation index that can reflect the characteristics of different industries from the perspective of the characteristics of information ecosystem and by evaluating information ecosystems such as enterprise information systems, e-commerce websites, social media, and portal websites, by applying the Analytic Hierarchy Process, the Fuzzy Evaluation Method, Data Envelopment Analysis or other evaluation methods (e.g., [7, 16, 61, 69, 70, 72]); (3) by analyzing information service, communication via social media (e.g., [27, 36]), and the evolution of network structure in Web 2.0 (Web 3.0) and cloud computing by applying the theory of infection, the theory of density-dependence, and the theory of ecosystem evolution and coevolution from the perspective of ecosystem theories (e.g., [18, 25, 35, 38]).

Second, at the technology level, for the development for ICT, scholars should explore the information ecology issues caused by the rapid development of new technologies such as cloud computing, the Internet of Things, and big data (e.g., [26, 71]). Scholars can resolve these issues in the following ways: (1) by analyzing how to achieve harmony among human beings, technology, and the information environment in the evolution of new technologies by designing better human–machine interfaces for mobile end user devices, such as smart phones and PDA, in the context of mobile commence from the perspective of cloud computing applications and by analyzing ways to fix the security issues of private data by constructing better information ecosystems in cloud computing (e.g., [1, 37]); (2) from the perspective of Internet of Things applications, by analyzing how to construct an environment monitoring system, a carbon tracking system, and a user-perception-based multimedia conscious system based on the key technologies of the Internet of Things, and by analyzing the construction of the information ecosystem in a supply chain information collaborative environment to promote a green supply chain (e.g., [57]); (3) from the perspective of the big data environment, by analyzing how to build information ecosystems that have certain security characteristics and can meet the requirements of unstructured data to fix the information security issues and data storage issues in the big data environment; and from the perspective of the data life cycle, by analyzing the ecosystem of big data in each step of data processing, including data generating, data processing, value extraction, and data destruction (e.g., [55]).

Third, from the perspective of society, scholars should conduct research at the national level, the industry level, and the firm level by applying the theories in information ecology and by using case study and empirical research methods. Scholars can conduct information ecology research at the following three levels: (1) at the national level, by studying how information ecology environment impacts IT technology selection (e.g., [59]), applications of e-commerce, the Internet of Things, cloud computing, and big data in different countries; by analyzing technology transfer in multi-cultural societies, knowledge sharing, and information ecology issues in foreign affairs in different countries (e.g., [39, 65]); by exploring ways to apply ICT to fix hot spot issues in social development, such as aging populations, firms' social responsibilities, the low-carbon economy, and natural disasters (e.g., [2]); (2) at the industry level, by analyzing how to build harmonic information ecosystems between users and information providers in diverse industrial organizations (e.g., [22]), including educational institutions, medical institutions, communities, governments, and libraries, to meet users' information demands (e.g., [54, 62]); and by exploring ways to use ICT to promote city ecology to achieve sustainable development in cities; (3) at the firm level, by analyzing information the ecology characteristics and components of information ecosystems in IT construction and the development of e-commerce websites; by exploring how to achieve the interactions between humans and information systems inside an organization and the interaction between users and e-commerce websites by building good information ecosystems; by taking into consideration

the popular social media at present, namely Twitter, Facebook, and blogs, and by analyzing the information ecology issues existing between user groups and between users and the social network environments (e.g., [17, 48]).

Finally, this paper argues to encourage cross-level and cross-regional cooperation in information ecology research, such as coordinating research between firms, regions, and organizations with diverse cultural backgrounds. The paper also argues to encourage international cooperation in information ecology research by the means of building cross-discipline research teams consisting of both researchers and practitioners. The research subjects can be the global cooperation mechanism in the context of information ecology, the global information ecosystem, and the consideration of how to achieve sustainable development among diverse cultures with the help of ICT in information ecosystems.

5.3 Limitations

The research conducts a study on existing information ecology papers, the characteristics of information ecology, and information ecosystems based on published papers from 1992 to 2013 collected by SSCI and SCI databases. It generates insightful results, based on which recommendations for future information ecology are proposed. However, there are some limitations to this study. For example, the keywords do not include knowledge ecology and knowledge ecosystem. In addition, only published papers collected by SSCI and SCI were selected. Furthermore, the research methods are limited to bibliometrics and knowledge mapping. Future studies need to expand the keywords in searching and select more databases. Meanwhile, other research methods, quality methods in particular, are needed to get more insightful results.

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