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Profile of Reliability Engineering & System Safety in the 21 years of the 21st century: An informetric – based analysis

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ABSTRACT

The objective of this study is to provide a case study of informetric and bibliometric analysis, by building up a profile for the journal of Reliability Engineering & System Safety in the 21st century, based on the data collected in Web of Science and the tool of VOSViewer. 4821 articles published in the journal in 2001-2021 have been adopted as the dataset. The keywords of these articles are analyzed and clustered, the main applications of these studies are identified, and the temporal development trend of the topics are discussed. The most productive countries/regions, institutions and individual researchers for the journal are presented and the collaboration relationships at the national and institutional levels are investigated and visualized. Distribution of author genders is surveyed based on a sample. Then, the citation situation of articles in the journal is analyzed, and the potential impact factors on citations, including number of authors, number of participating institutions and countries/regions, number of references, and topics are studied. Finally, evidence on whether open access can influence citations of articles is provided. Readers of this article are expected to understand more about how bibliometric analysis support journal analysis and development analysis in a certain domain.

KEYWORDS

Reliability engineering & system safety; Profile; Bibliometric analysis; Topical analysis; Author gender; Collaboration; Open access

1 Introduction

Informetric and bibliometric analysis has been well adopted to study the research trend and development of academic societies. For example, many scientific journals have recently presented bibliometric analysis results of their publications in different timeslots (Goerlandt & Li, 2022; Merigó et al., 2019; Kumar, 2021; Islam et al., 2022). In this study, we expect to utilize the bibliometric tools for a journal analysis, to investigate the research advance and current interests of the journal, illustrate the analyzing procedure and the effectiveness of the analysis tools.

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The study objective here is the journal of *Reliability Engineering & System Safety* (RESS), with an older name of *Reliability Engineering*, started in 1981 (Rausand et al., 2020), and it has been one of the most important worldwide platforms for sharing the knowledge for the enhancement of the safety and reliability of societal-technological systems. RESS publishes original research articles for analyzing substantive problems related to the reliability of complex systems and presenting techniques and/or theoretical results for solving the above problems, as well as review articles, case studies, recommendations, and communication letters. RESS has been recognized as a high-quality journal in both the fields of Engineering (section of Safety, Risk, Reliability and Quality, and section of Industrial and Manufacturing Engineering) and Operations Research & Management Science.

Based on the information given on the website of RESS, the journal offers authors two options of Open Access and subscription to publish their research. The Impact Factor of RESS in 2020 (obtained in 2021) is 6.188, the citation score in 2020 (obtained in 2021) is 9.2, and the current acceptance rate for submissions is around 30%. At this moment, 69 researchers from 26 countries/regions are in the editorial board, including three renowned associated editors, and the journal is indexed by Science Citation Index, Scopus and 10 other indices.

Since 1981, RESS has published more than 6000 articles, where the names of almost all the important researchers who have promoted the advancement of reliability and safety engineering can be found. Given the significant role of RESS in disseminating new knowledge in the domain, a comprehensive overview on the publications of the journal is expected to be helpful for new comers and students to understand the development trend and the ongoing situations of the reliability/safety society. The profile of the journal may also be interesting for those senior researchers and veterans to look back at the way they have walked.

To present and visualize the recent evolutions and state-of-art of RESS to reflect the development trend of reliability and safety engineering, we put eyes on the new century, namely the period of 01-Jan-2001 to 31-Dec-2021. To have a full profile, our studying objects are not only methodologies and technologies used in these articles, but the academic community who have developed and adopted these research results. Specifically, by analyzing the 4821 publications, the following questions about RESS are expected to be answered in this study:

- Question 1: What does RESS look like? In other words,
  - -How many and what kind of publications have occurred on RESS in the period?
  - -What are the focused topics of these publications, including methods and applications?
  - -What are the changes in the research topics compared with those 20 years ago?
  - -Which topics are occurring more recently?
- Question 2: Who makes RESS look like this? In other words,
  - -Who are the important contributors to RESS?
  - -How are the contributors distributed in terms of their countries/regions, institutions, and genders?
  - -What is the situation of collaborations between these contributors?
  - -Are there some changing trends for the contributors in the period?
- Question 3: How well does RESS look? In other words,
  - -How well are publications on RESS cited by the following studies in the period?
  - -What are the impact factors that make a study on RESS more interesting? For example, what topics are more cited, and can collaborations or open access result in more citations?
  - -Who is influencing the research on RESS and who is influenced by the research on

RESS?

To answer these questions and draw a comprehensive profile for RESS as possible, a bibliometric/scientometric analysis will be conducted in this study. Bibliometrics/scientometrics is a measuring technique in library and documentation science, and it was first proposed in 1969 by Pritchard (1969). Bibliometric analysis is often the combination of visualization techniques with the statistical methods for analyzing journals, books, and other medias, to visually represent the analysis results to facilitate interpretations (Small, 1999). Such an approach has increasingly appeared in the fields of risk and reliability (Goerlandt & Li, 2021; Li et al., 2021). For example on RESS, several articles of bibliometric analysis have been published, with the attention on system resilience (Hosseini et al., 2016), human reliability analysis (Patriarca et al., 2020), and failure mode and effect analysis (Huang et al., 2020), respectively. It is shown that bibliometric analysis is very effective in providing insights into the development of research activities, identifying the collaboration networks of collaborations, and communicating with readers.

However, to our knowledge, there is no such scientometric analysis with a specific focus on the journal of RESS itself, which is the motivation for initiating this study. Our aim is to produce a high-resolution profile image of RESS for researchers, students and practitioners who have interest in knowing more about the journal. We will try to avoid repeatedly presenting messages that can be easily found on the website of the publisher or information that can be simply discovered using search engines (like Web of Science or Scopus), but reveal more interesting facts based on statistics and analysis.

The focus of this study is to present facts, and we, as the authors, to the greatest extent, exclude ourselves from showing preferences, proposing causalities, making judgments, giving implications, or providing recommendations. Some publications on RESS have reviewed the research development and acted as the overall or specific guidelines for perspective studies in different domains of reliability engineering and risk assessment, such as the articles by Zio (2009), Aven (2012), Ouyang (2014), Hosseini et al. (2016), and Zio (2018), for the topics of reliability engineering, risk and resilience. This study has no similar ambition but would like to offer more evidence of the achievement of the journal itself.

The remainder of this study is organized as follows: Section 2 describes the adopted bibliometric/scientometric analysis tool and general situation of data, and Section 3 investigates the focused topics of RESS in the period of 2001-2021. Then, Section 4 analyzes the main contributors of RESS at the national level, institutional level, and individual level, respectively. Citation analysis occurs in Section 5, and some conclusions are provided at the end.

2 Method of analysis

2.1 Analysis tool

In addition to basic statistic programs, an important tool for analyzing and then visualizing data in this study is VOSviewer, which was first developed by the researchers from CWTS (Centre for Science and Technology Studies) at Leiden University. This software program provides a unified approach to mapping and clustering the bibliographic networks, and includes collaboration network, bibliographic coupling network and co-citation network, etc. (Van Eck & Waltman, 2010). VOSviewer is also able to handle large datasets, extract authors' keywords or identify noun phrases from titles and abstracts of the documents in the datasets, and generate maps of scientific domains based on these phrases (Van Eck & Waltman, 2010).

With more than 10 years of development, the VOSviewer has become one of the most widely-used scientometric software tools for mapping the landscape of the research domains (Goerlandt et al., 2022; Li et al., 2020a), authors (Li et al., 2020b) or journals (Gaviria-Marin et al., 2019; Goerlandt & Li, 2022) in the scientific community. Taking journal analysis as an example, while the Journal Citation Report (JCR) can provide some key knowledge of a journal, some information not included in the report, such as co-citation situation and co-authorship, is also interesting for understanding the journal. This missing information can be discovered in the bibliometric analysis and visualized with VOSviewer to the relevant researchers.

The flowchart of the bibliometric analysis of a journal with VOSviewer can be found in Figure 1. Brief explanations for each step are as follows:

- Objective specification: The objective here is to draw the profile of RESS.
- Data source selection: To be discussed in subsection 2.2.
- Data collection: This step includes the selection of data retrieval strategies, e.g., document types in search and search types, as well as the activity of data pre-processing.
- Study unit selection: The task is to determine what study objects should be considered in the analysis. In this study, we consider authors, author affiliations, countries/regions of authors, references of articles, keywords of articles, and times being cited of articles.
- Analysis & visualization: VOSviewer is used in this step for co-occurrence analysis, visualization, and clustering analysis. Some basic statistic tools are also used in this study.
- Results evaluation: Differences in the included data, study objects, and analysis tools can bring different results, which need to be evaluated for their informative values.
- Data cleaning: Given that analysis results are not informative, cleaning works are needed on original data to improve the visualization effects. For example, some similar keywords can be merged to increase the visibility of their common research area.

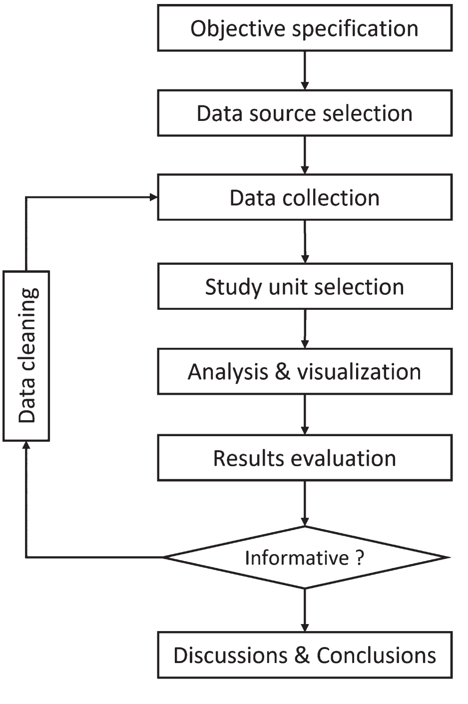


Figure 1 Flowchart of the bibliometric analysis

2.2 Data collection

The analysis is based on the data collected on the platform Web of Science (WOS) Core Collection, which is currently owned by Clarivate Analytics. WOS is the most widely used database for the analysis of scientific publications and has facilitated the literature search for scientometric analysis. Data is collected with the search for: PUBLICATION NAME: (RELIABILITY ENGINEERING & SYSTEM SAFETY), and the date of data collection is 07-Jan-2022, and the data download format is plain text with full record and cited references.

In this bibliometric analysis, we select the period of the new century from 2001 to 2021 to illustrate the recent development in the fields of reliability and safety and the reflections on RESS. Based on WOS, in the 21 years from 01-Jan-2001 to 31-Dec-2021, 4821 articles have been published on RESS consisting of the studied dataset, and their average publication year is 2013.78, which is calculated by the sum of publication years of all articles divided by the number of articles. These samples include 4611 regular research papers, 289 proceeding papers, 90 review articles, 88 editorial articles, 17 letters, 14 corrections and 1 obituary information. In the rest of this study, we do not distinguish these paper types and do not exclude any articles. When the presenting paper is prepared, some new articles have been published on RESS in 2022, but they are not incorporated in the dataset. Among the studied 4821 articles, 835 are published with open access. The number of publications on RESS and the number of open-access publications each year is shown in Figure 2.

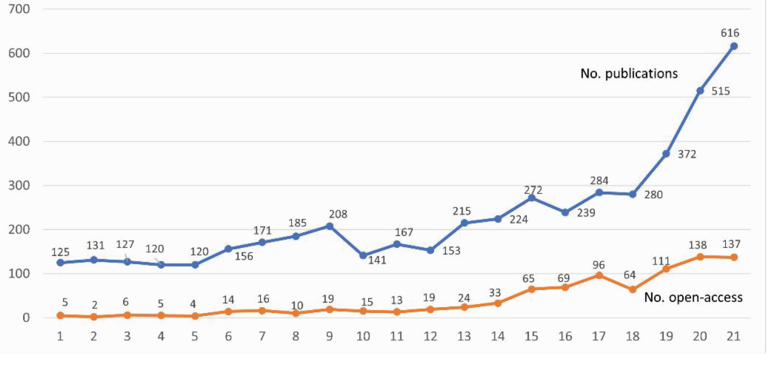


Figure 2 Number of publications and open-access articles on RESS in each year

For the 21 years of study, they are divided into three sections: 2001-2007, 2008-2014, and 2015-2021, for some temporal analyses and comparisons. The first and simplest reason for such division is that 21 can be divided by 3 and 7, and other considerations lie in the technical development and global trends of interests. Smart phones occurred in 2007-2008, and 3G networks began to be deployed at the same time, and they changed some manners and the cycle time of product development. The financial crisis in 2008 also impacted the industries to re-evaluate their investment and respond to market requirements. The second time point is located around 2014-2015, when several promising concepts and visions were set, like Industry 4.0, and artificial intelligence and internet-of-things became more and more popular. Attention to sustainability and climate change have also been much more emphasized since that time. It is of interest to investigate how such trends are reflected in the journal and in the fields of reliability and safety engineering.

It should be noted that we do not involve an article on RESS in the reference list of this paper if we do not use any methods, statements, or conclusions from the article. For example, titles of some articles appear in tables of this paper, but they are regarded as the representation of empirical data instead of references.

3 Topical analyses of publications

The first task is to explore the covered and focused topics of RESS, so as to provide answers to Question 1. We originally extracted 11585 keywords from all studying articles and present analysis results mainly based on the occurring frequencies of these words in the 21 years. Since many keywords with the same meaning are used in slightly different ways, we conduct a data cleaning before visualization by merging similar words into one word. In addition, some keywords with too detailed information are merged into one word to increase their visibility as a whole. For example, the keywords 'accelerated degradation test', 'accelerated degradation testing', 'accelerated degradation testing (adt)' and 'accelerated degradation test data' are merged in 'accelerated degradation test'. 'Virtual age', 'virtual age method', 'virtual age model', 'virtual age models' and 'virtual age process' are merge as 'virtual age'. Admittedly, all the data cleaning works are finished on the basis of the judgment of the first author of this paper, and his subjectivity and knowledge insufficiency can lead to biased results.

3.1 Clustering of keywords

We select those keywords occurring at least 5 times on RESS after merging, and 620 words are included for frequency and clustering analysis. Figure 3 is a network diagram of keywords for illustrating what kind of topics are more focused on RESS in 2001-2021.

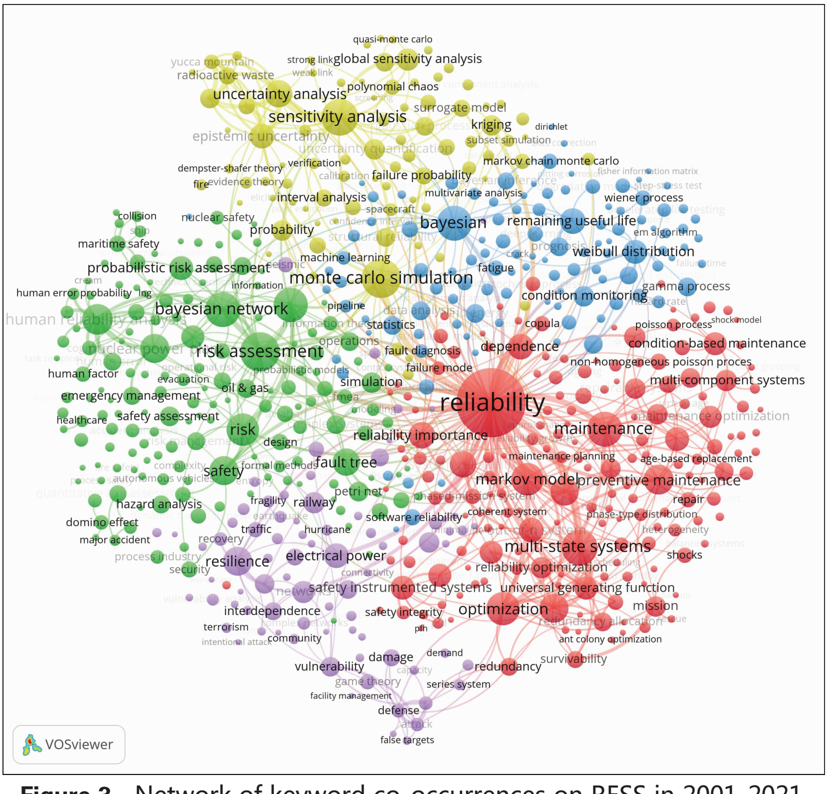


Figure 3 Network of keyword co-occurrences on RESS in 2001-2021

The sizes of nodes in Figure 3 denote their occurring times in the period, and a larger node means a higher occurrence frequency. It can be found that 'reliability' is the most occurring keyword, and some nodes, such as 'risk assessment', 'risk', 'Monte Carlo simulation', and 'Bayesian' are also very visible. As we have mentioned, the subjectivity in the merging process influences the image shown. For example, if the keywords of 'risk assessment', 'risk' and 'probabilistic risk assessment' are merged, a larger node of 'risk' can be expected, but considering some studies discuss the implications of risk qualitatively, these words are kept separately.

Another function of Figure 3 is to present the co-occurrence relationships of the keywords of RESS. The arc between two nodes represents the co-occurrence of the associated two keywords, and a wider arc means more co-occurrences of the two words. The difference between the widths of arcs is not obvious, but we still can find that, for example, the link between 'reliability' and 'Monte Carlo simulation' is stronger than most of the others. The link strength between these two nodes is actually 35, meaning that they co-occur as keywords in 35 articles. The distance between two nodes is not always meaningful, but more co-occurrences of two keywords often can result in a shorter distance of two nodes when the software program organizes such a figure.

Colors are used to illustrate the clustering results based on the co-occurrence situations of all the involved keywords. In general, these highly occurring keywords are clustered into 5 groups:

- Group Red – Reliability: A common term or summary of this group can be Reliability. The keywords here are mainly related to reliability, optimization, systems, and maintenance. For those words including the element of maintenance, they are closer to the Group Blue. The term of 'Markov model' is located in this group due to more co-occurrences with the surrounding words.
- Group Green – Risk/Safety: Most of the keywords are related to risk and safety. The node of 'Bayesian network' is in this group and is closer to Group Yellow. The node of 'fault tree' is green but with many connections with Group Red and Group Purple.
- Group Yellow – Uncertainty: The keywords are related to uncertainty, sensitivity, and Monte Carlo simulation. The node of 'Monte Carlo simulation' is very close to the center of the figure, intensively interacting with the other groups.
- Group Blue – Degradation: The keywords include those for remaining useful life, condition monitoring, Weibull distribution, Gamma process, etc. These nodes are close to those representing maintenance.
- Group Purple – Network: The keywords cover interdependence, resilience, vulnerability, and some applications with networked systems, such as electrical power (power grid) and railway.

3.2 Main application areas

It can be found in Figure 3 that the most visible nodes are about methodologies, models, and generic methods in reliability and safety engineering. Some small nodes related to applications can only be seen at corners only if we observe the figure very carefully. To investigate which industries attract more attentions from researchers of RESS, we extract those keywords representing application areas while hiding all the other nodes in Figure 3, to develop Figure 4. Therefore, Figure 4 is a part of Figure 3, and all the nodes in Figure 3 keep their locations in Figure 3.

The following key application areas of the studies on RESS can be detected:

- Nuclear industry: There are several relevant keywords with strong links between each other, such as 'nuclear power plant', 'nuclear safety' and 'radioactive waste' shown in Figure 2, and most of these words are located in the area of Risk/Safety.
- Electrical power: The shown node of 'electrical power' actually includes several keywords such as power grid and grid. It is located in the area of Network and has many interactions with critical infrastructures and other networked systems like railway and water distribution. Electrical power is also close to the keywords related to natural hazards, such as hurricane and flood.
- Transportation: The keywords of 'railway', 'traffic' and 'aviation' are very close, located in the area of the Network. Meanwhile, there is an obvious cluster of keywords related to 'maritime', including 'maritime safety', 'maritime', 'ship' and 'collision', in the area of Risk/Safety.

In addition, the sizes of nodes for oil & gas, process industry, wind energy, and spacecraft are noticeable. Some new applications, such as autonomous vehicles (autonomy), and battery, have been emerging in Figure 4.

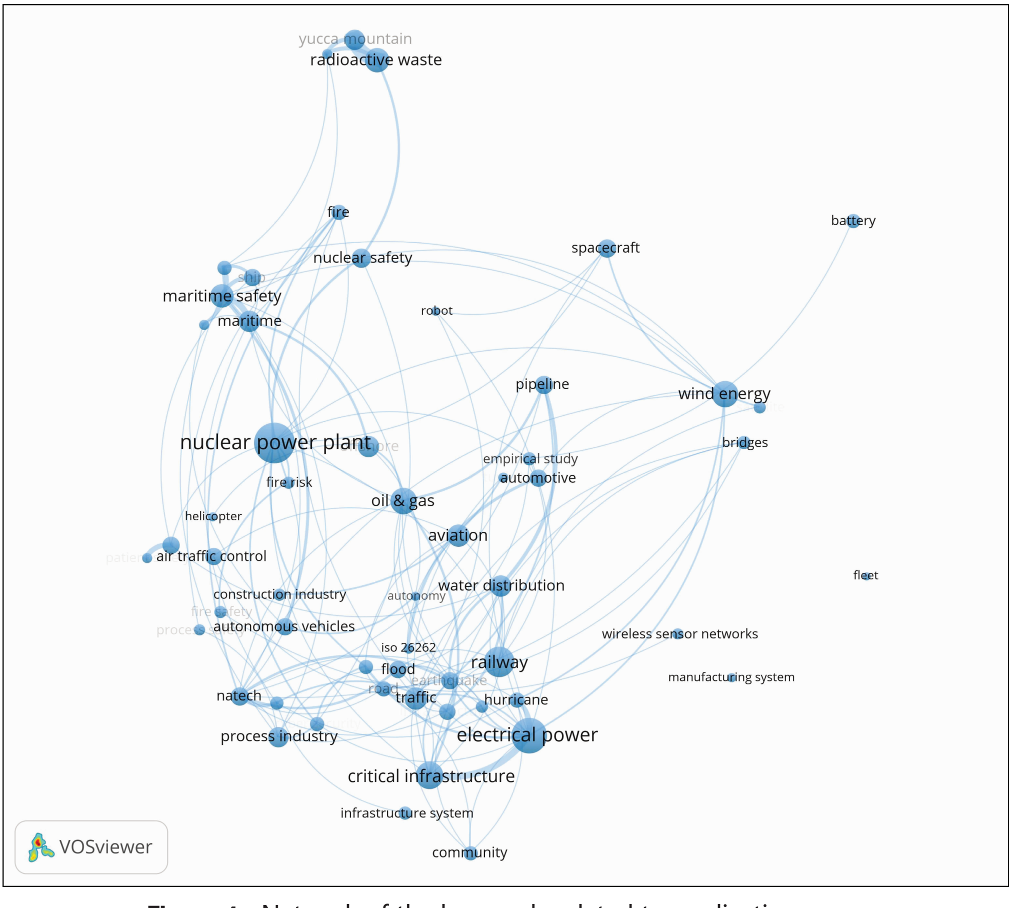


Figure 4 Network of the keywords related to application areas

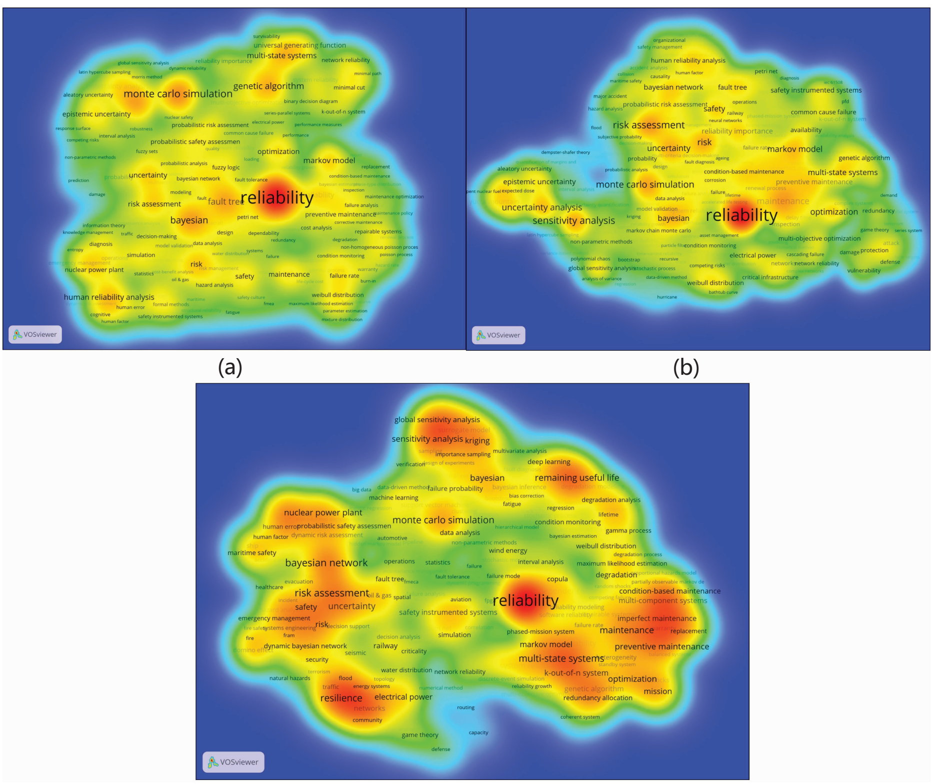
3.3 Temporal analysis of keywords

Then we would like to identify whether the intensity or popularity of keywords changes with time by using thermal images in Figure 5. The keywords occurring respectively no less than 5 times in 2001-2007, 2008-2014 and 2015-2021 are included. In Figure 5, the areas with colors closer to red represent that the associated keywords occur more in the period. It should be noted that since there are more publications in 2015-2021, more areas show red naturally.

Both similarities and differences in the keywords of the three sections can be found. Some keywords occur in all three figures with high frequencies, such as the general keywords of 'reliability', 'risk assessment' and 'uncertainty', as well as the keywords of widely used analysis approaches including 'Monte Carlo simulation', 'Bayesian' and 'Markov model'. On the other hand, some keywords emerge in the period of 2015-2021, especially the ones related to the following two topics:

- Resilience: Such a keyword is not visible in Figures 4(a) and 4(b) but presents high frequency in Figure 5(c) at the bottom-left corner. Resilience often co-occurs with some other newly visible keywords, such as 'network' and 'electrical power'.
- Condition-based maintenance: Several relevant keywords, including 'condition-based maintenance', 'remaining useful life', 'preventive maintenance', 'degradation', 'imperfect maintenance' and 'condition monitoring' become much more visible and Figure 5(c).

At the same time, for the methodological part, it can be found that the Kriging method, machine learning, and surrogate models (e.g., useful for dynamic risk analysis and digital twins) have obtained more attention recently. For the application part, in addition to electrical power, railway and maritime industries are emerging focused areas.



(a) (b)

(c)

Figure 5 Intensity diagrams of keywords in 2001-2007 (a), 2008-2014 (b) and 2015-2021 (c) on RESS

4 Productivity analysis

In this section, we would like to answer Question 2, to identify the main contributors of RESS in terms of their geographic distributions at the national and institutional levels.

4.1 Distribution at the national level

In the period of 2001-2021, researchers from 82 countries/regions published their works on RESS. The number of countries/regions that have 10+ contributions is 43, as shown in Table 1.

Table 1 List of countries/regions that have 10+ publications on RESS in 2001-2021

Country/region	N	TC	AC	APY	AAC	NPC	CS
United States	1137	37661	33,12	2013,56	3,92	46	587
China	1099	21999	20,02	2017,50	4,45	41	708
France	449	14992	33,39	2014,05	4,20	44	339
United Kingdom	425	9881	23,25	2013,79	2,83	44	292
Italy	391	13662	34,94	2013,27	4,00	35	352
Norway	310	8535	27,53	2014,07	3,47	29	176
South Korea	268	4842	18,07	2013,42	2,11	30	139
Canada	266	8387	31,53	2014,17	4,03	30	207
Netherlands	209	5375	25,72	2013,87	3,16	34	189
Spain	177	4563	25,78	2012,64	2,75	26	94
Israel	153	3672	24,00	2012,26	2,46	16	206
Australia	139	3602	25,91	2013,22	2,95	32	109
Germany	131	2732	20,86	2013,34	2,41	26	90
Taiwan	116	2996	25,83	2012,01	2,59	10	42
Iran	108	2133	19,75	2016,65	3,69	22	63
Japan	90	1631	18,12	2012,59	1,94	23	56
India	83	1657	19,96	2012,51	2,10	13	23
Brazil	80	2048	25,60	2015,08	3,70	20	56
Finland	80	2424	30,30	2012,70	3,26	18	59
Singapore	80	2609	32,61	2014,33	4,25	12	56
Switzerland	77	2457	31,91	2014,65	4,34	17	61
Belgium	68	1532	22,53	2013,75	2,73	17	76
Portugal	55	1254	22,80	2013,64	2,73	17	37
Sweden	55	1626	29,56	2013,58	3,51	21	50
Turkey	54	683	12,65	2016,78	2,42	8	21
Greece	49	1262	25,76	2011,82	2,53	14	31
Russia Federation	43	1294	30,09	2016,35	5,33	13	83
South Africa	43	844	19,63	2013,13	2,21	11	75
Chile	40	604	15,10	2016,13	2,57	16	46
Poland	35	921	26,31	2014,03	3,30	13	29

Country/region	N	TC	AC	APY	AAC	NPC	CS
Venezuela	35	1146	32,74	2010,83	2,93	10	43
Denmark	31	735	23,71	2014,68	3,24	14	30
Slovenia	25	938	37,52	2010,52	3,27	3	4
Mexico	24	966	40,25	2014,83	5,61	9	28
Czech Republic	22	329	14,95	2013,18	1,70	9	13
Ireland	16	217	13,56	2016,13	2,31	11	19
Saudi Arabia	16	423	26,44	2015,75	4,23	10	19
Egypt	12	231	19,25	2011,00	1,75	4	6
New Zealand	12	343	28,58	2010,17	2,42	8	12
Austria	10	135	13,50	2014,70	1,85	5	5
Colombia	10	143	14,30	2017,60	3,25	7	9
Hungary	10	340	34,00	2008,20	2,46	3	3
Thailand	10	321	32,10	2013,30	3,69	5	10

* N- Number of published articles; TC- total citations; AC- average citation per article; APY- average published year; AAC- average annual citation per article, NPC– number of partner countries; CS-Collaboration strength.

In Table 1, we also can find the information about the total citations (TC), average published year (APY) of the publications by the country/region, as well as the average citation per article (AC), and average annual citation per article (AAC). APY is calculated with the sum of all publication years divided by the number of publications (N), AC=TC/N, while AAC is equal to AC/(2022-APY). All three indicators are related to citations, and we will discuss them in section 5.3.

Figure 6 visualizes the information in Table 1 and also includes the countries with less than 10 publications. Larger nodes denote more contributions, and a lighter color means that the associated contributions occurred more recently. Figure 6 also illustrates the collaborations between countries/regions, which will be discussed in section 3.4.

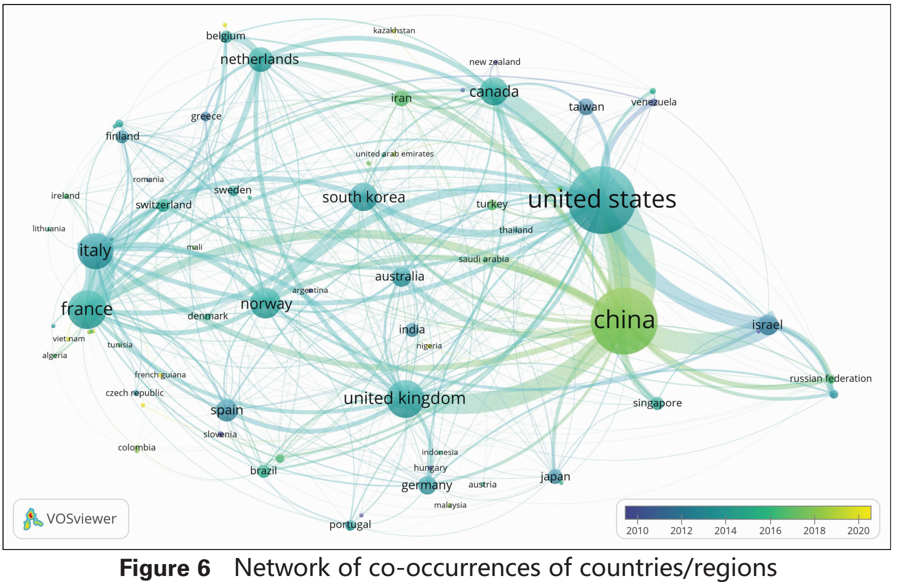


Figure 6 Network of co-occurrences of countries/regions

4.2 Distribution at the institutional level

Publications of RESS in 2001-2021 are from around 2400 organizations, including universities, research organizations, governmental and non-governmental organizations, and industrial companies. Table 2 lists the top contributive organizations that have (co-)published at least 30 articles in the period of 2001-2021 on RESS.

It should be noted that there are some difficulties in data cleaning for institution analysis, due to the inconsistency of the names of some institutions. We realize that some universities share the same names, but they run very independently, for example, China University of Petroleum in Beijing and East China, and Indian Institute of Technology at several places. The challenges lie in that some researchers do illustrate their campuses, and some do not. The software program of data collection cannot distinguish these organizations. In some special cases, such as the three Northeast Universities in US, China, and Japan, we manually re-calculate their publications, but in more cases, we simply merge the publications of such kinds of institutions even though we know there can be some arguments. In addition, some institutions have organizational changes in these years, for example, the merge of école Centrale Paris with Supélec and then to University Paris Saclay, as well as the change of name of DNV to DNV GL and back to DNV. For the cases we know, we merge the contributions from different names. However, it is impossible to grasp all histories of all institutions worldwide, and thus some merges may be inappropriate, but we believe that such uncertain situations have very little impact on the analysis results.

Table 2 lists all the institutions that published at least 40 articles on RESS in the period of 2001-2021, including the information of publication numbers and situations of citations.

Table 2 List of institutions that have 30+ publications on RESS in 2001-2021

Institution	N	TC	AC	APY	AAC	NPI	CS
Politecnico Milano	165	6472	39,22	2013,52	4,63	30	172
University of Stavanger	148	4501	30,41	2013,28	3,49	11	40
Univ Elect Sci & Technol China	134	2901	21,65	2016,90	4,25	24	185
Delft University Technology	132	3721	28,19	2014,18	3,60	21	77
Israel Elect Corp Ltd	126	3108	24,67	2011,98	2,46	16	172
Norwegian Univ Sci & Technol	117	3103	26,52	2015,08	3,83	17	39
Beihang University	108	1820	16,85	2018,49	4,80	22	67
University of Paris–Saclay	97	3313	34,15	2015,60	5,34	24	119
Northwestern Polytech Univ	83	1585	19,20	2017,59	4,35	12	20
Sandia National labs	82	4635	56,52	2011,65	5,46	7	41
Korea Atom Energy Res Inst	78	984	12,62	2011,71	1,23	2	17
University of Massachusetts	74	1468	19,84	2017,07	4,02	14	101
Tsinghua University	70	1218	17,40	2014,44	2,30	20	32
University of Maryland	65	2413	37,12	2013,12	4,18	14	31
Univ Technol Troyes	60	2731	45,52	2012,40	4,74	7	25
CNR	53	2619	49,42	2009,66	4,00	11	25
Korea Adv Inst Sci & Technol	53	928	17,51	2008,23	1,27	2	14

Institution	N	TC	AC	APY	AAC	NPI	CS
National Univ Singapore	51	2115	41,47	2013,43	4,84	12	24
Beijing Inst Technol	49	745	15,20	2018,98	5,03	10	15
Vanderbilt University	47	1944	41,36	2012,87	4,53	7	8
City Univ Hong Kong	46	1489	32,37	2015,39	4,90	21	47
Huazhong Univ Sci & Technol	46	2173	47,24	2017,43	10,34	11	18
Arizona State University	44	4032	91,64	2011,09	8,40	6	35
Georgia Inst Technol	44	1555	35,34	2013,57	4,19	8	11
Stevens Inst Technol	43	2277	52,95	2012,16	5,38	5	25
Rutgers State University	42	3130	74,52	2013,48	8,75	13	23
Mem Univ Newfoundland	40	1673	41,83	2017,33	8,96	5	9
Univ Sci & Technol Beijing	40	1214	30,35	2016,65	5,67	15	42
University of Alberta	39	1726	44,26	2012,97	4,90	13	27
Shanghai Jiao Tong Univ	38	896	23,58	2017,11	4,82	10	11
Indian Inst Technol	37	815	22,03	2013,32	2,54	2	2
Univ Politecn Valencia	37	871	23,54	2012,14	2,39	2	3
Natl Univ Defense Technol	36	946	26,28	2017,08	5,34	5	11
KU Leuven	35	888	25,37	2016,94	5,01	9	48
University of Illinois	35	1121	32,03	2014,49	4,26	7	9
Ohio State University	34	855	25,15	2016,09	4,26	5	5
University of Strathclyde	34	521	15,32	2013,71	1,85	11	15
Beijing Univ Technol	33	264	8,00	2020,09	4,19	9	27
University of Michigan	33	509	15,42	2016,94	3,05	9	17
Paul Scherrer Inst	32	905	28,28	2013,06	3,16	4	14
Aalto University	30	1501	50,03	2016,43	8,98	8	19
Cranfield University	30	665	22,17	2014,60	3,00	7	10
MIT	30	1116	37,20	2009,57	2,99	8	8
Tongji University	30	535	17,83	2018,30	4,82	10	14

* N- Number of published articles; TC- total citations; AC- average citation per article; APY- average published year; AAC- average annual citation per article, NPI– number of partner institutions; CS- Collaboration strength.

Table 3 illustrates the changes of most productive institutions in the three timeslots. It can be found that some institutions keep themselves relatively stable in the three sections, while some institutions have a significant increase in the recent period. There are 9 institutions occurring in all three lists, but in the 30 institutions listed in 2015-2021, 14 of them have never occurred before. It also can be noted that contributions are more distributed among more researchers in some institutions, while key researchers greatly influence other institutions. The contributions of individual researchers to institutions are not further investigated in this study, considering the privacy issues.

Table 3 List of the most productive institutions on RESS in 2001-2007, 2008-2014, and 2015-2021

Institution 2001–2007	N	Institution 2008–2014	N	Institution 2015–2021	N
Israel Elect Corp Ltd	34	Univ Stavanger	74	Beihang univ	98
Korea adv inst sci & technol	31	Politecn Milan	56	Univ Elect Sci&Technol China	97
Korea atom energy res inst	28	Sandia Natl Labs	46	Politecn Milan	82
Politecn Milan	27	Israel Elect Corp Ltd	41	Delft Univ Technol	77
Delft Univ Technol	22	Univ Elect Sci&Technol China	37	NTNU	74
Sandia Natl Labs	22	Univ Paris Saclay	34	Northwestern Polytech Univ	65
CNR	19	Delft Univ Technol	33	Univ Paris Saclay	62
Univ Maryland	16	NTNU	31	Univ Stavanger	61
Los Alamos Natl Lab	15	Stevens Inst Technol	22	Univ Massachusetts	56
Univ Technol Troyes	15	CNR	21	Israel Elect Corp Ltd	51
MIT	14	Georgia Inst Technol	20	Beijing Inst Technol	47
Arizona State Univ	13	Univ Maryland	20	Huazhong Univ Sci&Technol	40
Natl Univ Singapore	13	Arizona State Univ	19	Tsinghua univ	40
Rutgers State Univ	13	Univ Technol Troyes	19	Korea Atom Energy Res Inst	35
Tsinghua Univ	13	Northwestern Polytech Univ	17	Beijing Univ Technol	33
Univ Stavanger	13	Tsinghua univ	17	Mem Univ Newfoundland	32
NTNU	12	Univ Massachusetts	17	Shanghai Jiao Tong Univ	31
Bhabha Atom Res Ctr	11	Univ Politecn Valencia	16	City Univ Hong Kong	29
Indian Inst Technol	11	Korea Atom Energy Res Inst	15	Itmo Univ	29
Vanderbilt Univ	11	Cent Univ Venezuela	14	Univ Maryland	29
Cent Univ Venezuela	10	Univ Laval	14	Univ Sci & Technol Beijing	28
Feng Chia Univ	10	Los Alamos Natl Lab	13	KU Leuven	27
European Communities	9	Univ Alberta	13	Natl Univ Def Technol	27
Paul Scherrer Inst	9	Vanderbilt Univ	13	Natl Univ Singapore	27
Univ Newcastle	9	Changsha Univ Sci & Technol	12	Tongji Univ	27
Univ Tecn Lisboa	9	City Univ Hong Kong	12	Xi´an Jiao Tong Univ	27
Univ Alberta	8	Cranfield Univ	12	China Univ Petr	26
Univ Glasgow	8	Texas A&M Univ	12	Kyung Hee Univ	26
				Univ Michigan	26
				Univ Technol Troyes	26

* N- Number of published articles

4.3 The most productive authors

Table 4 lists the top contributing individuals in three sections of the studied period, namely 2001-2007, 2008-2014, and 2015-2021 respectively. One reason why we skip the general table for the whole 21 years is that some researchers published much more articles in 2015-2021, and thus a general table will miss those who contributed more to the earlier years. Another consideration is to avoid a table including the individual information of average publication year, average citation, and personal collaboration that may result in unnecessary arguments. It is noted that five authors in 2008-2014 are excluded from the table because they only participated in a series of 7 papers in a special issue in 2008 and have no contribution to any other articles at any other time. In the section of 2015-2021, the listed authors in the table are different from the simple search result on WOS, because contributions from some different authors with similar abbreviated given names are wrongly regarded as those by one author on the website.

The listed numbers in the three-time slots are slightly different (39 in 2001-2007, 40 in 2008-2014, and 42 in 2015-2021) since there are some researchers who published the same number of articles. 8 researchers appear in all three lists for different timeslots.

Table 4 The most productive authors for RESS in 2001-2007, 2008-2014, and 2015-2021 respectively

Authors in 2001–2007	N	Authors in 2008–2014	N	Authors in 2015–2021	N
Levitin G	32	Zio E	47	Zio E	74
Zio E	24	Levitin G	46	Levitin G	60
Seong PH	17	Aven T	44	Xing LD	51
Yeh WC	14	Helton JC	31	Peng R	38
Helton JC	13	Ramirez–Marquez JE	22	Aven T	37
Podofillini L	13	Sallaberry CJ	22	Cui LR	29
Aven T	12	Hausken K	18	Khan F	29
Marseguerra M	11	Hansen CW	17	Finkelstein M	28
Rocco CM	11	Xing LD	17	Reniers G	28
Vaurio JK	11	Saleh JH	14	Lu ZZ	27
Xie M	11	Lu ZZ	13	Dai YS	26
Mahadevan S	10	Mahadevan S	13	Cozzani V	23
Mosleh A	10	Martorell S	13	Li YF	23
Oberkampf WL	10	Rausand M	13	Park J	23
Coit DW	9	Jiang R	12	Khakzad N	20
Jung WD	9	Rocco CM	12	Huang HZ	18
Kushwaha HS	9	Wang WB	12	Mahadevan S	18
Ramirez–Marquez JE	9	Zuo MJ	12	Eryilmaz S	17
Soares CG	9	Berenguer C	11	Kang R	17
Berenguer C	8	Nourelfath M	11	Kim Y	17
Park J	8	Richard RP	10	Liu Y	17
Rauzy A	8	Sevougian SD	10	Liu YL	17
Johnson JD	7	Finkelstein M	9	Zuo MJ	16
Lisnianski A	7	Mosleh A	9	Soares CG	15
Martorell S	7	Tarantola S	9	Xiang YP	15
Tarantola S	7	Vinnem JE	9	Dang VN	14
Zuo MJ	7	Xie M	9	Mosleh A	14
Chatelet E	6	Bedford T	8	Utne IB	14
Cooke RM	6	Cozzani V	8	Wu SM	14
Dutuit Y	6	Dai YS	8	Xiao H	14
Finkelstein MS	6	Guikema SD	8	Coit DW	13
Frangopol DM	6	Khan F	8	Di Maio F	13

Authors in 2001–2007	N	Authors in 2008–2014	N	Authors in 2015–2021	N
Grall A	6	Soares CG	8	Dui HY	13
Ha J	6	Cadini F	7	Si SB	13
Kim MC	6	Frangopol DM	7	Yeh WC	13
Melchers RE	6	Li YF	7	Barros A	12
Murthy DNP	6	Nakagawa T	7	Coolen FPA	12
Singh N	6	Park J	7	Droguett EL	12
Yang JE	6	Pedroni N	7	Flage R	12
		Vaurio JK	7	Landucci G	12
				Liao HT	12
				Ramirez–Marquez JE	12

* N- Number of published articles

4.4 Analysis of genders of authors

Gender equality is an important worldwide topic. In this subsection, we would like to present some investigation results about the gender information of the authors who publish on RESS. It should be noted that we do not try to provide any societal explanations for the statistics, as well we do not make any judgment or reach any conclusions based on the data. Gender analysis is motivated by Table 4, where among the most productive researchers, 0 females are in 2002-2007, 2 females in 2008-2014, and 5 females in 2015-2021. This gender information is obtained based on the public information of all the listed researchers on their official webpages.

We realize that there can be different gender recognition by people, but we have no resources to make a more detailed investigation. Then we investigate the articles published in the most recent 3 months (01-Oct-2021 to 31-Dec-2021) as an example for analyzing the general contributions from females and males. We identify the genders' first authors, corresponding authors, and last authors of the 239 articles published in the three months based on their names and their public information of on internet. Both last authors and corresponding authors are counted because there are different manners for ranking senior researchers or principal investigators of a research project in the author list in different countries. Some researchers are also inquired about the genders of their co-authors by strictly keeping all information confidential, but still genders of some authors cannot be identified. The numbers of authors of different genders on RESS are shown in Table 5.

Table 5 Gender distribution of authors who published on RESS during 01.10.2021-31.12.2021

	First author	Last author	Corresponding author
Female	38	28	31
Male	160	182	182
Unknown	41	29	31

It can be found that more females act as the first authors for their works, compared with other two roles. In consideration of more information missed for the first authors, the female/male ratio for the first author (23.75%) is higher than the ratios in the other two categories (15.38% and 17.03%).

Among the 239 articles, there are 5 where the same female authors act as both the last authors and the corresponding authors. 3 articles are written by only female authors. In addition, there are 11 articles with solo authors in the samples, and none of them is made by a female.

Note that as illustrated in the bottom row of Table 5, the genders of many authors are unknown in this study, and thus the real situation can be slightly different from the number provided above.

4.5 Collaboration network analysis

Figure 6 in subsection 4.1 illustrates the co-authorships between the countries/regions that have published at least one article on RESS. The width of the arc between two nodes reflects the number of co-published articles between the two countries/regions. It should be noted that the collaboration strength is calculated based on the number of international co-authorships instead of co-authors, meaning that if one researcher has co-authored two articles, her/his co-authorships are counted twice. The last two columns of Table 1 provide the number of partners of each country/region (NPC) at the national level and the collaboration strength (CS, based on the number of international co-authorships). For example, the value of CS of South Africa is 75, and it has 43 partner countries, implying that each article by South Africa has more than 1 international co-author on average.

In terms of the temporal evolution of collaborations, Figures 7 can clearly illustrate that collaborations are generally enhanced with time between the contributors of RESS in the period of 2001-2021. We adopt three indicators of collaboration in this study: the average number of authors per article, the average number of institutions that the authors are affiliated per article, and the number of involved countries where authors are located per article. We collect, analyze, and visualize the relevant year by year. Values of all the indicators show the increasing trend on personal, institutional, and national collaborations. However, it should be noted that the average number of involved countries does not show an obvious increase after 2015, and even starts to decrease after 2019. The reason is not well investigated here, but such a trend coincides with some political tensions and the pandemic of COVID-19.

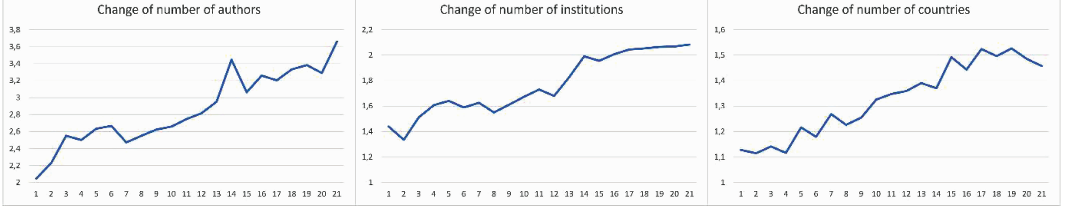


Figure 7 Temporal change of the situation of collaborations: (a) Change of number of authors per article, (b) change of number of institutions per article, and (c) change of number of involved countries per article, in the period of 2001-2021.

Figure 8 is then produced for all the institutions that have published at least 20 articles on RESS in the period of 2001-2021. A larger node denotes a more productive institution, and a wider arc between two nodes means more collaborations between the two associated institutions. The clustering of some institutions is partly because they are closer in the geographical distance and partly because the key researchers in those institutions have common research interests. The last two columns in Table 2 list the number of partner institutions of

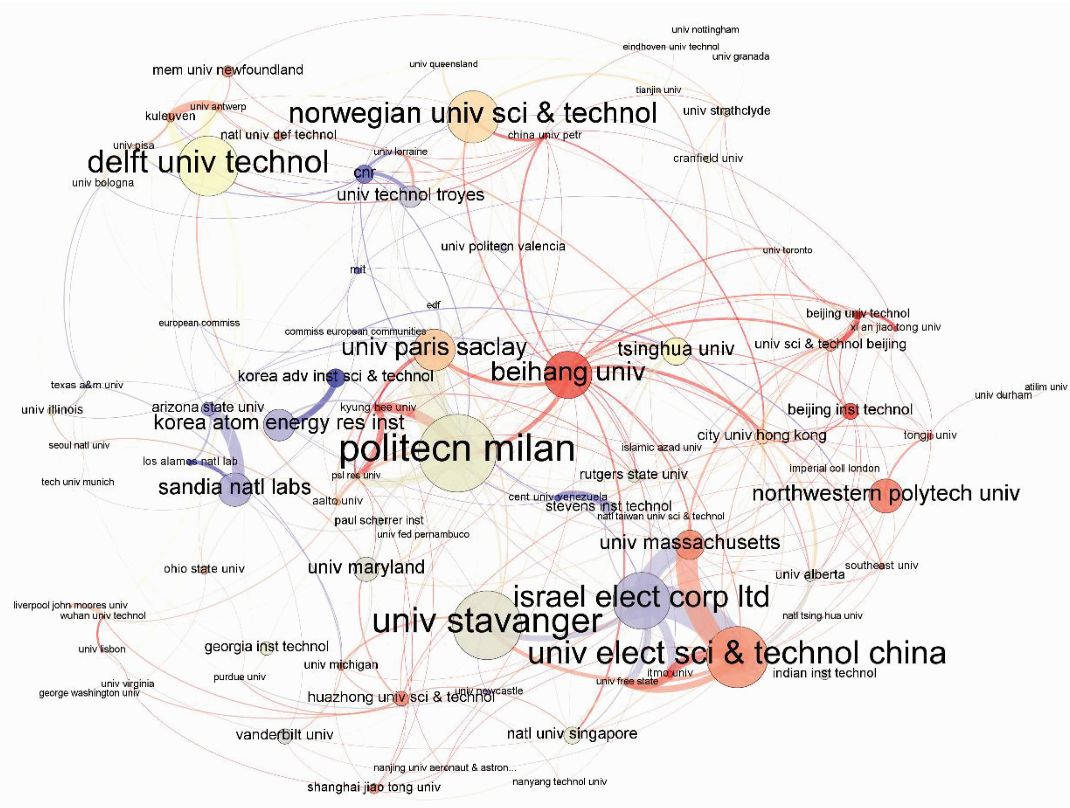


Figure 8 Network of contributing institutions with at least 20 articles on RESS in 2001-2021

each item and its collaboration strength, meaning the number of co-authorships at the institutional level and mapping with the arc width in Figure 8.

We also can discover the stronger collaborating trend among the most productive authors. Based on Table 4, if we compare the total publications of these authors and the sum of numbers of their own publications, it can be found that in 2001-2007, the ratio is $289/375 \approx 77.07\%$, in 2008-2014, the ratio is 76.51%, while in 2015-2021, the ratio is $648/901 \approx 71.92\%$. The decrease of ratio with time implies that the collaborations among the most productive authors of RESS are enhanced (For example, consider 2 individuals, if each of them registers one article, they need to publish 2 separately or only 1 in collaboration). We do not conduct further investigation on the collaborations between different researchers in consideration of privacy issues.

5 Citation analysis

This section will be used to answer Question 3: How well does RESS look, namely, what is the citation situation of the journal.

5.1 Overview on citations of RESS

Firstly, we can have an overview on the situation that the articles on RESS are cited by following studies. Table 6 provides the development of journal impact factor (JIF) of RESS in the 21 years and other relevant information. The data was collected on 07-Jan-2022.

Table 6 Citation information of RESS in 2001-2021

Year	TC	JIF	JIF u/sc	5–Y JIF	N	JIF%[1]	JIF%[2]
2001	733	0,500	0,202	n/a	101	82,26	63,73
2002	660	0,545	0,277	n/a	119	81,67	70,75
2003	779	0,700	0,300	n/a	128	79,69	73,15
2004	813	0,741	0,389	n/a	119	83,33	79,82
2005	885	0,551	0,364	n/a	110	53,03	50,89
2006	934	0,747	0,520	n/a	115	71,21	65,18
2007	1 402	0,920	0,591	n/a	147	82,81	75,83
2008	1 774	1,004	0,653	1,3	159	83,33	75,83
2009	2 490	1,379	1,124	1,666	168	80,3	75,78
2010	3 890	1,908	1,370	2,305	200	90,54	80,14
2011	3 477	1,899	1,446	2,023	139	90,79	79,33
2012	3 994	1,770	1,301	2,170	163	89,53	91,56
2013	4 783	1,901	1,371	2,441	151	85,23	86,71
2014	5 497	2,048	1,462	2,593	210	87,21	90,51
2015	6 527	2,410	1,712	2,693	220	91,86	89,51
2016	7 092	2,498	1,716	2,873	269	94,32	85,98
2017	9 362	3,153	2,438	3,461	234	89,77	87,35
2018	11 985	4,139	3,205	4,330	278	90,43	93,45
2019	12 968	4,039	3,117	4,302	277	90,22	87,5
2020	15 379	5,040	3,897	5,156	367	88,54	93,37
2021	20 787	6,188	4,705	6,336	513	78,57	87,5

* TC – total citations, JIF – journal impact factor, JIF u/sc – journal impact factor without self-citations, 5-Y JIF – 5-year Journal impact factor, - N-Number of citable articles; JIF% 1-average journal impact factor percentile in Industrial Engineering; JIF%2-average journal impact factor percentile in Operational Research & Management Science.

Both total citations and JIF of RESS keep increasing in the period of study. Then, based on the data in Table 6, we regard citation situation of the journal in 2001 as the basis, and calculate the increasing ratio of the JIF and JIF without self-citations in the future years, and develop the curves in Figure 9. The values of points are both of the curves reflect the relative increase from the beginning, rather than the absolute change. For example, the point on the orange curve (JIF without self-citations) for the year of 2021 is obtained by calculating. It can be found that the curve for JIF without self-citations increases faster than that for JIF, including self-citations, illustrating that research works on RESS are more recognized by publications in other media.

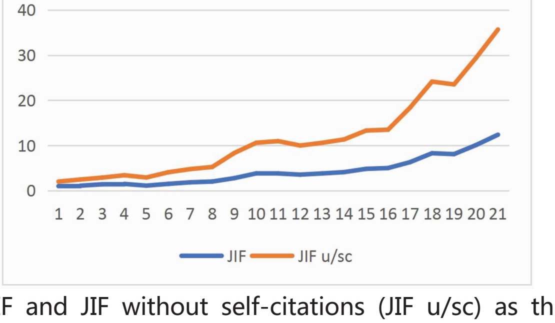


Figure 9 Trends of JIF and JIF without self-citations (JIF u/sc) as the times of the basis number in 2001

5.2 Citation and keywords

Next, we explore what keywords in an article are correlated with more citations. We can go back to Figure 3 but repaint the nodes in the network based on the number of citations of the articles where the associated keywords are included. In this newly drawn Figure 10, the size of a node still means the number of publications, but the color denotes the average citation of articles using this keyword. A warmer color represents higher citations on average.

Some clusters of nodes with warmer colors can be detected:

- Cluster of keywords of 'uncertainty', 'uncertainty analysis' and 'sensitivity analysis'.
- Cluster of keywords of 'condition-based maintenance', 'prognosis', 'gamma process', 'maintenance optimization' and 'opportunistic maintenance'.
- Cluster of keywords of 'resilience', 'network', and 'interdependence'.

Some large nodes can be noticeable with warmer colors, such as 'Monte Carlo simulation', 'Bayesian network', 'risk' and 'genetic algorithm'. In addition, a small cluster of 'maritime', 'maritime safety' and 'collision' with warm colors can be found as a highly cited application area.

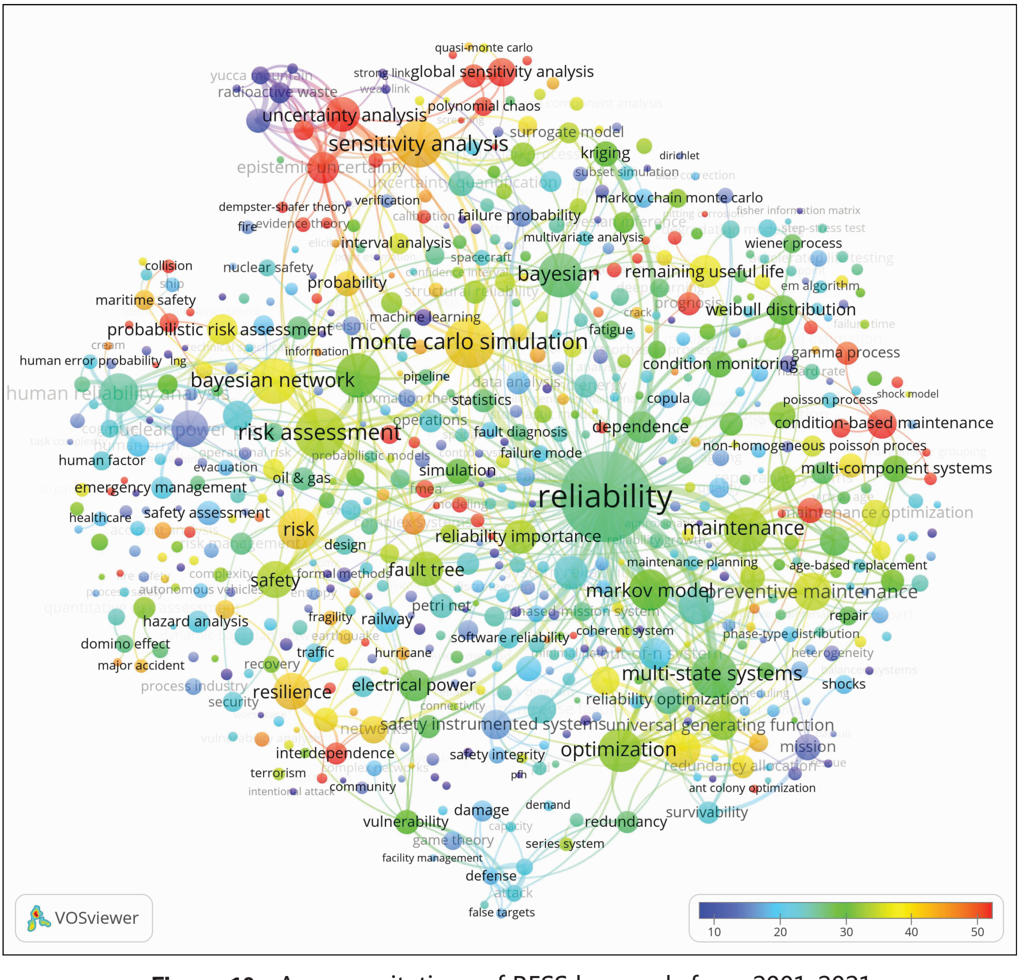


Figure 10 Average citations of RESS keywords from 2001-2021

5.3 Geographic analysis of citations

In Table 2 in section 4.2, we can find the total citations (TC), average citations per article (AC), and average annual citations per article (AAC) by researchers from the most productive countries/regions. All three indicators are useful to illustrate the impacts of publications produced in a country/region. Figure 11 is then plotted based on the AC value of the publications from those countries that have published at least 1 article on RESS. The size of a node still represents the publication number, but the color of the node reflects the average citations by the articles from the country. The width of the arc between two nodes reflects the Collaboration strength between the two countries/regions.

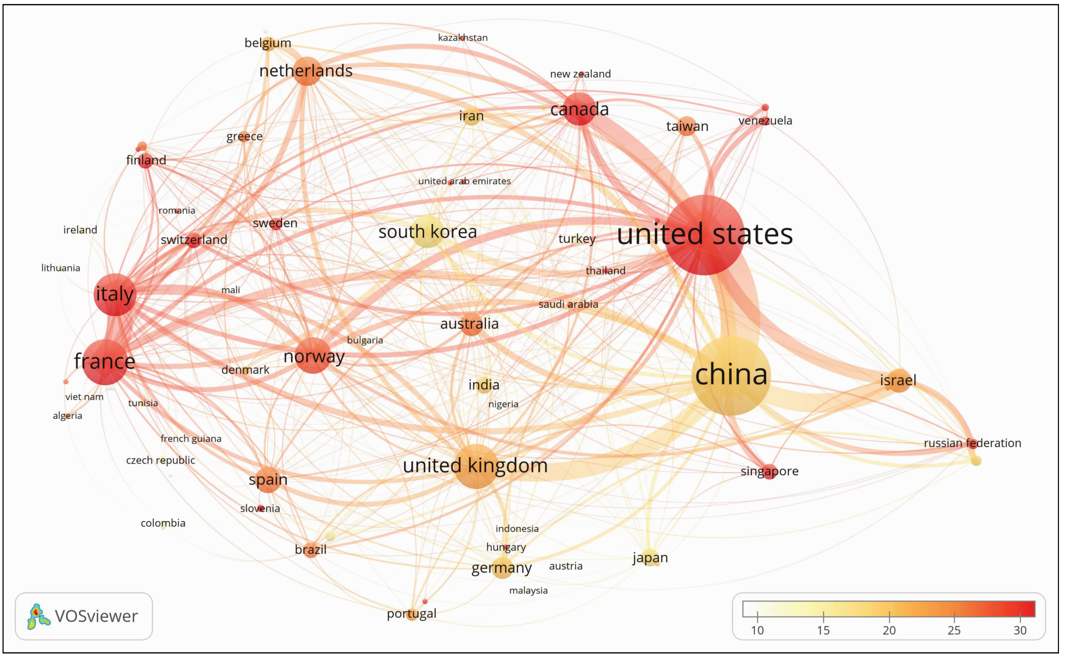


Figure 11 Network of Collaboration relationships between different countries/regions.

However, it should be noted that even though the TC and AC can reflect the impacts of articles in some degree, the reflection is much weakened by the difference in the publication dates of articles. In other words, it is natural to assume that if an article was published earlier, it has more time and more opportunities to be cited. This is the reason why the AAC is introduced in this study, which is simply calculated by dividing AC with the value of (2022-average publication year). AAC can be complementary of TC and AC, but it is not perfect and is supposed to be more friendly to the countries with more recent articles, since the average citations of articles increase naturally with more publications in total.

5.4 Highly cited publications

After the general citation analysis, we specify the top 50 highly cited publications from both perspectives of total citations in the 21 years and average annual citations per year.

Table 7 The top 50 highly cited publications in terms of total citations (TC) by 07-Jan-2022

Title	Year	TC	Authors
Multi–objective optimization using genetic algorithms: A tutorial*	2006	1800	Konak, A; Coit, DW; Smith, AE
Latin hypercube sampling and the propagation of uncertainty in analyses of complex systems*	2003	1224	Helton, JC; Davis, FJ
Global sensitivity analysis using polynomial chaos expansions*	2008	1128	Sudret, B
A survey of the application of gamma processes in maintenance*	2009	708	van Noortwijk, JM
Survey of sampling–based methods for uncertainty and sensitivity analysis*	2006	704	Helton, JC; Johnson, JD; Sallaberry, CJ; Storlie, CB
A review of definitions and measures of system resilience*	2016	587	Hosseini, S; Barker, K; Ramirez–Marquez, JE
Review on modeling and simulation of interdependent critical infrastructure systems*	2014	538	Ouyang, M
Improving the analysis of dependable systems by mapping fault trees into Bayesian networks*	2001	529	Bobbio, A; Portinale, L; Minichino, M; Ciancamerla, E
A new uncertainty importance measure*	2007	527	Borgonovo, E
Reliability engineering: Old problems and new challenges*	2009	459	Zio, E
A metric and frameworks for resilience analysis of engineered and infrastructure systems*	2014	440	Francis, R; Bekera, B
Bayesian analysis of computer code outputs: A tutorial*	2006	427	O´Hagan, A
Generic metrics and quantitative approaches for system resilience as a function of time*	2012	390	Henry, D; Ramirez–Marquez, JE
Remaining useful life estimation in prognostics using deep convolution neural networks*	2018	390	Li, X; Ding, Q; Sun, JQ
Safety analysis in process facilities: Comparison of fault tree and Bayesian network approaches*	2011	372	Khakzad, N; Khan, F; Amyotte, P
Polynomial chaos expansion for sensitivity analysis*	2009	367	Crestaux, T; Le Maitre, O; Martinez, JM
Sensitivity analysis practices: Strategies for model–based inference*	2006	367	Saltelli, A; Ratto, M; Tarantola, S; Campolongo, F
Modified failure mode and effects analysis using approximate reasoning	2003	355	Pillay, A; Wang, J
Failure diagnosis using deep belief learning based health state classification*	2013	350	Tamilselvan, P; Wang, PF
Bayesian networks in reliability	2007	312	Langseth, H; Portinale, L
A condition–based maintenance policy for stochastically deteriorating systems	2002	309	Grall, A; Berenguer, C; Dieulle, L
A review on condition–based maintenance optimization models for stochastically deteriorating system*	2017	303	Alaswad, S; Xiang, YS
Error and uncertainty in modeling and simulation	2002	298	Oberkampf, WL; DeLand, SM; Rutherford, BM; Diegert, KV; Alvin, KF
Theorems and examples on high dimensional model representation	2003	296	Sobol, IM
A Bayesian Belief Network modelling of organisational factors in risk analysis: A case study in maritime transportation	2008	290	Trucco, P; Cagno, E; Ruggeri, F; Grande, O
The risk concept–historical and recent development trends*	2012	287	Aven, T

Title	Year	TC	Authors
A combined Importance Sampling and Kriging reliability method for small failure probabilities with time –demanding numerical models*	2013	282	Echard, B; Gayton, N; Lemaire, M; Relun, N
Challenge problems: uncertainty in system response given uncertain parameters	2004	277	Oberkampf, WL; Helton, JC; Joslyn, CA; Wojtkiewicz, SF; Ferson, S
Classes of imperfect repair models based on reduction of failure intensity or virtual age	2004	277	Doyen, L; Gaudoin, O
A modified Weibull extension with bathtub –shaped failure rate function	2002	275	Xie, M; Tang, Y; Goh, TN
The PHI2 method: a way to compute time–variant reliability	2004	272	Andrieu –Renaud, C; Sudret, B; Lemaire, M
Four concepts for resilience and the implications for the future of resilience engineering*	2015	267	Woods, DD
A discrete–time Bayesian network reliability modeling and analysis framework	2005	248	Boudali, H; Dugan, JB
Reprioritization of failures in a system failure mode and effects analysis by decision making trial and evaluation laboratory technique	2006	241	Seyed –Hosseini, SM; Safaei, N; Asgharpour, MJ
Condition–based maintenance optimization by means of genetic algorithms and Monte Carlo simulation	2002	240	Marseguerra, M; Zio, E;Podofillini, L
Fuzzy assessment of FMEA for engine systems	2002	238	Xu, K; Tang, LC; Xie, M; Ho, SL; Zhu, ML
An approach for modelling interdependent infrastructures in the context of vulnerability analysis	2010	234	Johansson, J; Hassel, H
On the concept of e–maintenance: Review and current research	2008	227	Muller, A; Marquez, AC; Iung, B
The beta exponential distribution	2006	227	Nadarajah, S; Kotz, S
Risk assessment in maritime transportation	2001	225	Soares, CG; Teixeira, AP
Efficient computation of global sensitivity indices using sparse polynomial chaos expansions	2010	224	Blatman, G; Sudret, B
Uncertainty quantification using evidence theory in multidisciplinary design optimization	2004	219	Agarwal, H; Renaud, JE; Preston, EL; Padmanabhan, D
Particle filtering prognostic estimation of the remaining useful life of nonlinear components	2011	218	Zio, E; Peloni, G
An exploration of alternative approaches to the representation of uncertainty in model predictions	2004	216	Helton, JC; Johnson, JD; Oberkampf, WL
Implementation and evaluation of nonparametric regression procedures for sensitivity analysis of computationally demanding models	2009	212	Storlie, CB; Swiler, LP; Helton, JC; Sallaberry, CJ
Dynamic fault tree analysis using Monte Carlo simulation in probabilistic safety assessment	2009	206	Rao, KD; Gopika, V; Rao, VVSS; Kushwaha, HS; Verma, AK; Srividya, A
Data –driven uncertainty quantification using the arbitrary polynomial chaos expansion	2012	203	Oladyshkin, S; Nowak, W
Some considerations on the treatment of uncertainties in risk assessment for practical decision making	2011	202	Aven, T; Zio, E
A data –driven fuzzy approach for predicting the remaining useful life in dynamic failure scenarios of a nuclear system	2010	198	Zio, E; Di Maio, F
Application of the fault tree analysis for assessment of power system reliability	2009	198	Volkanovski, A; Cepin, M; Mavko, B

Table 8 The top-50 highly cited publications in term of average annual citations (AAC) by 07-Jan-2022

Title	Year	AAC	Authors
Multi–objective optimization using genetic algorithms: A tutorial	2006	112,50	Konak, A; Coit, DW; Smith, AE
A review of definitions and measures of system resilience	2016	97,83	Hosseini, S; Barker, K; Ramirez–Marquez, JE
Remaining useful life estimation in prognostics using deep convolution neural networks	2018	97,50	Li, X; Ding, Q; Sun, JQ
Global sensitivity analysis using polynomial chaos expansions	2008	80,57	Sudret, B
Review on modeling and simulation of interdependent critical infrastructure systems	2014	67,25	Ouyang, M
Latin hypercube sampling and the propagation of uncertainty in analyses of complex systems	2003	64,42	Helton, JC; Davis, FJ
A review on condition–based maintenance optimization models for stochastically deteriorating system	2017	60,60	Alaswad, S; Xiang, YS
A metric and frameworks for resilience analysis of engineered and infrastructure systems	2014	55,00	Francis, R; Bekera, B
A survey of the application of gamma processes in maintenance	2009	54,46	van Noortwijk, JM
Survey of sampling–based methods for uncertainty and sensitivity analysis	2006	44,00	Helton, JC; Johnson, JD; Sallaberry, CJ; Storlie, CB
Deep learning–based remaining useful life estimation of bearings using multi–scale feature extraction	2019	41,33	Li, X; Zhang, W; Ding, Q
Remaining useful life predictions for turbofan engine degradation using semi–supervised deep architecture	2019	39,00	Ellefsen, AL; Bjorlykhaug, E; Aelig soy, V; Ushakov, S; Zhang, HX
Generic metrics and quantitative approaches for system resilience as a function of time	2012	39,00	Henry, D; Ramirez –Marquez, JE
Failure diagnosis using deep belief learning based health state classification	2013	38,89	Tamilselvan, P; Wang, PF
Four concepts for resilience and the implications for the future of resilience engineering	2015	38,14	Woods, DD
Reliability engineering: Old problems and new challenges	2009	35,31	Zio, E
A new uncertainty importance measure	2007	35,13	Borgonovo, E
Safety analysis in process facilities: Comparison of fault tree and Bayesian network approaches	2011	33,82	Khakzad, N; Khan, F; Amyotte, P
Modeling and analysis of cascading node–link failures in multi–sink wireless sensor networks	2020	33,50	Fu, XW; Yang, YS
A new adaptive sequential sampling method to construct surrogate models for efficient reliability analysis	2018	33,50	Xiao, NC; Zuo, MJ; Zhou, CN
A combined Importance Sampling and Kriging reliability method for small failure probabilities with time –demanding numerical models	2013	31,33	Echard, B; Gayton, N; Lemaire, M; Relun, N
Gated recurrent unit based recurrent neural network for remaining useful life prediction of nonlinear deterioration process	2019	30,00	Chen, JL; Jing, HJ; Chang, YH; Liu, Q
A system active learning Kriging method for system reliability–based design optimization with a multiple response model	2020	29,50	Xiao, M; Zhang, JH; Gao, L
LIF: A new Kriging based learning function and its application to structural reliability analysis	2017	29,40	Sun, ZL; Wang, J; Li, R; Tong, C

Title	Year	AAC	Authors
The risk concept–historical and recent development trends	2012	28,70	Aven, T
Reliability analysis of complex multi–state system with common cause failure based on evidential networks	2018	28,50	Mi, JH; Li, YF; Peng, WW; Huang, HZ
Challenges in the vulnerability and risk analysis of critical infrastructures	2016	28,50	Zio, E
Polynomial chaos expansion for sensitivity analysis	2009	28,23	Crestaux, T; Le Maitre, O; Martinez, JM
Probabilistic Physics of Failure–based framework for fatigue life prediction of aircraft gas turbine discs under uncertainty	2016	27,67	Zhu, SP; Huang, HZ; Peng, WW; Wang, HK; Mahadevan, S
A quantitative method for assessing resilience of interdependent infrastructures	2017	27,60	Nan, C; Sansavini, G
A dual–LSTM framework combining change point detection and remaining useful life prediction	2021	27,00	Shi, ZY; Chehade, A
Bayesian analysis of computer code outputs: A tutorial	2006	26,69	O´Hagan, A
New approach for failure mode and effect analysis using linguistic distribution assessments and TODIM method	2017	25,80	Huang, J; Li, ZJ; Liu, HC
A general failure–pursuing sampling framework for surrogate–based reliability analysis	2019	25,67	Jiang, C; Qiu, HB; Yang, Z; Chen, LM; Gao, L; Li, PG
Practical options for selecting data–driven or physics–based prognostics algorithms with reviews	2015	25,57	An, D; Kim, NH; Choi, JH
Improving the analysis of dependable systems by mapping fault trees into Bayesian networks	2001	25,19	Bobbio, A; Portinale, L; Minichino, M; Ciancamerla,
Availability–based engineering resilience metric and its corresponding evaluation methodology	2018	24,75	Cai, BP; Xie, M; Liu, YH; Liu, YL; Feng, Q
Variable importance analysis: A comprehensive review	2015	24,57	Wei, PF; Lu, ZZ; Song, JW
A combined multi–criteria approach to support FMECA analyses: A real–world case	2018	24,25	Carpitella, S; Certa, A; Izquierdo, J; La Fata, CM
Hybrid preventive maintenance of competing failures under random environment	2018	24,00	Yang, L; Zhao, Y; Peng, R; Ma, XB
Recent advances in prognostics and health management for advanced manufacturing paradigms	2018	24,00	Xia, TB; Dong, YF; Xiao, L; Du, SC; Pan, ES; Xi, LF
Resilience assessment of interdependent infrastructure systems: With a focus on joint restoration modeling and analysis	2015	23,00	Ouyang, M; Wang, ZH
Sensitivity analysis practices: Strategies for model–based inference	2006	22,94	Saltelli, A; Ratto, M; Tarantola, S; Campolongo, F
Remaining useful lifetime prediction via deep domain adaptation	2020	22,50	da Costa, PRD; Akcay, A; Zhang, YQ; Kaymak, U
The future of risk assessment	2018	22,25	Zio, E
Maritime transportation risk analysis: Review and analysis in light of some foundational issues	2015	22,14	Goerlandt, F; Montewka, J
REIF: A novel active–learning function toward adaptive Kriging surrogate models for structural reliability analysis	2019	22,00	Zhang, XF; Wang, L; Sorensen, JD
Resilience–based network component importance measures	2013	21,78	Barker, K; Ramirez –Marquez, JE; Rocco, CM
A systematic literature review of resilience engineering: Research areas and a research agenda proposal	2015	21,43	Righi, AW; Saurin, TA; Wachs, P
A novel failure mode and effect analysis model for machine tool risk analysis	2019	21,33	Lo, HW; Liou, JJH; Huang, CN; Chuang, YC

The 22 articles marked with * in Table 7 actually occur in both Table 7 and Table 8. If we compare the author names in Table 8 and those in Table 4, we can find that at least 14 are repeated.

5.5 Citations and references

A regression analysis is conducted to investigate the relationship between the number of references in an article and the citation impact of the article published on RESS. In this subsection, we use AAC to denote the citation impact. As shown in Figure 12, a positive correlation between these two variables can be found, meaning that articles with more references are more cited by the following studies. P-value in such analysis is less than 10E-15. However, we do not provide any recommendation on increasing references in an article, because the relationship of correlation does not imply any causality. It also should be noted that the analysis above does not distinguish reviews and research papers, and the former type often have more references and are cited by the following papers.

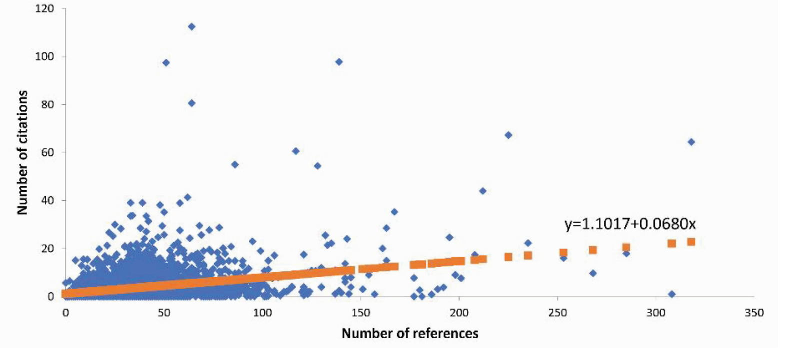


Figure 12 Correlation between the number of references and number of citations

5.6 Citations and collaborations

It is of interest to investigate whether the numbers of authors, involved institutions and involved countries have impacts on the citations of publications on RESS, since previous studies (Puuska et al., 2014; Tahamtan et al., 2016) have discovered some trends in general scientific fields. In this analysis, we firstly rank all 4821 articles since 2001 on RESS according to their AACs, and then exclude the 821 articles at the bottom from the analysis, because most of them were published in recent years and have no or very few citations up to date and it is not fair to evaluate their impacts at this moment. The rest 4000 papers are categorized into 4 groups simply based on AAC: Group 1 includes the papers with the highest AAC, and Group 4 includes the papers with the lowest AAC. Most articles have 2-4 authors from 1-2 institutions and 1-2 countries, meaning that most of data points are condensed in a small area in a regression analysis. We rely on such grouping works to make the comparison results clearer.

We calculate the AAC for each group and plot the obtained values in Figure 13 to illustrate the relationship between the impact of an article and the number of authors, the number of involved institutions and the number of involved countries/regions, respectively. From Figures 12(a), (b) and (c), it can be found that RESS indicates the same trend found in the general scientific metric studies that articles with more authors, more participating institutions, and more involving countries/regions, have higher citation impacts. For reasons behind this, readers can find more information in the relevant literature (Puuska et al., 2014; Tahamtan et al., 2016). Table 9 provides the detailed numbers obtained in the analysis.

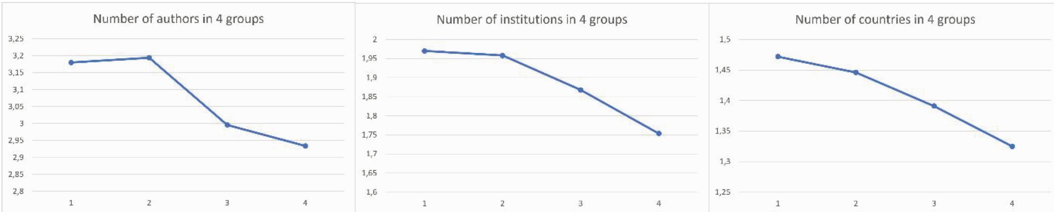


Figure 13 Relationships between the average annual citation of the number of authors (a), the number of participating institutions (b), and the number of involving countries/regions

Table 9 Average number of authors, institutions and countries/regions in different groups

Group	No. Authors	No. Institutions	No. Countries
1	3,180	1,970	1,472
2	3,194	1,958	1,446
3	2,996	1,868	1,391
4	2,934	1,754	1,325

To verify such a conclusion, we conduct simple linear regression analyses between the average annual citations based on the 4 groups and the number of authors, the number of involved institutions and the number of involved countries, respectively. The coefficients of those regressed curves are not very meaningful, but all of analyses have P-values lower than 10E-5, showing strong confidence on the results. Regression analyses for the whole samples without exclusion of data or grouping can show the same trend.

5.7 Reference co–citation cluster analysis

In this section, we try to identify the most important documents that are references to the articles published on RESS in 2002-2021. Figure 14 illustrates all the references that are cited at least 20 times on RESS and the clustering relationships among these literatures. In total, there are 503 documents included in the figure. The references are not necessarily from RESS or WOS, and some of them are not even a journal publication, for example, the two noticeable nodes in the cluster green, denoted as Levitin G., 2005, and Rausand M., 2004, respectively, represent two books (Levitin, 2005; Rausand & Høyland, 2004). It is noted that a larger node in Figure 13 means that the associated document is cited by more publications on RESS, namely, a more important reference.

The clusters in Figure 14 illustrate that the references to RESS mainly come from the following 6 domains:

- Cluster Green: Documents related to system reliability modeling, and methods for reliability analysis and optimization.
- Cluster Red: Documents related to degradation, test and maintenance.
- Cluster navy blue: Documents related to human factor, human safety/risk and human reliability analysis.
- Cluster chartreuse: Documents related to sensitivity analysis and relevant mathematical models.
- Cluster purple: Documents related to resilience.

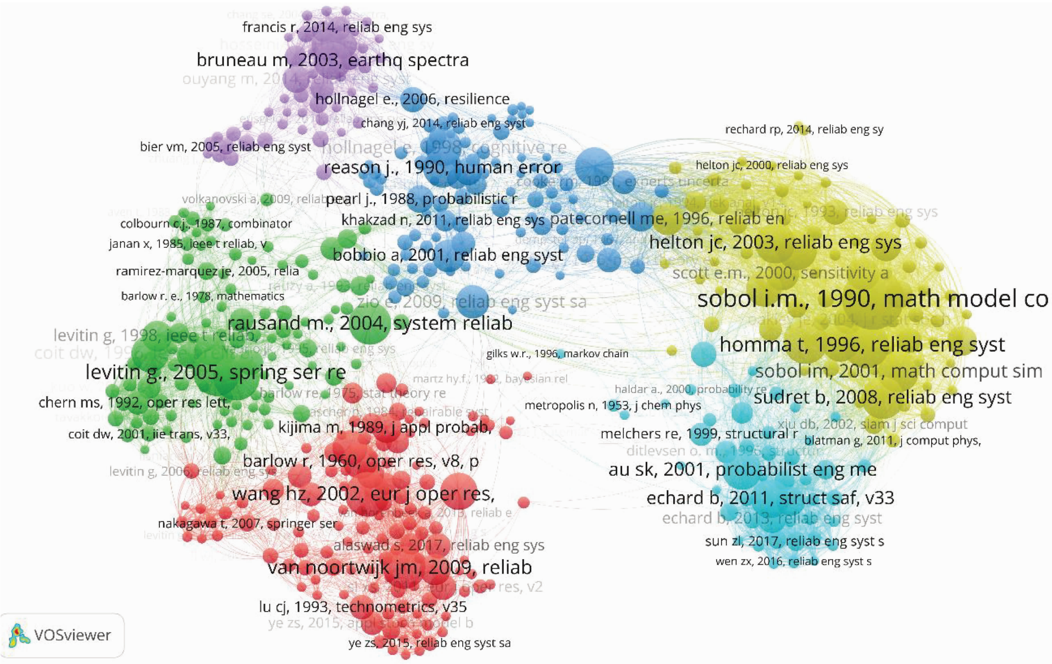


Figure 14 Clusters of important references of publications on RESS

- Cluster azure: Documents are mainly related to methods used in probability analysis, such as Bayesian method and Monte Carlo simulation.

5.8 Open access and citations

It has been seen in Figure 1 in section 2.1 that a significant increase in open-access articles published on RESS has occurred since 2015. We here conduct a simple analysis of whether there is a difference between the citations of articles with open access and the citations of articles that need a subscription, motivated by the arguments about the citation impacts of open-access papers (Craig et al., 2007; Harnad & Brody, 2004). There are 682 with Golden open access in the total 2578 publications on RESS in 2001-2021. As a complementary experiment, we downloaded the citation data of publications in 2015-2021 on the date of 21-02-2022. The total citations of all articles up to date are 35790, while the citations of the open-access articles are 11101. On average, the citation per open-access article is 16.27, while the citation per article needing a subscription is 15.11. Statistics can show strong confidence in the difference between the values of the two groups.

6 Conclusions

We have illustrated the usefulness of bibliometric analysis by developing a profile for the journal of RESS in 2001-2021, since many of the analysis results are not directly provided in the JCR and other online public resources to interested readers. Insights on the evolutionary trends of RESS, leading contributors and the academic impacts of the journal are given. The evidence in this study shows the emerging research in some fields, for example, condition-based maintenance and resilience, and more collaborations within the academic community. To some degree, the findings of this study can reflect the current development in reliability, maintenance, and safety engineering. The situation of gender distributions of authors has been first surveyed, and the impact of open-access publication options is also investigated in this bibliometric analysis. Readers are expected to have a clearer picture in their minds of the relevant areas of reliability engineering and system safety.

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