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Review

A bibliometric review: Energy consumption and greenhouse gas emissions in the residential sector

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ABSTRACT

Residential sector has been one key sector for reducing its greenhouse gas emissions due to its significant contribution to global warming. Researchers in different countries have studied household energy consumption patterns and greenhouse gas emissions in order to promote low-carbon lifestyles. However, few review papers have been published in this regard, leading to a lack of systematic understanding on the related research achievements. Hence, by using a bibliometric approach, this paper aims to review the existing literature and examine the evolution of such a field so that the research trends can be uncovered, including popular research methods. Citation analysis is performed to assess the influence of most productive journals, countries/territories, and authors. Network analysis is also conducted to evaluate the relationship among different countries/territories, authors, and keywords. Research outcomes of this paper present a comprehensive research picture on residential energy consumption and corresponding greenhouse gas emissions (REE) related papers published from 1997 to 2016. The most productive journals, countries/territories, authors are also analyzed based on citation analysis and network analysis. In addition, results also revealed that behavioral analysis, input-output analysis, life cycle assessment, and cost-benefit analysis are the most commonly used methods in this field. Results obtained from this study can provide valuable information for researchers interested in the REE-related field.

Contents

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1. Introduction

Residential sector is one of the major contributors to energy consumption and greenhouse gas (GHG) emissions, which represented 25–30% of the total electricity use in OECD countries in 2012 (Iwafune and Yagita, 2016). According to Energy Information Administration (EIA, 2016a), in the U.S. the majority of direct residential energy goes to space heating and electric appliances. Similarly, it is the second largest sector on energy consumption and corresponding GHG emissions in China (Wang and Yang, 2016; Zhang et al., 2016a). In the case of Arabian countries, the residential sector accounts for approximately 40% of the total energy consumption, even with a figure of 60% in Palestine (Abu-Madi and Rayyan, 2013). With rapid economic development and urbanization in the past few decades, residential energy consumption and emissions have increased dramatically. It is projected that by 2050 the total urban population will reach to 66% of the global population, leading to more energy demand (UN, 2014). In addition, the increasing household incomes and improved living standards will bring a serious threat to the efforts on responding climate change.

Academically, extensive studies on residential energy consumption and corresponding GHG emissions have been conducted with aims to find and promote low-carbon development pathways. Although barriers still exist, some progresses have been made due to the increasing application of renewable energy and energy efficient technologies and equipment. For instance, coal consumption has already decreased in the USA and it is expected to decrease in China as well in the near future (EIA, 2016b). Publications referred to different aspects of Residential Energy and Greenhouse Gas Emissions (REE) have been released, resulting in more innovative ideas and solutions to energy conservation and efficiency in the household sector. For example, Gholami et al. (2014) investigated GHG emissions of using plug-in electric vehicles and renewable energy sources based on a combined economic emission dispatch. Amini et al. (2015) designed an automated framework for residential use which incentivizes both utilities and end-users to adopt technologies dynamically optimizing energy demand based on periodic pricing signals. The security and privacy issues of smart grids were also investigated given the growing trend in the power systems from a centralized producer-driven grid to a smarter interactive customer network (Boroojeni et al., 2017). Parikh and Parikh (2016) explored policy options to promote the utilization of energy efficient appliances in order to realize the reduction of energy consumption and related emissions. In order to summarize the related research achievements, several review papers were also published. For example, Iwatsubo (2003) overviewed energy demand and energy saving technologies in Japan's residential sector and identified the difficulties of persuading residential energy users to apply energy efficient equipment and technologies. Bhattacharjee and Reichard (2011) reviewed 51 relevant papers and uncovered the key factors affecting residential energy use. Hager and Morawicki (2013) reviewed how residential cooking influenced residential energy consumption in developed nations. These papers summarized energy consumption in the residential sector from different perspectives and countires. However, none of them employed a bibliometric analysis method, nor can any of them provide a comprehensive picture on REE due to their narrow review topics.

Bibliometric analysis is a statistical analysis method on evaluating research outputs, importance, and influence of authors, institutes, journals, etc., within a certain field (Chiu and Ho, 2007). It is useful for both individual researchers and organizations to demonstrate the values and impacts of their works and can help them get promotions, grants, investment, and enhance their academic influences. It is also helpful to examine weaknesses and strength, identify research gaps and future research directions in one certain area. Bibliometric analysis has been widely used in various fields such as database tomography (Kostoff et al., 2001), personalized medicine (Stelzer et al., 2015), data mining (Yeo et al., 2015), dye-sensitized solar cell (Li et al., 2015), pricing strategies on wind power (Gao et al., 2016), emergy research (Chen et al., 2017), and natural resource accounting (Zhong et al., 2016). The results from bibliometric analysis can help researchers to better select their potential research fields, recognize future academic collaborators, and identify the appropriate institutes to pursue their academic degrees or conduct joint research.

Although papers referred to various aspects of REE have been published, none of them was based on bibliometric analysis, resulting in a lack of comprehensive capture on related research achievements in this field. In order to fill such a research gap, this paper aims to investigate the performance of REE-related researches published from 1997 to 2016. In addition, research trends, topics, leading papers and methods in this area would be identified through statistical and citation analysis on the related publications. This study is performed by four main steps, which is depicted in Fig. 1. The remainder of this paper is structured as follows. After this introduction section, Section 2 describes the research methods and data sources. Research results are presented in Section 3, citation analysis results are presented in Section 4, and the most popular methods on residential greenhouse gas related studies are presented in Section 5. Finally, conclusions are drawn in Section 6.

2. Methodologies, data sources and analyses

2.1. Methodologies

Bibliometric analysis, originally developed by Professor Olle

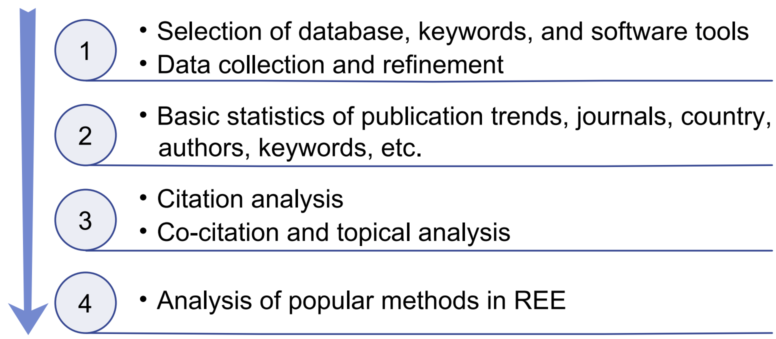


Fig. 1. Research framework.

Persson, is a powerful and widely preferred tool due to its flexibility and ability to handle big data. In order to explore the structure, features, as well as patterns of the underlying science and technology, mathematical and statistical techniques have been applied in bibliometric analysis (Du et al., 2015). In this study, impact factors (IF) referred from the Journal Citation Reports 2015 are applied to evaluate the influence of journals. IF is assessed by dividing the total citations of papers from a journal published in the preceding two years cited in the Journal Citation Reports (JCR) by the total amount of papers published in that journal in the same previous period. The *h*-index is another indicator for evaluating the research achievement of a scholar considering both quality and quantity aspects (Hou et al., 2015; Hirsch, 2010). According to Hirsch (2010), *h*-index implies that the total articles published by one person are cited at least *h* times. In this study, *h*-index is used to assess the influence of authors. In addition, social network analysis (SNA), a quantitative approach for evaluating the relationship among the social actors (Hou et al., 2015), is applied to investigate the academic collaboration of the most productive authors and that of the most productive countries/territories.

2.2. Data sources

The literature dataset for this study were collected on March 13, 2017 from Scopus— one of the largest online databases in the world, covering over 20,000 peer-reviewed journals. Scopus is equipped with smart tools useful for basic visualization and statistical analysis of papers. In addition, it provides full record of all necessary information of literature in RIS (Research Information Systems) format that can be imported into and analyzed by bibliometric software tools for further analysis. Prior to dataset collection, it is crucial to accurately define the study topic in order to identify the most appropriate keywords for a database search (Fahimnia et al., 2015b). Scopus provides various search options, such as authors, institutions, languages, ISSN codes, DOI, conference proceedings, etc. In order to obtain most relevant publications, the option with “Titles, abstracts and keywords” was selected, containing selected keywords which were listed in Table 1. The time range was set from 1996 to 2016. The initial search found 2021 papers in total. Among them, articles (1342 publications) are the major contributions to REE, accounting for approximately 66.40% of the total published papers, followed by proceeding papers. Other publications belong to reviews (3.28%) and others (e.g., letters, books, and short surveys). Since research articles usually provide more original research findings and have more information on authors and their affiliations, only journal articles published in English were considered for further analysis. This filtering process resulted in 1197 papers, which were exported into RIS format for bibliometric analysis.

2.3. Analysis tools

In this study, bibexcel is used to extract general statistical information of related publications, and Gephi is used to visualize their network. Hence, the RIS file containing the information of the 1197 papers was then imported to BibExcel. This software produces numerous files in various formats including *.net in the process of analysis. Finally, in order to visualize the results, these files were converted into *.net format that can be imported into other graphic programs. For network analysis and visualization, Gephi was selected due to its high resolution outputs and multiple useful features.

3. Results and discussions

3.1. Publication trend

Publication trend related to REE is shown in Fig. 2. Results show that the annual publications present an increasing trend. This result may be explained by the increasing global concerns on energy depletion and climate change. The general growth period can be divided into two stages, namely a relatively slow growth period between 1996 and 2006 (with an annual growth rate of 3.30%) and a fast growth period between 2007 and 2016 (with an annual growth rate of 12.49%), reflecting more attentions on such a topic during the recent decade.

3.2. Academic disciplines

According to Scopus, studies contributed to this research topic involved in 25 different academic disciplines (see Fig. 3). Among them, environmental science is ranked as the No. 1 REE-related discipline, with the highest percentage and accounting for 26% of the total investigated publications, followed by energy (20%), engineering (15%), and social sciences (9%). Publications involved in earth and planetary science, agricultural and biological science, and economics fields also contributed to the development of REE-related studies, each with 4% of the total studied publications, while other academic disciplines together contributed to the remaining 18%.

3.3. Key journals related with REE

The selected 1197 papers were published in 423 different journals, but most of these journals (69.01%) only published one REE-related article. Table 2 lists the top ten journals with the most contributions to REE. Generally speaking, citation times of a paper could reflect its influence although miscounting citations may occur. Thus, total citations (TC) and the average number of citations

Table 1
Keyword assembly.

Keyword type	Search keywords	Search field	Total	Refined
Main keyword	carbon OR "greenhouse gas" OR "greenhouse gas" OR GHG OR CO_2 OR emission* OR "global warming" OR "climate change" OR "air pollution" OR "air quality" OR energy	Article title	2021	1197
Context keyword	Emission* OR consumption OR consum* OR emit* OR footprint OR impact* OR embed* OR contribut* OR affect*	Article title		
Scope keyword	Household OR resident* OR housing OR apartment OR home OR lifestyle	Article title		

per paper of a journal (TC/P) between 1996 and 2016 are also shown in Table 2.

In terms of journals' performance, Energy Policy was the most productive journal with a total of 105 papers, followed by Energy and Buildings (89 papers) and Atmospheric Environment (44 papers). Energy Policy also presented the highest TC score (2997), followed by Environmental Science & Technology (2326), and Energy and Buildings (1735). In addition, Environmental Science &

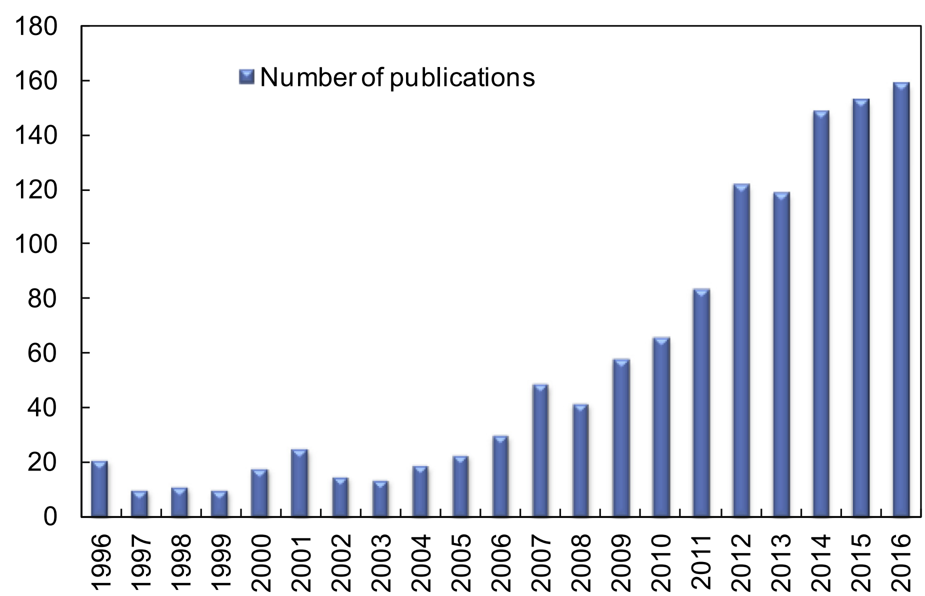


Fig. 2. Trends in REE publications (1996–2016).

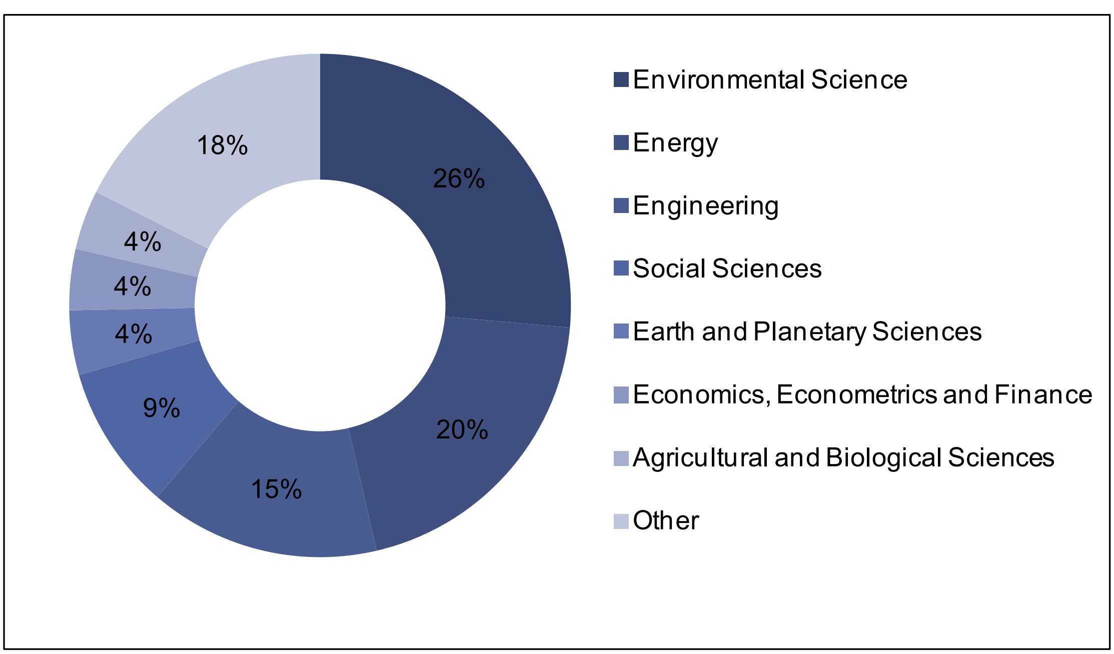


Fig. 3. REE-related disciplines.

Table 2
Top ten contributing journals on REE-related studies.

#	Journals	Pubs[a]	%[b]	TC[c]	TC/P[d]
1	Energy Policy	105	8.77%	2997	28.54
2	Energy and Buildings	89	7.44%	1735	19.49
4	Atmospheric Environment	44	3.68%	1272	28.91
3	Environmental Science &Technology	39	3.26%	2326	59.64
5	Applied Energy	36	3.01%	1072	29.78
6	Energy	31	2.59%	693	22.35
7	Building and Environment	26	2.17%	973	37.42
8	Energy Economics	20	1.67%	470	23.50
9	Journal of Cleaner Production	19	1.59%	221	11.63
10	Renewable Energy	16	1.34%	255	15.94
10	Renewable & Sustainable Energy Reviews	16	1.34%	349	21.81

[a] Publication (Pubs): total number of publications related to REE.
[b] Percentage (%): percentage of publications in the dataset of 1197 papers.
[c] TC: the total citations of a journal.
[d] TC/P: average number of overall citations per paper of a journal.

Technology (EST) had the highest TC/P score (59.64), followed by Building and Environment (37.42), and Applied Energy (29.78). Fig. 4 illustrates the journals' performance on REE. Results imply that Energy Policy, Energy and Buildings, and EST are key journals in this field. Other important journals include Atmospheric Environment, Applied Energy, Energy, Building and Environment, and Journal of Cleaner Production. It is interesting that most of them are published by Elsevier, except EST published by American Chemical Society (ACS).

In order to better measure the overall scientific importance of one journal, four journal assessment indicators were used, including IF, SCImago Journal Rank (SJR), Impact per Publication (IPP), and Source Normalized Impact per Paper (SNIP). IF is the primary and widely used indicator on assessing one journal's significance and is used by several major databases such as Web of Science (Colledge et al., 2010). However in recent years, it has been criticized for inaccuracies induced by self-citations, language bias, editorial policies, etc. (Colledge et al., 2010; Ramin and Shirazi, 2012). Unlike IF, SJR, a Scopus based indicator, does not regard all citations as equal, but assesses scientific prestige of one journal by focusing on subject fields, quality, and public reputation (JournalMetrics, 2016b). Another indicator is IPP, namely the ratio of yearly number of citations in the previous three years divided by the number of studies published in those years. IPP can only provide a rough assessment because it is not normalized for the subject field (JournalMetrics, 2016a), but its evaluation results closely correlate with IF scores. SNIP is the normalized version of IPP. It represents a ratio between one journal's per paper average citation number and the citation possibility of its research field by taking into consideration the citation frequency of other papers in the reference list, the development speed of citation impact, and the database's coverage extent of the field (JournalMetrics, 2016c). In general, different indicators employ different evaluation approaches, leading to different evaluation outcomes. However, none of them can provide the best results. Therefore, it is rational to combine different indicators in order to offer more comprehensive and complete perspectives on identifying most influential journals in such a research field.

Under such a circumstance, the competency of the top ten productive journals were compared by using their IF, SJR, IPP, and SNIP scores for year 2015, shown in Fig. 5. It is clear that EST, Applied Energy, Energy, Journal of Cleaner Production, and Renewable and Sustainable Energy Review have higher IF and IPP scores. The SJR scores of Energy policy, Applied Energy, EST, Energy economic, and Renewable and Sustainable Energy Review are higher than others, while Applied Energy, Building and

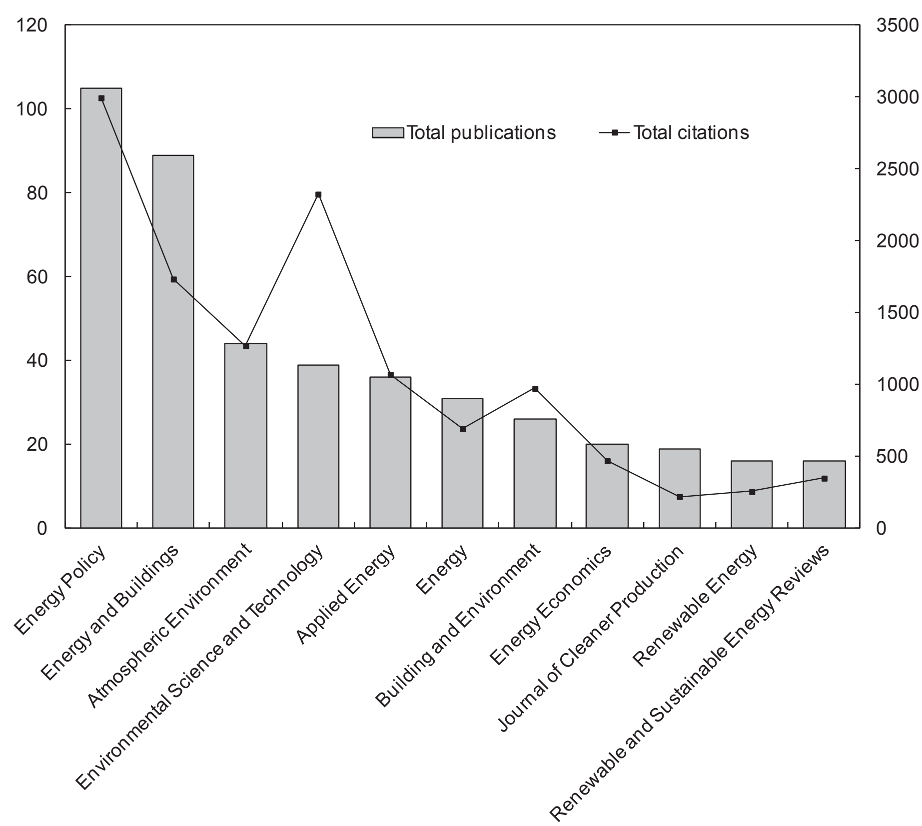


Fig. 4. Journals' performance on REE.

Environment, Journal of Cleaner Production, and Renewable and Sustainable Energy Review have higher SNIP scores. Due to the disparity of different disciplines, it is hard to say which journal is more important than others. But the aforementioned indicators can provide some useful insights to researchers in such a field so that they can select more appropriate journals for their submissions. At least these top ten journals welcome submissions related with REE, indicating that they are potential target journals for such a topic.

3.4. Countries/territories

From countries perspective, institutions from 87 countries/territories published their papers related with REE although 21.8% of these 87 countries contributed only one paper. Table 3 lists the top 16 most productive counties on such a research topic. The United States has the most publications in this area, followed by China, the largest GHG emission country in the world (Ge et al., 2014; CAIT, 2015). Canada, Australia, and South Korea are also productive. In general, the US and China are the most productive countries in such a field, showing their great research interests on REE. Particularly, as one developing country, China is a leading country on REE although its per capita GHG emission is still relatively lower than those developed countries. The main reason is that China's rapid economic development has led to improved life quality. The Chinese residents have soaring demand on more opulent life, resulting in increasing energy consumption (Tian et al., 2016). However, with the coal as the main energy source, China has to seek an innovative pathway to move toward low carbon development due to its largest population. In addition, the Chinese government is actively promoting its own strategy on responding climate change and provided more research funds to support relevant studies, which in turn led to more research papers.

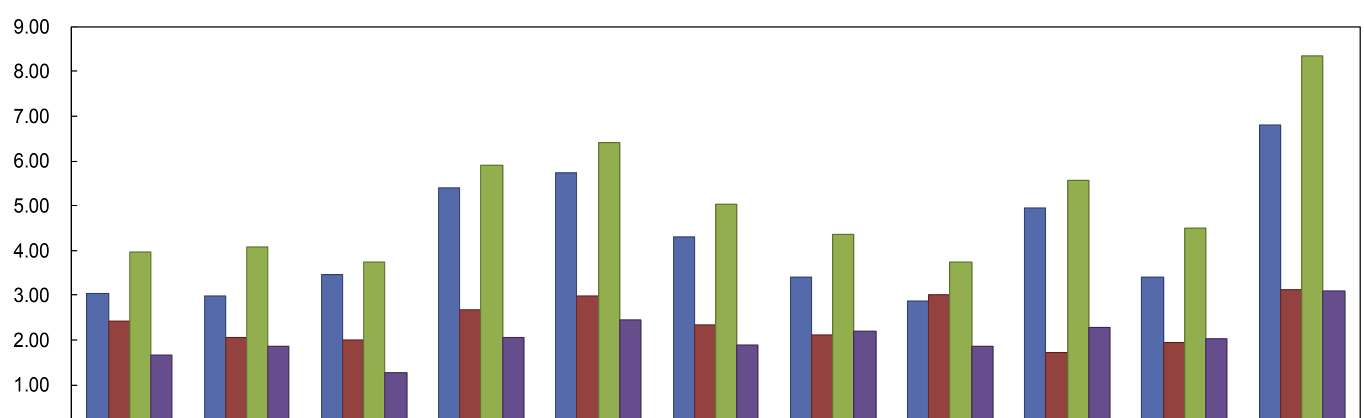
3.5. Authors

In total, 3426 authors were acknowledged for making their contributions to this topic although only 524 authors participated in more than one paper. Key authors in REE are listed in Table 4, including their respective publication numbers, *h*-indices (Hirsch, 2005), and countries/territories of origin. The *h*-index of each author was obtained from Scopus, a non-static indicator for measuring the author's productivity and the impact of his/her research. Shen G. is the most productive author with 21 papers, followed by Tao S. and Ugursal V.I. (each with 14 and 12 papers). From *h*-index perspective, the publication amounts on REE are not proportional to the authors' *h*-index scores. The reason is that studies related with energy and GHG emissions are very interdisciplinary and require the involvement of researchers from different fields. For instance, Wang R, one of less prolific authors listed in Table 4, has higher *h*-index score as he is more influential in his own research area (environmental science and chemistry). Table 5 lists key co-authors in this field, showing the research collaboration among the key authors in this field. Interestingly, the key authors in Table 4 were also listed in Table 5, indicating that the field of REE requires knowledge integration from different authors. For instance, Shen G, Tao S, Shen H, Huang Y. and Zhang Y co-authored several papers together. Although they are all based at Peking University in China, they are from different academic fields, including environmental science, engineering, and chemistry. Their studies mainly focus on the concentration of air pollutants generated by household sector by investigating the original sources, including different types of fuels, stoves, appliances, etc., therefore, requiring different knowledge from combustion science, carbon accounting, electricity and chemical analysis. Another example is Heinonen from Iceland and Junnila from Finland, focusing on

Table 3
The most productive countries/territories in REE.

#	Country	Pubs[a]	%[b]	#	Country	Pubs[a]	%[b]
1	United States	291	24.31	11	Finland	39	3.26
2	China	223	18.63	12	Italy	37	3.09
3	United Kingdom	90	7.52	13	Norway	29	2.42
4	Japan	76	6.35	14	India	27	2.26
5	Canada	75	6.27	15	Spain	23	1.92
6	Australia	66	5.51	16	Denmark	21	1.75
7	Sweden	44	3.68	17	Switzerland	20	1.67
8	South Korea	42	3.51	18	Austria	19	1.59
9	Germany	41	3.43	19	France	19	1.59
10	Netherlands	40	3.34	20	Greece	15	1.25

[a] Publication (Pubs): total number of publications of a country.
[b] Percentage (%): the percentage of publications of a country.



	Energy Policy	Energy Build.	Atmos. Environ.	Environ. Sci. Technol.	Appl. Energy	Energy	Build. Environ.	Energy Econ.	J. Clean. Prod.	Renew. Energy	Renew. Sust. Energ. Rev.
IF	3.045	2.973	3.459	5.393	5.746	4.292	3.394	2.862	4.959	3.404	6.798
SJR	2.436	2.073	1.999	2.664	2.998	2.35	2.121	3.025	1.721	1.961	3.12
IPP	3.98	4.07	3.73	5.911	6.4	5.03	4.37	3.74	5.57	4.51	8.35
SNIP	1.653	1.866	1.267	2.049	2.439	1.898	2.197	1.851	2.272	2.029	3.109

Fig. 5. Comparisons of IF, SJR, IPP, and SNIP scores for year 2015 for the top ten productive journals on REE.

Table 4
Key authors in REE.

#	Author	Pubs[a]	*h*-index	Country	#	Author	Pubs[a]	*h*-index	Country
1	Shen, Guofeng	16	21	China	9	Chen, Yingjun	9	21	China
2	Tao, Shu	14	55	China	10	Chen, Yuanchen	9	2	China
3	Ugursal, V. Ismet	12	6	Canada	11	Li, Wei	9	19	China
4	Junnila, Seppo	11	14	Finland	12	Huang, Ye	9	19	China
5	Shen, Huizhong	11	21	USA	13	Zhang, Yanyan	8	19	China
6	Wang, Xilong	10	31	China	14	Wang, Rong	8	20	China
7	Heinonen, Jukka	10	11	Iceland	15	Fung, Alan S.	8	16	Canada
8	Wang, Xiaohua	10	10	China	16	Feng, Yanli	8	16	China

[a] Publication (Pubs): total number of publications of an author.

Table 5
Key co-authors.

#	Author 1	Author 2	Pubs[a]
1	Shen, Guofeng	Tao, Shu	11
2	Heinonen, Jukka	Junnila, Seppo	10
3	Shen, Guofeng	Shen, Huizhong	10
4	Shen, Guofeng	Wang, Xilong	9
5	Shen, Guofeng	Zhang, Yanyan	8
6	Shen, Huizhong	Wang, Xilong	8
7	Shen, Guofeng	Huang, Ye	7
8	Shen, Guofeng	Chen, Yuanchen	7
9	Chen, Yingjun	Feng, Yanli	7
10	Huang, Ye	Wang, Xilong	7

[a] Publication (Pubs): total number of collaborated publications of two authors.

environmental management and economics related with residential GHG emissions. Their main research method is life cycle assessment (LCA), evaluating the impact of residential buildings on air quality.

Further, the Fruchterman-Reingold layout (Fruchterman and Reingold, 1991) in Gephi was adopted for visualizing the authors' collaboration network (Fig. 6). This figure presents all the major REE research communities and can help researchers identify the academic relations. Through the application of modularity algorithm (Newman and Girvan, 2004), five major author networks were identified and differentiated by using different colors. Also, insignificant clusters were colored in grey or omitted at all in order to clearly present the key research communities. Each node represents an individual author and the size of one node indicates his/her research publications. The largest cluster in green belongs to Tao S. and his colleagues from Peking University. The research communities at Peking University are interconnected with the other three smaller clusters, except the second largest cluster in red, which belongs to different European institutes. This indicates that the research community at Peking University has active international collaboration.

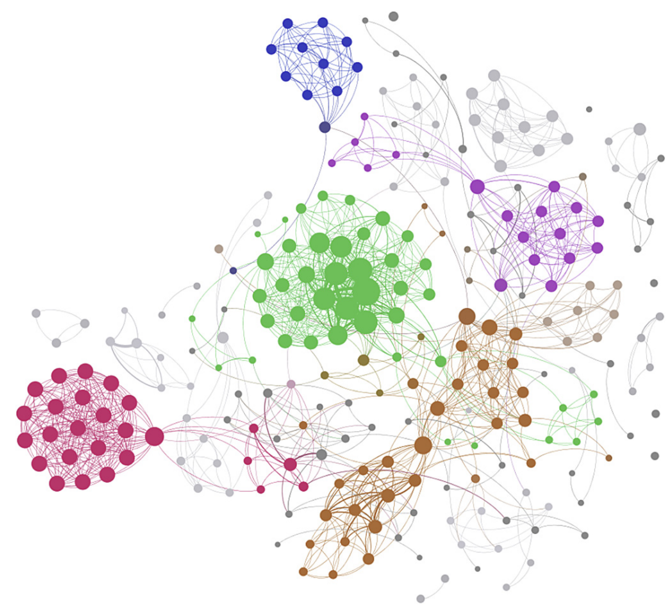


Fig. 6. Authors collaboration network shown by their origins.

Table 6
Top contributing organizations.

#	Organization	Country	Pubs[a]
1	Chinese Academy of Sciences	China	36
2	University of California	United States	30
3	Tsinghua University	China	25
4	Peking University	China	21
5	United States Environmental Protection Agency	United States	18
6	Dalhousie University	Canada	14
7	Beijing Institute of Technology	China	14
8	Tongji University	China	13
9	Lanzhou University	China	13
10	Lawrence Berkeley National Laboratory	United States	11

[a] Publication (Pubs): total number of publications of an affiliation.

3.6. *Affiliations*

Table 6 lists the top ten most productive organizations on REE. Among them, six organizations locate in China and the most productive organization is the Chinese Academy of Sciences (CAS), with 36 publications. This confirms again that China is one active country on such an issue. In the case of the USA, University of California is the most productive one, while the second most productive organization is the laboratories and research centers of U.S. Environmental Protection Agency (EPA). Such statistical data can provide valuable information to researchers who have interests in the field of REE to choose the potential collaborators or pursue their degrees within such a field.

Table 3 (Section 3.3) lists USA as the most productive country on REE. Not surprisingly, it is also the most active country for international collaboration in this field. Table 7 lists that the key collaboration countries with USA include China, Australia, and Germany. Interestingly, USA has more diversified collaboration countries in the world, while China has only several specific collaboration countries, such as Japan, USA, and Australia. This can be explained that the Chinese researchers like to cooperate with western countries in order to enrich their research outcomes and improve their English presentation, while USA is a leading research country and an English speaking country, attracting many international researchers from different countries/territories.

The collaboration network among countries/territories is further visualized in Fig. 7. The size of each node indicates the joint

Table 7
International collaboration in REE research.

#	Country 1	Country 2	Pubs[a]	#	Country 1	Country 2	Pubs[a]
1	China	Japan	22	9	Mexico	United States	6
2	China	United States	22	10	South Korea	United States	6
3	Australia	China	15	11	United Kingdom	United States	6
4	China	United Kingdom	10	12	Canada	United States	5
5	Germany	United States	8	13	Canada	China	5
6	Australia	United States	8	14	Spain	United States	5
7	China	Norway	7	15	Portugal	United States	5
8	Austria	United States	6	16	China	Netherlands	5

[a] Publication (Pubs): total number of collaborated publications of two countries.

paper number of each country with other countries, while the thickness of each line indicates the cooperation strength between the two countries. It is clear that USA has the most cooperation countries, with a total number of 35 across the world, followed by UK (23), Germany (23), Australia (19), and Finland (17). Most of them are English speaking countries/territories, showing their language advantages over other countries/territories. China is a leading developing country for its international cooperation, with a total of 15 cooperative countries. However, as the highest per capita emitters, both Saudi Arabia (7) and Russia (5) has less international collaboration partners, all with European countries. The reason remains unclear. Maybe they do not regard energy saving as one of their priorities due to their rich oil reserves, or they do not prefer to publish their research findings in English language journals due to language barrier.

3.7. Keywords

In order to understand the focus areas of one subject in a particular region or during a particular period, it is necessary to study keywords since they can provide valuable information (Wei et al., 2015). 8599 keywords were extracted from our dataset. Most of them are similar with slight variations, such as "greenhouse gas", "greenhouse gases", or "GHG". The most frequently adopted keywords are listed in Table 8, including their variations.

As mentioned in Section 1, studies on REE can be divided into two main periods based on their annual publications. The keywords

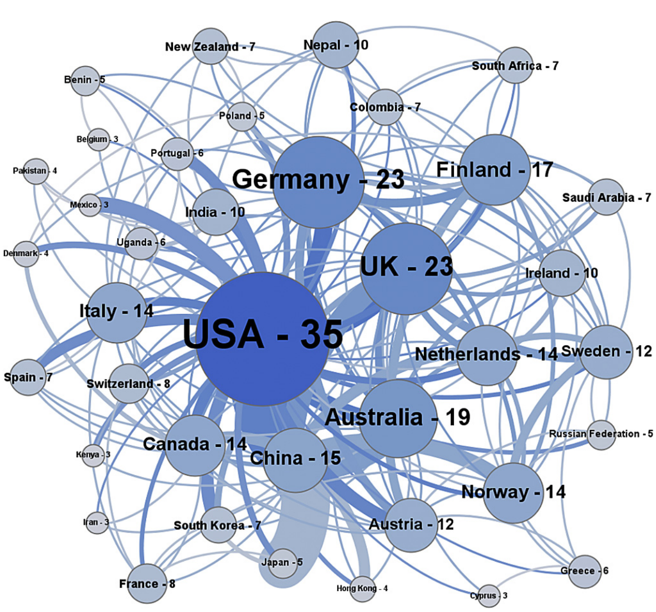


Fig. 7. Collaboration ranks and strengths among different countries/territories.

search can help identify the major research themes during the two stages. Gephi was used again to visualize the most frequently used keywords and their network during Stage 1 (1996–2006) and Stage 2 (2007–2016), shown in Figs. 8 and 9, respectively. Research themes are marked in different colors so that the relevant keywords can be linked together. It is clear that the keywords had shifted significantly during the last ten years. Fig. 8 demonstrates that during the first stage researchers mainly focused on the emission contents (clusters 1-1 and 1–2), climate change issues (cluster 1–3) and energy management (cluster 1–4) from a broad perspective. Fig. 9 demonstrates that in the second stage, the research themes shifted into four large clusters, namely emissions contents (cluster 2–1), impacts brought by individual household characteristics, their dietary habits and lifestyles, the effects of air pollution on human health, management policies (cluster 2-2), and efforts to optimize residential buildings and heating/cooling systems to lower their greenhouse gas effects (cluster 2–3). Such results indicate that researchers began to pay more attentions on life quality and environmental management with the rapid economic development.

4. Network analysis

4.1. Citation analysis

Originated from Science Citation Index (SCI) in 1961 (MacRoberts and MacRoberts, 1996), citation analysis is a widely used method for evaluating one scholar's academic performance (Hirsch, 2005). Theoretically, if one paper is cited by another one, it means that the research outcomes from this paper may provide useful information for others and therefore is valuable. The more citations each paper has, the more valuable this paper is. Consequently, the total citation number is one valid indicator for measuring one paper's academic value (MacRoberts and MacRoberts, 1996), at least partially.

The very simple way on citation analysis is to account the total number of citations one paper received. However, it may lead to bias since some authors often tend to cite their own papers, while some citations are negative (such as the critiques of one paper). Therefore, the total citations do not always indicate a higher scientific value of one paper. Fortunately, PageRank (PR), an evaluation algorithm developed by Google to rank web pages by their importance, can help resolve this issue. This method measures the prestige of one paper by considering the citation number it received from other highly cited papers (Fahimnia et al., 2015b). It forms a numerical weight distribution over papers within the given amount of papers (i.e. dataset), thus the sum of all PR scores gives 1. Tables 9 and 10 show the top ten papers based on their TC/Y and PR scores, respectively. In total, 225 papers (18.80%) in our dataset have not been cited at all. It is clear that the recently published papers cannot be as popular as the earlier ones, thus citations per

Table 8
The most frequent keywords and their variations.

#	Keywords	Frequency	Keyword variations (frequency)	Total
1	Energy utilization	339	electricity-consumption (28), electric power utilization (18), total energy consumption (16), electricity usage (3), electricity consumption (10), energy needs (4), energy intensity (8), energy requirements (7), electricity use (7), energy expenditure (6), electric power consumption (2), energy use (181), energy demand (16), electricity demands (3), energy consumption (162)	810
2	Housing	238	houses (36), households (20), residential house (9), social housing (7), housing sectors (5), urban housing (3), house (2), rural housing (2)	322
3	Energy efficiency	227	residential energy efficiency (7), energy management (45), energy saving (16), energy efficient (14), efficiency (15), energy-saving measures (8), energy-saving effect (3), energy savings (8), electricity saving (7), energy efficiency improvements (6), energy efficiency programs (4)	360
4	Carbon dioxide	204	CO_2 (6)	210
5	Energy conservation	193	conservation (5)	198
6	Heating	145	space heating (27), heating and cooling (12), heating energy (8), district heating (8), heating system (7), residential heating (6), heating and cooling systems (3), domestic heating (2), heating demand (2)	220
7	Carbon emission	142	carbon emissions (52), CO_2 emissions (45), carbon dioxide emissions (22), CO_2 emissions (5), CO emissions (5)	271
8	Household energy	142	residential energy consumption (57), household electricity consumption (6), household energy consumption (43), residential building energies (8), residential consumption (7), rural household energy consumption (4), household electricity consumption (6), rural household energy (9), household consumption (21), residential energy use (5), household energy use (15), household energy consumption behavior (4), residential building energy (3), household carbon footprint (2), domestic energy use and CO_2 emissions (2), household carbon emissions (2), domestic energy (2)	338
9	China	136		136
10	Emission control	133	pollution control (6), pollution monitoring (6), emission reduction (28), air pollution control (16), air monitoring (6)	195

year (TC/Y) should be considered as well. Table 9 shows a noticeable gap between TC/Y and TC. For instance, although the work of Fischer (2008) is frequently cited with the highest TC/Y scores, it is not as globally popular as the one completed by Bowman et al. (2004) which received the top TC scores. When measuring these by their PR scores (see Table 10), the results were completely different from those from citation analysis. Papers with highest PR scores are not the ones with the most citations. For instance, the paper written by Büchs and Schnepf (2013) received the top PR score, but with relatively lower scores on TC and TC/Y.

The paper with the highest TC/Y score in Table 9 is the one written by Fischer (2008), in which the author explored features of the most successful feedback on electricity consumption, which may help customers save energy. This paper combined model analysis with empirical evidence from international experience. Results first confirmed that feedback stimulates electricity savings. High-frequency and long-term feedback with appliance-specific breakdown, computerized and interactive tools, and clear and appealing information were considered the most successful one.

Another important paper, namely the one conducted by McDonald et al. (2000), is more technology-oriented. The aim of this paper is to define emissions rates and characteristics of various types of wood and appliances used in wood-burning households. Numerous experiments were conducted on different types of wood and appliances, with total samples of over 350 elements, organic and inorganic compounds so that their emissions can be accurately accounted through the application of various techniques. The major findings of this study is that emission rates and contents greatly depend on the appliance type used for burning wood, the amount and type of wood, burning condition, and wood moisture content.

The paper written by Büchs and Schnepf (2013) received the highest PR score within our dataset, with aims to raise policy implications for direct and indirect residential energy use. This paper presents how household income, size, education, ethnicity, composition, employment status, and location affect its total CO_2 emissions. 24,446 households across the whole UK were

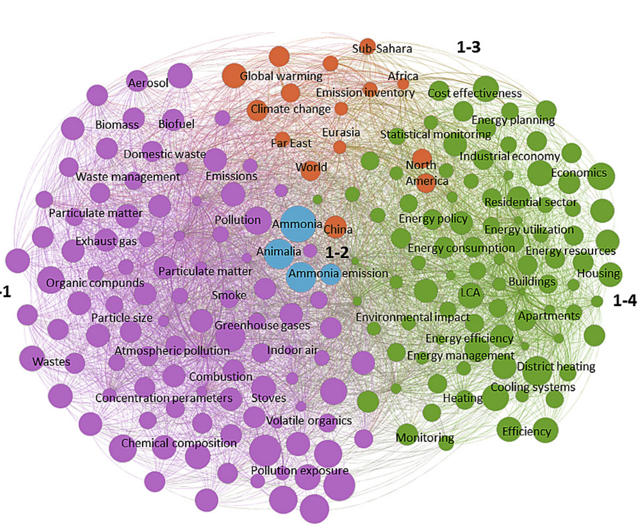


Fig. 8. Keywords network in Stage 1 (1996–2006). Note: not all keywords are shown on the image.

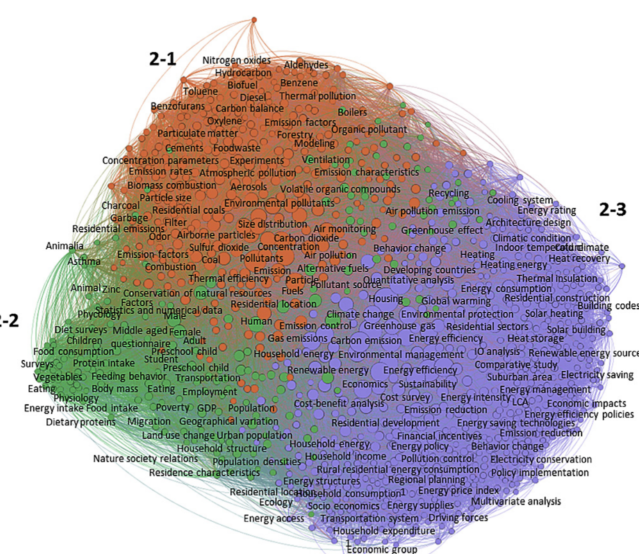


Fig. 9. Keywords network in Stage 2 (2007–2016). Note: not all keywords are shown on the image.

Table 9
Top ten highly cited papers based on Total Citation (TC).

#	Author	Year	Journal	TC/Y[a]	TC
1	Fischer (2008)	2008	Energy Efficiency	49.89	449
2	Dietz et al. (2009)	2009	Proceedings of the National Academy of Sciences of the United States of America	46.63	373
3	Bowman et al. (2004)	2004	Pediatrics	43.15	561
4	Kavgic et al. (2010)	2010	Building and Environment	28.43	199
5	Venkataraman et al. (2005)	2005	Science	25.83	310
6	Druckman and Jackson (2009)	2009	Ecological Economics	25.00	200
7	Weber and Matthews (2008)	2008	Ecological Economics	23.33	210
8	Jetter et al. (2012)	2012	Environmental Science & Technology	23.20	116
9	McDonald et al. (2000)	2000	Environmental Science & Technology	22.41	381
10	Jain et al. (2014)	2014	Applied Energy	21.33	64

[a] Citation per year (TC/Y): average number of yearly citations.

Table 10
Top ten papers based on PageRank score.

#	Author	Year	Journal	PageRank	TC	TC/Y
1	Büchs and Schnepf (2013)	2013	Ecological Economics	0.0821	36	9
2	Kaza (2010)	2010	Energy Policy	0.0424	49	7
3	Lee and Lee (2014)	2014	Energy Policy	0.0368	30	10
4	Wei et al. (2007)	2007	Energy Policy	0.0325	115	11.5
5	Feng et al. (2011)	2011	Energy	0.0303	81	13.5
6	Holden and Norland (2005)	2005	Urban Studies	0.0269	151	12.58
7	Niu et al. (2012)	2012	Energy Policy	0.0259	16	3.2
8	Dai et al. (2012)	2012	Energy Policy	0.0245	40	8
9	Boman et al. (2011)	2011	Energy and Fuels	0.0199	54	9
10	Duarte et al. (2010)	2010	Energy Economics	0.0183	23	3.29

investigated in order to provide a more complete picture. From method point of view, a multivariate OLS regression model was used to examine whether education and location influence household emissions. The results demonstrated that education plays an important role in residential carbon footprint, namely, the less educated the members of a household, the higher their emissions level. Also, families with children living in rural areas tend to emit more compared to urban families without children. In addition, their analysis also showed that households with jobless members had higher home energy use and lower transportation emissions. Their Chi squared tests confirmed that all household characteristics except for ethnicity had a significant impact on their carbon footprint. Such studies are useful in enacting fair emission mitigation policies that take account of regional and household characteristics.

4.2. Co-citation and topical analysis

Co-citation analysis is a method used to identify relationship between articles based on their citations. It can be done in two ways: co-citation and bibliographic coupling (Saukko, 2014). Co-citation refers to that two articles are jointly cited in other papers, and bibliographic coupling refers to that the same article appears in the reference of two or more papers making the citing papers somehow connected each another. In this study, co-citation analysis is employed. In total, 374 out of 1197 papers were cited by other studies within the same dataset, and the co-citation analysis was performed on these 374 papers. Modularity test in Gephi identified four major clusters representing different topics based on co-citation network of the papers. If papers are frequently co-cited, they are likely to have a strong relationship (Fahimnia et al., 2015a). Fig. 10 depicts topical classifications where each node represents each individual paper and the size is based on its PR score. The links show connections among paper citations. A thicker link represents closer relation between the two connected nodes within the similar subject area of the clusters. Each cluster contains a certain number of papers. The largest amount of papers belongs to clusters 1 and 2, each with a total of 48 publications. Due to the large amount of papers, only the top five papers with highest PR scores from each cluster were analyzed in order to identify the subject areas. These leading papers are listed in Table 11.

Table 12 lists different research foci of different clusters. Clusters 1 and 4 have closer interconnection, both focusing on similar

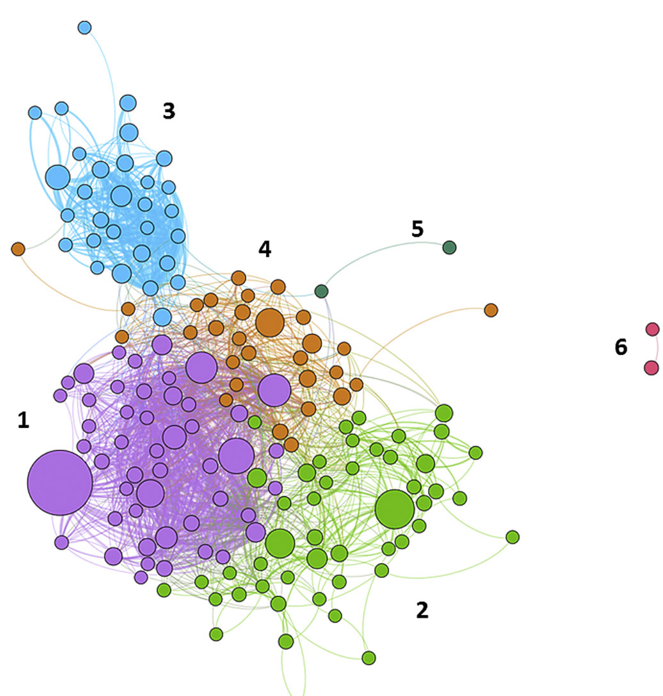


Fig. 10. Topical clusters of cited papers.

Table 11
Leading papers of major clusters based on PageRank score.

Cluster 1	Cluster 2	Cluster 3	Cluster 4
Büchs and Schnepf (2013)	Kaza (2010)	Boman et al. (2011)	Niu et al. (2012)
Lee and Lee (2014)	Holden and Norland (2005)	Venkataraman et al. (2005)	Cayla et al. (2011)
Wei et al. (2007)	Ewing and Rong (2008)	Jetter and Kariher (2009)	Feng et al. (2010)
Duarte et al. (2010)	Haas et al. (1998)	Zhu et al. (2013)	Wang and Feng (2005)
Dai et al. (2012)	Shorrock and Dunster (1997)	Olsson et al. (2003)	Zhao et al. (2012)

research topics, namely consumer behaviors and lifestyles, direct and indirect residential energy consumption patterns, association between household characteristics and their energy demand, energy consumption and emissions differences between urban and rural households, aiming to provide better insights into residential emissions and energy demand for policy makers to assist in the development of more suitable regulations. Cluster 2, on the other hand, focuses on energy use and emissions of various building types, space heating and cooling, land use, housing sizes, neighborhood density, energy loss due to transmission and distribution or building insulations, etc. The main research outcomes from this cluster provide policy implications on building standards, energy-efficient houses, housing areas, etc. Unlike the other groups, Cluster 3 is loosely connected to other clusters, indicating its distinct research area. Its subject area mainly focuses on performance analysis, consumption, burning rates, and emissions of different residential stoves and burning appliances, identification of chemical properties of various fuels, biomass, wood, and coal in order to propose better solutions to residential combustion and lower the corresponding emissions.

Table 13 lists the publication numbers in each cluster so that the evolution trend of different clusters can be presented. It is clear that there is no new topic among the clusters except for Cluster 3, namely, emissions from residential stoves which have been initiated since 2000 with rather steady yearly publications. Other clusters do not show any rapid "late-bloomer" signs except for Cluster 1, namely, direct and indirect household emissions with slightly more attentions. Also, papers in this cluster had the highest Page Rank scores, indicating that studies on this topic are frequently cited by other highly cited papers.

5. Popular methods on REE

Methods related with REE studies were uncovered through the application of the keyword frequency approach. Numerous methods and models were identified by filter search using words 'model', 'analysis', 'method', and 'assessment'. The most widely adopted four methods are demonstrated in Fig. 11, showing the application trend from 1996 to 2016 and the total publication numbers for each method. The brief descriptions and their purposes in REE are summarized in Table 14.

5.1. Behavioral analysis

Behavioral analysis is the most frequently employed method in REE-related studies. It has been actively used in order to estimate both direct and indirect residential emissions. Studies on behavioral analysis were mainly conducted through questionnaire surveys on households, such as national household expenditure surveys (De Almeida et al., 2011; Yu and Zhang, 2015), daily individual household investigations (Streimikiene and Volochovic, 2011), and structured interviews through questionnaires (Crosbie, 2008; Hara et al., 2015; Hondo and Baba, 2010). However, some researchers argue that questionnaire surveys and interviews may give inaccurate results since self-reported data may not always match the real behaviors (Steg and Abrahamse, 2010). Also, the selection of interviewees may also lead to bias due to incomplete sample coverage of stakeholders. In general, this method can complement other engineering and economic approaches to estimate residential energy use and carbon footprint (Dietz et al., 2009; Fan et al., 2013; Hamamoto, 2013; Hirano et al., 2016; Hondo and Baba, 2010; Langevin et al., 2013; Streimikiene and Volochovic, 2011). It has been widely accepted that behaviors on energy saving can substantially reduce GHG emissions with a minimal cost in a considerably short time (Dietz et al., 2009; Hamamoto, 2013; Hara et al., 2015; Streimikiene and Volochovic, 2011). But household characteristics, incomes, education levels, housing types and climate zones are different, leading to different barriers toward low carbon consumption. In order to raise appropriate mitigation policies, this method is crucial so that regional disparities can be uncovered and more specific mitigation measures can be prepared by considering the local realities.

5.2. Life cycle analysis (LCA)

Life cycle analysis (LCA) is the second most widely used method in this research area. It provides guidelines to assess the environmental impact of one product or service throughout its life cycle. The results obtained from LCA can be used in decision making processes of an organization to develop more environmentally friendly products and services (ISO, 2006). Many papers in our dataset adopted this method to assess the performance of residential buildings (Atmaca and Atmaca, 2015; Balaras et al., 2005; Choi et al., 2014; Forsythe and Ding, 2014; Fujita et al., 2009; Gardezi et al., 2016; Gong et al., 2012; Gustavsson et al., 2010; Kim et al., 2015; Kyrö et al., 2012; Seo and Hwang, 2001; Serrano and Álvarez, 2016; Su and Zhang, 2016; Surahman et al., 2015; Zhang et al., 2016b). In terms of research outcomes from LCA, while some researchers found that the construction stage of one building is energy consumption and GHG emission intensive (Serrano and Álvarez, 2016), their studies found that energy consumption and GHG emissions during the operation phase are much higher than those from the construction stage, in which most were related with space heating and cooling (Atmaca and Atmaca, 2015; Balaras et al., 2005). Another key LCA finding is that the direct energy consumption and GHG emissions were largely dependent on the sources and types of energy. In this regard, district heating has been proved to be more energy-efficient, while individual house consumes more energy (Serrano and Álvarez, 2016). These findings can guide potential house buyers to rationally purchase their estates and help both engineers and architects to improve their designs and construction, such as selection of green construction materials and energy efficient appliances, innovative renovation and refurbishment of old buildings, and the application of ground source heat pumps (Geng et al., 2013).

Moreover, several studies employed LCA to assess environmental performance of residential activities, such as waste and food consumption (Inaba et al., 2010; Jones and Kammen, 2011; Kauppinen et al., 2010), their water and ecological footprints (Song et al., 2015), energy use of domestic Rainwater Tank Systems

Table 12
Research foci of four major clusters.

Cluster	Pubs	Research foci
1	48	Direct and indirect impact of household characteristics and lifestyle on their emissions level; Residential consumption pattern, household energy demand and emissions level;
2	48	Energy use and emissions level of residential buildings, space heating and cooling, land use, transportation, energy efficiency technology, etc.;
3	30	Chemical properties, burn rate, and intensity of residential emissions generated from coal, fuel, biofuels, and wood burning; Performance, fuel consumption, and emissions level of various residential stoves and burning appliances;
4	29	Household energy consumption patterns; Association between household income and energy consumption; Energy saving and efficiency;

Table 13
Publication trend of clusters from 1996 to 2016.

Year	Cluster 1	Cluster 2	Cluster 3	Cluster 4	Year	Cluster 1	Cluster 2	Cluster 3	Cluster 4
1996	1	2			2007	3	4	2	
1997		2		1	2008	2	6	2	1
1998		2			2009	6	2	3	2
1999	1	1		2	2010	4	4	2	2
2000	2	2	3		2011	5	8	2	4
2001	1	1	1		2012	9	2	3	4
2002		1	1		2013	8		2	2
2003		2	1	1	2014	4	1	1	6
2004		1	1		2015			1	
2005	1	4	4	2	2016				
2006	1	3	1	2	Total	48	48	30	29

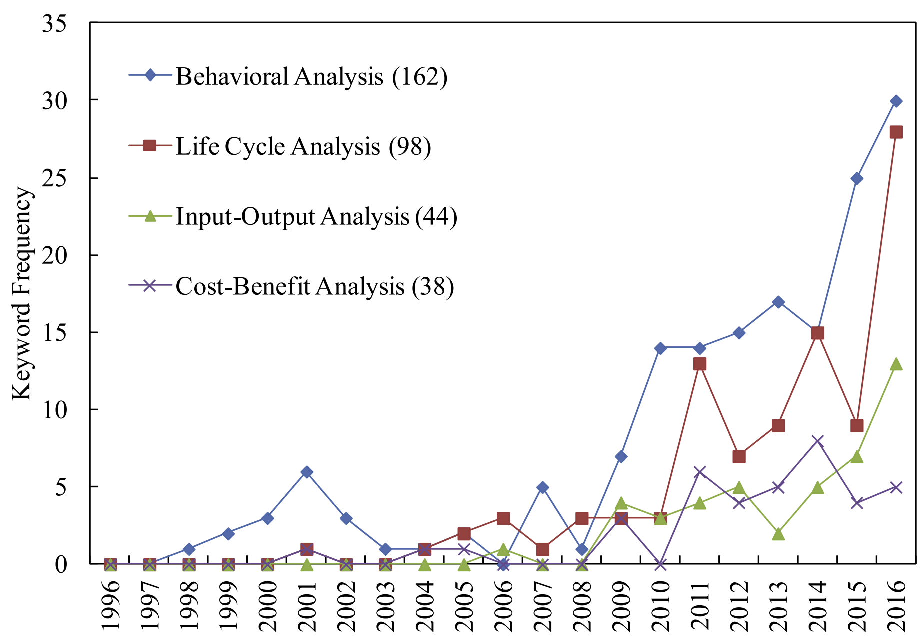


Fig. 11. Major REE-related methods. Note: The total number of keywords to the corresponding methods is shown in brackets. Sometimes research methods are not mentioned in keywords, thus it is possible that some of them are much more frequently used than shown on the above graph.

(RWTS) (Siems and Sahin, 2016), Residential Water Heating Systems (RWHS) (Taborianski and Prado, 2004), life-cycle GHG emission of used plastic materials within one household (Yano et al., 2014), and GHG emissions from home composts (Quirós et al., 2014).

5.3. Cost-benefit analysis (CBA)

Cost-benefit analysis is based on the use of some foundational principles, which are not controversial, but have nevertheless considered plausibility (Sen, 2000). CBA is an economic method that helps decision makers to evaluate investment costs and benefits in the long run of programs, investments, businesses, and policies. In addition, it consists of multiple steps and is a time and data-intensive method since it covers a wide range of information.

The aim of CBA is to offer a consistent procedure for evaluating decisions in terms of their consequences. Cost-benefit analysis clearly embraces an enormous field. It could help decision makers to evaluate investment costs and benefits in the long term of investments, programs, businesses, and policies (Drèze and Stern, 1987). In our dataset, CBA was used to analyze cost-benefits, emissions reduction, energy saving from retrofitting the lighting

Table 14
Brief descriptions of the main methods.

#	Methodology	Data collection	Purpose in our dataset
1	Behavioral Analysis	• Survey Questionnaire • Interview • National household expenditure survey	• Residential consumption behavior • The role of income in household energy consumption • Household characteristics and their association with the energy use and emissions
2	Life Cycle Analysis	• On and off-site data collection • Literature and research review • Public database • Annual financial statements and reports of companies	• Environmental impact of residential buildings in its entire life span • Environmental performance of residential activities such as waste and food consumption • Energy and emissions of domestic water, heating, cooling systems • Direct and embedded energy and emissions of domestic utilities and electric appliances
3	Cost-Benefit Analysis	• Survey Questionnaire • Interview • On-site investigation and data collection	• Energy efficiency scenarios such as retrofitting lighting systems, energy efficiency program, installation of photovoltaic panels, building insulations and refurbishment, etc.
4	Input-Output Analysis	• National household expenditure survey • Input-Output table • Price index of fuel and energy	• Direct and indirect household energy consumption including imported products • Energy consumption comparison of local households and tourists • Emissions from residential buildings

system (Mahlia et al., 2005), energy efficient upgrade scenarios (Guler et al., 2001), roof-mounted photovoltaic systems (Hendrickson et al., 2013) in residential sector, the cost and benefit of energy-efficient solar stoves for rural households (Niu et al., 2014), case analysis of energy efficiency program for residential buildings (Ameer and Krarti, 2016), etc.

5.4. Input-output analysis (IOA)

Input-Output Analysis (IOA), proposed by Leontief in the late 1930, is one of the most widely used methods in economics. The purpose of this method is to analyze the interdependence of industries and their products within an economy (Miller and Blair, 2009). IOA model has been developed for a particular economic zone such as a country, a state, or a region for a specific time period. IOA is now extensively used in environmental economics and sustainability context. For instance, scholars have used this method to assess environmental impact of an area for over four decades (Cellura et al., 2011). The main strength of this method is that it provides a standard assessment framework that can be applied to other economic areas with the same manner (Fan et al., 2012). On the other hand, it is a data-intensive method that requires household expenditure survey, environmental accounts, fuel prices, emission factors, etc. Selected papers in our dataset adopted various types of IOA, such as Environmentally-Extended Input-Output model (EEIO), Multi-Regional Input-Output model (MRIO), Quasi-Multi-Regional Input–Output model (QMRIO). The main IOA equation is shown in Equation (1), where X is the total production or output of a particular sector, I is one identity matrix, A is one technical coefficients matrix, and Y is the total final demand for that particular sector. The inverse matrix $(I-A)^{-1}$ is referred to as *Leontief inverse matrix*.

$$\boldsymbol{X} = (\boldsymbol{I} - \boldsymbol{A})^{-1}\boldsymbol{Y} \tag{1}$$

In our dataset, the majority of selected papers used IOA for quantifying the total direct and indirect households energy consumptions in a particular region (Baynes et al., 2011; Das and Paul, 2014; Druckman and Jackson, 2009; Seriño and Klasen, 2015). Other relevant papers include studies on emissions from residential buildings (Choi et al., 2014; Onat et al., 2014; Surahman et al., 2015), or quantification of the share of emissions produced by tourists in the residential emissions, in which important insights for tourism-active regions were provided (Cadarso et al., 2015; Konan and Chan, 2010).

5.5. Other methods

Beyond the above methods, some authors used hybrid methods that merge two methods such as Regression with LCA (Gardezi et al., 2016), or Economic Input-Output Life Cycle Assessment (EIO-LCA) (Ferguson and MacLean, 2011; Lenzen and Crawford, 2009; Onat et al., 2014). The main reason is that these methods complement each other's strengths. For example, LCA allows obtaining detailed information on environmental impact of a product, whereas IOA calculates aggregate results for the whole economy (Cellura et al., 2011). Other methods include Customer Lifecycle Approach (CLA), Environmental Impact Assessment, Standard Impact Assessment, Cross-Section Analysis, Emergy, MDCEV model (Biying et al., 2012; Yu and Zhang, 2015), Cross-section analysis, Working leser model, Multilevel SEM analysis, Quantile regression analysis, etc.

6. Conclusions

Residential sector is one key sector on energy consumption and GHG emissions. With the rapid development and increasing incomes, it is estimated that energy demand from residential sector will continue to increase and may lead to more GHG emissions. Such a reality requires policy makers to prepare appropriate mitigation policies. Many studies have been conducted on residential energy use and GHG emissions in order to understand their demand and propose feasible mitigation measures. Consequently, it is critical to summarize the existing studies and identify the key research areas so that future research directions can be recognized. Under such a circumstance, this paper employs bibliometric analysis to review REE-related papers so that researchers in this field can better understand the existing research findings and choose their own research topics.

A holistic picture of the primary performance of REE-related literature published from 1996 to 2016 is presented. By using Scopus database and manual screening, 1197 papers published from 1996 to 2016 were collected. In the early stage, namely from 1996 to 2006, the total publication amounts were limited. But with the increasing concerns on climate change, more papers were published from 2007 to 2016, covering more aspects and reflecting more attentions from different stakeholders. Results show that most REE-related studies focus on environmental science, energy, and engineering. Energy Policy, Energy and Buildings, and EST are the most important journals in this REE-related field. From a country point of view, USA and China are the top two most productive countries. Especially, USA is the most active country for international cooperation, while China had close collaboration with only a few countries, such as USA, Japan and Australia.

In terms of hot research topics, four major clusters were identified, two of which were similar to each other and focused on direct and indirect household energy consumption and corresponding GHG emissions. The other two clusters refer to emission contents from fossil fuels combustion in residential buildings, and environmental impact of various residential buildings, respectively. In terms of research methods, behavioral analysis, LCA, CBA, and IOA are the most widely used methods. Some of them were also combined together so that more holistic and comprehensive perspectives can be achieved. This indicates that no single method can solve all the problems and the integration of different methods can help overcome the shortcomings of one single method. It also provides valuable insights to future researchers in this field so that they can consider combining different methods to deal with different problems.

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