Bibliometric analysis of greenhouse gas research on a global scale from 2000 to 2014

Wei Yang, Haijin Zhou, Fuqi Si, Cheng Liu, Wei Wang, Youwen Sun, Wenqing Liu and Changgong Shan*

A bibliometric approach is used in this study for the assessment of greenhouse gas (GHG) research trends on a global scale. The relevant literature published from 2000 to 2014 in journals of all subject categories of the Science Citation Index Expanded from the Web of Science Core Collection databases has been used. The strings 'greenhouse gas' or 'green house gas*' are used for retrieving data. The information of GHG research-related literature is analysed, including the types and languages of literature, characteristics of articles published, source countries/territories of articles, distribution of articles in different subject categories and journals, frequency/number of words in the title of articles and the frequency/number of keywords used. Over the past 15 years, an obvious growth trend is seen in the number of published articles, and countries/territories involved in the study of GHG. The number of the world articles published by the seven most developed industrialized countries (G7) is maximum in the field of GHG research. The G7 countries have played a predominant role in GHG research in the last 15 years. Analysis of the title words, author keywords and keywords plus showed that 'greenhouse gas emission' and 'climate change' were the keywords with highest frequency during the whole research period. Carbon sequestration and biotechnology have been widely used in reducing the environmental pressure of the greenhouse effect and the dependence on fossil energy.*

Keywords: Bibliometric analysis, climate change, global trends, greenhouse gas research, SCI.

GREENHOUSE gases (GHGs) are important constituents in the atmosphere that can absorb solar radiation and re-emitted radiation[1,2]. GHG emissions lead to global warming, sea-level rise[3,4], extreme weather and change in agricultural pattern[5]. The major constituents of GHG are carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O). The main sources of GHG emission are burning of fossil fuels, solid waste degradation, biological respiration and agriculture soil[6–9]. The study of GHGs has become a hot topic of global research.

As human activities continue to cause an increase in GHG emissions, the earth's surface temperature is expected to rise, causing the global climates to change[10]. More and more countries/territories have joined the study of GHGs, but there is a gap between developing countries and developed countries on GHG research[11]. However, in the past few years many developing countries are being involved in GHG research. Furthermore, more scientific research articles are being published from these countries on the reduction of GHG emission, carbon sequestration, biotechnology and energy applications[12–14].

There are a variety of statistical analysis methods to assess scientific literature data. Bibliometric study is one such method; it is convenient and quick to evaluate data[15,16]. This method is widely used in the literature analysis of different hotspots in scientific research[17]. The indicators of bibliometrics, which include the types and languages of articles, characteristics of articles published, source countries/territories of articles, distribution of articles in subject categories and journals, frequency/number of title words, author keywords used and keywords plus, have been widely used to analyse the trends of different scientific research fields[11,18–20].

The present study aims to analyse the status and trends of GHG research in the last 15 years on a global scale. The analysis of data shows some important research hotspots related to GHG. The changing trend of the research on GHG in different countries/territories is analysed. This study will help to understand the development of global GHG research.

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Table 1. Characteristics of articles published every year during 2000–2014

Year	TA	PG	PG/TA	NR	NR/TA	AU	AU/TA	J	TA/J
2000	330	3884	11.77	10,286	31.17	1001	3.03	164	2.01
2001	412	4640	11.26	12,867	31.23	1295	3.14	180	2.29
2002	409	4757	11.63	13,463	32.92	1425	3.48	189	2.16
2003	485	5761	11.88	15,436	31.83	1669	3.44	215	2.26
2004	545	6493	11.91	18,582	34.10	2039	3.74	242	2.25
2005	650	7485	11.52	22,406	34.47	2361	3.63	249	2.61
2006	761	9112	11.97	27,722	36.43	2874	3.78	269	2.83
2007	866	9376	10.83	30,284	34.97	3353	3.87	306	2.83
2008	1191	12,778	10.73	43,256	36.32	4368	3.67	421	2.83
2009	1381	14,432	10.45	51,131	37.02	5376	3.89	458	3.02
2010	1745	19,285	11.05	74,362	42.61	7282	4.17	540	3.23
2011	2153	24,995	11.61	96,857	44.99	9527	4.42	602	3.58
2012	2278	25,441	11.17	100,081	43.93	10,159	4.46	664	3.43
2013	2742	31,352	11.43	126,479	46.13	13,129	4.79	678	4.04
2014	2899	33,690	11.62	139,322	48.06	13,795	4.76	732	3.96

TA, Total number of articles per year; PG, Sum of the page numbers; PG/TA, Average page number per article; NR, Sum of cited reference numbers; NR/TA, Average cited reference numbers per article; AU, Total number of authors; AU/TA, Average number of authors per article; J, Number of journals published articles and TA/J, Average number of articles published per journal.

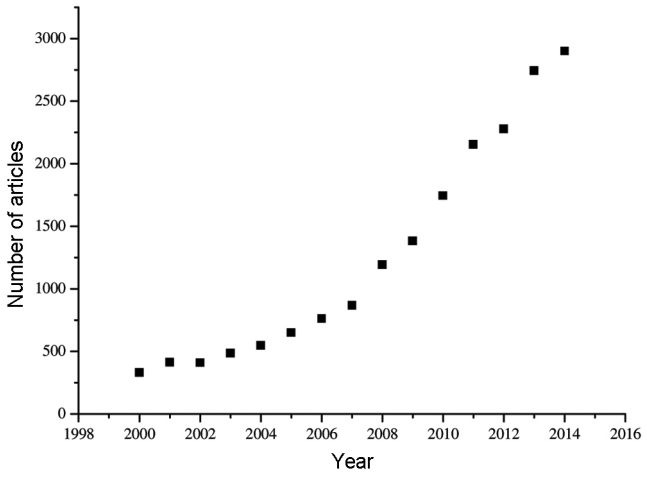

Figure 1. Number of articles on greenhouse gas research during 2000–2014.

Datasets and methods

The data for this study are obtained from the Science Citation Index Expanded (SCI-EXPANDED) database, which is widely used to analyse scientific publications[21]. This is a sub-database of the Web of Science (WoS) database of Thomson Scientific, USA. 'Greenhouse gas*' or 'greenhouse gas*' was used as the string to search titles, abstracts, keywords and other information regarding papers from 2000 to 2014. The records were then downloaded to a local disk. The collected data were examined carefully to ensure their accuracy. Then the data were analysed using Microsoft Excel 2010. For the analysis, England, Scotland, North Ireland and Wales were grouped under the United Kingdom. Articles from Taiwan were not included under China.

Results and discussion

Types and languages of publications

There were 21,378 papers related to research on GHG in the SCI-EXPANDED database, including 11 types of papers. Articles (18,847) accounted for 88.16% of the total amount of papers, followed by reviews (1795; 8.40%), proceedings papers (1145; 5.36%), editorial materials (273; 1.28%) and news items (225; 1.05%). The others included meeting abstracts (118), book chapters (100), letters (79), corrections (36), book reviews (4) and reprints (1). The contribution of articles was the maximum; so they were used for further data analysis. On the other hand, English was the most widely used language, accounting for 98.37% of all published articles.

Characteristics of articles published

Table 1 shows the characteristics of articles on GHG research from 2000 to 2014. It can be observed that the annual number of articles published, average number of cited references, average number of authors per paper and average number of articles published in each journal have increased rapidly. The number of articles has increased to nearly nine times from 330 in 2000 to 2899 in 2014. There were 31 references cited per article on an average in 2000; this increased to 48 references per article in 2014. The average number of authors per article rose from 3.03 to 4.76. Besides, the average number of articles published per journal rose steadily from 2.01 in 2000 to 3.96 in 2014. However, the average length of articles did not change during the entire study period.

Table 2. Top 20 most productive countries/territories with respect to articles published during 2000–2014

Country/territory	2000–2014 TA	2000–2014 (%)	2000–2004 R (%)	2005–2009 R (%)	2010–2014 R (%)	Change
USA	5974	31.70	1 (35.90)	1 (30.44)	1 (31.44)	– –
UK	2289	12.15	2 (12.98)	2 (12.11)	2 (12.01)	
Canada	1728	9.17	3 (10.64)	3 (11.16)	5 (8.08)	–
Germany	1720	9.13	4 (9.31)	4 (9.05)	4 (9.12)	
China	1692	8.98	8 (4.17)	5 (6.04)	3 (11.07)	+++
Australia	1289	6.84	6 (5.18)	6 (5.82)	6 (7.57)	+
France	958	5.08	7 (5.14)	9 (5.42)	7 (4.93)	
Japan	914	4.85	5 (5.91)	8 (5.49)	9 (4.39)	–
The Netherlands	868	4.61	9 (3.62)	7 (5.51)	8 (4.42)	
Italy	732	3.88	15 (2.20)	10 (3.67)	10 (4.28)	+
Sweden	572	3.04	10 (3.26)	12 (2.64)	12 (3.16)	
Switzerland	571	3.03	14 (2.25)	11 (3.65)	13 (2.92)	
Spain	517	2.74	19 (1.05)	14 (2.23)	11 (3.27)	+
India	471	2.50	13 (2.38)	13 (2.47)	15 (2.53)	
Denmark	450	2.39	12 (2.43)	15 (2.10)	17 (2.50)	
Brazil	432	2.29	16 (2.15)	17 (1.81)	16 (2.51)	
Norway	398	2.11	18 (1.15)	16 (1.98)	18 (2.34)	+
South Korea	385	2.04	20 (1.01)	20 (1.13)	14 (2.61)	+
Finland	384	2.04	11 (2.66)	19 (1.69)	19 (2.07)	
Austria	346	1.84	17 (1.70)	18 (1.75)	20 (1.90)	

TA, Total number of articles from 2000 to 2014; R(%), Rank and percentage of articles from different countries/territories per five years and (+,++,+++) increasing trend and (–,– –,– – –) decreasing trend.

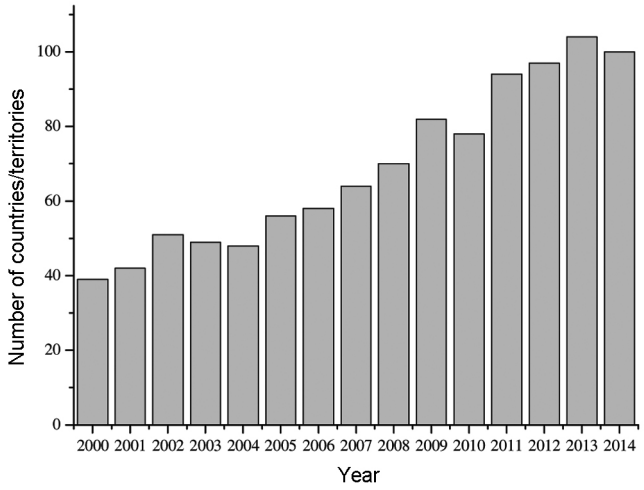

Figure 2. Number of countries/territories participating in greenhouse gas research in 2000–2014.

Figure 1 shows the changing trends in the number of published articles each year from 2000 to 2014. It can be seen that the number of articles has increased steadily from 2000 to 2007, while a sharp increase occurred after 2007.

Publication distribution from countries/territories

There are 144 articles without any address information related to the authors in WoS and 18,703 articles are from 153 countries/territories. The number of countries/territories participating in GHG research is shown Figure 2, indicating notable increasing trend during 2000–2014. Such increasing trends indicate that GHG research has received attention from several countries/territories.

Table 2 lists the top 20 countries/territories with respect to the number of articles published from 2000 to 2014. The seven most developed industrialized countries (G7), i.e. USA, UK, Canada, Germany, France, Japan and Italy are in the top 10. In the three different 5-year periods, USA and UK published the most number of articles; they are always in a leading position. The percentage of articles from Canada decreased slightly during the period from 2000 to 2014. However, for Italy and Spain, the percentage of articles in the last 15 years showed a steady growth trend. In many fields of scientific research, G7 countries are in the dominant position in the publication of articles[22], reflecting correlations of economic development and academic levels of these countries[23]. In addition, three of BRIC countries, i.e. China, India and Brazil are in the top 20 and show notable growth. Especially for China, the number of articles showed a rapid growth trend among BRIC countries, while Russia was ranked the 22th place during 2000–2014. With regard to the total number of SCI articles, China was ranked third place in the third five-year period from 2010 to 2014, and fifth place during the entire period from 2000 to 2014. This may be attributed to the rapid development of science and technology and rapid growth in the economy over the past few decades[11,24,25].

Distribution of articles in subject categories and journals

There are about 100 subject categories related to the study of GHGs in the *Journal Citation Reports* (*JCR*) of the ISI. Table 3 lists the top 20 subject categories

Table 3. Top 20 subject categories with the most articles during 2000–2014

Subject category	2000–2014 TA	2000–2014 (%)	2000–2004 R (%)	2005–2009 R (%)	2010–2014 R (%)	2000–2014 Change
Environmental sciences and ecology	7059	37.45	1 (31.64)	1 (37.18)	1 (38.64)	+++
Engineering	4089	21.70	3 (16.41)	2 (19.30)	2 (23.65)	+++
Energy and fuels	3483	18.48	4 (13.34)	3 (18.75)	3 (19.32)	++
Meteorology and atmospheric sciences	3065	16.26	2 (25.22)	4 (17.03)	5 (14.29)	– – –
Agriculture	2764	14.67	6 (10.18)	5 (14.68)	4 (15.49)	++
Geology	1563	8.29	5 (11.83)	6 (9.12)	6 (7.30)	– –
Chemistry	811	4.30	8 (4.45)	7 (4.74)	7 (4.10)	
Science and technology – other topics	794	4.21	7 (5.14)	8 (4.37)	9 (3.98)	–
Biotechnology and applied microbiology	643	3.41	13 (1.88)	9 (2.70)	8 (3.99)	+
Water resources	596	3.16	9 (3.35)	11 (2.54)	10 (3.39)	
Thermodynamics	574	3.05	10 (3.12)	10 (2.70)	11 (3.17)	
Forestry	383	2.03	16 (1.51)	13 (2.12)	12 (2.09)	
Physics	371	1.97	11 (2.93)	14 (2.04)	15 (1.76)	–
Business and economics	362	1.92	12 (1.97)	12 (2.43)	16 (1.70)	
Materials science	316	1.68	18 (1.24)	16 (1.55)	14 (1.81)	
Transportation	310	1.65	17 (1.33)	19 (0.97)	13 (1.98)	
Biodiversity and conservation	270	1.43	14 (1.56)	17 (1.46)	18 (1.40)	–
Construction and building technology	242	1.28	20 (0.78)	20 (0.72)	17 (1.61)	
Plant sciences	237	1.26	15 (1.56)	18 (1.24)	19 (1.21)	– –
Electrochemistry	234	1.24	19 (0.83)	15 (1.67)	20 (1.14)	

TA, Total number of articles from 2000 to 2014; R (%) Rank and percentage of articles published in different subject categories per five years; (+,++,+++) increasing trend and (–,– –,– – –) decreasing trend.

Table 4. Top 20 journals with the most articles during 2000–2014

Journals	TA
Energy Policy	801
Environmental Science and Technology	422
Geophysical Research Letters	416
Climatic Change	404
Journal of Climate	355
Journal of Geophysical Research – Atmospheres	320
Energy	317
Journal of Cleaner Production	289
Agriculture Ecosystems and Environment	260
Applied Energy	237
Atmospheric Environment	232
Climate dynamics	232
Environmental Research Letters	220
Biomass and Bioenergy	213
Proceedings of the National Academy of Sciences of the United States of America	192
Atmospheric Chemistry and Physics	182
Global Change Biology	176
International Journal of Life Cycle Assessment	162
Science of the Total Environment	152
Ecological Economics	147

publishing the most number of articles. The number and percentage of articles of three periods (every five years from 2000 to 2014) are also shown in the table, environmental sciences and ecology (37.45%), engineering (21.70%), energy and fuels (18.48%), meteorology and atmospheric sciences (16.26%) and agriculture (14.67%) are the five most popular subject categories. Environmental sciences and ecology has been the most important topic for the past 15 years. The subject categories of engineering, energy and fuels and agriculture show the most rapid growth rate. The growth trends indicate that a large amount of energy and fuels was used in the modern industry, resulting in the increase of GHG emissions[26,27]. Stability and distribution of world food production are under the influence of GHG emissions[28]. So the subject category of agriculture received more attention during the entire period. Agricultural soils are also the main source of GHG emission[29–31]. It is estimated that each year, 5–20% of CO_2, 15–30% of CH_4 and 80–90% of N_2O in the air are emitted from soils[32]. The percentage of articles for biotechnology and applied microbiology increased from 1.88 to 3.99, indicating that biotechnology and microbiology are widely used in energy and fuels for bioenergy research and development[33,34]. Besides, biotechnology and applied microbiology has been a hot research topic during the study period. However, significant decrease in percentage was observed for the following categories: meteorology and atmospheric sciences, geology, and construction and building technology.

In the past 15 years, 18,847 articles were published in 1919 different journals. Table 4 lists the top 20 journals publishing the most number of articles. There are seven different journals which published more than 300 articles on GHG research in 15 years. *Energy Policy*, *Environmental Science and Technology*, *Geophysical Research Letters*, *Climatic Change* and *Journal of Climate* published most number of articles in these 15 years. Among them, *Energy Policy* published the most articles (801; Table 4). These observations indicate that countries around the world pay more and more attention to low-carbon energy policy, energy consumption, energy

Table 5. Top 30 highest frequency of title words during 2000–2014

Title words	2000–2014 TA	2000–2014 (%)	2000–2004 R (%)	2005–2009 R (%)	2010–2014 R (%)	2000–2014 Change
Emission	4255	23.20	2 (8.20)	1 (11.35)	1 (17.19)	+++
Gas	3549	19.35	3 (7.77)	2 (9.93)	2 (13.82)	++
Greenhouse	2951	16.09	5 (6.60)	4 (8.06)	3 (11.52)	++
Climate	2680	14.61	1 (9.54)	3 (8.53)	6 (8.66)	–
Impact	2624	14.30	6 (5.46)	6 (6.78)	4 (10.65)	++
Carbon	2493	13.59	8 (4.23)	7 (6.68)	5 (10.01)	++
Change	2210	12.05	4 (7.77)	5 (7.19)	8 (7.11)	
Energy	1840	10.03	13 (3.04)	8 (5.19)	7 (7.50)	+
Model	1688	9.20	7 (4.37)	9 (5.16)	9 (6.25)	
CH_4	1541	8.40	10 (3.44)	10 (4.46)	11 (5.80)	+
CO_2	1445	7.88	11 (3.18)	12 (3.85)	12 (5.63)	
Soil	1435	7.82	12 (3.06)	11 (4.11)	13 (5.60)	+
System	1379	7.52	19 (1.79)	13 (3.44)	10 (5.97)	+
Cycle	1121	6.11	28 (0.97)	19 (2.05)	15 (4.21)	++
Assessment	1069	5.83	22 (1.33)	16 (2.39)	14 (4.79)	+
Global	1048	5.71	9 (3.73)	14 (3.25)	17 (3.47)	
Environmental	956	5.21	14 (2.15)	15 (3.04)	16 (4.21)	
Potential	816	4.45	17 (1.87)	17 (2.28)	19 (3.18)	+
Oxide	749	4.08	16 (1.89)	22 (1.86)	20 (2.98)	
Life	732	3.99	30 (0.58)	28 (1.33)	18 (3.46)	+
Forest	670	3.65	18 (1.85)	23 (1.83)	21 (2.43)	
Warming	637	3.47	15 (1.97)	21 (1.94)	25 (2.18)	
Fuel	622	3.39	23 (1.29)	18 (2.06)	26 (2.16)	
Dioxide	591	3.22	26 (1.09)	20 (1.96)	24 (2.20)	
Management	560	3.05	25 (1.13)	27 (1.49)	23 (2.21)	
N_2O	532	2.90	24 (1.19)	26 (1.54)	27 (2.07)	
Temperature	521	2.84	20 (1.41)	24 (1.66)	28 (1.84)	
Water	514	2.80	29 (0.83)	30 (1.18)	22 (2.23)	
Waste	448	2.44	27 (0.99)	29 (1.29)	30 (1.72)	
Nitrous	112	0.61	21 (1.41)	25 (1.66)	29 (1.84)	

TA total number of title words from 2000 to 2014, R (%) the rank and percentage of title words per five years; (+,++,+++) Increasing trend; (–,– –,– – –) decreasing trend.

exploitation and sustainable development of the ecological environment[35,36].

Analysis of title words

The titles of articles contain key information that the authors wish to express. Therefore, every word in the title can be used to analyse the development trends of GHG research. Title words like, 'the', 'a', 'and', 'analysis', 'study' etc. are not used for analysis. The name of countries/territories in the titles of articles is also not used for analysis. Table 5 shows the top 30 highest frequency of title words used, their percentage of the total number and rank. In addition, title words with similar meaning, e.g. 'emission' and 'emissions', 'gas' and 'gases', are grouped into 'emission' and 'gas' respectively. Except the following two words 'greenhouse' and 'gas', 'emission', 'climate', 'impact', 'carbon' and 'change' showed the highest frequency in article titles during the 15-year study period, indicating that research on climate change and carbon emission has been the hot topic in recent years. The words 'emission', 'gas', 'greenhouse', 'climate' and 'impact' were in the top position during the entire study period; most of them increased rapidly, except for 'climate' which decreased slightly. Two words, 'carbon' and 'energy' in the top 10 also showed a large increase, which reflects that more fossil energy consumption resulted in an increase in carbon emissions and the greenhouse effect has been more obvious in the past 15 years. CH_4, CO_2 and N_2O also appear in the top 30 highest frequency of title words, because the three gases contribute up to 80% of the greenhouse effect[37]. The word 'soil' is also ranked among the top 30. As mentioned before, soil is one of the sources of GHGs. 'Life', 'cycle' and 'assessment' can be grouped into 'life cycle assessment (LCA)', and the three words are ranked in the top 30; at the same time, rapid growth occurred in them. LCA is an environmental assessment tool, which attracts concern on GHG[38,39].

Analysis of author keywords and keywords plus

As keywords in the articles present effective and valuable information, they can be used to analyse research trends. The method of analysing keywords is effective to evaluate and predict the development of research topics[11].

Table 6. Top 30 highest frequency of author keywords used during 2000–2014

Author keywords	2000–2014 TA	2000–2014 (%)	2000–2004 R (%)	2005–2009 R (%)	2010–2014 R (%)	2000–2014 Change
Greenhouse gas	2179	8.20	1 (6.96)	1 (6.97)	1 (6.50)	
Climate change	1418	5.34	2 (5.64)	2 (4.66)	3 (4.12)	– –
Greenhouse gas emission	1174	4.42	6 (1.88)	4 (3.06)	2 (4.40)	++
Methane	969	3.65	4 (2.83)	3 (3.11)	5 (3.10)	
Life cycle assessment	919	3.46	12 (0.73)	7 (1.67)	4 (3.41)	++
Nitrous oxide	891	3.35	3 (3.06)	6 (2.85)	6 (2.79)	–
Carbon dioxide	790	2.97	5 (2.78)	5 (3.00)	7 (2.26)	–
Global warming	381	1.43	7 (1.43)	8 (1.50)	11 (1.05)	
Carbon sequestration	335	1.26	8 (0.98)	9 (1.16)	9 (1.06)	+
Biofuels	318	1.20	28 (0.08)	11 (0.86)	8 (1.26)	++
Sustainability	265	1.00	22 (0.22)	26 (0.42)	12 (1.00)	
Biomass	253	0.95	14 (0.51)	10 (0.87)	13 (0.88)	
Energy	247	0.93	16 (0.48)	13 (0.81)	14 (0.83)	
Renewable energy	224	0.84	13 (0.59)	16 (0.71)	18 (0.73)	
Carbon footprint	207	0.78	30 (0.00)	30 (0.15)	10 (1.06)	++
Bioenergy	205	0.77	21 (0.25)	23 (0.54)	17 (0.78)	
Energy efficiency	191	0.72	23 (0.22)	17 (0.68)	20 (0.65)	
Denitrification	186	0.70	11 (0.81)	22 (0.55)	23 (0.57)	
Agriculture	183	0.69	18 (0.42)	20 (0.59)	21 (0.62)	
Environmental impact	183	0.69	19 (0.28)	21 (0.56)	19 (0.67)	
Emissions	169	0.64	10 (0.90)	12 (0.82)	15 (0.82)	
Mitigation	169	0.64	24 (0.22)	25 (0.49)	22 (0.61)	
Global warming potential	165	0.62	25 (0.22)	18 (0.61)	16 (0.79)	
Carbon	152	0.57	15 (0.51)	24 (0.50)	24 (0.53)	
Environment	130	0.49	17 (0.45)	19 (0.60)	28 (0.34)	
Kyoto Protocol	130	0.49	9 (0.95)	15 (0.76)	30 (0.17)	–
Biodiesel	130	0.49	29 (0.03)	28 (0.35)	25 (0.52)	+
Ammonia	124	0.47	20 (0.28)	27 (0.39)	27 (0.45)	
Hydrogen	122	0.46	26 (0.20)	14 (0.77)	29 (0.28)	
Biogas	121	0.46	27 (0.20)	29 (0.29)	26 (0.47)	

TA, Total number of author keywords from 2000 to 2014; R (%), Rank and percentage of author keywords per five years; (+,++,+++) Increasing trend and (–,– –,– – –) decreasing trend.

According to statistics, 26,577 different author keywords have been used from 2000 to 2014. Among them, 75.72% (20,123) was used only once; this reflects a lack of continuity in the study and also the research focus is different[40]. Table 6 lists the highest frequency of top 30 author keywords used in the 15 years of study.

Except for the word 'greenhouse gas', the two most frequently used keywords are 'climate change' and 'greenhouse gas emission'; these two words are closely related. Methane (CH_4) and nitrous oxide (N_2O) are two important GHGs and put great pressure on greenhouse effects. Methane accounts for 15% of the greenhouse effect[32], it ranks fourth in Table 6. Nitrous oxide contributes up to 5% of the greenhouse effect; it ranks sixth in Table 6. Greenhouse potential of methane is 21–23 times that of carbon dioxide[32] and the greenhouse potential of nitrous oxide is 296–300 times that of carbon dioxide[41]. As mentioned before, carbon dioxide is the most important GHG, it is ranked seventh in the top 30 highest frequency of author keywords during the entire study period. The keywords 'life cycle assessment' had the most significant growth from 0.73 in 2000–2004 to 3.41 in 2010–2014. LCA is one of the most widely used products and systems[42], which aims to improve the environmental protection and can be used in different areas related to environmental protection. The author keywords 'carbon sequestration' is ranked ninth in Table 6. Carbon sequestration is a technology to reduce carbon in the atmosphere; it includes the process of carbon capture separation of carbon dioxide from the atmosphere, and long-term safe storage[43]. The development of the technology of carbon sequestration indicates that more new methods are being used to reduce GHG emission. Many keywords related to energy are mentioned, such as 'biofuels', 'biomass', 'bioenergy', 'biodiesel' and 'biogas'; this indicates that more biotechnologies are used in the study of new energy. The research of new energy contributes to reduce the dependence on fossil energy, and reduce the pressure on the environment.

Keywords plus is a supplement for the title words and the author keywords, and it can also reflect information that the author wishes to express[44]. Table 7 lists the highest frequency of top 30 keywords plus used in the 15 years of study. An analysis of keywords plus, reveals similar words between author keywords and keywords plus. As with the author keywords, 'green house gases', 'climate change', 'greenhouse gas emission', 'methane', 'life cycle assessment', 'nitrous oxide', 'carbon dioxide',

Table 7. Top 30 highest frequency of keywords plus used during 2000–2014

Keywords plus	2000–2014 TA	2000–2014 (%)	2000–2004 R (%)	2005–2009 R (%)	2010–2014 R (%)	2000–2014 Change
Carbon dioxide	1739	8.32	1 (6.53)	1 (5.61)	2 (6.13)	
Model	1511	7.22	2 (5.40)	2 (5.32)	4 (5.38)	
Greenhouse gas emissions	1424	6.81	19 (1.24)	8 (2.92)	1 (6.92)	+++
Emissions	1367	6.54	7 (2.98)	3 (4.01)	3 (5.68)	+
Climate change	1193	5.70	5 (3.14)	5 (3.41)	6 (4.90)	
Systems	1120	5.36	21 (1.15)	6 (3.10)	5 (5.02)	++
Greenhouse gases	1116	5.34	4 (3.25)	4 (3.82)	12 (3.58)	
Nitrous oxide emissions	1018	4.87	17 (1.50)	12 (2.69)	7 (4.39)	++
Impact	921	4.40	14 (1.91)	15 (2.55)	10 (3.92)	+
Nitrous oxide	904	4.32	11 (2.28)	9 (2.84)	11 (3.67)	
Energy	884	4.23	24 (0.91)	16 (2.10)	9 (4.13)	++
Temperature	858	4.10	3 (3.44)	7 (3.01)	16 (2.64)	– –
Methane	844	4.04	8 (2.71)	11 (2.74)	13 (3.18)	
Life cycle assessment	799	3.82	30 (0.11)	27 (1.07)	8 (4.28)	++
Soil	736	3.52	12 (2.09)	14 (2.65)	15 (2.72)	
Management	706	3.38	23 (0.94)	18 (1.99)	14 (3.10)	+
Variability	675	3.23	6 (3.11)	10 (2.79)	20 (2.05)	–
Simulation	669	3.20	9 (2.50)	13 (2.67)	19 (2.21)	
Carbon	597	2.85	16 (1.64)	19 (1.99)	17 (2.29)	
Climate	556	2.66	13 (2.09)	17 (2.08)	23 (1.82)	
Fluxes	534	2.55	15 (1.80)	21 (1.83)	22 (1.95)	
Methane emissions	524	2.51	25 (0.91)	23 (1.47)	18 (2.26)	
Biomass	479	2.29	26 (0.70)	25 (1.43)	21 (2.05)	+
Trends	471	2.25	10 (2.42)	20 (1.88)	28 (1.41)	–
Denitrification	455	2.18	18 (1.50)	22 (1.72)	25 (1.59)	
Water	393	1.88	22 (0.97)	24 (1.45)	27 (1.47)	
Dynamics	373	1.78	19 (1.24)	26 (1.27)	30 (1.37)	
Performance	360	1.72	29 (0.13)	30 (0.68)	24 (1.80)	
Agriculture	346	1.65	28 (0.43)	29 (0.96)	26 (1.53)	
Land use	330	1.58	27 (0.48)	28 (1.00)	29 (1.38)	

TA, Total number of keywords plus from 2000 to 2014; R (%), Rank and percentage of keywords plus per five years; (+,++,+++) increasing trend and (–,– –,– – –) decreasing trend.

'energy', 'denitrification', 'agriculture', 'emissions', 'carbon' and 'biomass' also appears in the top 30 frequently used keywords plus. The growth rate of keywords plus 'Greenhouse gas emission' is fastest (Table 7).

Conclusion

In this study, information has been obtained about the trends of GHG research during the period from 2000 to 2014. The number of published articles and participating countries/territories in this research have increased rapidly in these 15 years. There are 18,847 articles published in 1919 journals involving 100 SCI subject categories. Research in the fields of GHG is concentration in the fields of environmental sciences and ecology, engineering, energy and fuels and agriculture. Meanwhile, more attention was paid to biotechnology and applied microbiology in the last 15 years. The journal *Energy Policy* published the most number of articles.

The G7 countries played a predominant role in GHG research and published the most number of articles. However, their growth rate was slower than BRIC countries in last 15 years and their contribution decreased slightly per five-year period. On the contrary, the growth rate of BRIC countries was fast and their contribution increased slightly. It can be concluded that developing countries paid more attention to GHG research. Greenhouse effect has become a common concern for both developing and developed countries.

Title words like 'emission', 'climate', 'impact', 'carbon' and 'change' were the five most frequently used in the 15 years period, which indicates that on climate change and carbon emission are hot topics in GHG research. The analysis of author keywords and keywords plus shows that 'greenhouse gas emission' is one of the most frequently words used through the 15 years period. 'Carbon sequestration' and 'biotechnologies' are recent major topics of reducing carbon emission. Thus this study may help in the field of greenhouse gas research to understand the development state of global greenhouse gas research, and make an accurate predict for greenhouse gas research.

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