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ORIGINAL PAPER

Scholarly output of energy and fuels research in Saudi Arabia during 1972–2020: a bibliometric analysis

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Abstract

This study explored the dynamics and patterns of the energy and fuels research published by authors affiliated with Saudi Arabian institutions. The bibliometric method has been used to carry out this research, and the Web of Science (WoS) Core Collection was selected for data retrieval. Records of publications related to the energy and fuels domain, published between 1972 and 2020 by authors affiliated with Saudi Arabia, were analyzed. The results of the study revealed that there has been a dramatic increase in the number of publications during the last decade. This is consistent with the recent initiatives undertaken by KSA to promote scientific research in the Kingdom, especially in the energy sector. King Fahd University of Petroleum and Minerals, King Abdullah University of Science and Technology, and King Abdulaziz University have been the top three contributors. The energy and fuels' researchers in KSA have collaborated with scientists from all over the world. Multi-authored journal articles have been the most frequent form of publication. Out of the top ten preferred journals, nine were under the Q1 and Q2 category, and one was under Q3. The findings of this study would help decide the future direction of research in energy and fuels and aid the institutions in delivering their expected output. Even though research in this domain has been progressing at a dramatic rate, it still needs further attention. As per the authors' best knowledge, this is the first study that presents the landscape of energy and fuels research in Saudi Arabia.

Keywords Energy · Research · Bibliometric study · Saudi Arabia · Fuels

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Introduction

The generation of usable energy from the primary sources, its rapidly growing consumption by various sectors, and the associated environmental impacts are major concerns of any nation. The Kingdom of Saudi Arabia (KSA) is the largest and the richest country in the Middle East and is of the world's largest consumers of energy. The discovery of huge oil reserves in the Kingdom's Eastern Province in 1938 transformed KSA into a leading oil producer and exporter in 1939. More than 60% of its national budget, 75% of export revenues, and 40% of its gross domestic product (GDP) are supplied by oil exports (Krane 2019). However, the Kingdom's domestic energy economy has attracted little attention to date, even though many researchers have provided detailed insights into the energy consumption and generation patterns in KSA, the scope of energy conservation in its various sectors, and the great potential of exploiting renewable energy resources (Abdul Mujeebu & Alshamrani 2016; Alkhathlan & Javid 2013; Alshahrani & Boait 2019; Alshehry & Belloumi 2015;

Alsuhaibani & Hepbasli 2013; Eltamaly 2013; Krane 2019; Krarti et al. 2017; Matar et al. 2017; Salam & Khan 2018).

The installed capacity of KSA has increased to 82 GW in 2018 from 60 GW in 2010 (Ansari 2018). The electricity consumption of the Kingdom is expected to more than double by 2025 (Salam & Khan 2018). Therefore, KSA has undertaken many initiatives to shift its dependency from oil to renewable and nuclear energy sources to meet a significant part of the total energy demand from alternate sources in the future. There is a plan in place to install a 41 GW solar-electric plant in the Kingdom and invest $108.9 billion by 2032 (Salam & Khan 2018). To achieve energy efficiency in all its sectors, KSA initiated the National Energy Efficiency Program (NEEP) in 2003, which was later established as the Saudi Energy Efficiency Center (SEEC) in 2010 (Fattouh & El-Katiri 2014). In the same year, the King Abdullah City for Atomic and Renewable Energy (KACARE) was also established to promote renewable and atomic energy technologies in the Kingdom, with a target capacity of 54 GW by 2032 (Hauff et al. 2015). Moreover, in line with its Vision 2030, KSA is committed to reducing its carbon emissions by 130 million tons by 2030 by adopting energy efficiency and renewable energy technologies. A recent review (Amran et al. 2020) has outlined the current scenario and prospects of renewable and sustainable energy production in KSA.

The subsidization of energy in KSA has led to extensive overuse and misallocation of the oil and natural gas resources and a remarkable level of demotivation towards saving energy by the end-users (Alshehry & Belloumi 2015). In addition, the large fuel subsidies have contributed to a 7% increase in energy consumption annually (Alshahrani & Boait 2019; US Energy Information Administration 2017) and hindered the implementation of more efficient power generation and industrial technologies. Ansari (2018) reported that the growth in energy demand could be attributed to many factors such as an increase in living standards, population, urbanization, strong economic growth, and subsidies. Regarding the environmental impact, KSA has experienced a drastic increase in carbon emissions in recent years as a result of its increased use of fossil fuels (Alshehry & Belloumi 2015). The steps taken to protect the environment by preserving energy resources have important implications for the sustainable development of the Kingdom. However, the level of development of sustainable energy investments is still low (Abdul Mujeebu & Alshamrani 2016).

In the recent past, a lot of researchers have focused on the diverse facets of energy and the related environmental issues in the Saudi Arabian context, as evident from the growth in the number of publications in the domain. While most of these researches have been reported from Saudi Arabian universities, a remarkable number of works were from outside the KSA, mostly by Saudi Arabian authors doing research in various international universities (Akash et al. 2016). Kumar and Jain (2014) reviewed the research collaborations on energy and fuels in the OIC (organization of Islamic countries) nations and compared the scenarios with Malaysia and Turkey. Akash et al. (2016) reviewed the progress of solar energy research in the Gulf Cooperation Council (GCC) using the Scopus database and found that KSA had the highest research output (above 60%), followed by the United Arab Emirates (about 17%), and the rest of the GCC states. Likewise, there were few articles covering the research productivity of the Arab world, on specific domains such as groundwater (Zyoud et al. 2015), and general areas such as science and technology (Sarwar & Hassan 2015). However, an exclusive bibliometric analysis of the scholarly output of energy and fuels research in KSA is still lacking. By considering the ever-growing significance of the topic, particularly in the context of the Saudi Vision 2030, and the remarkable amount of literature available, such a study would certainly help institutions and policymakers understand the trends and help them plan for future research in this domain. Accordingly, the present study has focused on the trend and productivity of research on energy and fuels, based on the published articles affiliated to KSA published from 1972 to 2020 in the WoS indexed journals. This study will provide insights into the growth of research productivity, global ranking, most productive institutes and researchers, authorship patterns, international collaborations, and topic-wise focus of publications in this domain. The following research questions were formulated for the study:

1. What has been the publishing trend and global position of KSA in energy and fuels research during the 1972–2020 period?
2. What are the preferred journals and document types of energy and fuels researchers in KSA?
3. What are the most productive authors and institutes in energy and fuels research in KSA?
4. What are authorship and collaborative research patterns of energy and fuels researchers in KSA?
5. What are the most frequent and the major keywords used in energy and fuels research in KSA?

Methodology

The present study has relied on the Web of Science (WoS) database for data collection. The WoS is the most renowned database that indexes the relevant and authoritative research journals (Davarazar et al. 2019; Olawumi & Chan 2018).

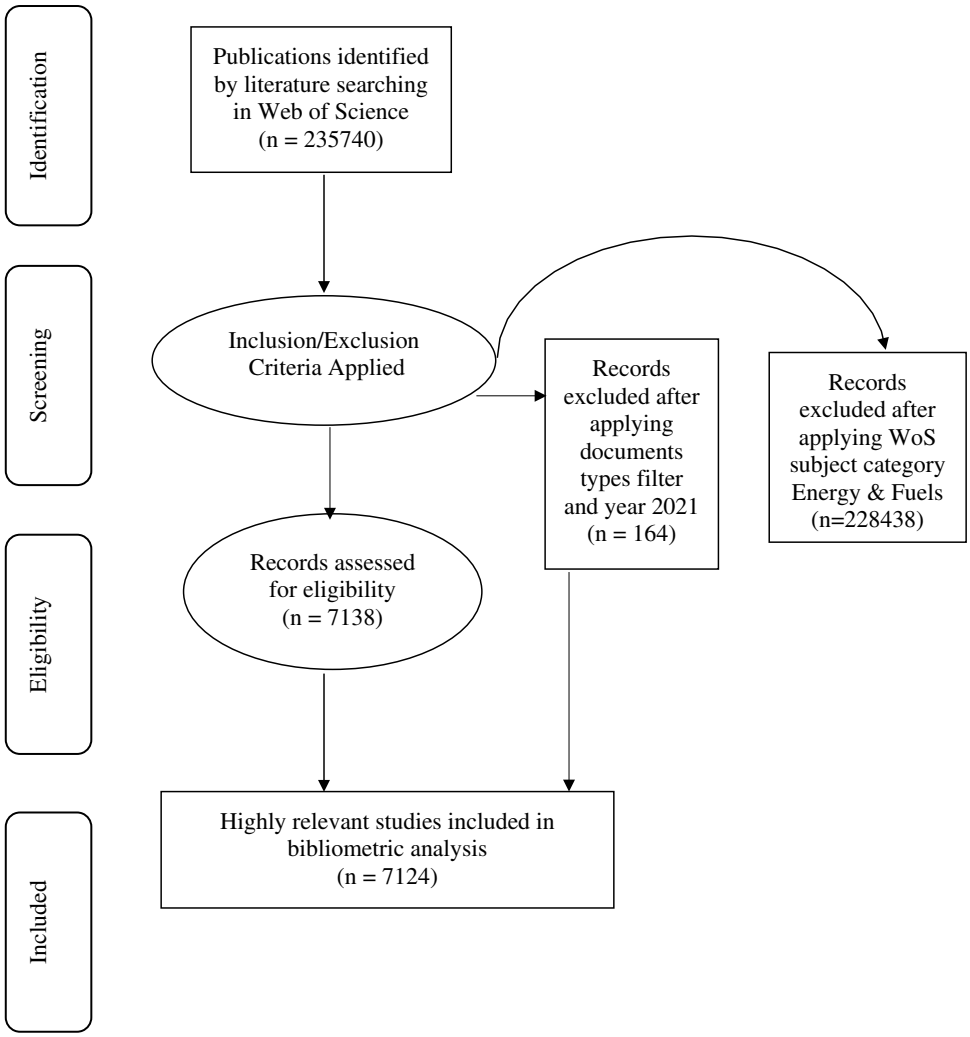

Fig. 1 Four phase flow chart of data extraction and filtration process

Figure 1 illustrates the data extraction and filtration process used in this study. The data was retrieved from the WoS core collection on January 5, 2021. The search was conducted by using the keyword "Saudi Arabia" in the 'affiliation country' field in the advanced search interface, which initially retrieved 235,740 results. The results were refined by the WoS subject category "energy & fuels," resulting in a total record of 7302 items. The year 2021 was excluded, and search results were further refined by research articles, review papers, and conference papers. This resulted in a total of 7138 documents. Fourteen duplicate records were also removed. Eventually, 7124 items were finalized. All publications published during the 1972–2020 period with at least one author affiliated with KSA were considered in this study. Microsoft Access, Excel, and Biblioshiny (Aria & Cuccurullo 2017), were used for data visualization and analysis. The inconsistencies found in the names of affiliated organizations and authors were rectified by unifying them to ensure the accuracy and reliability of the data and the results.

Search query

CU = ("Saudi Arabia*")

Refined By: WEB OF SCIENCE CATEGORIES: (ENERGY FUELS) AND [excluding]: PUBLICATION YEARS: (2021) AND [excluding]: DOCUMENT TYPES: (EDITORIAL MATERIAL OR RETRACTION OR DISCUSSION OR CORRECTION OR RETRACTED PUBLICATION OR NOTE OR MEETING ABSTRACT OR NEWS ITEM OR LETTER)

Results

General overview of results

The current study analyzed 7124 documents, with 14,981 author keywords, published between 1972 and 2020 in the energy and

fuels category. The results revealed that there were 13,724 total contributing authors. Seven hundred thirty-three documents were single-authored, and 6390 documents were multi-authored. The average number of citations per document was 20.97. The document per author was almost 52%, and the collaboration index was 2.08 indicating the high number of collaborations in the energy and fuels literature. The key findings according to the research questions are presented in the following sections.

Publishing trend and global ranking of energy and fuels research in KSA

Figure 2 depicts the chronological distribution of the research contribution from KSA in the energy and fuels category. It can be seen that the first research contribution by authors affiliated with KSA was indexed in the WoS in 1972. The first 2 years (1972 and 1973) were the least productive, with only a total of two research publications. There was also an almost linear trend in the publication growth rate during the first 20 years (1972 to 1991), followed by a progressively increasing trend between 2009 and 2020. The most productive year was 2020, with 983 (13.80%) research publications. More than half of the energy and fuels research emerging from Saudi Arabia was produced during the last 5 years (2016–2020) of the research period, with a total of 4067 (57%) research publications published between 2016 and 2020. As presented in Table 1 and Fig. 3, the increasing trend of publications in the last decade was also reflected in the global ranking of KSA. The Kingdom was ranked 27th in 2011 and 17th in 2020.

Top twenty preferred sources of publications in energy and fuels

Table 2 displays the twenty most preferred journals by the energy and fuels researchers of Saudi Arabia. These journals published 58% ($n=4172$) of the energy and fuels research emerging from the country. The International Journal of Hydrogen Energy was the most preferred journal publishing 358 publications over the study period. The Journal of Materials Chemistry attracted the highest citations ($n=14{,}263$) with a citation impact of 48.68 and an h-index of 63. The Renewable and Sustainable Energy Reviews had the best citation impact of 59.75 with a 12.11 impact factor. It is worth noting that all of these top 20 journals are indexed in the WoS with impact factor, and they are based in Europe and the USA.

Document type

As presented in Table 3, the original research article was the most preferred document type, with a total of 5657 items (79.41%) published as such, garnering 112,539 citations with a citation impact of 19.89. Proceeding papers amounted to 997 publications (13.99%) receiving 6330 citations with a citation impact of 6.35, while there were 469 (6.54%) review articles with 30,216 citations and a citation impact of 64.43.

Most prolific Saudi Researchers in energy and fuels discipline

Table 4 illustrates the ten most productive authors in energy and fuels research in Saudi Arabia and their affiliations. Cumulatively, the most contributing authors were affiliated with King Fahad University of Petroleum and Minerals (KFUPM), which is a teaching and research university in the Eastern region of the Kingdom. Sarathy from King Abdullah University of Science and Technology (KAUST) was the most prolific author from the Kingdom with the highest number of publications ($n=137$), followed by Habib from KFUPM. The highest citation impact of 66.27 was observed

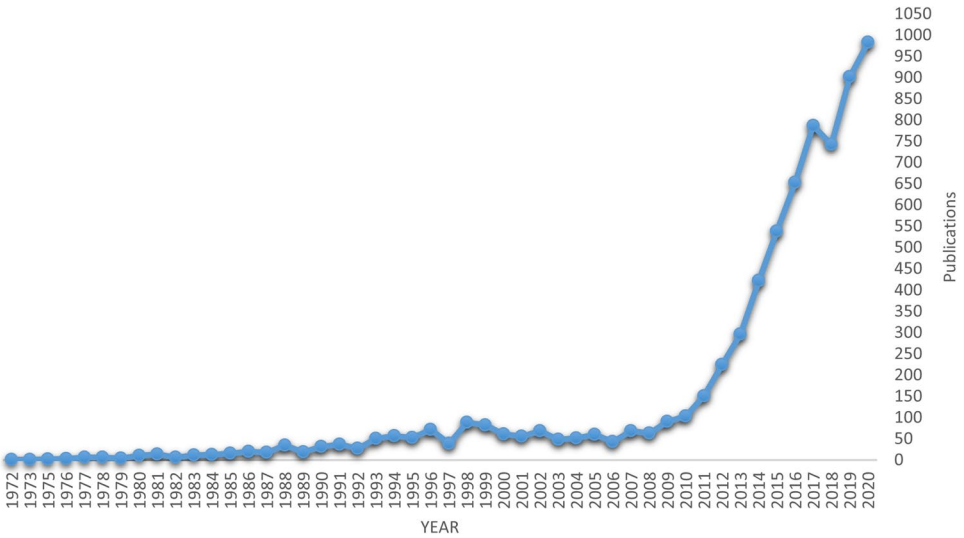

Fig. 2 Chronological distribution of publications on energy and fuels research in KSA during 1972–2020

Table 1 Global position of KSA in energy and fuels research publications

Country	Total number of publications									
	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020
China	6043	9616	12,153	12,131	14,911	15,325	19,749	21,781	24,702	22,740
USA	4933	5430	6821	7777	7806	8277	8868	8706	8994	6977
India	931	1360	1848	2626	2518	4905	3705	4513	3587	4155
Germany	1481	1525	1872	2506	2512	2857	3198	3073	3199	2551
England	1107	1071	1673	1833	2126	2391	2893	2793	3058	2749
Japan	1145	1363	2085	1998	1764	1738	2172	2159	1969	1697
Canada	1164	1052	1446	1662	1793	1913	1892	1972	2103	1912
Italy	800	965	1349	1855	2355	1963	2709	2077	2415	1960
France	942	973	1322	1529	1532	1614	1841	1535	1758	1342
South Korea	858	1058	1597	1783	1795	1850	2098	2210	2462	2600
Spain	1010	1042	1406	1700	1754	1904	2055	2022	2089	1765
Australia	757	929	118	1381	1732	1752	2220	2092	2541	2114
Iran	732	725	869	1282	1399	1787	1946	1857	2282	2350
Russia	390	432	422	572	806	1204	1533	1189	1315	1031
Turkey	624	715	625	637	810	900	914	975	980	1254
Brazil	596	440	811	748	1127	965	1276	1041	1450	1185
Taiwan	690	918	1023	1003	769	751	787	768	856	853
Sweden	397	469	656	843	814	869	1043	970	1009	820
Netherlands	458	452	640	722	693	802	837	777	875	752
Malaysia	307	525	799	949	768	874	1132	903	1051	994
Denmark	322	346	518	794	758	856	917	913	990	827
Poland	294	180	288	384	496	641	1077	755	1034	1392
Switzerland	268	298	411	516	573	590	775	665	849	521
Norway	301	387	518	607	516	642	786	575	639	622
Saudi Arabia	154	229	304	426	544	662	798	763	950	1093
Singapore	201	271	445	481	547	590	852	803	765	689
Egypt	159	160	202	302	349	601	694	719	651	748

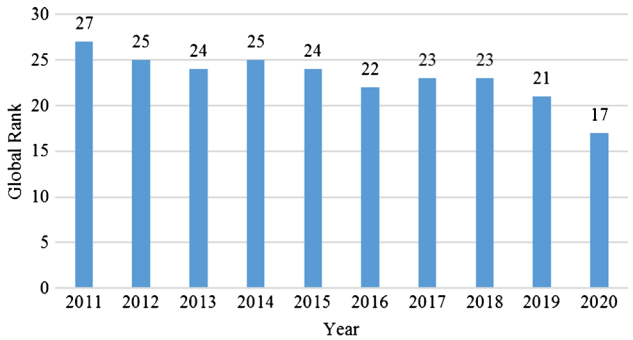

Fig. 3 Global ranking trend of energy and fuels publications in KSA

for Dincer (from KFUM), with 6693 citations from 101 publications.

The most productive Saudi institutions

Table 5 illustrates the ten most productive Saudi institutions in terms of research publications in the field of energy and fuels. King Fahad University of Petroleum and Minerals had the highest number of publications ($n = 1807$) and citations ($n = 36{,}735$), followed by KAUST with 1202 publications and 30,894 citations with an average of 25.70 citations per publication (C/P). King Abdulaziz University (KAU) placed third by producing 936 publications attracting citations with the highest C/P (31.49). Two non-teaching institutes, the Saudi Arabian Oil Company (Saudi ARAMCO) and King Abdulaziz City for Science and Technology (KACST), also made it to the list of the top 10 most productive Saudi institutions with 439 and 172 publications, respectively.

Authorship pattern

Figure 4 shows the authorship pattern and citations of the publications on energy and fuels research in KSA during the study period. Almost 90% of the publications were multi-authored, with three-author collaboration being the most common, followed by two-author ones. Three-author publications received the highest number of citations ($n = 24{,}607$),

Table 2 Top 20 highly productive journals in energy and fuels

Source title	TP	TC	CI	h-index	IF (2019)	Publisher	Quartile rank (2019)
International Journal of Hydrogen Energy	358	6605	18.45	36	4.939	Elsevier	Q2
Energies	328	2105	6.42	22	2.702	MDPI	Q3
Energy Conversion and Management	294	9291	31.60	51	8.208	Elsevier	Q1
Journal of Materials Chemistry A	293	14,263	48.68	63	11.301	Royal Society of Chemistry	Q1
Energy	270	6103	22.60	39	6.082	Elsevier	Q1
Solar Energy	252	5563	22.08	40	4.608	Elsevier	Q2
Energy & Fuels	242	2780	11.49	28	3.421	American Chemical Society	Q2
Journal of Petroleum Science and Engineering	217	2624	12.09	26	3.706	Elsevier	Q2
Renewable & Sustainable Energy Reviews	215	12,847	59.75	61	12.110	Elsevier	Q1
International Journal of Energy Research	212	2859	13.49	25	3.741	Wiley	Q2
Fuel	201	3502	17.42	30	5.578	Elsevier	Q1
Renewable Energy	198	5982	30.21	44	6.274	Elsevier	Q1
Combustion and Flame	186	3828	20.58	33	4.570	Elsevier	Q2
Applied Thermal Engineering	173	4017	23.22	33	4.725	Elsevier	Q2
Applied Energy	164	5550	33.84	42	8.848	Elsevier	Q1
Oil & Gas Journal	139	136	0.98	6	0.055	Pennwell Publishing	Q4
Advanced Energy Materials	130	7855	60.42	46	25.245	Wiley	Q1
Petroleum Science and Technology	116	731	6.30	16	0.976	Taylor & Francis	Q4
Proceedings of The Combustion Institute	95	1460	15.37	21	5.627	Elsevier	Q1
Bioresource Technology	89	3382	38.00	32	7.539	Elsevier	Q1

TP, total number of publications; TC, total citations; CI, citation impact; IF, impact factor

Table 3 Document type

Document type	TP (%)	TC	CI
Article	5657 (79.41)	112,539	19.89
Proceedings Paper	997 (13.99)	6330	6.35
Review article	469 (6.58)	30,216	64.43
Book Chapter	1 (0.01)	33	33.00
Total	7124	149,118	140.83

TP, total publications; TC, total citations; CI, citation impact

while the best citation impact of 41.55 was observed for publications with 13 authors. Furthermore, single-author publications made up 10% of the research with 733 publications.

International collaboration (institutions and countries/regions)

The authors affiliated with Saudi Arabian institutions collaborated around the world for energy and fuels

Table 4 Ten most prolific authors affiliated with KSA

Rank	Authors	Affiliation	TP	TC	CI
1	Sarathy, SM	King Abdullah University of Science & Technology	137	2906	21.21
2	Habib, MA	King Fahd University of Petroleum & Minerals	111	1989	17.92
3	Roberts, WL	King Abdullah University of Science & Technology	104	1388	13.35
4	Dincer, I	King Fahd University of Petroleum & Minerals	101	6693	66.27
5	Chung, SH	King Abdullah University of Science & Technology	99	2062	20.83
6	Rehman, S	King Fahd University of Petroleum & Minerals	97	4620	47.63
7	Zubair, SM	King Fahd University of Petroleum & Minerals	95	2084	21.94
8	Al-Sulaiman, FA	King Fahd University of Petroleum & Minerals	91	2995	32.91
9	Yilbas, BS	King Fahd University of Petroleum & Minerals	85	1720	20.24
10	Mahmoud, M	King Fahd University of Petroleum & Minerals	78	589	7.55

TP, total publications; TC, total citations; CI, citation impact

Table 5 Top ten productive Saudi institutions in energy and fuels

Organizations	Type	Founded in	TP	h-index	TC	C/P	Region
King Fahd University of Petroleum & Minerals (KFUPM)	Teaching	1963	1807	174	36,735	20.33	Eastern
King Abdullah University of Science & Technology (KAUST)	Teaching	2009	1202	164	30,894	25.70	Western
King Abdulaziz University (KAU)	Teaching	1967	936	99	29,470	31.49	Western
King Saud University	Teaching	1957	926	85	20,550	22.19	Central
Saudi Arabian Oil Company (Saudi ARAMCO)	Non-teaching	1933	439	84	4721	10.75	Eastern
King Abdulaziz City for Science & Technology (KACST)	Non-teaching	1977	172	53	2805	16.31	Central
Umm Al Qura University	Teaching	1981	112	30	1529	13.65	Western
King Khalid University	Teaching	1998	102	21	946	9.27	South Western
Prince Sattam Bin Abdulaziz University	Teaching	2009	100	25	1084	10.84	Central
Qassim University	Teaching	2004	99	18	1061	10.72	Central

TP, total publications; TC, total citations; CI, citation impact; C/P, citation per paper

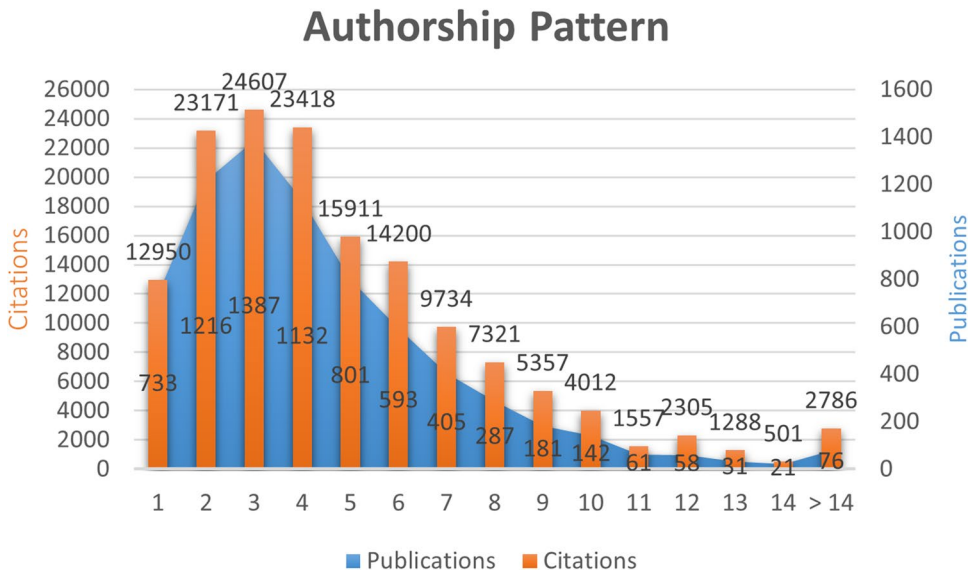

Fig. 4 Authorship pattern of energy and fuels research

Table 6 Top ten international collaborating institutions

Organization	Country	TP	TC	h-index	C/P
University of Malaya	Malaysia	148	4029	36	27.22
Chinese Academy of Sciences	China	144	5685	48	39.48
Minia University	Egypt	76	1299	21	17.09
Universiti Teknologi Malaysia	Malaysia	72	1487	23	20.65
COMSATS University Islamabad	Pakistan	69	1131	33	16.39
Helwan University	Egypt	68	661	17	9.72
University of Ontario Institute of Technology	USA	67	2432	38	36.30
Mansoura University	Egypt	67	1190	18	17.76
Massachusetts Institute of Technology	USA	66	2179	29	33.02
Cairo University	Egypt	64	627	17	9.80
Tanta University	Egypt	64	1743	22	27.23

TP, total publications; TC, total citations; C/P, citation per paper

Table 7 Temporal evaluation of frequently used keywords in Energy & Fuels research in KSA

Rank	Keyword	TP	TC	C/P	Temporal evolution		
					1991–2010	2011–2015	2016–2021
1	Solar energy	173	4463	25.80	12	50	111
2	Renewable energy	141	4842	34.34	15	39	87
3	Efficiency	118	3819	32.36	12	47	59
4	Optimization	118	2498	21.17	15	32	71
5	Energy	115	5235	45.52	41	35	39
6	Exergy	96	4373	45.55	25	37	34
7	Hydrogen	96	1586	16.52	7	26	63
8	Photovoltaic	84	1882	22.40	7	22	55
9	Energy efficiency	76	1475	19.41	9	16	51
10	Biodiesel	73	1734	23.75	1	18	54
11	Wind energy	61	1305	21.39	13	17	31
12	Desalination	58	1656	28.55	5	20	33
13	Hydrogen production	55	2303	41.87	0	24	31
14	Modeling	53	1506	28.42	12	15	26
15	Pyrolysis	53	1212	22.87	8	16	29
16	Smart grid	51	890	17.45	0	10	41
17	Shock tube	49	1306	26.65	0	19	30
18	Simulation	48	772	16.08	5	19	24
19	Adsorption	48	956	19.92	2	21	25
20	Heat transfer	48	1162	24.21	10	13	25
21	Energy storage	44	1051	23.89	5	9	30
22	Exergy analysis	42	998	23.76	11	18	13
23	Performance	42	1061	25.26	10	8	24
24	Thermal energy storage	41	2609	63.63	9	4	28
25	Solar cells	40	1409	35.23	6	11	23
26	Artificial neural network	37	560	15.14	2	7	28
27	Combustion	37	971	26.24	2	14	21
28	PV	37	955	25.81	2	3	32
29	Water splitting	36	1166	32.39	1	4	31
30	Biomass	36	914	25.39	0	14	22
31	Solar	35	843	24.09	2	14	19
32	Entropy generation	34	754	22.18	11	11	12
33	Phase change material	33	1589	48.15	3	4	26
34	Sustainability	32	694	21.69	1	14	17
35	Gasoline	32	1006	31.44	3	9	20
36	Renewable energy sources	32	596	18.63	2	5	25
37	Soot	31	875	28.23	1	13	17
38	CFD	31	367	11.84	3	4	24
39	Diesel	31	979	31.58	3	16	12
40	Solar radiation	30	1713	57.10	9	11	10
41	Air conditioning	30	459	15.30	11	6	13
42	Hydrogen storage	30	319	10.63	1	5	24
43	Wind speed	29	720	24.83	7	12	10
44	Energy consumption	29	776	26.76	2	9	18
45	Methane	29	473	16.31	2	4	23
46	Stability	28	672	24.00	3	4	21
47	Natural gas	28	557	19.89	2	7	19
48	Perovskite solar cells	28	772	27.57	1	2	25
49	Nanofluid	28	783	27.96	3	3	22

Table 7 (continued)

Rank	Keyword	TP	TC	C/P	Temporal evolution		
					1991–2010	2011–2015	2016–2021
50	Wind power	27	498	18.44	5	3	19

TP, total publications; TC, total citations; C/P, citation per paper

research. The ten most collaborative international organizations with their productivity data are listed in Table 6. The most collaborative institution was University of Malaya (Malaysia), followed by Chinese Academy of Sciences (China). The other collaborating institutions in the top 10 list represented Egypt, Pakistan, and USA.

Most frequently used keywords

Authors' supplied keywords are important indicators that represent the topics covered in the publications. Table 7 presents the 50 most used author keywords identified in the energy and fuels domain based on the frequency of their occurrence. The keyword solar energy was the most used with 173 occurrences and received 4463 citations with an average of 25.80 citations per publication. Renewable energy was ranked second with 141 occurrences, and efficiency and optimization were both ranked third with 118 occurrences each. The highest number of citations ($n = 5235$) were received for the keyword energy, while the highest average citations per publication were recorded for the keyword thermal energy storage.

Figure 5 provides a visual map of the evolution of keywords in three different time periods: 1972–2010, 2011–2015, and 2016–2021. Solar radiation, renewable energy, entropy generation, and wind energy were the most commonly used keywords during the last three decades of the twentieth century. Renewable energy and solar energy were equally popular during the first two decades of the twenty-first century. Figure 5 presents an overview of the popular keywords in the energy and fuels research emerging from KSA during the different periods. Wind energy, solar radiation, entropy generation, and renewable energy were the main keywords used during the 1972–2010 period, whereas socket tube, biodiesel, solar cells, and efficiency were popular during the 2011–2015 period. Solar energy, renewable energy, and biodiesel remained equally popular in the recent 5 years, while energy storage and pyrolysis were new areas of research.

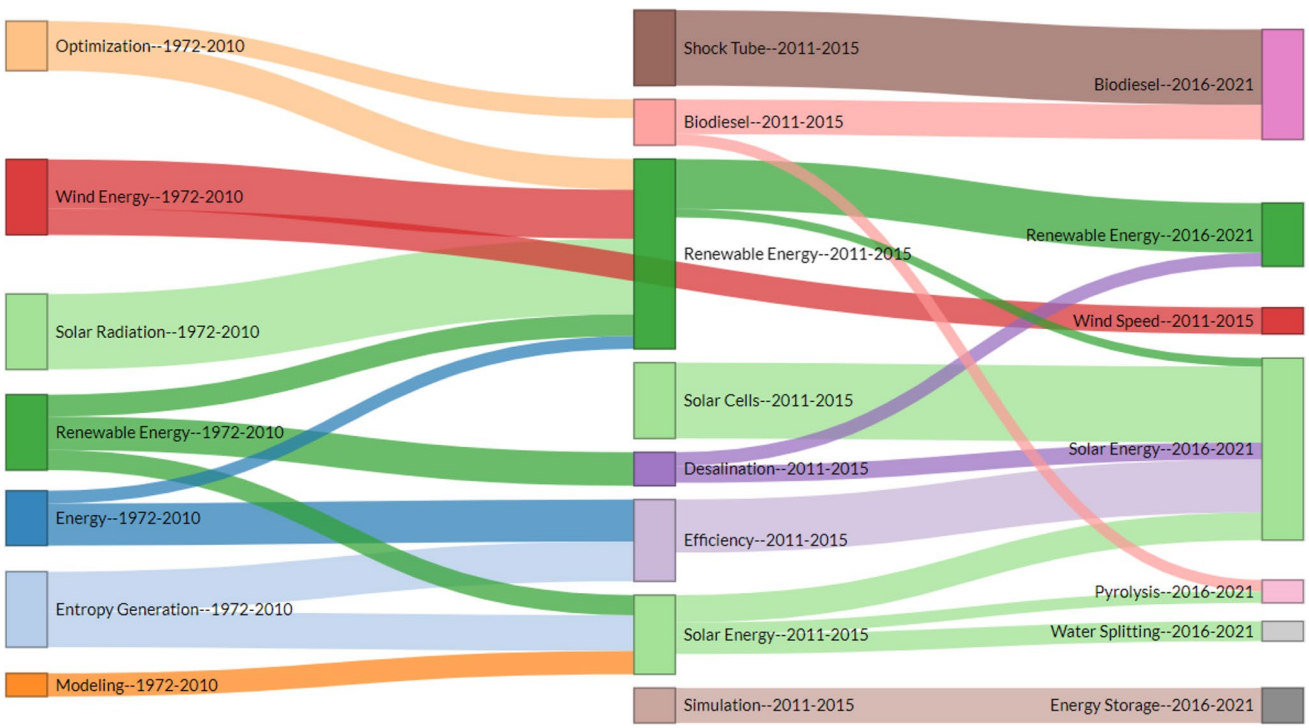

Fig. 5 Keywords evolution of energy and fuels research in KSA

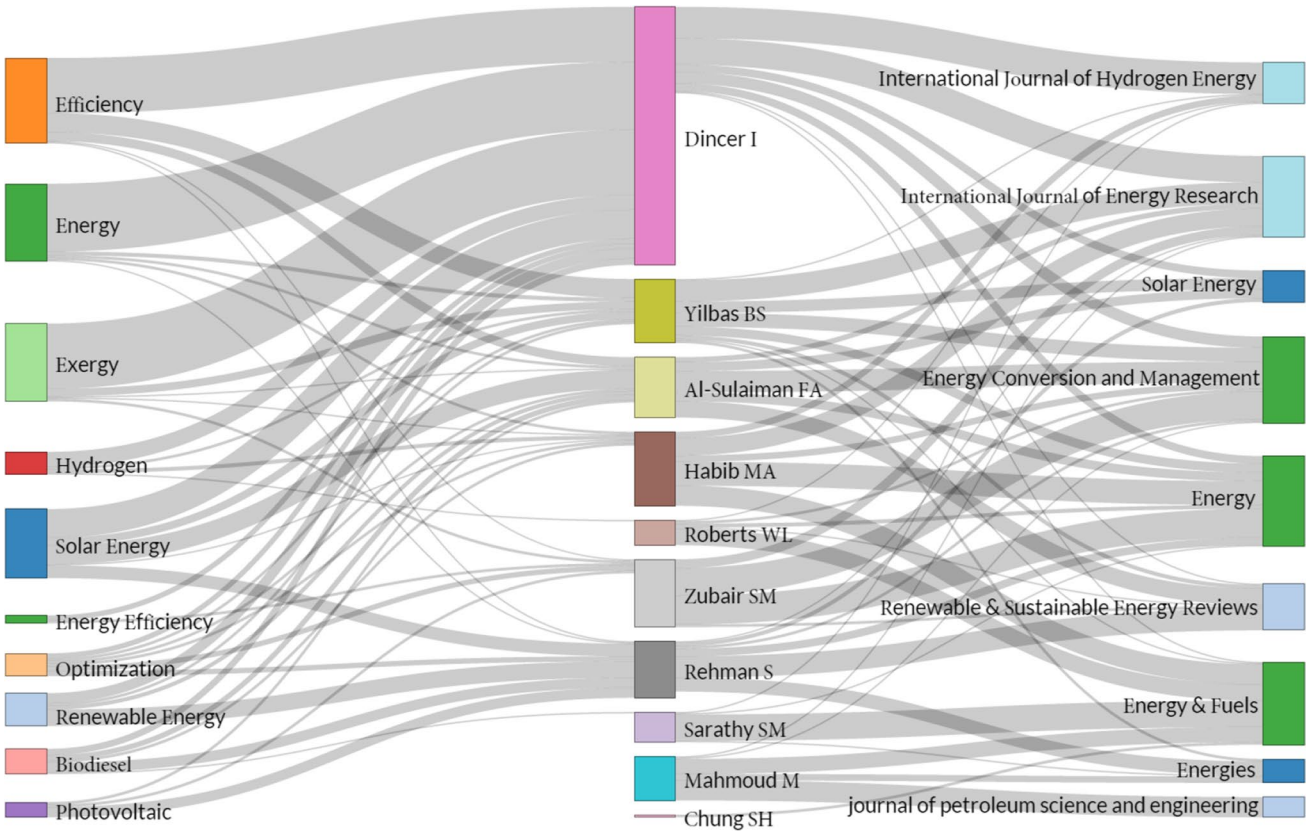

Fig. 6 Three-field plot of keywords (left), authors (authors), and journals (right)

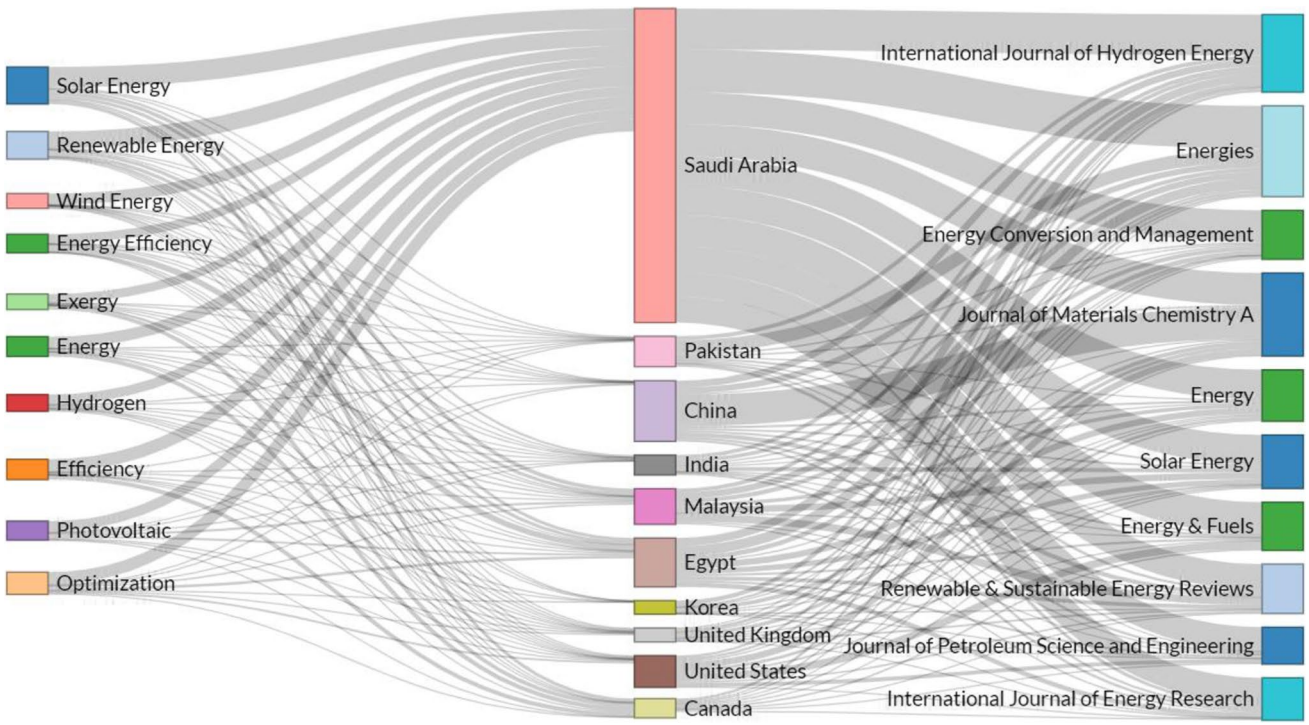

Fig. 7 Three-fields plot of keywords, countries, and journals

Figure 6 presents the three-plot analysis of keywords (left), authors (authors), and journals (right). The size of the box shows the strength of the relationship. The figure explains the strong relationship of one of the prolific authors *Dincer I*, to the efficiency, energy, and exergy keywords and the International Journal of Hydrogen Energy and the International Journal of Energy Research journals. The other prominent authors, Zubair SM and Al-Sulaiman FA and Habib MA with keywords, solar energy, exergy, and renewable energy, preferred to publish their research in the Energy Conversion and Management, the Energy, and the Energy and Fuels journals.

A three-field analysis was conducted using the Biblioshiny visualization tool to uncover the relationship present among the energy and fuels keywords, countries, and journals as displayed in different colors in Fig. 7. The size of the rectangle indicates the strength of the relationship between these elements. The figure indicates that Saudi Arabia had a strong relationship with the solar energy, renewable energy and optimization keywords, and the Energies, the International Journal of Hydrogen Energy, and the Journal of Materials Chemistry A journals.

Figure 8 presents the citation burst of the most frequently used keywords observed during the 1972 to 2020 period. The highest burst strength (17.98) was observed for the keyword energy, which lasted for 14 years from 1999 to 2012. The burst that lasted for the longest period was recorded for the keyword solar radiation that lasted for 18 years from 1994 to 2011.

Discussion

The trends analysis of the KSA affiliated publications in the energy and duels domain during the 1972 to 2020 period (Fig. 1) has indicated that there had been virtually no publications during the 1970s. However, this gradually changed in the 1980s, and the publication activity picked up in the next two decades. Furthermore, there has been a drastic increase in these publications since the beginning of the year 2010 to date. This dramatic increase in publications during the last decade can be attributed to several factors such as the huge investment in the higher education sector (Onsman 2011), increased number of higher education institutions (HEIs) (Alshuwaikhat et al. 2016), scholarship programs for higher education (Alamri 2011) in the Kingdom, enhanced investment for energy research, and the establishment of technology parks and centers of excellence (Alshumaimri et al. 2017). Alongside these initiatives, the Ministry of Education has given prime importance to scientific research and publishing, which have been incorporated into the strategic priorities of all HEIs in KSA (Al-Youbi 2017). Accordingly, HEIs have included research skills and research productivity as major criteria for the recruitment, promotion, and renewal of contracts of their faculty. They have enhanced the policies in favor of the researchers by offering attractive incentives such as publication rewards, monthly incentives during research projects, and financial assistance for publication. Moreover, a highly competitive environment has been developed in the Higher Education sector, wherein the HEIs are mandated to achieve national as well as international recognition for their reputation and long-term survival. Apart from the research funding schemes in the HEIs, the Ministry has recently established a Research and Development Office (RDO, n.d.) to promote collaborative research with international universities and research organizations. These initiatives have prompted the HEIs to enhance their research productivity in terms of the number of publications and patents.

As elaborated in the introduction section, this decade has witnessed significant progress in the energy sector in terms of innovative research, development, and commercial ventures. According to the Saudi Vision 2030, 20% of the energy production is targeted to be from renewable sources in the future (Allhibi et al. 2019). The government has declared its plan to install 41 GigaWatt solar power generation units and

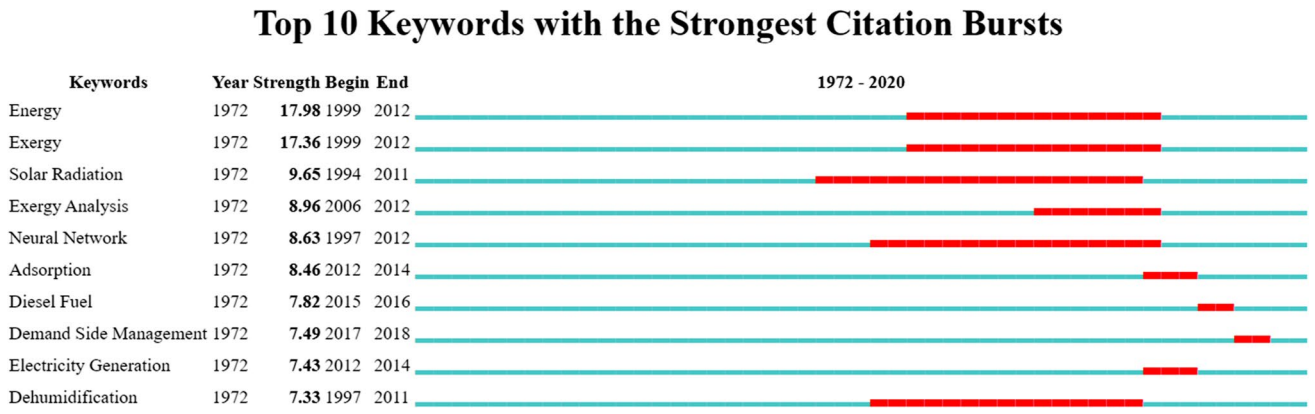

Fig. 8 Citations burst of the most frequently used keywords

to invest $108.9 billion by 2032. Mosly and Makki (2018) highlighted several governmental initiatives under Vision 2030 toward shifting from conventional to renewable energy generation and application. The extensive research activities in energy and fuels domain in the leading universities such as KFUPM and KAUST have contributed to the dramatic progress in scholarly publications in the recent past.

Several factors govern the decision of authors in choosing the right journal for publication. First, like many other countries, the HEIs in KSA have adopted stringent policies to ensure that their research findings are published in high-quality indexed journals. Faculty and research scholars have been provided with a list of journals that are indexed mainly by the WoS and/or Scopus database. Therefore, the authors always prefer journals from this list to ensure that their publications are duly recognized and credited by their institution. When we investigated the energy and fuels domain, we found many journals that were indexed in the WoS or Scopus. However, the authors had chosen the journals mostly by considering their processing times and author-friendliness during the submission process. It is clear from Table 2 that thirteen out of the top twenty journals were published by Elsevier. According to the statistics provided by Elsevier (Elsevier Journal Metrics Visualization-Review Speed 2020), over a period of 5 years (2016–2020), these journals have taken around 5 weeks (average) for the first decision of submission and about 8 weeks (average) for the final decision. The other journals have also maintained their record of reasonable article processing times. The quartile rank and impact factor of the journal were other criteria for the authors' choice of journals. Most Saudi universities insist that their faculty publish in the Q1 and Q2 journals or at least in the Q3 journals. It is evident from the results that ten journals were in the Q1, and seven were from the Q2. Regarding the impact factor of the journals, most authors preferred publishing in journals with a high impact factor (Table 2). It is worth noting that the journal "Energies" published by MDPI, a renowned open-access publisher, was ranked second with 328 publications even though it is in the below Q3 category of the WoS. This can be attributed to the recent trend of publishing with payable open-access publishers that maintain time-bound review and publishing processes. As publishing is mandatory for most funded projects, and the article processing charge is paid from the research funding, researchers tend to opt for such open-access publishers to ensure the timely completion of their research.

The results also revealed that research articles in journals led the way in terms of the authors' choice of document type and the most cited document category (Table 3). This highlights the completeness and quality of research works in the energy and fuels domain. Full-length research articles are frequently generated out of successfully completed research with interesting findings. When these articles are submitted to reputed journals, they undergo a rigorous peer review and revision process before being accepted for publication. It is interesting to note that even though the frequency of review articles was very low (only 6.54%) as compared to that of research articles (79.41%), they had the highest (64.43) citation impact. The research articles only had a citation impact of 19.89. This is because review articles are normally published by established researchers in the field and contain comprehensive information on the topic, including history, research progress, full literature background, and directions for future research. Therefore, review articles are considered very useful sources of information for new researchers in the field to build the background and decide on the areas needing extended work. Consequently, these articles tend to attract a wider readership and receive higher citations as compared to research articles.

Table 4 highlights that the most productive authors in the energy and fuels domain belonged to the five top-ranked universities in KSA ranked according to four different world ranking systems (Best 5 Universities and Colleges in Saudi Arabia 2020). A close observation also reveals that the authors were mostly expatriates. This scenario can be explained by the established research infrastructure in the leading universities of KSA and their rigorous process for hiring faculty with excellent research skills and backgrounds. These top universities also have specific research programs in energy and fuels, e.g., KAUST has King Abdullah City for Atomic and Renewable Energy (KACARE), KAUST Solar Center, Clean Combustion Research Center, and the Green Campus initiative, and KFUPM has established centers of research excellence in renewable energy, energy efficiency, and refining and petrochemicals. Furthermore, unlike in the past, HEIs in KSA have now implemented strict recruitment criteria to ensure that all recruits not only possess doctoral degrees from well-recognized universities as the minimum criterion but also have a substantial record of research and publication in reputed journals. Retention of qualified staff has also been a priority.

Among the top ten productive organizations in energy and fuels research (Table 5), the first four belonged to the top five public universities of KSA; they have specific research centers in this area. Saudi Aramco, ranked fifth in Table 5, is the Kingdom's fully integrated energy and chemicals company and has put energy efficiency in its strategic priorities (ARAMCO 2021). The Aramco's research and development unit has a highly talented, world-class research team to perform innovative research. King Abdullah City for Science and Technology, ranked sixth, is a government institution that supports and enhances scientific research in KSA (KACST 2021). Subsequent positions were achieved by Umm Al Qura University, King Khalid University, Prince Sattam Bin Abdulaziz University, and Qassim University, respectively. These are well known for their dedicated programs and activities in the energy field.

Regarding the number of authors in publications, the present findings (Fig. 4) have revealed that the majority of the publications were multi-authored, indicating the trend of collaborative research. This can be attributed to the fact that with the enhanced funding opportunities and infrastructure, most of the research activities in KSA are occurring via funded research projects, which generate multi-authored publications. As far as the international research collaborations in the field of energy and fuels are concerned, the top ten collaborators were from five countries: Malaysia, China, Egypt, Pakistan, and USA (Table 6). It is worth noting that, among these countries, China and the USA led in the list of global leaders in energy and fuels research (Table 1). The lack of collaborative publications with the other countries indicates the lack of research collaboration with them, which should be a matter of concern for HEIs in KSA. As the current WoS ranking of KSA for energy and fuels research productivity is 17, there is enough ample scope to elevate it to the top ten in the nearest future through effective international collaboration.

The author keywords are provided by the authors according to the topics covered. Therefore, their frequency of occurrence can indicate the extent of research focus on a specific topic. For instance, as shown in Table 7, *Solar energy* was the most frequently used author keyword, indicating that this was the most extensively researched topic. This observation is consistent with the dramatic pace of solar energy research in Saudi Arabia. The next frequently used keyword was identified as "Renewable Energy" with a frequency of 451 times. It is a clear indication of the enhanced research in this area through various initiatives such as KACARE. Most of the keywords were found to be related to the energy domain, and only a few represent the fuels domain. This highlights the dominant focus of research on "energy" compared to "Fuels." This observation somewhat justifies the real scenario of KSA, where there is a lack of research focus on fuels and combustion. King Abdullah University of Science and Technology and Saudi Aramco are the leading entities in fuels and combustion research, and KFUPM and KACST have some contributions in this direction. Due to the widespread availability of inexpensive oil in the Kingdom, alternate fuels have been an ignored topic of research. Therefore, alongside energy, there is a vast scope for research on the fuels and combustion domain as well, which would indeed bring substantial revolution in the development of the automobile and aeronautical industries in KSA. Moreover, clean combustion technologies can significantly contribute to the mitigation of greenhouse gas and other harmful emissions.

Limitations and future research directions

This study was limited to the publications indexed in the WoS on the subject area of energy and fuels published by authors affiliated with KSA between 1972 and 2020. It was beyond the scope of our study to ascertain whether the included research was carried out in KSA or not. The Saudi researchers working outside KSA with no current affiliation inside the Kingdom might have been omitted. Other databases like Scopus and Google Scholar were not considered in this analysis. Future studies might verify the present findings with the data from these sources. Future research might also focus on the bibliographic coupling of countries, journals, and authors in this domain.

Conclusion

This study has successfully documented the productivity and trends related to the energy and fuels research in KSA, which has not been reported earlier. The literature search was based on the publications indexed in the Web of Science database from 1972 to 2020. The findings of the study have revealed that there has been a drastic increase in high-quality publications in the energy and fuels domain during the last decade. This could be attributed to the increase in the number of higher education institutions in the Kingdom and enhanced investment in energy research, as well as the establishment of technology parks, centers of excellence, and governmental policies to promote scientific research in the Kingdom. This has resulted in a promising improvement in the global ranking of KSA on energy and fuels research. The Kingdom has successfully moved from the 27th rank in 2011 to the 17th rank. King Fahd University of Petroleum & Minerals was the most prolific institution, followed by King Abdullah University of Science & Technology, King Abdulaziz University, and King Saud University. The most productive institutions and authors were in the Central, followed by the Western and Eastern regions of the Kingdom. Other regions need further attention in this regard. The results have also highlighted that most of the publications have been multi-authored with significant regional and international collaborations. Furthermore, the fuels and combustion subdomains of energy and fuels require further attention. It is hoped that the findings of this study would help guide the researchers and policymakers to maintain the current trend and productivity in this area of research and help decide the direction of future research.

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Data availability Figshare https://doi.org/10.6084/m9.figshare.16870649

Code availability NA.

Declarations

Conflict of interest The authors declare no competing interests.

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