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Saudi Arabia Energy Transition in the Context of Scholarly Publications

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Abstract

The article is devoted to a bibliometric analysis of scientific publications reflecting trends in scientific publications related to the energy transition of leading universities in Saudi Arabia. The universities were selected based on the presence of joint publications with the Saudi Arabian Oil Company, they are: King Fahd University of Petroleum and Minerals, King Abdullah University of Science and Technology, and King Saud University. The importance of studying the experience of Saudi Arabia for Russia in the context of the energy transition was highlighted. The analysis was based on Scopus platform data related to Subject Areas: Physical Sciences. Scientists from Saudi Arabian universities are increasingly publishing with co-authors from China, India, Egypt, Pakistan, and Malaysia, while maintaining high interaction with co-authors from the United States, South Korea, and the United Kingdom. Authors from the Russian Federation publish poorly with co-authors from Saudi Arabia. The trends in the topics of scientific publications were investigated, and their connection with the renewable energy topic was shown. The VOSviewer software was used to determine the main research areas using the cluster analysis method based on the co-occurrence of key terms. The analysis was done for both Author's keywords and Index keywords of the Scopus system. Graphical representation of the final choice of terms to describe research trends was proposed.

Keywords: Saudi Arabia, energy transition, bibliometric analysis, Scopus, VOSviewer, research trends

Introduction

In the context of growing contacts between Russia and Saudi Arabia in the framework of OPEC+ decisions, it is reasonable to consider the priorities and trends in scientific research of this partner.[1]

Since the 2010s, Russia has made significant progress in developing closer economic, political and security relations with the Gulf countries [1].

The initiative of national leaders to create a Charter for Cooperation among oil-producing countries will promote dialogue and cooperation among oil-producing countries at the ministerial and technical levels for the benefit of both oil-producing and consuming countries and the world economy.[2]

The Gulf countries need to diversify their economies away from dependence on oil and gas, which involves creating a next-generation energy market and improving access to markets in China, India and other developing countries. [2]. This trend can be traced not only at the political level, but also at the level of research cooperation, which can be assessed by analyzing bibliometric data on scientific publications.

Fossil fuels are the main source of economic income in the Gulf countries. On the other hand, climate change is closely linked to the use of fossil energy, and this has motivated the Gulf countries to look for alternative solutions, such as renewable energy technologies to comply with the Paris Agreement [3].

Countries have unequal natural resources, economic power and capacity. Achieving the Sustainable Development Goals is about making the best use of a country's resources and capabilities [4].

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1 Saudi Arabia and Russia Agree on Second Phase of Economic, Scientific, and Technical Cooperation
2 https://www.spa.gov.sa/viewfullstory.php?lang=en&newsid=2170582

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Economies that focus on hydrocarbons will have to determine the prospects and opportunities for a more sustainable future. The enormous untapped renewable energy (RE) potential in the Gulf Cooperation Council (GCC) countries, combined with the growing liquidity of money in new climate regimes, is paving the way for RE-based technologies [5].

The economy of Saudi Arabia as well as that of Russia is significantly dependent on hydrocarbon exports, and both countries have to adapt to the challenges of the energy transition. Therefore, it is of particular interest to identify changes in the direction of scientific research in Saudi Arabia in recent years in the field of natural sciences (or Physical Sciences as by Scopus).

Note: According to the categories of the Scopus abstract database, the subject area "Physical Sciences" includes: Chemical Engineering, Chemistry, Computer Science, Earth and Planetary Sciences, Energy, Engineering, Environmental Sciences, Materials Sciences, Mathematics, and Physics and Astronomy subject areas.

The objective of the study, the reasoning for the choice of bibliometric data and the main results of their analysis.

The aim of this paper is to identify trends in scientific research in Saudi Arabia in the context of the energy transition, based on an analysis of bibliometric data presented in abstract databases.

It is advisable to analyze trends in scientific research using the metadata of abstract databases, such as Web of Science, Scopus, The Lens, and Dimensions.

The Lens, and Dimensions abstract databases have a pronounced specificity in the structure of exported data, so it is advisable to use them in separate bibliometric studies beyond the scope of this article.

The data of the Scopus platform were used in this work. The choice of Scopus is due to the fact that the Index Keywords of the Scopus platform describe the publication topic in much more detail than the Keywords Plus of the WoS platform. The main emphasis of the article is on the analysis of changes in research topics, which are best described by keywords, both the author's own and those offered by the abstract base itself.

Major Trends in Scientific Research at Saudi Aramco and Related Universities

It is the source of about 80% of revenues to the Saudi budget. Therefore, it is of interest to analyze the direction of development of scientific research of this company in the context of the energy transition. The company's website announces the main priority of the company's development in these conditions - circular economy. "In 2020 Aramco set itself a path to become a leading circular economy company"[3]. The main tasks for the realization of the declared goals can be traced through scientific publications. However, the main sources of publications are universities. Therefore, it is useful to identify which universities in Saudi Arabia most frequently publish with Saudi Aramco and include the metadata of their articles.

Selection of the abstract database

On the Scopus platform, you can detect an organization identifier and then use it to filter publications whose authors are affiliated with that organization. Affiliation name: Saudi Arabian Oil Company, Scopus affiliation ID: 60025307.

Scopus indexed 6,093 documents for all years with LIMIT-TO (AF-ID, "Saudi Arabian Oil Company" 60025307) as of 2 September 2021

But WoS indexes publications only since 1975, so we impose the PUBYEAR > 1974 restriction for comparison.

I got 6,768 results for AF-ID ("Saudi Arabian Oil Company" 60025307) AND PUBYEAR > 1974 of them Conference Paper (4,498) and Article (1,979).

[3] https://www.aramco.com/en/magazine/elements/2021/circular-economy

On the WoS platform I get: 1,973 results for OG=(Saudi Aramco) Indexes=SCI-EXPANDED, ESCI Timespan=1975-2021 (In the classic WoS interface)

Thus, the number of articles indexed in Scopus and WoS for the period 1975-2021 is almost the same. The advantage of Scopus is the large number of indexed conference proceedings and the greater number of Index Keywords compared to the Keywords Plus of the WoS platform.

To understand which topics are of most interest to Saudi-Aramco, let's analyze Index Keywords of the 2000 most relevant conference papers obtained by the query: AF-ID ("Saudi Arabian Oil Company" 60025307) AND PUBYEAR > 2011 AND (LIMIT-TO (DOCTYPE, "cp"). The predominant Index Keywords is shown in Tab. 1.

Table 1. Top 40 Index Keywords for 2000 most relevance Conference Paper by Saudi Aramco in 2011-2021 (as by 2 sent 2021)

Index Keywords	N	Index Keywords	N
gasoline	429	efficiency	93
oil wells	338	well stimulation	92
petroleum reservoir evaluation	286	well testing	92
petroleum reservoirs	269	hydraulic fracturing	91
infill drilling	254	hydrocarbons	90
boreholes	238	cost effectiveness	87
petroleum reservoir engineering	176	drilling fluids	87
gas industry	171	sulfur compounds	85
horizontal wells	167	crude oil	84
fracture	143	reservoir management	84
gases	134	oil well logging	82
oil field equipment	129	oil field development	81
offshore oil well production	125	floods	78
carbonation	118	coiled tubing	75
seismology	115	well completion	74
oil well flooding	114	secondary recovery	70
petroleum engineering	102	petroleum prospecting	69
enhanced recovery	100	natural gas wells	66
carbonate reservoir	99	porosity	65
oil fields	97	petroleum industry	64

Oil and gas companies stick to classic topics, even in conference proceedings, which reflect new topics more quickly than peer-reviewed articles.

Usually, universities develop new research areas. Therefore, it is useful to identify those that most often publish joint articles with Saudi Aramco, which can be done by analyzing the affiliation of the co-authors.

To identify such universities, I query the Scopus database with the following filters: years — 2012-2021; language — English; article type — journal article; Subject Arears — Physical Sciences; affiliation — the Saudi Arabian Oil Company organization, the following affiliations for co-authors in the format Affiliation number of publications are obtained:

- Saudi Arabian Oil Company 842
- King Fahd University of Petroleum and Minerals 156
- King Abdullah University of Science and Technology 112
- Korea Advanced Institute of Science and Technology 26
- Massachusetts Institute of Technology 19

- King Saud University 17

For further analysis, we will limit it to the Arab universities. Below is a summary of four institutions (Saudi Arabian Oil Company, King Fahd University of Petroleum and Minerals, King Abdullah University of Science and Technology, and King Saud University), whose publication activities will be discussed later. A summary of the Subject Areas for each of the organizations is shown in Fig. 1.

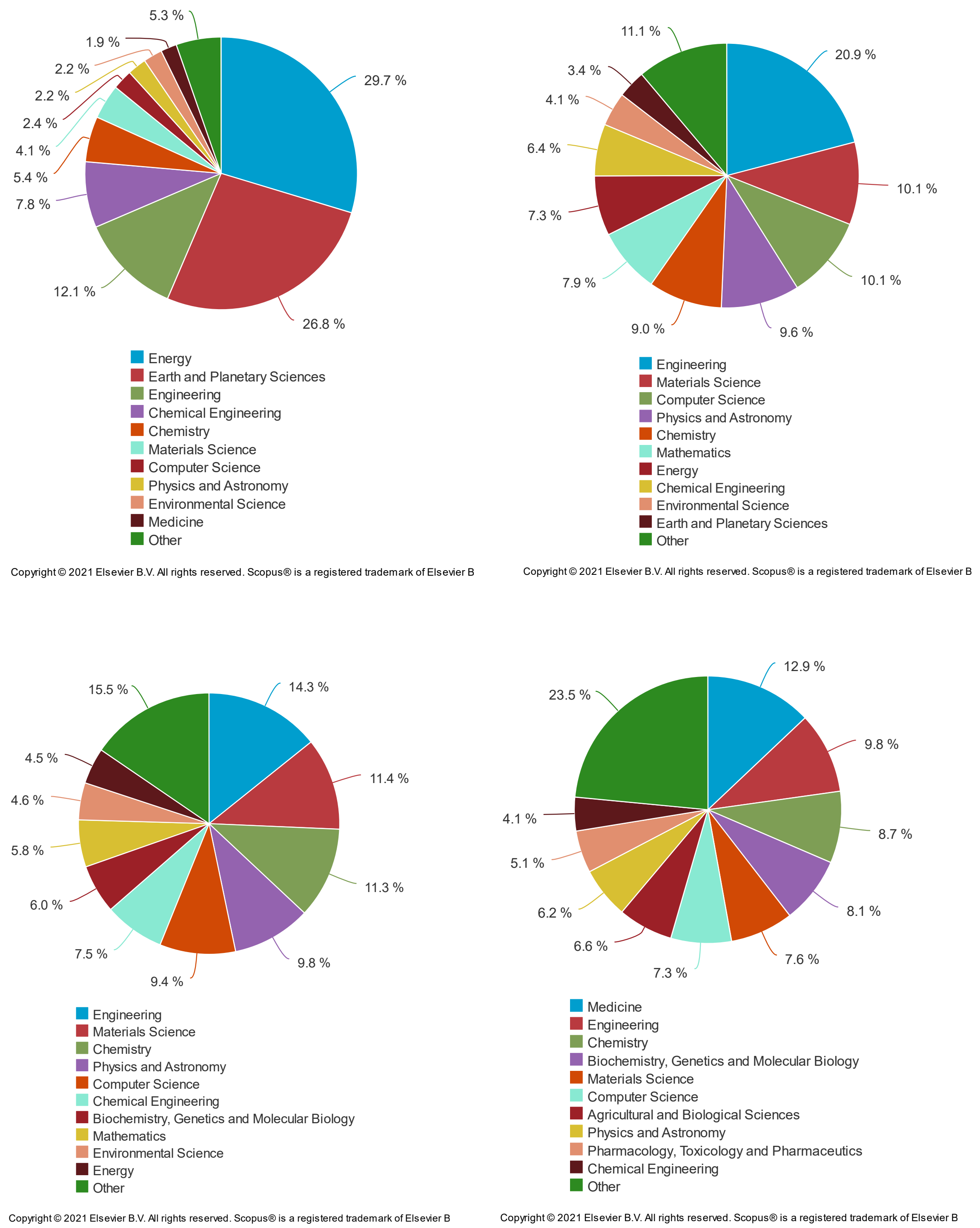

Fig. 1. Main Subject Arears of the four organizations Saudi Arabian Oil Company, King Fahd University of Petroleum and Minerals, King Abdullah University of Science and Technology, King Saud University. Data exported from the Affiliation details section of Scopus.

Fig. 1 shows that the first three organizations are mostly published in natural sciences disciplines, so the number of joint publications of King Fahd University of Petroleum and Minerals, King Abdullah University of Science with Technology and Saudi Arabian Oil Company is greater than that of King Saud University, which pays more attention to research in the field of medicine.

But King Saud University is great, and the total number of publications on the topic of interest to us is also large:

- Engineering 12010 publications
- Chemistry 10570
- Computer Science 8921
- Energy 2656

Whereas King Fahd University of Petroleum has the following total number of publications in these disciplines:

- Engineering 10454
- Computer Science 5028
- Chemistry 4510
- Energy 3660

Thus, it is advisable to take into account the publications of King Saud University.

Creation the main query to the abstract database Scopus, the data on which will be further exploited

The assignment of a publication to a particular institution was determined by the affiliation ID in Scopus.

The affiliation ID for the four institutions will be expressed in the query as follows: (AF-ID (60025307) OR AF-ID (60009506) OR AF-ID (60092945) OR AF-ID (60013183))

The Scopus natural science area is listed as Subject Areas: Physical Sciences, and includes the following subjects:

- Chemical Engineering (CENG)
- Chemistry (CHEM)
- Computer Science (COMP)
- Earth and Planetary Sciences (EART)
- Energy (ENER)
- Engineering (ENGI)
- Environmental Science (ENVI)
- Materials Science (MATE)
- Mathematics (MATH)
- Physics and Astronomy (PHYS)

In a query to the database, it will be as follows: SUBJAREA (CENG OR CHEM OR COMP OR EART OR ENER OR ENGI OR ENVI OR MATE OR MATH OR PHYS)

Additional data filtering was used: type of publication article — LIMIT-TO (DOCTYPE, "ar"), in a journal — LIMIT-TO (SRCTYPE, "j"), in English — LIMIT-TO (LANGUAGE, "English") published after 2011 — PUBYEAR > 2011

The final request: "Your query : ((PUBYEAR > 2011) AND SUBJAREA(CENG OR CHEM OR COMP OR EART OR ENER OR ENGI OR ENVI OR MATE OR MATH OR PHYS) AND (AF-ID(""Saudi Arabian Oil Company"" 60025307) OR AF-ID(""King Fahd University of Petroleum and Minerals"" 60009506) OR AF-ID(""King Abdullah University of Science and Technology"" 60092945) OR AF-ID(""King Saud University"" 60013183)) AND (LIMIT-TO (DOCTYPE,""ar"")) AND (LIMIT-TO (LANGUAGE,""English"")) AND (LIMIT-TO (SRCTYPE,""j"")))" gave out metadata of 45,988 documents.

The main parameters of the publication activity of the given organizations, which correspond to the request, are presented in Fig. 2 and 3.

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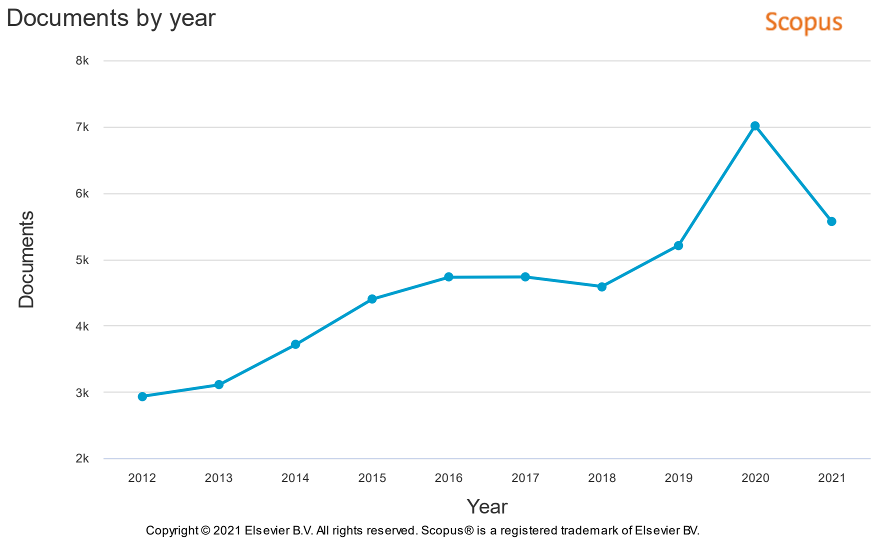

Fig. 2. Number of publications by year. Scopus data: Analyze search results.

The decade can be conditionally divided into three periods: 2012-2015 — growth from a small number of publications, 2016-2018 - no growth, 2019-2021 rapid growth of the present (data as of August 06, 2021, not all 2021 documents are indexed yet). Next, I will analyze these intervals in more detail.

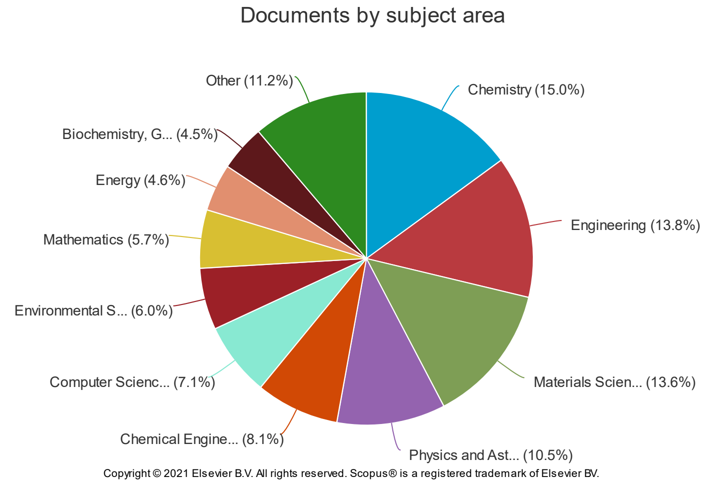

Fig.3. Distribution of publications corresponding to the above query by Subject Areas. Scopus data — Analyze search results.

The main Subject Areas of research are: Chemistry, Engineering and Materials Science. Energy takes up a modest 4.5%. Computer Science (7.1%) and Mathematics (5.7%) suggest a significant role for digitalization in the scholarly research of these institutions.

The distribution of publication topics in the three previously noted intervals: 2012-2016; 2017-2019; and 2019-2021, is shown in Tab. 2.

Table 2. Distribution of publication topics by three-time intervals

Number of results: 14145		Number of results: 14050		Number of results: 17793	
2012-2015		**2016-2018**		**2019-2021**	
SUBJECT AREA	N	SUBJECT AREA	N	SUBJECT AREA	N
Chemistry	5076	Chemistry	4555	Engineering	5453
Engineering	3955	Engineering	4310	Materials Science	5384
Materials Science	3899	Materials Science	4223	Chemistry	5243
Physics and Astronomy	3342	Physics and Astronomy	3181	Physics and Astronomy	3940

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Chemical Engineering	2215	Chemical Engineering	2449	Chemical Engineering	3368
Mathematics	1966	Computer Science	2002	Computer Science	3190
Computer Science	1918	Environmental Science	1738	Environmental Science	2558
Environmental Science	1652	Mathematics	1660	Energy	2128
Energy	978	Energy	1467	Mathematics	2019
Earth and Planetary Sciences	913	Earth and Planetary Sciences	1207	Earth and Planetary Sciences	1286

The relative number of Chemistry publications declined between 2019 and 2021, with Engineering and Materials Science coming in first and second during this period.

The number of publications in Computer Science has been increasing since the second interval, while the number of publications in Mathematics has been decreasing.

Recently, energy topics have been attracting more and more attention. It can be assumed that such changes reflect the process of the energy transition, which requires new engineering solutions and materials (especially for renewable energy storage systems), as well as methods for optimizing operations in energy systems, which requires new solutions in the field of computer science.

While Tab. 2 shows the ranking of topics by publication activity in a particular time interval, Tab. 3 shows the distribution of publications by year for each of the Subject Arears.

Table 3. Distribution of publications by year for main Subject Arears

SUBJECT AREA	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
Chemical Engineering	409	423	581	802	834	845	770	912	1382	1074
Chemistry	1113	1058	1337	1568	1615	1541	1399	1549	2056	1638
Computer Science	370	450	529	569	586	671	745	910	1266	1014
Earth and Planetary Sciences	136	214	213	350	399	406	402	421	469	396
Energy	160	212	261	345	423	481	563	631	814	683
Engineering	809	867	1024	1255	1350	1574	1386	1618	2149	1686
Environmental Science	313	367	432	540	617	572	549	633	974	951
Materials Science	836	798	1009	1256	1303	1504	1416	1565	2175	1644
Mathematics	480	471	481	534	562	528	570	627	761	631
Physics and Astronomy	773	718	846	1005	1101	1065	1015	1150	1519	1271

The following list reflects the increase in the relative number of publications in 2020 compared to 2012 for Subject Arears that I believe are particularly important for the energy transition:

- Chemical Engineering 1382/409=3.38
- Computer Science 1266/370=3.42
- Energy 814/160=5.09
- Engineering 2149/809=2.66
- Materials Science 2175/836=2.60
- Environmental Science 974/313=3.11

While Engineering and Materials Science have grown in absolute terms, Energy has seen the highest relative growth, followed by Computer Science, Chemical Engineering, and Environmental Sciences-the picture is not contradicted by the growing interest in the energy transition to clean energy.

For clarity, the data in Table 3 are shown graphically in Fig. 4.

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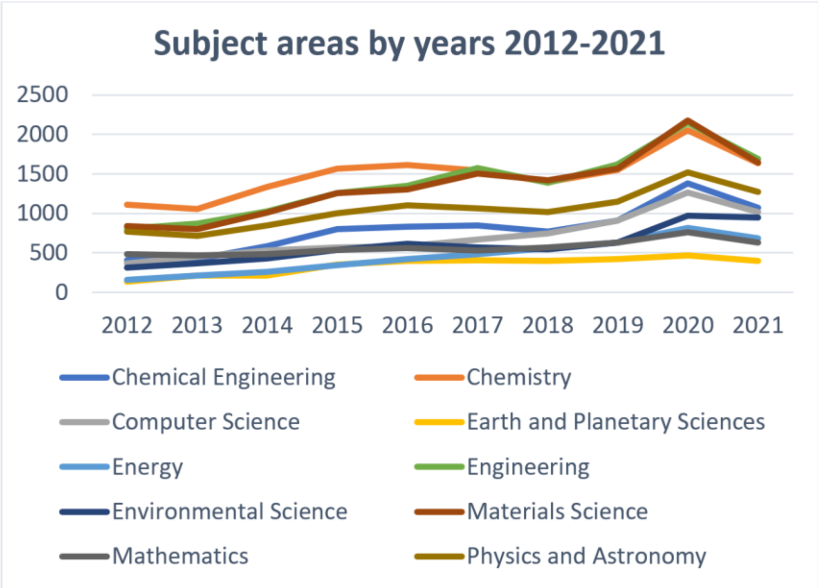

Fig. 4. Subject areas by years 2012-2021

In order to catch trends in the development of research, it is crucial to know which countries are cooperating with, thus determining the potential for expanding the geographical scope of the topic.

Table 4 shows the distribution by year of co-authorship for 10 countries. Data as of August 6, 2021.

Table 4. The distribution by year of co-authorship for 10 countries

COUNTRY	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021
China	214	165	261	354	437	502	563	734	1079	872
Egypt	293	364	515	598	669	574	449	586	1034	716
India	192	214	265	463	443	453	472	453	809	870
Malaysia	235	174	230	266	236	227	186	232	335	289
Pakistan	149	115	203	298	338	341	344	508	811	726
Russian Federation	11	6	8	29	40	44	73	71	72	57
Saudi Arabia	2925	3093	3703	4387	4724	4720	4576	5195	6964	5433
South Korea	97	112	129	197	185	173	163	192	307	330
United Kingdom	118	129	170	227	233	267	259	315	373	324
United States	382	435	500	605	596	595	626	633	703	523

Table 4 shows that prior to 2018, the majority of co-authors were from the U.S. Beginning in 2019, co-authors from China dominate, with an increase in the number of publications with U.S. co-authors continuing.

Authors from India, Egypt, Pakistan, and Malaysia are consistently in print along with authors from Saudi Arabia, a rate that increases significantly in 2020.

Publications with co-authors from South Korea and the United Kingdom steadily increasing over a whole ten-year period.

Authors from the Russian Federation publish poorly with co-authors from Saudi Arabia, even though there has been a relative increase over the years. The potential for cooperation between the Russian Federation and Saudi Arabia in the field of joint research remains unrealized, despite the extensive cooperation between the countries within the framework of OPEC+.

Using VOSviewer for Analysis of Scientific Publications Landscape

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Bibliometric data of the 2,000 most-cited publications for each year were used to analyze trends in scientific research based on co-occurrence of key terms. Data as of September 09, 2021.

Why it makes sense to consider Author and Index keywords separately

Here is the Scopus definition for Author and Index keywords:

- Author keywords: These are keywords chosen by the author(s) which, in their opinion, best reflect the contents of their document.
- Indexed keywords: These are keywords chosen by content suppliers and are standardized based on publically available vocabularies. Unlike Author keywords, the Indexed keywords take into account synonyms, various spellings, and plurals.[4]

For example, for the 343 records of Elsevier B.V., I obtained an average of 54.7 Indexed Keywords per record, for the 115 records of Academic Press Inc. - an average of 55.57 Indexed Keywords per entry, and for the 48 entries of the Royal Society of Chemistry, an average of 29.3. While for all of these publishers, I got an average of 5.5 Author keywords per entry.

To elaborate, here are two records:

Ref. [6]

Indexed keywords: larvicidal agent; nanocrystal; plant extract; Quisqualis indica extract; silver nanoparticle; unclassified drug; virus vector; insecticide; metal nanoparticle; plant extract; silver; acute toxicity; Aedes aegypti; Anisops bouvieri; Anopheles stephensi; aquatic species; Arbovirus; Article; atomic force microscopy; Combretaceae; crystal structure; Culex quinquefasciatus; Diplonychus indicus; Gambusia affinis; infrared spectroscopy; LC50; mosquito; nanofabrication; nonhuman; one pot synthesis; particle size; plant leaf; Plasmodium malariae; priority journal; Quisqualis indica; scanning electron microscopy; transmission electron microscopy; ultraviolet spectroscopy; X ray diffraction; Zika virus; animal; Anopheles; aquatic species; chemistry; Combretaceae; drug effects; growth, development and aging; larva; malaria; metabolism; mosquito vector; spectrometry; ultrastructure; ultraviolet spectrophotometry; Zika virus; Animals; Anopheles; Aquatic Organisms; Combretaceae; Insecticides; Larva; Malaria; Metal Nanoparticles; Microscopy, Atomic Force; Microscopy, Electron, Scanning; Mosquito Vectors; Particle Size; Plant Extracts; Plant Leaves; Silver; Spectrometry, X-Ray Emission; Spectrophotometry, Ultraviolet; Zika Virus – 73 terms.

Author keywords: AFM; Arbovirus; Green synthesis; Mosquito-borne diseases; Nanobiotechnology.

Ref. [7]

Indexed keywords: Carbon nitride; Chemical detection; Electrocatalysts; Electrodes; Electron transport properties; Fabrication; Green manufacturing; Iron compounds; Manganese compounds; Nanosensors; Nanostructured materials; Neurophysiology; Sonochemistry; Ultrasonic applications; Electrocatalytic activity; Electron transfer rates; High intensity ultrasonic; Neurotransmitter detection; Powder X ray diffraction; Real-time application; Sonochemical synthesis; Synthesis parameters; Electrochemical sensors; carbon; ferrous chloride; manganese sulfate; nanomaterial; neurotransmitter; serotonin; sodium dihydrogen phosphate; agents interacting with transmitter, hormone or drug receptors; cyanogen; ferric ion; manganese derivative; manganese ferrite; nitrile; aqueous solution; Article; chemical composition; controlled study; electrochemical detection; electron transport; elemental analysis; high intensity ultrasound; human; limit of detection; nanofabrication; nonhuman; priority journal; surface property; synthesis; X ray powder diffraction; animal; blood; brain; catalysis; chemistry; electrochemical analysis; green chemistry; metabolism; procedures; rat; ultrasound; X ray diffraction; Animals; Brain; Catalysis; Electrochemical Techniques; Ferric Compounds; Green Chemistry Technology; Humans; Limit of Detection; Manganese Compounds; Neurotransmitter Agents; Nitriles; Rats; Sonication; X-Ray Diffraction – 78 terms.

Author keywords: Bimetal oxides; Graphitic carbon nitride; Hybrid materials; Neurotransmitter detection; Sonochemical synthesis.

[4] https://service.elsevier.com/app/answers/detail/a_id/21730/supporthub/scopus/

The validity of this expansion of the list of Indexed Keywords requires a separate study, which is beyond the scope of this publication. In this case, we can only assume that the Indexed Keywords broadly reflect the potential fields of research to which a particular article may be assigned.

Analysis of Scientific Publications Landscape by Index Keywords for 20,000 Records

As noted earlier, the main query yielded metadata of 45,988 documents.

For constructing and visualizing Index keywords networks, 2,000 metadata records of the most cited publications were taken for each year (20,000 records in total). Then, using the VOSviewer software, a network was constructed using the specified metadata, based on the co-occurrence of Index keywords.

The total number of Index keywords in this sample was 79295, of which 12598 occur more than 5 times and 6318 occur more than 10 times; 1000 Index keywords out of 6318 with maximum link strength are further used to construct a term co-occurrence network.

After an initial review of the results, a partial replacement of the most frequent terms was performed, e.g., terms can occur in plural or singular form in different records, or have a hyphen between words or not, etc. After this substitution, the total number of terms was 79250 of which 6273 occurred more than 10 times. The condition more than 10 in cluster was used to enlarge the clusters; this yielded 4 clusters, which are shown in Figure 5.

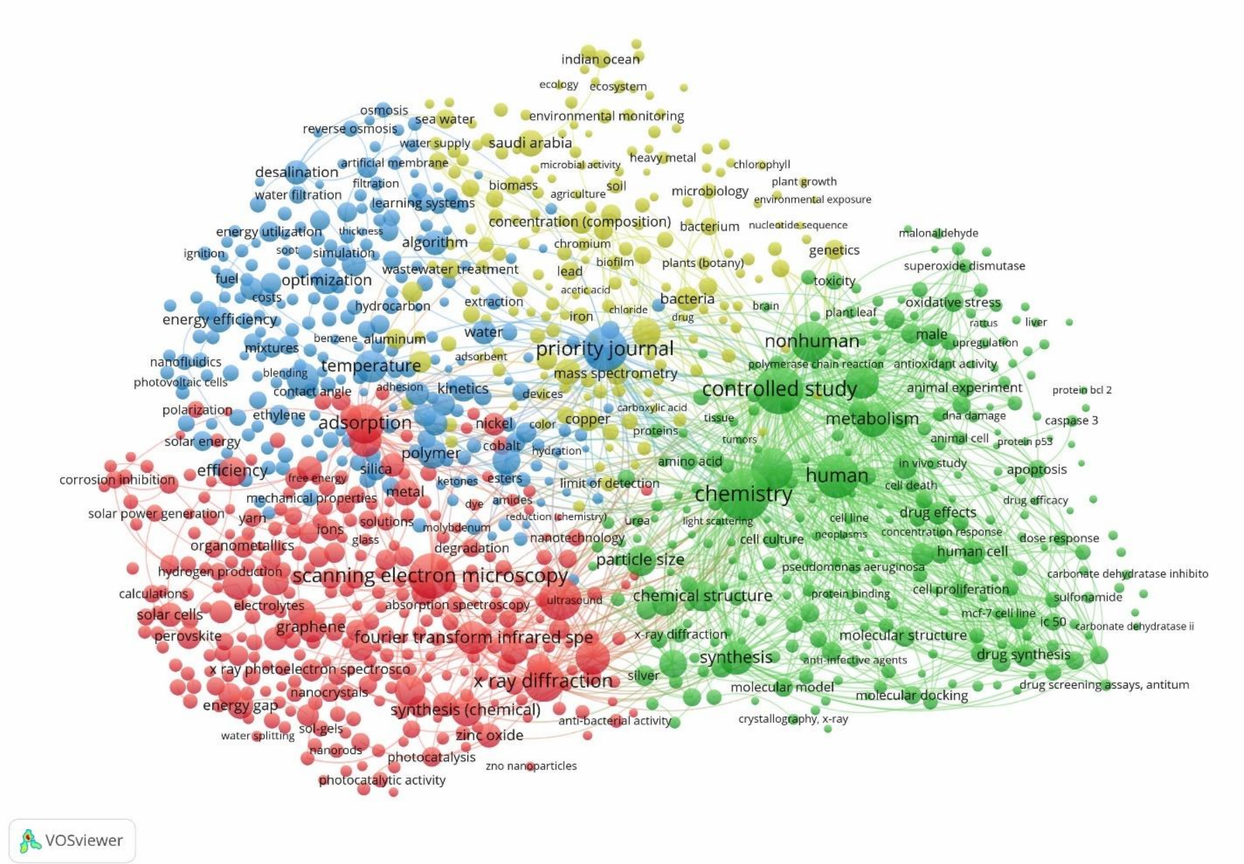

Fig. 5. Clustering results based on the co-occurrence of Index keywords

The following list shows the frequency data for each of the clusters in the format: number of unique terms/total number of terms:

1. 303/50164
2. 272/35835
3. 239/33723
4. 185/19733

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Table 5: The most frequent Index keywords for each of the four clusters. Here: label cl I - name of the term in the I cluster, N - occurrence of the term in the sample

label cl 1	N	label cl 2	N	label cl 3	N	label cl 4	N
scanning electron microscopy	1239	chemistry	1667	priority journal	1193	procedures	508
nanoparticle	1073	controlled study	1417	temperature	639	saudi arabia	422
x ray diffraction	1029	human	1155	carbon dioxide	637	ph	391
adsorption	935	unclassified drug	1063	polymer	526	bacteria	360
transmission electron microscopy	705	nonhuman	966	surface properties	473	copper	308
fourier transform infrared spectroscopy	665	metabolism	738	optimization	450	nitrogen	300
carbon	635	animal	697	energy efficiency	411	concentration (composition)	297
synthesis (chemical)	582	synthesis	687	kinetics	411	mass spectrometry	285
nanocomposites	571	particle size	581	algorithm	377	water treatment	254
density functional theory	555	chemical structure	542	desalination	363	zinc	254
efficiency	533	metal nanoparticles	482	membranes	358	aluminum	241
graphene	525	infrared spectroscopy	390	oxidation	349	genetics	239
catalysis	473	drug effect	348	water	347	"water pollutants, chemical"	239
electrode	473	human cell	330	porosity	337	water pollutant	231
energy gap	425	drug effects	319	thermodynamics	320	wastewater treatment	229
catalysts	416	drug synthesis	317	chemical analysis	316	sea water	227
metal	414	in vitro study	313	combustion	310	indian ocean	212
morphology	386	male	313	silica	284	lead	201
chlorine compounds	368	molecular structure	266	performance assessment	263	isolation and purification	199
solar cells	366	antioxidant	265	membrane	262	biomass	192
zinc oxide	366	hydrogen bond	264	energy utilization	258	water purification	192
high resolution transmission electron microscopy	354	escherichia coli	263	ethylene	252	physiology	191
crystal structure	347	silver	262	hydrophobicity	252	waste water	190
catalyst activity	346	enzyme activity	238	heat transfer	247	concentration (parameters)	188
titanium dioxide	345	oxidative stress	237	mixtures	240	water management	187
oxygen	342	antiinfective agent	236	internet of things	239	bacterium	185
perovskite	326	animal experiment	230	solar energy	236	organic compound	183
nickel	325	metal nanoparticle	228	forecasting	235	aqueous solution	178
thin films	312	female	227	fuel	234	iron	178
heterojunctions	306	antineoplastic agent	225	polymerization	233	limit of detection	167

The first cluster theme:

- adsorption, catalysis, morphology, solar cells, thin films, heterojunctions
- nanoparticle, carbon, nanocomposites, graphene, metal, chlorine compounds, zinc oxide, titanium dioxide, perovskite
- scanning electron microscopy, x ray diffraction, transmission electron microscopy, fourier transform infrared spectroscopy

The second cluster theme:

- chemistry, metabolism, synthesis, drug synthesis, chemical structure, enzyme activity, oxidative stress, antiinfective agent, male, female
- unclassified drug, animal, human cell, metal nanoparticles, antioxidant, escherichia coli
- infrared spectroscopy, controlled study, in vitro study, animal experiment

The third cluster theme:

- optimization, energy efficiency, energy utilization, internet of things, solar energy,
- carbon dioxide, polymer, water, membranes, silica, ethylene, fuel
- kinetics, algorithm, thermodynamics, chemical analysis, performance assessment, forecasting

The fourth cluster theme:

- Saudi Arabia, wastewater treatment, sea water, waste water, water management
- bacteria, copper, nitrogen, zinc, aluminum, lead, biomass, organic compound
- mass spectrometry, Ph, concentration, isolation and purification, limit of detection

Terms do not occur evenly over time; the simplest estimate of this is to use the average year of occurrence of the term in the metadata of publications, <Avg. pub. Year>, the results for some of the terms in the four clusters are shown in Table 6. This parameter will be used later in the construction of the final graphs: Fig. 15. and Fig. 16.

Table 6: Average year of occurrence of some terms in publication metadata for the four clusters

label cl 1	**Avg. pub. year**	**label cl 2**	**Avg. pub. year**	**label cl 3**	**Avg. pub. year**	**label cl 4**	**Avg. pub. year**
photocatalytic activity	2019.7	hep-g2 cell line	2018.4	deep learning	2019.7	concentration (parameter)	2020.0
surface morphology	2019.5	tumor necrosis factor	2018.3	machine learning	2019.1	detection method	2019.0
x ray photoemission spectroscopy	2019.3	targeted drug delivery	2018.1	internet of things	2018.8	inorganic compound	2018.7
reduction (chemistry)	2019.3	malonaldehyde	2018.0	sustainable development	2018.6	plant growth	2018.5
supercapacitor	2019.1	photon correlation spectroscopy	2018.0	learning systems	2018.5	soil pollutant	2018.1
nanocatalysts	2019.0	enzyme	2017.9	diagnosis	2018.3	soil pollution	2018.0
potassium hydroxide	2019.0	brain	2017.8	network security	2018.2	photosynthesis	2018.0
green synthesis	2018.9	histopathology	2017.8	composite	2018.2	soil pollutants	2018.0
silver compounds	2018.9	diseases	2017.8	aluminum oxide	2018.0	adsorbent	2018.0
crystallinity	2018.9	tumors	2017.8	nanofluidics	2018.0	antibiotics	2017.9
layered semiconductors	2018.8	controlled drug delivery	2017.8	surface charge	2017.9	biochar	2017.8
energy storage	2018.8	histology	2017.7	flame	2017.8	plant root	2017.8
binary alloys	2018.8	glutathione reductase	2017.7	membrane distillation	2017.8	wastewater treatment	2017.6
lead compounds	2018.7	drug effect	2017.7	fluorine compounds	2017.6	water pollution	2017.6
oxide minerals	2018.7	chitosan	2017.7	wetting	2017.6	soil	2017.6
manganese compounds	2018.6	green chemistry	2017.7	thermal conductivity	2017.6	hydrogen peroxide	2017.5

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particle size analysis	2018.6	zinc oxide nanoparticle	2017.6	physical parameters	2017.6	ecosystem	2017.5
nanosheet	2018.6	plant leaf	2017.6	compressive strength	2017.6	atomic absorption spectrometry	2017.5
nickel compounds	2018.5	biomarkers	2017.6	energy utilization	2017.6	nutrients	2017.4
perovskite solar cells	2018.5	chemical compound	2017.6	support vector machines	2017.6	precipitation	2017.4
ii-vi semiconductors	2018.5	inflammation	2017.6	nitrogen oxides	2017.5	bioremediation	2017.4
electric discharges	2018.5	liver	2017.5	neural networks	2017.5	bacteriology	2017.4
electrochemical sensors	2018.5	nitric oxide	2017.5	classification (of information)	2017.5	metabolites	2017.3
additives	2018.4	antioxidant	2017.4	sodium hydroxide	2017.5	fruit	2017.3
reusability	2018.4	silver nanoparticle	2017.4	feature extraction	2017.5	arsenic	2017.3
electrochemical detection	2018.4	plant leaves	2017.4	forecasting	2017.4	pollutant	2017.2
steel corrosion	2018.4	superoxide dismutase	2017.4	stability	2017.4	heavy metals	2017.2
impedance spectroscopy	2018.4	catalase	2017.4	kinetic parameters	2017.4	chloride	2017.2
nanosheets	2018.3	biochemistry	2017.4	energy efficiency	2017.3	growth rate	2017.2
graphene oxide	2018.3	mtt assay	2017.3	digital storage	2017.3	physiology	2017.2

To identify trends in the topics of publications described by keywords, in addition to the average year of appearance of the term, it is important to assess the citation rate of publications in which the term is found. Given that the citation rate of publications increases over time, it is advisable to use citation normalization, e.g., over a certain period of time. I used the parameter <Avg. norm. Citations>, which is available in the map files exported by VOSviewer. The results for the terms with the highest Avg. norm. Citations for the four clusters are shown in Table 7.

Table 7. Average normalized citation of terms for a variety of Index keywords from each of the four clusters

.label cl 1	**Avg. norm. citations**	**label cl 2**	**Avg. norm. citations**	**label cl 3**	**Avg. norm. citations**	**label cl 4**	**Avg. norm. citations**
visible light	2.6038	radiation response	2.0813	film	2.5256	chemical oxygen demand	2.1164
methylene blue	2.1949	nuclear magnetic resonance imaging	1.6762	stoichiometry	2.1557	sulfate	1.7555
electron	2.0831	"microscopy, electron, transmission"	1.5672	photovoltaic system	1.8881	cation	1.6576
power conversion efficiencies	1.9981	complex formation	1.539	decomposition	1.8855	biochar	1.6296
electron transport	1.9593	"spectrophotometry, ultraviolet"	1.523	crystallization	1.8684	time factors	1.574
conversion efficiency	1.9518	hydrophobic and hydrophilic interactions	1.5014	nanofluidics	1.6661	charcoal	1.5456
metal organic framework	1.9129	ultraviolet spectrophotometry	1.4622	nanofluids	1.6031	"waste disposal, fluid"	1.5434
perovskite solar cells	1.8967	ferric compounds	1.4274	solar power	1.5972	sorption	1.543
water splitting	1.878	molecular interaction	1.4243	thickness	1.587	adsorption kinetics	1.4833
photo catalytic degradation	1.8728	ultrastructure	1.4237	gas	1.538	oxidation-reduction	1.4674
open circuit voltage	1.8591	cancer cell	1.4143	solar energy	1.5191	"nanotubes, carbon"	1.4475
photoelectron spectroscopy	1.8428	ferric ion	1.4032	low temperature	1.4447	adsorbent	1.4221
energy conversion	1.825	chemical phenomena	1.3988	chemical reaction kinetics	1.4403	water treatment	1.4202

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photocatalytic activities	1.8046	zinc oxide nanoparticle	1.381	thermostability	1.4297	time	1.4175
initial concentration	1.8002	magnetic resonance imaging	1.3728	water filtration	1.4237	methodology	1.4006
transition metals	1.7996	hela cells	1.3598	temperature effect	1.4093	biotechnology	1.3859
perovskite	1.7819	chitosan	1.3572	sustainable development	1.3993	water purification	1.3797
visible-light irradiation	1.7751	"microscopy, electron, scanning"	1.3372	separation	1.3851	inorganic compound	1.3689
plasmons	1.7718	conformation	1.3312	chemical reaction	1.3846	desorption	1.3684
monolayers	1.7484	hela cell line	1.3306	photovoltaic cells	1.3781	ecology	1.3627
solar power generation	1.7193	chemical structure	1.3301	solvent	1.3672	pollutant removal	1.36
azo dyes	1.6947	green chemistry technology	1.2901	seawater desalination	1.3628	water supply	1.3454
photolysis	1.6853	biomedical applications	1.2586	deep learning	1.3583	environmental impact	1.3437
electrochemistry	1.666	neoplasms	1.2541	composite	1.328	copper	1.3435
photodegradation	1.6278	tumors	1.2476	membrane permeability	1.327	hydrogen-ion concentration	1.3293
fuel cell	1.6169	x-ray diffraction	1.2395	water	1.3253	potassium	1.3245
nanorods	1.6037	bacillus subtilis	1.2353	gas permeable membranes	1.3248	oxidation reduction reaction	1.3145
activated carbon	1.5987	coordination compound	1.2186	internet of things	1.3157	lead	1.3111
quantum dot	1.5977	nanoencapsulation	1.2181	surface properties	1.3078	waste water management	1.3081
lead compounds	1.5922	"crystallography, x-ray"	1.2169	evaporation	1.3074	waste component removal	1.3066

The data given in Table 7 will be used to build the final graphs shown in Fig. 15 and Fig. 16.

The gradation of key terms can be very different, depending on the task at hand. For example, for a more detailed description of cluster topics, keywords can be assigned to different categories, conventionally labeled: research subject, materials, methods. In the lists below for each of the clusters, I have tried to intuitively divide the key terms into these categories. This is solely the author's categorization, given only to show that this division of terms can improve understanding of the topics of each of the clusters. To reduce biased judgments, a reasonable formalization of such categorization is necessary, which is beyond the scope of this paper, but can be accomplished by compiling for each of the categories its own vocabulary based on the occurrence of the terms in the corresponding sections of the full texts of the publications: introduction, materials, methods.

When selecting keywords to describe the cluster, it is important to consider what criteria were used to rank keywords. For example, in Table 5 they were ranked by occurrence, in Table 6 there was an additional ranking of frequently occurring keywords by <Avg.pub. Year>, and in Table 7 they were ranked by <Avg. norm. citation>. The leading keyword samples will be somewhat different, as will the cluster descriptions. At the same time, some commonality in the subject matter of the clusters is retained. This can be seen from the cluster descriptions in Table 5 below and the following cluster descriptions in Tables 7 and 6:

1 cluster, conditional division of key terms into categories: subject of research, materials, methods.

- power conversion efficiencies, perovskite solar cells, water splitting, solar power generation, fuel cell
- visible light, methylene blue, metal organic framework, transition metals, perovskite, monolayers, activated carbon, quantum dot, lead compounds
- open circuit voltage, photoelectron spectroscopy, photocatalytic activities, photolysis, electrochemistry, photodegradation

2 cluster

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- biomedical applications, green chemistry technology, chemical phenomena, nanoencapsulation
- ferric compounds, cancer cell, ferric ion, hela cells, zinc oxide nanoparticle, neoplasms, coordination compound
- nuclear magnetic resonance imaging, "microscopy, electron, transmission", ultraviolet spectrophotometry, "microscopy, electron, scanning", x-ray diffraction

3 cluster

- photovoltaic system, solar power, sustainable development, photovoltaic cells, seawater desalination, internet of things
- film, solvent, gas, composite, water
- stoichiometry, water filtration, decomposition, separation, evaporation

4 cluster

- water treatment, water purification, biotechnology, ecology, water supply, environmental impact, waste water management
- sulfate, biochar, charcoal, nanotubes, inorganic compound, copper, potassium, lead
- sorption, adsorption kinetics, pollutant removal, oxidation reduction reaction, waste component removal

The most affordable method of viewing the change in occurrence of terms over time is to use the VOSviewer Overlay graph for the time parameter. An example is shown in Fig. 6.

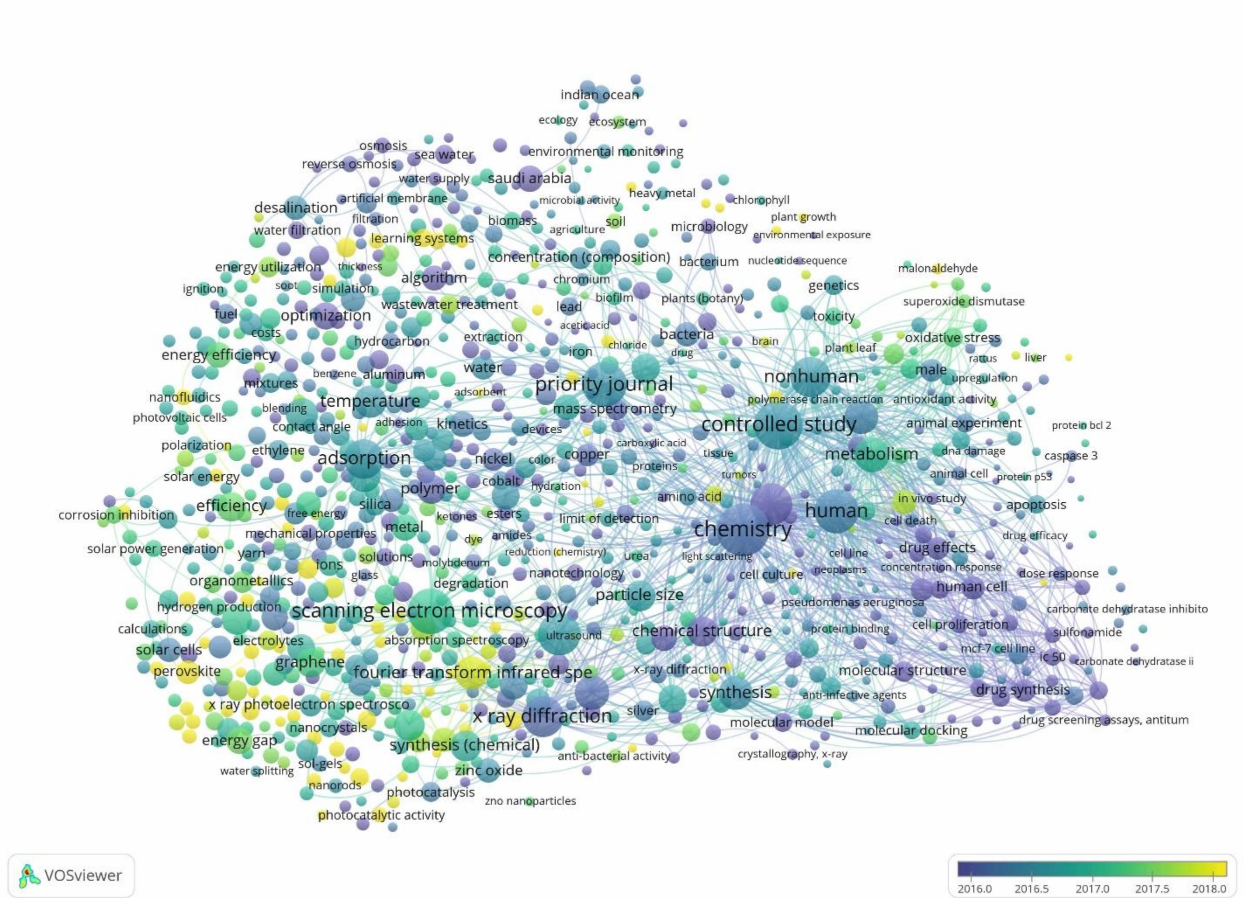

Fig. 6. Changes in the occurrence of Index keywords over time. Nodes of yellow color occur more often in the red cluster, if we compare with Fig. 5.

The developers of the VOSviewer program currently offer the ability to build and view graphs online. To do this, you need to upload graph files exported from the desktop VOSviewer at https://app.vosviewer.com/ , the json format is the most suitable. Readers of this preprint can use the attached files:

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Index KWs 2012-2021 JSON.json and Author KWs 2012-2021.json. The online interface is user-friendly and allows a more detailed review and study of the graphs presented in this publication in Figs. 5-10.

Analysis of Scientific Publications Landscape by Author Keywords for 20,000 Records

The data processing procedure for Author Keywords was the same as for Index keywords, described in the previous section.

The total number of Author Keywords in this sample was 40369, which is significantly less than the Index Keywords — 79295, of which 2455 occurred more than 5 times.

In the absence of cluster size restrictions, I got 16 clusters. Therefore, a limit of at least 120 terms per cluster was implemented, resulting in 6 clusters.

The connectivity of clusters for Author Keywords is significantly lower than for Index Keywords (Fig. 7.). There may be several reasons: a much smaller total number of Author Keywords compared to Index keywords, authors having their own opinion on the choice of keywords, for example, the terms: deep leaning, internet of things, and multi-step methods (green cluster) are more often used by authors than in Index keywords.

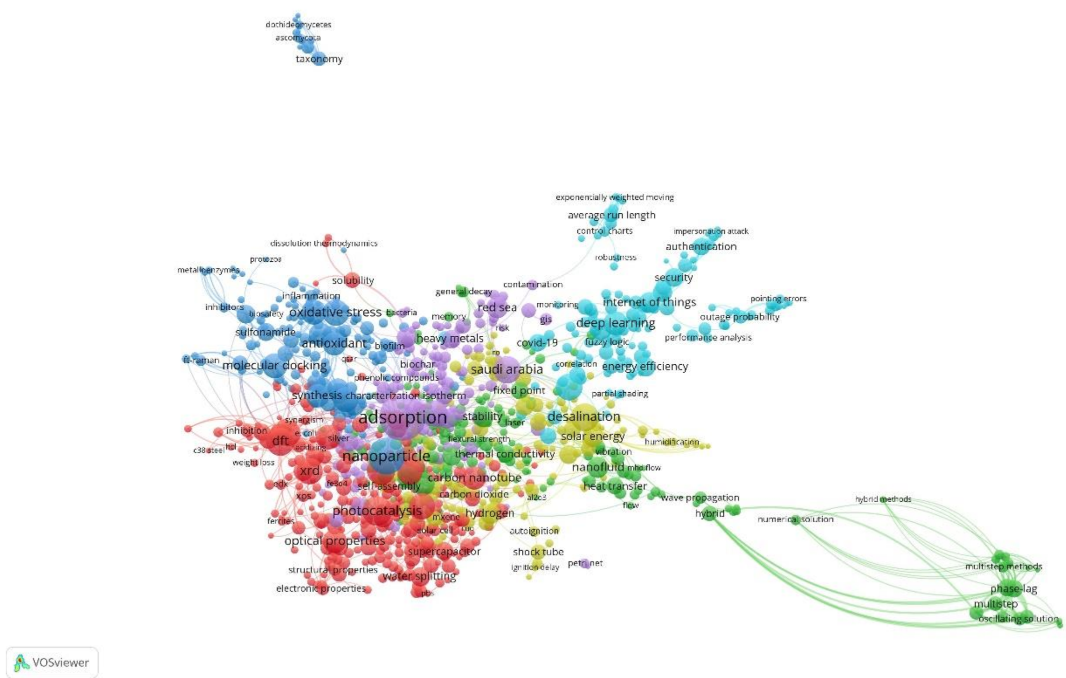

Fig. 7. Clustering results based on co-occurrence of Author's keyword

For better viewing, the central part of Fig. 7. Presented in enlarged format in Fig. 8.

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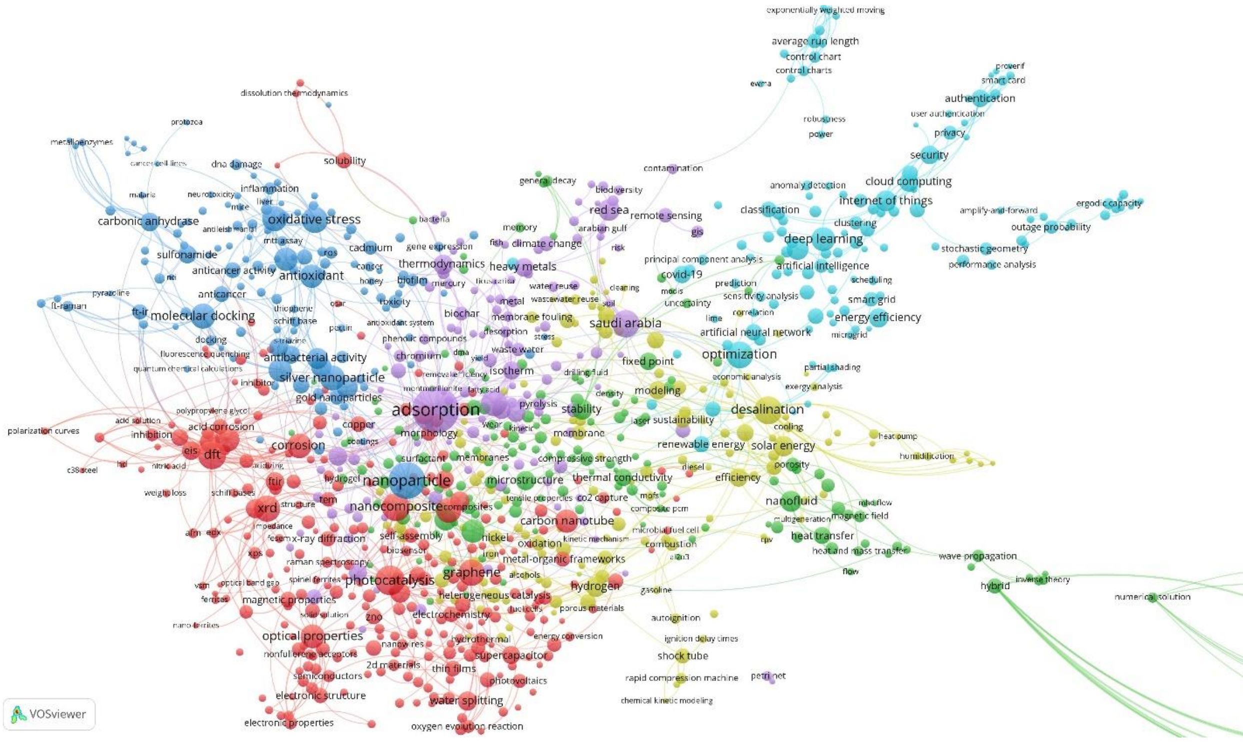

Fig. 8. Clustering results based on the co-occurrence of the Author's keywords, zoomed in of the central part of the graph in Fig. 7.

Fig. 9 shows the evolution of the occurrence of terms over time using the VOSviewer Overlay graph for the time variable.

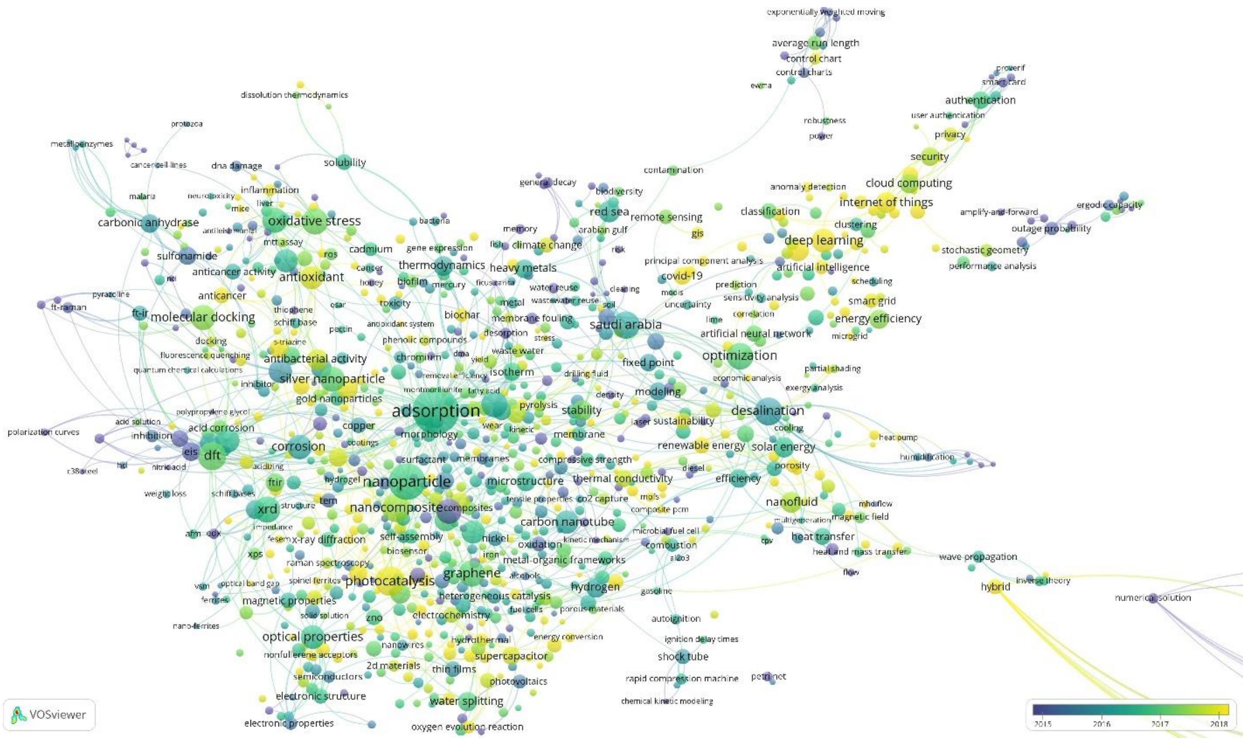

Fig. 9. Variation of occurrence of Author's keywords over time

Figure 9 shows that Author Keywords are likely to be indicative for terms that appear more frequently in new publications. I believe that it is the Author Keywords that are better suited for identifying emerging trends in scientific publications, and the Index Keywords are more interesting for identifying potential directions for expanding the application of results obtained in emerging trends.

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VOSviewer allows us to detect not only the change of key terms over time, but also to show the distribution of citations of publications in which a particular term occurs. In my opinion, in the available publications on bibliometrics this feature is rarely used, but it serves as an indirect expert assessment of the topics described by the terms given in this graph (Fig. 10).

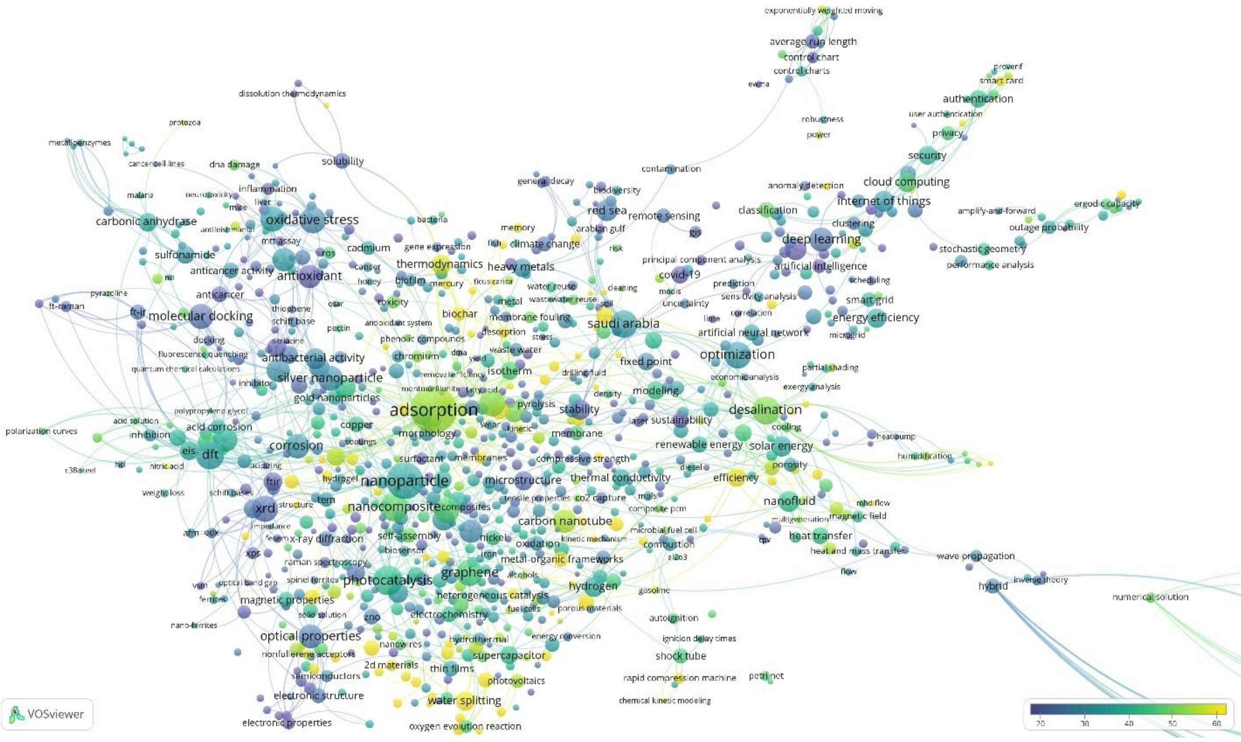

Fig. 10. Average Citation Rates of publications containing various Author keywords

The conjoint use of Figures 9 and 10 makes it possible to find keywords whose use is more common in new publications, and whose publications are highly cited. Figure 11 shows fragments of Figures 9 and 10 related to the term Visible light, which satisfies the above requirements.

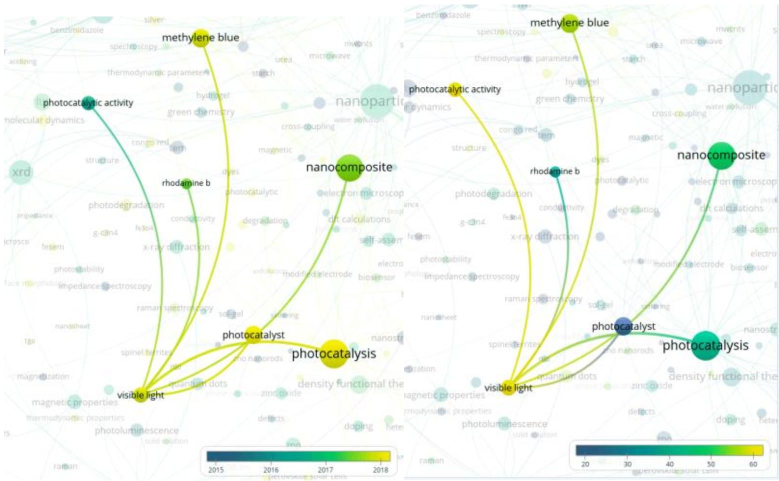

Fig. 11. The term Visible light. On the left is the occurrence over time,
on the right the average citation rate of publications with the given keyword.

The figure shows that the term Visible light is used in the context of the keywords Photocatalysis and Nanocomposites.

Figure 12 shows fragments of Figures 9 and 10 related to the term Chitosan, which satisfies only one requirement.

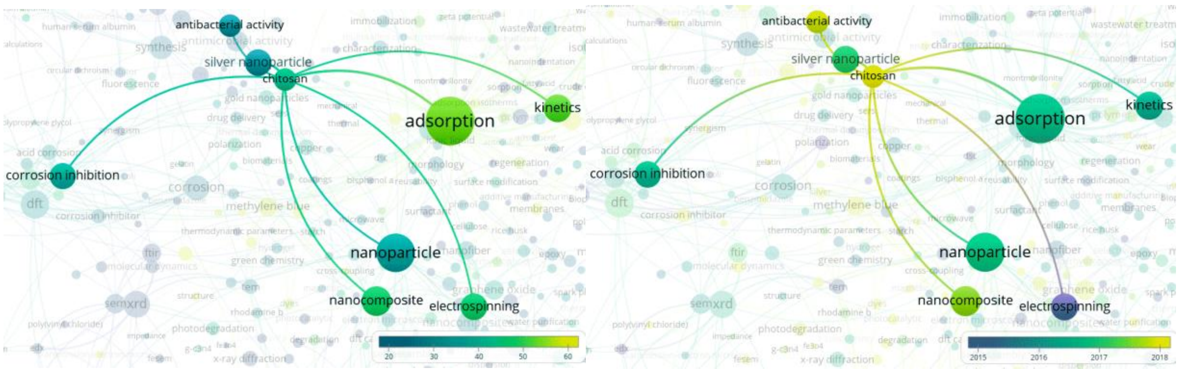

Fig. 12. The term Chitosan is often found in new publications,
but publications containing this keyword have an average citation rate.

As can be seen in Figures 11 and 12, using the average publication time of articles containing a given term (score_Avg_pub_year) and their average citation rate (score_Avg._citations) allows us to clearly assess possible research trends in scientific publications. The simplest formalization of the term selection process for such consideration may look as follows: we set a query to a file containing, for example, the Author's keywords and their score parameters. At the same time, we set restrictions on the threshold of occurrence of a key term, the average year of occurrence, and the average citation rate.

Let's look at an example result of such a query: select * from "Author KWs map csv" where "weight_Occurrences" > 10 AND "score_Avg_pub_year" > 2018 AND "score_Avg._citations" > 50.

Table 8: Some terms that satisfy the above query.

label	cluster	Weight Links	Weight Occurrences	Score Avg_pub_year	Score Avg._citations
mxene	1	23	21	2018.19	109.43
bending	2	10	16	2018.69	69.38
biochar	5	37	36	2018.03	68.00
co2 reduction	1	17	13	2018.15	67.77
vibration	2	8	20	2018.40	61.80
buckling	2	8	18	2018.89	58.89
nonfullerene acceptors	1	7	17	2018.71	57.53
dyes	5	28	17	2018.06	54.59
free vibration	2	7	18	2018.67	52.33
perovskite solar cells	1	11	17	2018.76	51.12
zinc	3	22	12	2018.17	50.75
composite pcm	2	14	11	2019.36	50.09

Some values are highlighted in yellow, by which terms can be selected for further, more detailed consideration of their role in describing research trends. The semantic significance of the selected terms can be determined using the description of the topics on the ScienceDirect platform:

- MXenes [https://www.sciencedirect.com/topics/materials-science/mxene]
- Biochar [https://www.sciencedirect.com/topics/agricultural-and-biological-sciences/biochar]
- Dyes [https://www.sciencedirect.com/topics/pharmacology-toxicology-and-pharmaceutical-science/dye]

The term composite pcm (phase change material (PCM)) is found in the most recent publications (Avg_pub_year 2019.36). Phase change materials are used to store thermal energy, which is the second most important task after electrical energy storage. Examples of papers exposing this topic are [8, 9]

The disadvantage of the considered approach is the use of Avg._citations indicator, which increases over time, to assess the importance of key terms it is more appropriate to use a normalized estimate of the average citation (Avg. norm. citations). It is also necessary to propose a graphical representation that is convenient for the final assessment of the importance of terms for the description of research trends.

Graphical representation of the final choice of terms to describe research trends

The structure of scientific research landscapes well reflects the overall picture of publication activity, clustering based on the co-occurrence of key terms makes it possible to identify the main areas in scientific research. The use of an overlay makes it possible to trace changes in the use of terms over time and determine the citation rate of publications containing certain terms. When analyzing trends in scientific publications, VOSviewer allows you to browse flexibly through particular areas of the scientific research landscape, as shown in Figure 5. and 7. But when compiling an analytical report based on bibliometric data, the interactivity provided by analytical platforms and programs is lost; moreover, the report should provide summaries highlighting the main conclusions of the bibliometric study. Therefore, it is advisable to supplement the overall picture of publication activity, relevant to the main query to the abstract database, with illustrations reflecting the main results.

In my opinion, in order to identify trends in the topics of scientific publications, it is advisable to reflect the following data on the final graph: key terms and their occurrence over time; the average normalized citation rate of publications containing the selected key terms. The above parameters can be retrieved from the data export files provided by VOSviewer. In such files, they are stored in the record fields: label, weight<Occurrences>, score<Avg. pub. year> and score<Avg. norm. citations>.

Thus, the final graph should reflect the four parameters and be two-dimensional for readability. Bubble charts meet these requirements and are further used to present the final results in Figures 13. and 14.

Given that different time intervals are characterized by the use of different key terms, and that too many bubbles in the graph make it unreadable, the bibliometric data were divided into two periods - before 2017 and after 2017 (horizontal axis).

The second parameter I used to limit the choice of terms for the final graph was the average normalized citation (vertical axis), which was taken above 1.0. Next, the 15 most frequent key terms were selected. Each term was represented by its color, and the size of each term corresponded to its frequency of occurrence in the sample.

The final graphs for Author keywords and Index keywords are shown in Figures 13 - 14 and Figures 15 - 16, correspondingly.

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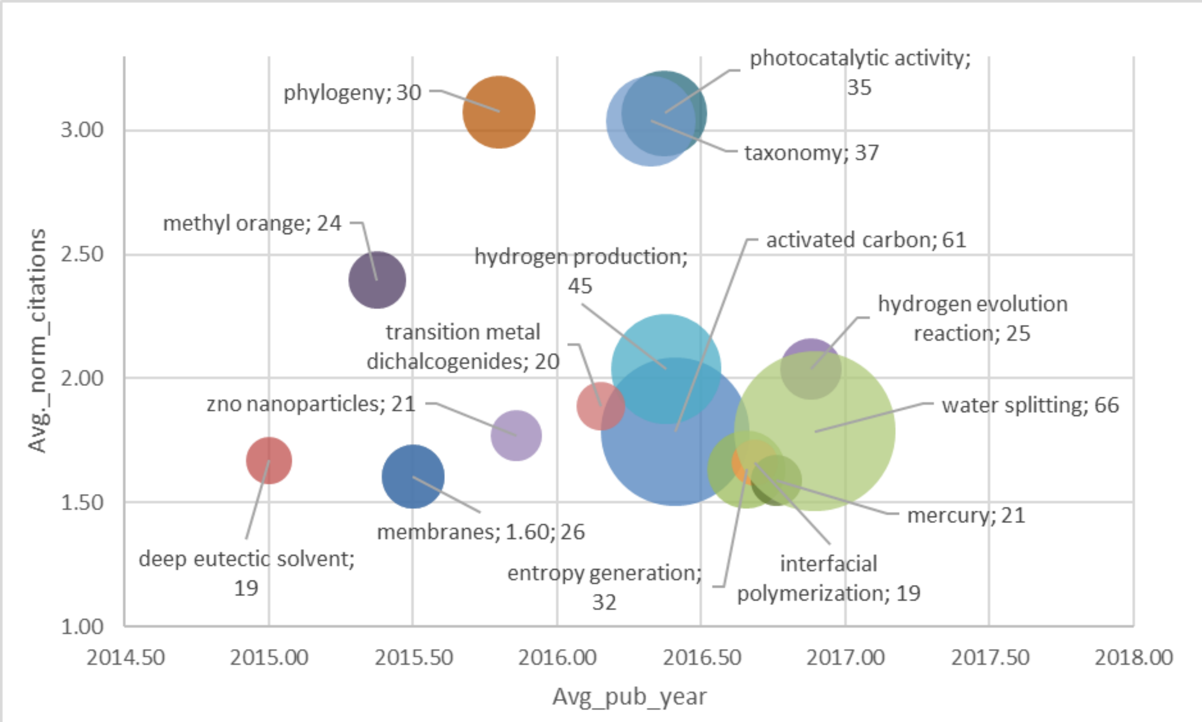

Fig. 13. The 15 most frequent and highly cited Author keywords for the time interval < 2017.

Water splitting, activated carbon and hydrogen production were the main terms in the publications and had an average normalized citation rate. Photocatalytic activity, taxonomy and phylogeny had the highest citation in the given time interval.

Examples of publications containing the Author keywords—Water Splitting:

- Photocatalytic Water Splitting: Quantitative Approaches toward Photocatalyst by Design [10]
- An Oxygen-Insensitive Hydrogen Evolution Catalyst Coated by a Molybdenum-Based Layer for Overall Water Splitting [11]
- Enhanced Photoelectrochemical Solar Water Splitting Using a Platinum-Decorated CIGS/CdS/ZnO Photocathode [12]
- Vertically aligned Ta_3N_5 nanorod arrays for solar-driven photoelectrochemical water splitting [13]
- Tungsten carbide nanoparticles as efficient cocatalysts for photocatalytic overall water splitting [14]

Definition: «In photoelectrochemical (PEC) water splitting, hydrogen is produced from water using sunlight and specialized semiconductors called photoelectrochemical materials, which use light energy to directly dissociate water molecules into hydrogen and oxygen»[5]

Examples of publications containing Author keyword — taxonomy. The context for the term taxonomy is not obvious, but the titles of the articles disclose it:

- Deep learning approaches for anomaly-based intrusion detection systems: A survey, taxonomy, and open issues [15]
- Constructing Features for Detecting Android Malicious Applications: Issues, Taxonomy and Directions [16]
- Internet of Things Architecture: Recent Advances, Taxonomy, Requirements, and Open Challenges [17]
- Survey of mobile device virtualization: Taxonomy and state of the art [18]
- Securing software defined networks: Taxonomy, requirements, and open issues [19]

[5] https://www.energy.gov/eere/fuelcells/hydrogen-production-photoelectrochemical-water-splitting

In Deep learning, Features extraction, anomaly detection — taxonomy is a structuring and conceptualization of data in a particular subject area, which allows to reduce the dimensionality of the task and increase the stability of the analysis results.

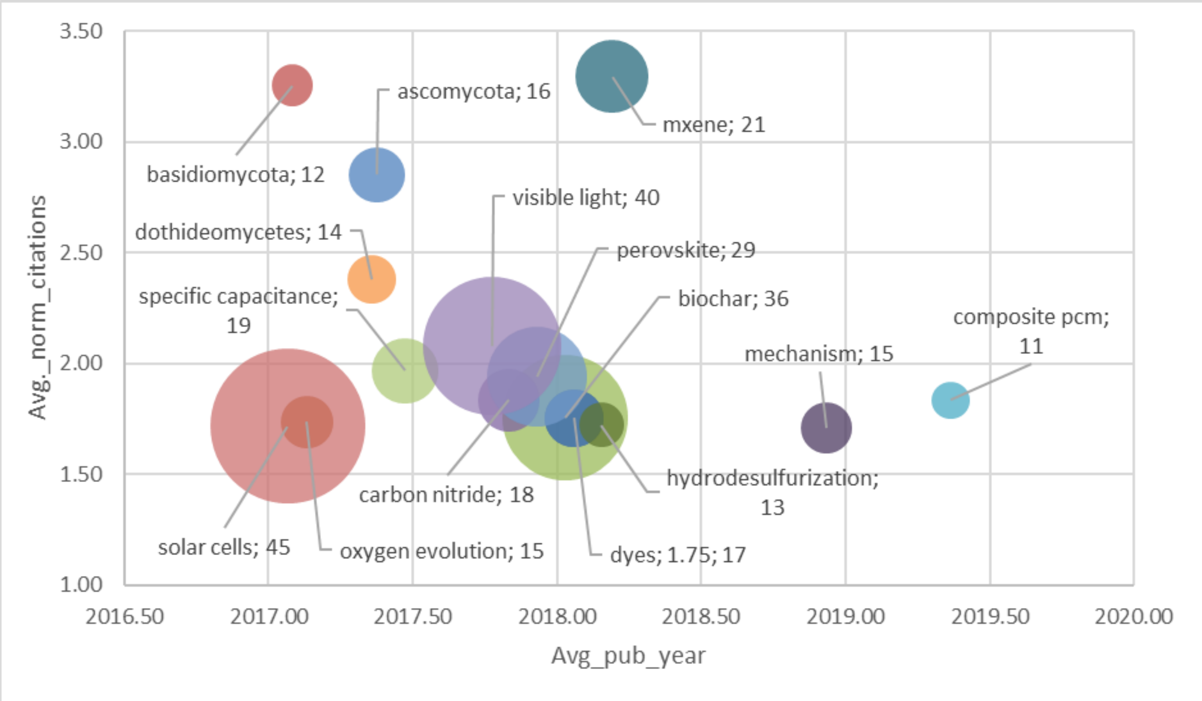

Fig. 14. The 15 most frequent and highly cited Author keywords for the time interval > 2017.

This time interval is most characterized by topics described by the keywords visible light, solar cells, perovskite, and biochar.

For identifying emerging trends in scientific publications, the terms Mxene and composite PCM are of most interest. The first is characterized by a high citation rate and the middle of the time interval, the second by an average citation rate, but the prevalence in newer publications.

Examples of publications containing the key term Mxene:

- Versatile N-Doped MXene Ink for Printed Electrochemical Energy Storage Application [20]
- Asymmetric Flexible MXene-Reduced Graphene Oxide Micro-Supercapacitor [21]
- Large Dielectric Constant Enhancement in MXene Percolative Polymer Composites [22]
- MXene Ti_3C_2: An Effective 2D Light-to-Heat Conversion Material [23]
- MXene-on-Paper Coplanar Microsupercapacitors [24]

Examples of publications containing the key term Composite PCM:

- Silica fume/capric acid-palmitic acid composite phase change material doped with CNTs for thermal energy storage [25]
- Preparation, characterization and thermal regulation performance of cement based-composite phase change material [26]
- Thermal characteristics of expanded perlite/paraffin composite phase change material with enhanced thermal conductivity using carbon nanotubes [27]
- Thermal energy storage characteristics of bentonite-based composite PCMs with enhanced thermal conductivity as novel thermal storage building materials [28]

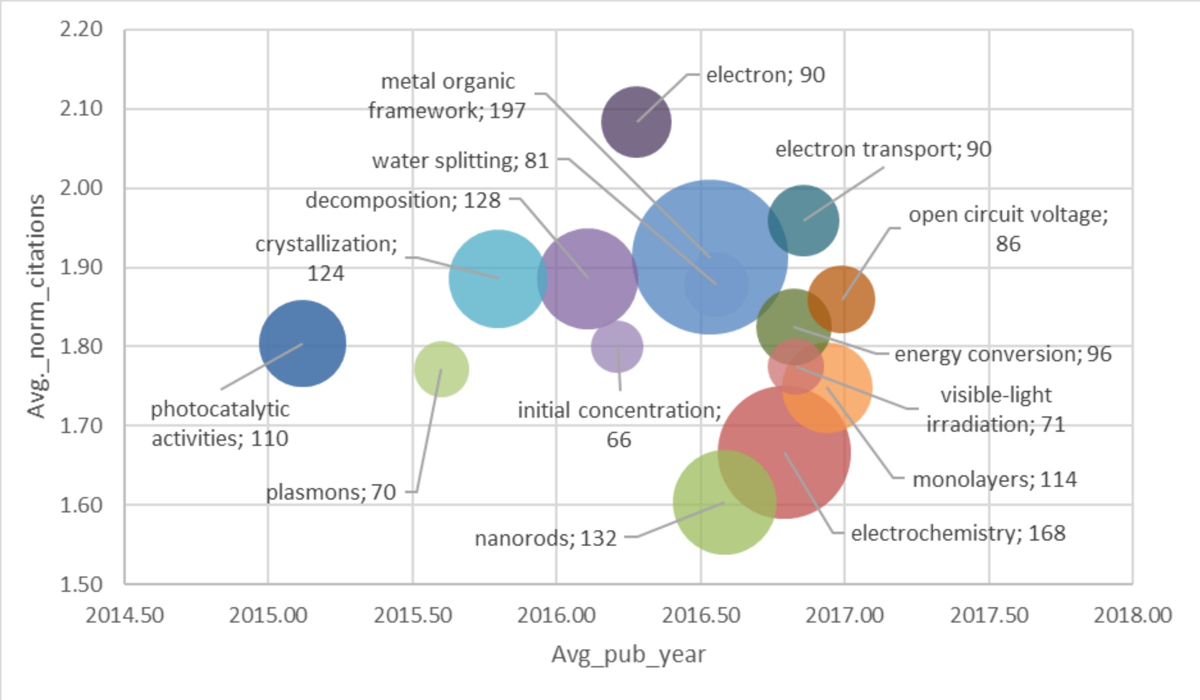

Fig. 15. The 15 most frequent and highly cited Index keywords for the time interval < 2017.

In this case, the main topics are described with the words metal organic frameworks, electrochemistry, monolayers, decomposition and crystallization.

Sample publications:

- A microporous metal-organic framework with naphthalene diimide groups for high methane storage [29]
- A microporous metal-organic framework with basic sites for efficient C_2H_2/CO_2 separation [30]
- Effects of structural crystallinity and defects in microporous Al-MOF filled chitosan mixed matrix membranes for pervaporation of water/ethanol mixtures [31]
- Light Hydrocarbon Adsorption Mechanisms in Two Calcium-Based Microporous Metal Organic Frameworks [32]

Electron and electron transport – terms that appear in the most cited articles.

Sample publications:

- Phototuning Selectively Hole and Electron Transport in Optically Switchable Ambipolar Transistors [33]
- Solution-Processed In_2O_3/ZnO Heterojunction Electron Transport Layers for Efficient Organic Bulk Heterojunction and Inorganic Colloidal Quantum-Dot Solar Cells [34]
- Hydrothermally synthesized titania nanotubes as a promising electron transport medium in dye sensitized solar cells exhibiting a record efficiency of 7.6% for 1-D based devices [35]

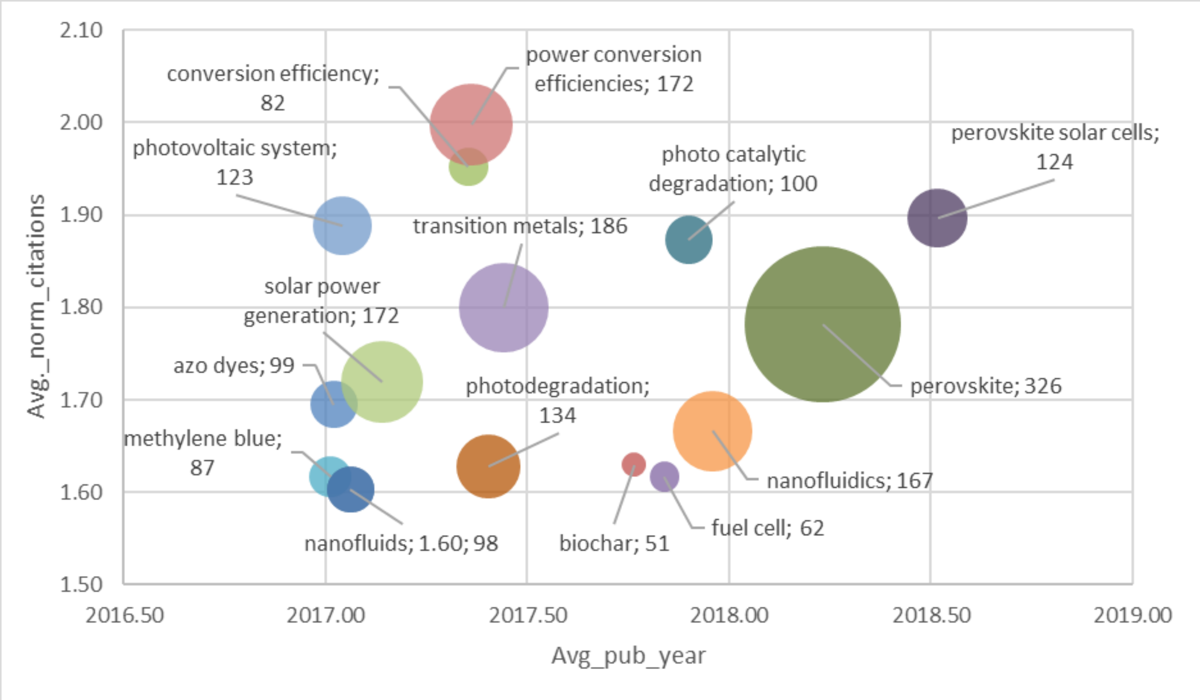

Fig. 16. The 15 most frequent and highly cited Index keywords for the time interval > 2017.

Perovskite, perovskite solar cells and power conversion efficiencies – highly cited topics well described by these Index keywords.

Sample titles of publications that reflect well on perovskite solar cells:

- Managing grains and interfaces via ligand anchoring enables 22.3%-efficiency inverted perovskite solar cells [36]
- Single-Crystal $MAPbI_3$ Perovskite Solar Cells Exceeding 21% Power Conversion Efficiency [37]
- Inorganic $CsPbI_2Br$ Perovskite Solar Cells: The Progress and Perspective [38]
- Phase Transition Control for High Performance Ruddlesden–Popper Perovskite Solar Cells [39]
- Highly efficient perovskite solar cells based on a nanostructured WO_3-TiO_2 core-shell electron transporting material [40]

Transition metals - it is advisable to disclose the use of this term in more detail, since its context is not obvious from the above chart. For this purpose, the publications in which the term Transition metals appears both in the Index keywords and in the titles of the articles have been picked.

Samples of article titles that give a good context for the term Transition metals:

- Synthesis and characterization of binary selenides of transition metals to investigate its photocatalytic, antimicrobial and anticancer efficacy [41]
- Heteroatom-doped magnetic hydrochar to remove post-transition and transition metals from water: Synthesis, characterization, and adsorption studies [42]
- Unraveling the role of entropy in tuning unimolecular vs. bimolecular reaction rates: The case of olefin polymerization catalyzed by transition metals [43]
- Complexation of trichlorosalicylic acid with alkaline and first row transition metals as a switch for their antibacterial activity [44]
- Molecule-Level g-C_3N_4 Coordinated Transition Metals as a New Class of Electrocatalysts for Oxygen Electrode Reactions [45]
- Liquid-phase exfoliated MoS_2nanosheets doped with: P -type transition metals: A comparative analysis of photocatalytic and antimicrobial potential combined with density functional theory [46]

From the list above we can see that the context for transition metals is the terms photocatalytic, antimicrobial and anticancer efficacy, olefin polymerization, and remove post-transition and transition metals from water which agrees well with the term photo catalytic degradation in Fig. 16.

Conclusions

A bibliometric analysis of scientific publications showing trends in scientific publications from leading universities in Saudi Arabia related to the energy transition was conducted.

The following universities were selected based on the presence of joint publications with the Saudi Arabian Oil Company they are: King Fahd University of Petroleum and Minerals, King Abdullah University of Science and Technology, and King Saud University.

According to data from the Scopus platform related to the subject areas: Physical Sciences, scientists from Saudi Arabian universities are increasingly publishing with co-authors from China, India, Egypt, Pakistan, and Malaysia, while maintaining a high level of interaction with co-authors from the US, South Korea, and the UK. Authors from the Russian Federation publish poorly with co-authors from Saudi Arabia.

A significant difference between the Scopus platform Index keywords and Author keywords has been shown, which should be taken into account when identifying trends in scientific publications.

The main subject areas of research are: Chemistry, Engineering, and Materials Science. Energy occupies a modest 4.5%. Computer Science (7.1%) and Mathematics (5.7%) indicate a significant role for digitalization in research at these institutions.

In recent years, the relative number of chemistry publications has declined, while engineering and materials science has taken the lead.

There has been a relative increase in attention to energy topics, reflecting the energy transition process, which requires new engineering solutions and materials (especially for renewable energy storage systems), as well as methods for optimizing performance in energy systems, which requires new computer science solutions.

Based on the co-occurrence of Index keywords, four sub-themes are identified, which can be briefly described by the terms:

- adsorption, catalysis, morphology, solar cells, thin films, heterojunctions, nanoparticle, carbon, nanocomposites, graphene, metal, chlorine compounds, zinc oxide, titanium dioxide, perovskite
- chemistry, metabolism, synthesis, drug synthesis, chemical structure, enzyme activity, oxidative stress, anti-infective agent, unclassified drug, animal, human cell, metal nanoparticles, antioxidant
- optimization, energy efficiency, energy use, internet of things, solar energy, carbon dioxide, polymer, water, membranes, silica, ethylene, fuel
- Saudi Arabia, wastewater treatment, seawater, wastewater, water management, bacteria, copper, nitrogen, zinc, aluminum, lead, biomass, organic compound

Shows the feasibility of using additional keyword ranking for <Avg.pub. Year> and <Avg. norm. citation> to identify promising areas of research.

The use of bubble charts to present the final results of bibliometric studies to identify emerging research topics has been proposed.

Based on the analysis, two areas of research that are advisable to study in more detail are: composite phase change materials (PCM) and MXenes - carbides and nitrides of transition metals, a fast-growing and already very large family of 2D materials.

In methodological terms, it is advisable to formalize in more detail the approaches proposed in the article to the graphical representation of the final data on the identification of promising areas of research and additional separation of keywords in the clusters by the categories Subject, Materials, and Methods.

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