

# Research Trends Analysis on Subject Materials Science for Energy Engineering by Scopus Data

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## ABSTRACT

**The objective of this article:** analysis of research trends on the topic "Materials Science for Energy Engineering" for the period 2012-2021.

**Materials and methods:** bibliometric analysis of data from the Scopus abstract database.

**Results.** It is shown that this topic is developing faster than the general energy topics.

The key feature of the research trends is a significant increase in work on the development of materials for renewable energy and a decrease in the number of publications related to nuclear power.

The primary goal of many studies is to increase the efficiency of renewable energy production through the use of new materials.

The importance of the topic is evidenced by the emergence of new journals that quickly entered the first quartile of the abstract databases Scopus and Web of Science, for example: ACS Applied Energy Materials.

There has been a significant increase of interest in perovskite solar cells, layered semiconductors, triboelectric nanogenerators, cobalt compounds, sulfur compounds, and oxygen and hydrogen evolution reaction during Electrolysis.

Publications on electric batteries are well represented in all time intervals. The focus is on electrode materials and battery efficiency.

**Keywords:** research topics, materials science, energy, Scopus, bibliometric analysis, trends, keyword clustering

## *Introduction*

The purpose of this work was:

- To analyze the significance of research on materials science for energy engineering according to the metadata of publications in the Scopus abstract database.
- To identify the major research trends in scientific publications on the specified topic based on keyword occurrence analysis.
- To demonstrate some methods of bibliometric analysis to solve the above tasks.

The relevance of the work is due to the ongoing energy transition to clean energy in all developed countries [1-3], supported by both well-funded national programs and international organizations, including the UN.<sup>1</sup>

Moreover, the energy transition is an essential component in the ongoing change in the economic paradigm [4-6] and forms new, fast-growing markets, the development of which requires a wide range of research works, the significance of which can be assessed using the metadata available in the leading abstract databases.

In the abstract databases of scientific publications, research related to the energy transition is most often classified under the subject categories "Renewable Energy Sustainability and the Environment".<sup>2</sup>

By analyzing the bibliometric data, it is possible to understand what scientific and engineering tasks are the most relevant for implementing of the energy transition to clean and affordable energy and what participation Russian researchers can take in their solution.

Such an analysis can be implemented using the metadata of the leading abstract databases Scopus, Web of Science, and the Lens. In this article, we mainly used the materials of the Scopus platform, which provides not only access to metadata but also to a significant number of full-text articles published by Elsevier. To reduce bias in our analysis, we will partially use data from the Lens database, in which the categorization of publication metadata by Fields of Study is close to the

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<sup>1</sup> <https://sdgs.un.org/goals/goal7> - Ensure access to affordable, reliable, sustainable and modern energy for all

<sup>2</sup> <https://www.elsevier.com/catalog?page=26&cat0=energy&cat1=renewable-energy-sustainability-and-the-environment> and <https://www.lens.org/lens/search/scholar/list?p=0&subject.must=Renewable%20Energy,%20Sustainability%20and%20the%20Environment>

categorization on the Scopus platform. It is convenient to use the data of this platform as complementary to the data of the Scopus system.

In the Lens, the subject category "Renewable Energy, Sustainability and the Environment" contains bibliometric data on 299,373 Scholarly Works (as of 03.03.2021). Table 1 shows the distribution of publications by the 20 most frequent Fields of Study values for the time interval 2012-2021.

**Таблица 1. Основные значения поля Fields of Study за 2012-2021 гг. по теме "Возобновляемая энергетика, устойчивое развитие и окружающая среда" по данным платформы the Lens**

**Table 1. Top Fields of Study for 2012-2021 for "Renewable Energy, Sustainability and the Environment" subject by the Lens platform data**

<b>Field of Study</b>	<b>Doc Count</b>	<b>Field of Study</b>	<b>Doc Count</b>
Materials science	99475	Waste management	16036
Chemistry	49385	Electrochemistry	15755
Chemical engineering	43525	Renewable energy	15231
Environmental science	37380	Sustainability	14728
Engineering	25962	Biomass	13262
Business	20064	Electrode	12917
Catalysis	19503	Electrolyte	12532
Inorganic chemistry	19412	Photovoltaic system	11233
Nanotechnology	16545	Optoelectronics	11211
Computer science	16303	Anode	11154

The Fields of Study "Materials science" dominates in the above subject area in the publications indexed by the Lens platform, which indicates its importance in solving engineering problems of the energy transition as well. [7-9].

This is mostly because of the importance of creating energy storage facilities for renewable energy. California's August 2020 electric "green blackouts" are a reminder that without clean energy storage, utilities are forced to enter spot markets for electricity produced from traditional sources. Without energy storage, new technologies cannot fully replace old ones. [10,11]

The relevance of Materials science topics is confirmed even by the names of journals related to the subject "Renewable Energy, Sustainability and the Environment" and included in Q1, as by Scimagojr.com. Examples of such journals are given in Table 2.

**Таблица 2. Список ведущих журналов по теме «Materials science for energy engineering»**

**Table 2. List of leading journals on materials science for energy engineering**

Title	SJR	SJR Quartile	H index
Advanced Energy Materials	9,513	Q1	186
Energy Storage Materials	5,044	Q1	54
Journal of Materials Chemistry A	3,432	Q1	185
Solar Energy Materials and Solar Cells	1,827	Q1	178
Materials Today Energy	1,653	Q1	22
Sustainable Materials and Technologies	1,355	Q1	18

Here: SJR - The SCImago Journal Rank indicator<sup>3</sup>. The very titles of the journals themselves testify to the importance of materials science in solving the problems of energy engineering.

### *Materials and methods*

Bibliometric materials for a detailed analysis of trends in publication activity on the topic Material Science for Industrial Energy were selected from the Scopus database. In the Scopus there are thematic filters "Subject Areas", allowing to form an actual query to a database, in our case filters Materials Science, Energy, Engineering and restriction on years of publication 2012-2021 were used. An additional filter Engineering was used to narrow the sample, for example, to exclude works closer to environmental or economic problems.

Query: SUBJAREA (ener) AND SUBJAREA (mate) AND SUBJAREA (engi) AND PUBYEAR > 2011 AND (LIMIT-TO (PUBSTAGE, "final") AND (LIMIT-TO (DOCTYPE, "ar"))) AND (LIMIT-TO (LANGUAGE, "English")) returned 28,674 document results. The query used additional restrictions to make the

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<sup>3</sup> [https://en.wikipedia.org/wiki/SCImago\\_Journal\\_Rank](https://en.wikipedia.org/wiki/SCImago_Journal_Rank)

sample more homogeneous and suitable for further analysis: language - English, document type - article ("ar"), publication status - "final".

The distribution of articles by year is as follows - YEAR (Doc count): 2021 (889); 2020 (5039); 2019 (4462); 2018 (4034); 2017 (3176); 2016 (2615); 2015 (2741); 2014 (2198); 2013 (1929); 2012 (1591).

The ratio of publications in 2020 vs 2012 is 3.17, which is slightly higher than the total increase in the number of publications in the Scopus database for these years for the entire energy subject - 2.6, indicating the relevance of our formulated query.

In addition to the frequency of occurrence of Fields of Study, keywords, and the number of publications in leading journals on the subject in question, this article studied the clustering of authors' and index keywords based on their co-occurrence. The clustering of terms makes it possible to distinguish topics within the collected bibliometric data. This procedure was performed using the VOSViewer software [12], a software tool for constructing and visualizing bibliometric networks, to cluster terms based on their co-occurrence.

For detailed bibliometric analysis, all data from Scopus for 2021, 2013 and 2012 were exported, for 2014-2020 - 2,000 most cited articles (limitation imposed by Scopus on data export) totaling 18,409 articles. For the general analysis, the files "Scopus\_exported\_refine\_values" were used, which contain summary data for the entire sample, including SUBJECT AREA and SOURCE TITLE fields.

### *Results and Discussion*

Table 3 shows the major SUBJECT AREA and SOURCE TITLE for all 28674 publications matching the query SUBJAREA (ener) AND SUBJAREA (mate) AND SUB-JAREA (engi) AND PUBYEAR > 2011 AND (LIMIT-TO (PUBSTAGE, "final")) AND (LIMIT-TO (DOCTYPE, "ar")) AND (LIMIT-TO (LANGUAGE, "English")).

**Таблица 3. 12 основных предметных областей исследований и названий журналов по данным всех 28674 публикаций**

**Table 3. Top 12 subject areas and journal titles for all 28674 publications' data**

SUBJECT AREA	N	SOURCE TITLE	N
Energy	28674	Nano Energy	5295
Engineering	28674	Fusion Engineering and Design	4759
Materials Science	28674	Nuclear Engineering and Design	4057

Physics and Astronomy	9431	ACS Applied Energy Materials	3159
Chemical Engineering	5149	Physica C Superconductivity and Its Applications	1689
Environmental Science	4946	Progress in Photovoltaics Research and Applications	1080
Chemistry	3938	Industrial Lubrication and Tribology	1025
Biochemistry, Genetics and Molecular Biology	1556	Fusion Science and Technology	854
Computer Science	1339	Solar RRL	795
Mathematics	656	Springerbriefs in Applied Sciences and Technology	656
Business, Management and Accounting	398	Pipeline and Gas Journal	636
Medicine	386	High Technology Letters	569

Energy; Engineering; Materials Science - are database query filters, so these topics apply to all 28674 publications.

Chemical Engineering, Chemistry, Environmental Science, and Computer Science are close in meaning to the data in Table 1. Although the classification is based on data from various abstract platforms. The Engineering filter was chosen to emphasize engineering tasks. If filters Chemical Engineering and Chemistry had been used, we would have received a different cross-section of data, but also relevant to the topic "Materials Science for Energy".

Table 4 presents the results of the analysis of trends in topic trends based on the distribution of author and index keywords (Author Keywords and Index Keywords fields) by year. Only the years 2014-2020 were considered, due to the strong change in keyword distribution in the years (2012-2013) compared to the years 2014-2020. Notations in the table: KeyWord = Author Keywords + Index Keywords, N - number of publications by year.

**Таблица 4. Распределение ключевых слов, встречающихся во всех публикациях за 2014-2020 годы, получено как внутреннее соединение исходных годовых таблиц**  
**Table 4. The distribution of keywords that occur in all publications for 2014-2020 is got as the inner join of the year-by-year tables**

KeyWord	N 2020	N 2019	N 2018	N 2017	N 2016	N 2015	N 2014
Efficiency	332	298	233	118	119	71	32
Lithium Compounds	299	231	216	82	77	72	23
Electrodes	269	224	240	246	196	171	46

Electrolytes	264	209	176	106	102	63	23
Cathodes	254	220	173	69	59	48	25
Anodes	229	216	159	82	65	67	43
Ions	215	226	204	115	99	76	26
Electrochemical Performance	201	143	119	58	42	52	36
Open Circuit Voltage	197	160	126	70	54	61	26
Thin Films	162	122	138	74	63	72	41
Carbon	161	147	137	90	88	98	31
Graphene	160	160	132	72	81	97	39
Nanotechnology	154	133	61	92	53	60	34
Energy Harvesting	151	170	86	72	40	35	18
Solar Cells	149	227	266	216	220	215	92
Titanium Dioxide	145	120	136	39	43	31	19
Electric Discharges	140	131	96	81	71	50	29
Lithium	136	87	107	176	130	122	53
Silicon	136	57	54	55	58	76	48
Scanning Electron Microscopy	132	120	123	55	60	53	48
Hydrogen	129	94	76	64	49	49	42
Magnetoplasma	123	169	125	160	111	89	50
Tokamak Devices	120	164	130	163	116	92	65
Nanoparticles	114	137	128	63	81	64	42

For the keywords Efficiency, Lithium Compounds, Electrolytes, Cathodes, there is an increase in the number of publications by over 10 times for 7 years and this despite the fact that the filter was Engineering not Chemical Engineering. The frequency of the keywords Solar Cells, Lithium, Tokamak Devices, Nanoparticles passed the stage of intensive growth.

A number of terms that occur frequently in publications in 2020 did not occur in the first 160 keywords in 2014 and 2015 and rarely in 2016, so we present them separately, comparing the occurrence in 2016 and 2020. The results for the 22 keywords that either rarely or not at all occur in 2016 but are widely used in 2020 are presented in Table 5.

**Таблица 5. Список терминов, которые часто встречаются в 2020 году и редко или совсем не встречаются в 2016 году**

**Table 5. List of terms that occur frequently in 2020 and rarely or not at all in 2016**

<b>KeyWord</b>	<b>N 2020</b>	<b>N 2016</b>	<b>KeyWord</b>	<b>N 2020</b>	<b>N 2016</b>
Perovskite	437	65	Electrochemical Electrodes	132	null
Perovskite Solar Cells	342	52	II-VI Semiconductors	131	null
Nanogenerators	190	null	High Energy Densities	128	null

Solid Electrolytes	173	null	Oxygen Evolution Reaction	115	null
Sulfur Compounds	169	null	Triboelectric Nanogenerator	112	null
Binary Alloys	167	null	Electron Transport Properties	111	Null
Morphology	163	null	Organic Solar Cells	109	Null
Lead Compounds	154	null	Lithium Batteries	108	Null
Nickel Compounds	152	null	Solid-State Batteries	107	Null
Supercapacitor	149	null	Copper Compounds	107	Null
Cobalt Compounds	136	null	Oxide Minerals	106	Null

There is a significant increase in interest in the topic described by the keywords Perovskite, Perovskite Solar Cells. The terms Nanogenerators and Triboelectric Nanogenerator did not appear in the top 160 keywords in 2016, and in 2020 the total number of occurrences of the term Nanogenerator and Triboelectric Nanogenerator reached 302.

The keywords containing the term Compound, which, unlike Lithium Compounds, did not appear in the top 160 keywords in 2016, are noteworthy: Sulfur Compounds (169), Lead Compounds (154), Nickel Compounds (152), Cobalt Compounds (136), Copper Compounds (107), Iron Compounds (103), Fluorine Compounds (93), Chlorine Compounds (91), Manganese Compounds (91), Selenium Compounds (88), Bismuth Compounds (76), Molybdenum Compounds (74), Zinc Compounds (74), Titanium Compounds (70), Bromine Compounds (69), Tin Compounds (68), Silicon Compounds (67), Sodium Compounds (66). Data format - keyword (occurrence in 2020).

The evolution of the general topic of the publications estimated by the Scopus query considered in the article can also be assessed by the number of publications in different journals. Table 6 shows the data for 10 highly cited journals well reflecting various aspects of research on materials science for energy.

**Таблица 6. Десять ведущих журналов по публикационной активности в 2020 и 2016 годах**

**Table 6. Top 10 journals by publication activity in 2020 and 2016**

Source Title	N 2020	N 2016
ACS Applied Energy Materials	1330	null
Nano Energy	1020	579
Fusion Engineering and Design	628	634
Nuclear Engineering and Design	430	431
Solar RRL	297	null

Industrial Lubrication and Tribology	124	91
Fusion Science and Technology	119	49
Physica C Superconductivity and Its Applications	113	145
Molecular Systems Design and Engineering	111	26
Progress in Photovoltaics Research and Applications	107	128

The increasing interest in the topic discussed in this article is confirmed by publications in ACS Applied Energy Materials, a Q1 journal published by the American Chemical Society, indexed by Scopus and WoS since 2018. The total number of journal publications in 2020 according to Scopus is 1364, of which 1330 satisfy our request.

Solar RRL is also not yet published in 2016 (previously published as Rapid Research Letters), but is now included in Q1 WoS and Scopus, with 297 of the 411 publications for 2020 included in our sample.

Nano Energy - for 5 years the number of publications increased from 579 to 1020, which indicates the growth of interest in nanotechnology in obtaining materials for energy.

In the journals Fusion Engineering and Design, Nuclear Engineering and Design, Physica C Superconductivity and Its Applications, and Progress in Photovoltaics Research and Applications, the publication activity in the subject we analyzed has not increased.

To assess the overall trend in changes in publication topics over the entire study period, a comparison (INNER JOIN) of the 1,000 most frequently used keywords between 2012-2016 and 2017-2021 was conducted; Table 7 shows the 45 terms with the highest growth over the period.

**Таблица 7. Ключевые слова с наибольшим темпом роста встречаемости в 2012-2016 и 2017-2021 годах**

**Table 7. Key words with the highest rate of increase in occurrence during 2012-2016 and 2017-2021**

<b>KeyWord</b>	<b>gain</b>	<b>KeyWord</b>	<b>gain</b>	<b>KeyWord</b>	<b>gain</b>
nanogenerators	17.94	bismuth compounds	6.50	organic polymers	5.07
layered semiconductors	15.44	metal organic framework	6.50	chemical stability	5.05
perovskite solar cells	11.74	ii-vi semiconductors	6.46	silicon compounds	5.00
oxygen evolution reaction	9.11	solid electrolytes	6.27	long term stability	4.92

triboelectricity	8.62	iron compounds	6.26	theoretical calculations	4.91
perovskite	8.45	hole mobility	6.00	cell engineering	4.88
cobalt compounds	8.18	positive ions	5.95	redox reactions	4.81
binary alloys	7.69	molybdenum com- pounds	5.91	electrocatalyst	4.67
sulfur compounds	7.64	coulombic efficiency	5.82	solid electrolyte inter- phase	4.62
triboelectric nanogen- erator	7.55	hydrogen evolution re- actions	5.69	thermo-electric materi- als	4.59
sodium-ion batteries	7.00	molecules	5.54	fullerenes	4.58
sodium compounds	6.84	selenium compounds	5.35	electrolysis	4.58
zinc compounds	6.82	density functional the- ory	5.34	transition metals	4.55
hydrogen evolution reaction	6.52	charge recombinations	5.18	power conversion effi- ciencies	4.55
organic solar cells	6.50	morphology	5.17	flexible electronics	4.48

The frequency of keywords nanogenerators, layered semiconductors, perovskite solar cells, oxygen evolution reaction, triboelectricity, perovskite, cobalt compounds, binary alloys, sulfur compounds, triboelectric nanogenerator, sodium-ion batteries have increased by 7 times or more during this period, which corresponds well with the results of Table 5. It should be highlighted that the diversity in the composition of samples for the construction of Tables 4, 5, 7 provides different slices of raw data, which makes the picture of changes in the topics of publications more diverse and sustainable.

The data in Table 7 can be helpful for a more detailed study of the dynamics of publication activity on more specific issues. For example, a precise query to the Scopus database: TITLE-ABS-KEY ("hydrogen evolution reaction") returns 14,608 document results, with only 121 papers published in 2012 and 3,125 in 2020. This means that the topic of "hydrogen evolution reaction" is developing rapidly and in a broader context than that of this article: Materials Science for Energy Engineering and, consequently, the work in this direction may be in high demand. In [13] an excellent overview of this topic is given.

In order to identify possible **emerging topics** for which keywords are still present in a few of publications, but whose occurrence growth is very high, it is necessary to maximize the list of keywords compared over the two periods under

consideration. Table 8 shows the terms that are rarely encountered, but are growing rapidly, according to the results of the analysis of 16,943 keywords.

**Таблица 8. 30 самых быстрорастущих ключевых слов из списка 16943 ключевых слов. Здесь  $N_n$  и  $N_o$ , соответственно, - количество публикаций за более новый и более ранний периоды**

**Table 8. Top 30 Fastest-Growing keywords from the list of 16943 keywords. Here  $N_n$  and  $N_o$ , respectively, are the number of publications for the newer and earlier periods**

KeyWord	$N_n$	$N_o$	gain	KeyWord	$N_n$	$N_o$	gain
Crystallinity	120	4	30.00	metal-organic frameworks	60	4	15.00
photocatalytic activity	110	4	27.50	reaction intermediates	55	4	13.75
lead compounds	329	13	25.31	mxene	40	3	13.33
wearable sensors	96	4	24.00	design for testability	66	5	13.20
ionic conductivity	67	3	22.33	ammonia	79	6	13.17
nickel compounds	264	13	20.31	chromium compounds	39	3	13.00
Nanogenerators	556	31	17.94	x ray scattering	38	3	12.67
hole transport layers	71	4	17.75	nanocatalysts	75	6	12.50
manganese compounds	153	9	17.00	faradaic efficiencies	62	5	12.40
image enhancement	49	3	16.33	oxygen vacancies	99	8	12.38
triboelectric nanogenerators	65	4	16.25	tio2 nanoparticles	37	3	12.33
electron transport layers	126	8	15.75	phosphorus compounds	107	9	11.89
layered semiconductors	247	16	15.44	small molecules	47	4	11.75
carbon nitride	77	5	15.40	sodium-ion battery	47	4	11.75
potassium hydroxide	122	8	15.25	perovskite solar cells	716	61	11.74

The degree of structural ordering of the material (crystallinity), photocatalytic activity, lead compounds and wearable sensors (a topic for medicine rather than energy, but new materials are needed to convert human activity into energy for such sensors) these may prove to be promising new research challenges.

Trends in research topics can also be assessed by comparing keywords that occur only in the metadata of publications for 2017-2021 but do not occur in 2012-2016, and vice versa. To limit the sample, a keyword occurrence threshold of 10 was used and then the 30 most frequent keywords in publications over the period were selected from these words. Tables 9 and 10 show the main keywords and their occurrence rate for the first and second cases, respectively.

**Таблица 9. 30 ключевых слов, которые наиболее часто появляются в новых публикациях, но не преодолели порог в 10 повторений в более ранний период**

**Table 9. Top 30 Keywords that appear frequently in new publications but did not pass the 10-occurrence threshold in an earlier period**

KeyWord	N	KeyWord	N	KeyWord	N
manganese compounds	153	iodine compounds	89	aluminum compounds	66
solid-state batteries	150	output performance	79	design for testability	66
electron transport layers	126	ammonia	79	triboelectric nanogenerators	65
potassium hydroxide	122	carbon nitride	77	halide perovskites	64
crystallinity	120	antimony compounds	76	co2 reduction	63
bromine compounds	113	alkalinity	76	silver compounds	63
photocatalytic activity	110	nanocatalysts	75	faradaic efficiencies	62
phosphorus compounds	107	ruthenium compounds	72	nitrogen compounds	61
oxygen vacancies	99	hole transport layers	71	metal-organic frameworks	60
wearable sensors	96	ionic conductivity	67	solid state devices	59

**Таблица 10. 30 ключевых слов, которые наиболее часто появляются в старых публикациях, но не преодолели порог в 10 повторений в более позднем периоде****Table 10. Top 30 keywords that appear frequently in older publications, but did not pass the 10-occurrence threshold at a later period**

KeyWord	N	KeyWord	N	KeyWord	N
experiments	208	critical currents	61	austenitic stainless steel	44
super capacitor	113	room temperature	59	josephson junction devices	43
algorithms	110	high temperature superconducting	53	magnetization	43
three dimensional	100	sodium cooled fast reactor	52	high-t	42
heavy water reactors	69	tio	48	safety analysis	41
critical current density	67	alloys	48	research reactors	41
experimental data	65	zirconium	45	reconfigurable hardware	40
superconducting films	63	mathematical models	45	cuprates	39
flow rate	63	vapors	45	journal bearings	39
iron-based superconductors	62	lubricating oils	45	superconducting devices	39

The above results on the discovery of trends in scientific publications were mainly based on the analysis of keywords for the query in question. A list of related words can better describe the topic than individual keywords. Words can be clustered using methods based on their co-occurrence. In this paper, keyword clustering was performed using free software VOSviewer [14] (a software tool for constructing and

visualizing bibliometric co-occurrence networks). Bibliometric data were grouped for three two-year periods - 2015-2016, 2017-2018, and 2019-2020. Each group included 4,000 records, which was sufficient to obtain six stable clusters. Tables 11-13 represent each of the 10 keywords and their occurrence for three of the six clusters with the highest number of co-occurring keywords. Each of the tables reflects data for a two-year interval. The most frequent keyword was used as the field name of the corresponding column of the table. This approach allows us to trace the changes in the position of the keyword cluster over time. It should be noted that the order of occurrence and even the 10 terms under consideration change over time in the cluster.

**Таблица 11. Три кластера с наибольшим количеством ключевых слов за период 2015-2016 гг.**

**Table 11. The three clusters with the highest number of keywords for the 2015-2016 period**

<b>solar cells</b>	<b>418</b>	<b>electrodes</b>	<b>355</b>	<b>nuclear reactors</b>	<b>193</b>
efficiency	181	lithium	244	heat transfer	174
silicon	130	electric batteries	180	design	172
thin films	122	graphene	172	tritium	155
solar power generation	120	carbon	170	tokamak devices	153
open circuit voltage	113	ions	162	computational fluid dynamics	152
deposition	101	electrolytes	160	finite element method	151
silicon solar cells	95	lithium-ion batteries	155	magnetoplasma	151
perovskite	92	lithium compounds	149	heat flux	150
power conversion efficiencies	92	secondary batteries	142	fuels	128

In this period, solar cells dominate, and the term perovskite is still quite rare. Nuclear power is well represented in the third cluster.

**Таблица 12. Три кластера с наибольшим количеством ключевых слов за период 2017-2018 гг.**

**Table 12. The three clusters with the highest number of keywords for the 2017-2018 period**

<b>electrodes</b>	<b>418</b>	<b>solar cells</b>	<b>401</b>	<b>heat transfer</b>	<b>124</b>
ions	250	perovskite	321	nuclear reactors	112
lithium-ion batteries	236	efficiency	277	breeding blankets	107

electrolytes	235	perovskite solar cells	277	computational fluid dynamics	106
lithium compounds	231	power conversion efficiencies	219	magnetoplasma	103
lithium anodes	222	solar power generation	187	tokamak devices	98
cathodes	207	open circuit voltage	170	tritium	93
electric batteries	194	temperature	166	fuels	88
carbon	193	heterojunctions	157	scanning electron microscopy	88
	182	thin films	157	thermal conductivity	88

This period is characterized by the fact that the topic of batteries and electrolysis begins to prevail over that of solar cells. Nuclear power remains well expressed in the third cluster, but more attention is paid to the specific task of heat transfer.

**Таблица 13. Три кластера с наибольшим количеством ключевых слов на период 2019-2020 гг.**

**Table 13. The three clusters with the highest number of keywords for the 2019-2020 period**

<b>perovskite</b>	<b>484</b>	<b>nanogenerators</b>	<b>346</b>	<b>lithium-ion batteries</b>	<b>322</b>
perovskite solar cells	399	triboelectricity	305	electrodes	299
efficiency	368	energy harvesting	247	lithium compounds	292
power conversion efficiencies	333	nanotechnology	234	electrolytes	285
open circuit voltage	241	nanogenerator	225	cathodes	282
solar cells	222	triboelectric nanogenerator	195	anodes	266
lead compounds	191	cost effectiveness	139	ions	257
stability	183	piezoelectricity	104	graphene	207
solar power generation	182	wearable technology	98	electrochemical performance	206
heterojunctions	179	fluorine compounds	91	solid electrolytes	176

In the last period under consideration, the topic of nuclear power is no longer included in the first three clusters; this place is now occupied by the topic of batteries and electrolysis. The first cluster is dominated by the specific implementation of solar panels - perovskite solar cells. The term perovskite appears 467 times in 2020 and 102 times in 2017, a fourfold increase in the number of publications containing the term perovskite over four years. Во втором кластере начинает доминировать новая тема - triboelectric nanogenerator.

Таким образом, выявлена нарождающаяся тема triboelectric nanogenerator, которая может представлять интерес для дальнейших исследований как для специалистов в области материаловедения и инженерных решений, так и для электропитания носимых датчиков, см. таблицу 8.

The decrease in attention to the topic of materials science for nuclear energy can be explained by the fact that the main funding in the EU, USA and China is aimed at the development of renewable energy. This emphasizes that bibliometric studies are a good reflection of political and economic interests in R&D. It should be noted that in recent years the term renewable energy has been increasingly replaced by clean energy, which includes nuclear energy.

### *Summary and Conclusions*

The topic "Materials Science for Energy Engineering" considered in the article has been steadily developing during the whole period under study, which is reflected in the bibliometric data of scientific publications. The great attention paid to the development of renewable energy is reflected in the fact that there is a significant increase in the number of studies on materials engineering for clean energy tasks, so this topic may have a good prospect for investment in this area of R&D. Emerging areas of research have been identified, an example of this is the triboelectric nanogenerator. The interest in research related to nuclear energy is decreasing - the main funding is going to renewable energy development. The author's private opinion, based not only on the analysis done in this article, is that the production of materials for clean energy is very power-consuming, and in this regard, a sustainable nuclear power industry can be both a reliable energy resource and a base for the development of new materials for clean energy, due to the significant research work done by nuclear industry in previous years, which will allow Russian researchers to take a good position in the global energy world.

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