INTERNATIONAL JOURNAL of RENEWABLE ENERGY RESEARCH
Nykyruy et al., Vol.8, No.4, December, 2018

Impact of Advanced Research on Development of Renewable Energy Policy: Case of Ukraine (Review)

G. Wisz*, L. Nykyruy**‡, V. Yakubiv***, I. Hryhoruk***, R. Yavorskyi****

*Department of Experimental Physics, Faculty of Mathematics and Natural Sciences, University of Rzeszow, al. Rejtana 16c; Subcarpathian Renewable Energy Cluster, 35-959 Rzeszow, Poland;

**Department of Physics and Chemistry of Solid State, Physical & Technical Faculty, Vasyl Stefanyk Precarpathian National University, 57 Shevchenko Str., Ivano-Frankivsk, 76018, Ukraine

***Department of Management and Business Administration, Institute of Postgraduate Education, Vasyl Stefanyk Precarpathian National University, 57 Shevchenko Str., Ivano-Frankivsk, 76018, Ukraine

**** Department of Physics and Chemistry of Solid State, Physical & Technical Faculty, Vasyl Stefanyk Precarpathian National University, 57 Shevchenko Str., Ivano-Frankivsk, 76018, Ukraine; Department of Experimental Physics, Faculty of Mathematics and Natural Sciences, University of Rzeszow, al. Rejtana 16c; 35-959 Rzeszow, Poland

(gwisz@ur.edu.pl, lyubomyr.nykyruy@gmail.com, yakubiv.valentyna@gmail.com, ira.hryhoruk@gmail.com, roctyslaw@gmail.com)

‡ Corresponding Author: Lyubomyr Nykyruy; Vasyl Stefanyk Precarpathian National University, Tel: +380956991785, lyubomyr.nykyruy@gmail.com

Received: 04.11.2018 Accepted:28.11.2018

Abstract- Modern research in the field of renewable energy determines the directions of practical implementation of different energy sources. The possibility of rapid practical application of such results is crucial for economic growth. The paper critically analyses the advanced publications as the results of fundamental researches for different directions of renewable energy and identifies the key points that have influenced the practical development of each of these areas. It is shown how scientific research in different countries after the practical implementation affects their economic development. The key players in the global renewable energy market have been determined. Among low-income economies, Ukraine has been considered as a country that has at the same time almost blank market for renewable energy and a high-level research potential based on a large number of universities and research institutes. The example of Ukraine shows two problems typical for countries with a weak economy: (1) the existence of a large gap between the results of scientific research and the possibility of their implementation; (2) the availability of advanced results in the directions that, due to the need for significant investments, are very difficult to be implemented practically (materials science for solar power, thermoelectricity, new types of batteries, etc.) and almost no research in the industries that are intensively developing and are potentially economically profitable (biofuels, bioenergy from agricultural waste, wind energy). Such data can help foreign companies to enter the Ukrainian market or facilitate the commercialization of research results of Ukrainian scientists.

Keywords Renewable energy, energy policy, h-index, sustainable development, Ukraine.

1. Introduction

Energy has been one of the basic human needs and now with the increasing the dependence of human life style on energy, this need becomes a key role for civilization development. Therefore, supplying a sustainable, clean, secure and available energy is one of the main challenges of the present century. Unleashing the potential of renewable energy should be a strategic priority for each state. This has several reasons.

- Ecology [1,2]. Combustion of fossil fuels results in the release of a significant amount of harmful substances that pollute the environment or increase the greenhouse effect through uncontrolled emissions of heat. The natural resources burned for energy are exhaustive and non-renewable; therefore their burning leads to a negative impact on environment and nature.

- Security [3]. Only a certain number of states have sufficient natural resources that can be used to generate electricity through their combustion. Other states have to buy the large amount of electric energy, as well as gas and oil. At the same time, they completely depend on the political influences of these states. Thus, energy security becomes a strategic issue for every state. However, it should be kept in mind that renewable energy can only contribute to security, but not solve it.

- Economics, politics [4-8]. Purchasing energy and power by non-producing countries is not economically viable. Therefore, a shift toward renewable energy sources will help to limit a support value necessary for growth and transformation of energy transmission systems that require urgent modernization and introduction of intelligent and optimal energy management [9].

Accordingly, every state today is trying in various ways to promote the introduction of renewable energy sources. On the one hand, there should be different incentives to introduce such technologies. On the other hand, it is necessary to involve science through supporting scientific research in significant fields.

Moreover, not only individual states want to ensure their energy security and independence, but also these processes are actively developed by international structures such as the EU, NATO, etc. [10-12]. For example, the EU Horizon 2020 program has a special direction for “Energy”, “Security”, and “Nanotechnologies, Advanced Materials, Advanced Manufacturing and Processing, and Biotechnology” that promote research and innovative business also towards the development of renewable energy.

Analysis of research provides information to identify factors that influence the global spread of renewables. Only high-quality research is being considered here. The results of such studies are published in high-level scientific publications and can be quoted by other researchers. This paper investigates publications in journals, which are indexed by Scopus and WoS international scientific and metric databases. These bases place high demands on scientific journals, which, in turn, is a guarantee of the quality and reliability of the published material. The websites of these science-metric databases provide the opportunity to process a large amount of statistical information, the analysis of which enables the implementation of professional forecasts.

2. Research Methods

At the first stage of research a global analysis of published scientific papers was performed. For this aim the publications were selected based on the keywords (tags) "Energy", "Renewable Energy", "Solar Energy", "Wind", "Geothermal energy", "Biofuels and Bioenergy", "Thermoelectric energy". The analysis was carried out according to the following criteria: year of publication, countries of authors, scientific direction (profile) of publication, the most cited publications and the most cited authors in the every research area. It is clear that making conclusions only by the specified keywords would be incorrect. It should be borne in mind that searching a keyword “Energy” will often give results, for example, related to energy states in crystals or energy of ionizing radiation. And under the term "Solar energy" there will be many publications related to astronomy and astrophysics. The term "Bioenergy" can often be related to human medicine and physiology, and so on. To avoid this, the rejection of unnecessary results was made in two ways: (I) searching for the statistical regularity of the frequency of published works on the specified keywords, but not related to energy; (II) adding to each of the keyword a number of additional keywords that refine the search.

For the first method (I), such parameter as a number of papers that do not correspond to the topic per hundred of publications was taken into account. All materials were not looked through, because only the tag "Energy" shows 3,935,988 publications on May 2018. Therefore, analysis were made on the first hundreds of the most cited publications (which became the foundation of research in this area) and on the first hundreds of the newest publications (which probably will determine the industry's development in subsequent years).

As for the second method (II), an alternative search with similar words was performed, as well as a search using the multiplication keywords tool.

Another approach used by the authors is the definition of a certain normalized h-index for comparing the link between a number of publications on each tag and the quality of published materials (h-index by tag). Here the increment of publications over the years is taken into account and the theoretical curve is constructed, which is superimposed on the schedule of such growth. The statistical analysis packages allow the equation of this theoretical curve to be obtained. The nature of these equations has made it possible to establish the basic patterns of the development of the interest of the scientific community in researching certain types of renewable energy and to determine the peak stages of the growth of such interest. It can be explained by various factors: the creation of fundamentally new approaches / technologies / materials or the adoption of relevant legislative acts, contributed to deepening economic interest in the development of certain areas.

At the last stage a similar rankings for authors from Ukraine was conducted. This enables to compare the growth rates of interest in research of different types of renewables in the world and in Ukraine. In particular, the comparison of h-index (h_{glob} / h_{ukr}) in certain areas in the world and in Ukraine was done, as well as the total amount of publications (N_{glob} / N_{ukr}) was compared, taking into account the correlation coefficient A. The growth of interest in certain directions of renewable energy in Ukraine and in the world was compared. The most important scientific results that have become the determining milestones of their development were shown.

Although Ukraine as one of the largest states in Europe is interested in strengthening stable prospects for economic growth, it is slowly introducing new ideas and technologies. Ukraine has a great demographic and industrial potential. Therefore, such analysis may be interesting both for researchers and industrial companies to develop cooperation directions and enter a new and promising market. And if we take into account a large number of energy-intensive enterprises (metallurgy, coal, chemical technologies), then, in the context of the state's commitment to gradually shift to clean energy, the renewable energy market in Ukraine is economically attractive and promising.

Another important type of renewable energy sources is a small hydroelectric station (up to 10 MW) [8]. However, the analysis of publications on the "Small Hydro Energy" tag has not been carried out for several reasons: the main emphasis in this paper was made on the renewable energy market analysis in Ukraine, where there are still public discussions on the feasibility of the implementation of small hydroelectric power stations and there are no research organizations in this field.

Therefore, "Hydro Energy" is provided for informational purposes only in graphic illustrations to take into account and to more fully analyse all important types of renewable energy sources. In addition, scientific approaches are more peculiar to the study of hydro power stations of high power. And the term "small hydroelectric" is often used in studies related to its impact on ecosystems, rather than technical characteristics: the problem of water purification, support of fish populations, etc., or through modelling the influence of weather factors on its development [13].

3. Analysis of The Results

3.1. Global renewable energy state of art.

An analysis of publications for the "Energy" tag requires careful consideration in the study. On the one hand, Scopus database has 3,935,988 publications for the entire period. But as it was mentioned above, not all publications are related to energy generation or conservation issues. Moreover, only a certain part corresponds to the direction of Renewable / Alternative Energy [14]. Therefore, first and foremost, it is important to highlight a group of "Renewable Energy" publications and divide it into specific areas. For ease of this analysis, we introduced a coefficient R (named as ratio of publications relevance for a particular direction). It was introduced using the following algorithm:

1) The analysis of the first 10 hundred publications in Scopus, which are sorted by quotation from the highest, is performed. A number of publications relevant to any process or research on traditional and renewable energy is selected. All other publications are dissipated (atomic energy, energy in astrophysics, medicine, rehabilitation, psychology, etc.).

2) The analysis of the first hundreds of publications in Scopus, which are sorted by the date of publication from the latest, is done. Here too, a sampling of publications as in paragraph 1 is carried out.

3) The proportion of relevant publications is allocated from their total number.

$$R = N_{rel} / N, \quad (1)$$

so that N_{rel} is the number of publications that correspond to the given topic (in this case, traditional and renewable energy) displayed as a result of the search, and N is the total number of publications displayed by the name of the selected tag.

A similar procedure is carried out according to other tags that correspond to the key directions in renewable energy research. The results are shown in Table 1.

Several important conclusions can be drawn from the table. The coefficient R = 1 is possible in a very idealistic case, where the name of the key tag will fully correspond to a specific and unique process. Such case is ideal and cannot be practically implemented, but in certain directions the value can be very close to 1.

As expected, the largest deviation from 1 is observed for the "Energy" tag. The analysis of the most cited and most recent publications of value R turned out to be different. This can be explained by the following considerations. The most cited works are papers that describe fundamentally new approaches or models or start a new direction of research.

Table 1. Relevance ratio of publications by directions

No	Direction	R_1 (by citation)	R_2 (by last years)
1.	Energy	0.47	0.68
2.	Wind energy	0.61	0.94
3.	Solar energy	0.84	0.91
4.	Biofuel energy	0.99	0.98
5.	Geothermal energy	0.88	0.97
6.	Thermoelectric energy	0.92	0.88

For the case of the "Energy" tag, it turned out that the most cited works were publications that describe the basic principles of *ab initio* calculations [15-17] or other theoretical calculations of electronic states [18,19]. This is understandable, since the principles given in these works became the basis of the mathematical apparatus of modern theoretical physics. Only the tenth in citation article [20] corresponds to the studied direction and contains 21,141 citations. Therefore, the relevancy ratio of 0.47 is real.

With regard to the relevance rate for the publications that were analyzed as the newest, the coefficient R increased to 0.68. This indicates a general growth of scientific interest in the energy issues. In this case, it is connected to the renewable energy sector, since renewable energy increasingly replaces the traditional one, which is based on the combustion of resources with the release of substances harmful to the environment, flooding of territories or the use of nuclear power stations. It reflects the general trend introduction of new ideas which will contribute to the overall improvement of the environmental and energy situation in the world.

As for other tags, several important patterns were found there. The coefficients R for the "Wind Energy" tag are very different. A rather low coefficient of 0.61 for the coincidence of publications with a high number of quotes is due to the presence of papers on the topics of astrophysics, describing processes in large space objects, the movement of galaxies, etc. [21, 22].

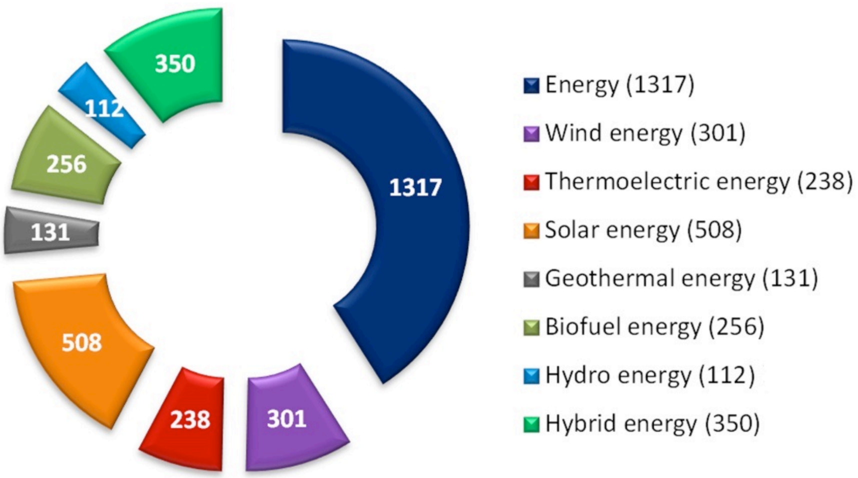
Moreover, a lot of publications are related to not directly generating electricity from wind, but physics and mechanics of individual parts of wind turbines that are used and cited in other directions (for example, "Solar Energy"), and bear on materials for accumulators or engine construction [23]. But in recent years the issue of transformation of wind energy into electric power has become most relevant for this search query. Here we should mention the design features of new models of wind turbines and their systems [24, 25], the environmental issues of their work [26, 27], as well as calculations of economic efficiency [28]. An important factor is that wind energy is one of the most commonly used type of renewable energy that is already actively produced and spread greatly each year in different countries. Thus, in 2015, 432 680 MW of wind power was produced in the world, and in 2016 it was 486 749 MW [29]. The cost of such electricity is also reduced. In particular, in 2018 it is planned to launch stations at the coast line at USD 0.04 / kWh [30]. There are more journals devoted to issues of wind power generation compared to astrophysical topics. Although astrophysical subjects are more cited, much smaller number of researchers studies them.

A similar picture is observed for the research of solar energy. Unlike other studies, it is combined into a single tag called "Solar Photoelectric / PV" and "Solar Heat Energy". Physics of these processes is fundamentally different, however, for them there is a common source of free energy – the Sun. The difference in this case between R_1 and R_2 is smaller, but there is a stable deviation of their values from 1. We can see that the transformation of solar energy into electricity or heat, which would be useful to humans, has been much more interesting for researchers. Now these amounts have stabilized on certain proportional to the number of publications values (0.84 and 0.91) in relation to other publications on these tags. Other areas of research include astrophysical (processes on the Sun), aerospace [31] and "clean" geographic and ecological studies [32]. Although values close to 0.9 indicate a high impact of solar energy research, supported both by government mechanisms in different countries and by business, for which innovation is both a commercial and a public success [33].

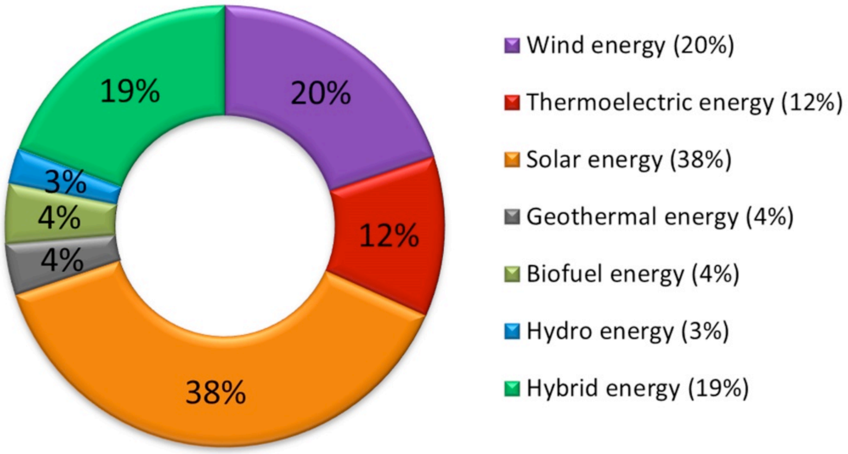
The other two tags for "Biofuel Energy" (including agro-biofuels, biomass, etc.) and "Geothermal Energy" refer to those types of renewable energy, which are now successfully implemented in practice and have scientific justification, but the quantity of produced energy is significantly less than Solar Energy and Wind Energy [34]. However, information about them is an integral and important part of all current reviews and reports [10, 29, 30]. As for Biofuel Energy, there are very close values of R_1 and R_2 (0.99 and 0.98, respectively). This indicates a clear thematic focus of such publications. With regard to Geothermal Energy, the relevance of publications in accordance with the theme of renewable energy in recent years is quite high and it is 0.97. Lower value among the number of the most cited publications in this area can be easily explained by studies in geology or science of the Earth.

This review proposes to consider another type of renewable energy – "Thermoelectric Energy". Although it has not been attracting a lot of attention of scientists, the thermoelectric industry is becoming more and more powerful. In particular, 557 organizations (universities, research centers and companies from around the world) took part in the 36th International Conference on Thermoelectricity ICT2017 (Pasadena, CA, USA: https://www.usasymposium.com/ict/who.php). Individual participants were much more. And, as it will be shown below, the number and quality of publications on this topic is one of the decisive one in the direction of renewable energy sources. Only for this direction value of R_1 is higher than R_2. That is, the most cited publications form the bulk of the other possible materials. For example, when we investigate materials or effects that could be optionally used for the production of thermoelectric energy, but they themselves are intended for other purposes [35, 36]. Today the practical possibility of direct conversion of heat into electricity without the use of complex mobile mechanisms and without special combustion of raw materials is an important economic and environmental factor [37, 38]. And the number and quality of publications in this direction grows annually.

Another interesting example is that until the 1970s, the number of publications on individual areas of renewable energy was about a dozen of publications per year. Since the beginning of the 1970s, the situation has changed and there has been initially smooth growth, and from 2001 to 2008 there has been a rapid nonlinear increase in the number of publications. That is, since then, the awareness of the global community to the topics of the exhaustion of natural resources and the need to reduce emissions into the environment has been growing [39].



a)



b)

Fig. 1. The total h-index (a) and the total number of publications in percent (b) related to energy in general and the separate types of renewable energy sources.

Accordingly, it is important to analyze the quality of publications, which is determined in the scientific community by the number of their citations. Fig. 1 shows the relation between the h-indexes of publications in the direction of renewable energy and power engineering (Fig. 1, a) and the number of publications in the separate directions of renewable energy (Fig. 1, b).

The total number of publications for the tag "Energy" is not taken into account, because this number includes, among other things, the number of publications for all types of renewable energy and it is significantly higher. This complicates the adequate perception of graphic material.

For this analysis, another additional tag "Hybrid Energy" has been considered, as very often today existing renewable energy systems are to be improved through a combination of different mechanisms in a single complex [40-43]. This allows us to get a system with significantly higher efficiency compared to the efficiency of each individual system at a lower cost. For two separate systems, the total efficiency can be higher, but their cost will be much higher than the hybrid system, which makes the use of two such systems separately economically unprofitable.

If we consider the separate directions, it is clearly seen that the tag "Solar Energy" has the highest value of both the citation and the number of publications: h = 508 (or 38%) of the total number of publications on the subject of renewable energy. The tag "Wind Energy" has very close indicators on both parameters (h = 301, or 20%), the same is this "Hybrid Energy" (h = 350, or 19%). Such values for these tags are clear and predictable. Solar and wind energy are decisive from an economic point of view and they were the first to be massively introduced [30]. The main publications are devoted to the high-tech sphere concerning fundamentally new ideas, which stimulate a new stage of the industry development. Thus, in [20], the possibility of developing cheap and commercially advantageous photocells with a thickness of 10 μm on the basis of optically transparent films of nanoparticles of titanium dioxide is described. These nanoparticles have a sufficiently high percentage of the solar radiation (46%) and demonstrate exceptional parameters for the conversion of photon energy into electric energy with a general efficiency (7.1-7.9) %. This work was revolutionary in 1991 and gave rise to research due-sensitized photocells.

Other works [44-46] are devoted to this kind of materials, where a certain chemical modification of these photocells based on TiO_2 is proposed due to the doping of nitrogen elements, the development of surface-active nanostructured titanium dioxide, etc. We see that research in the field of photovoltaic material science is the most cited. For "Wind Energy" the situation is different. More important (cited) here are the materials related to the systems of transformation of energy in general, as well as engineering and design solutions of wind farms [47-49]. There is also a part of materials that are relevant to materials science (5.4%), but not all of them concern materials for turbines, blades or hulls. A significant number of publications are devoted to battery materials, which can be used for other types of renewable energy [23].

Comparing the percentage content of the contribution of the papers from the field of Materials science to each type of Renewable Energy (open data from the Scopus database: www.scopus.com) as the section of most relevant to these fundamental areas of science, we can see the following distribution (including Chemical Engineering): Solar Energy – 40.4%, Wind Energy – 5.4%, Geothermal Energy – 11.3%, Biofuel Energy – 35.9%, Thermoelectric Energy – 50.4%, Energy – 42.6%. That is, Thermoelectric Energy, Solar Energy and Biofuel Energy are the most important areas of technology that have a strong scientific component.

Table 2. Statistics on the number of publications by country according to the different key tags.

No	Energy	Solar Energy	Wind Energy	Thermoelectric Energy	Biofuel Energy	Renewable Energy
1	1. USA 2. China 3. Germany 4. Japan 5. UK 6. France 7. India 8. Italy	1. USA 2. China 3. India 4. Germany 5. Japan 6. UK 7. Italy 8. France	1. USA 2. China 3. UK 4. Germany 5. India 6. Japan 7. Canada 8. France	1. USA 2. China 3. Japan 4. India 5. Germany 6. UK 7. South Korea 8. France	1. USA 2. China 3. India 4. UK 5. Germany 6. Brazil 7. Italy 8. Canada	1. USA 2. China 3. UK 4. Germany 5. India 6. Italy 7. Spain 8. Canada
2	1. CNRS 2. Univ. Tokyo 3. UC Berkeley 4. MIT 5. Inst. Nazionale de Fisica Nucleare	1. NASA Goddart Space Flight Center 2. Nat. Renewable Energy Lab. 3. CNRS 4. UC Berkeley 5. Cal. Tech.	1. NASA Goddart Space Flight Center 2. Danmarks Tek. Univ. 3. CNRS 4. UC Berkeley 5. Nat. Renewable Energy Lab.	1. MIT 2. Cal. Tech. 3. Tsinghua Univ. 4. CNRS 5. Wuhan Univ.	1. UC Berkeley 2. USDA Agr. Res. Center 3. US Deprt. Agr. 4. Univ. Sao Paolo 5. Oak Ridge Nat. Lab.	1. Nat. Renewable Energy Lab. 2. Tsinghua Univ. 3. Aalborg Univ. 4. Danmarks Tek. Univ. 5. North China Elect. Pow. Univ.
3	1. European Org. for Nuclear Research, Geneve, Switzerland 2. Tata Inst. of Fund. Research, Mumbai, India 3. Univ. Bergen, Bergen, Norway	1. Max Planck Institute for Solid State Research, Stuttgart, Germany 2. ETH Zurich, Zurich, Switzerland 3. University of Ontario Oshawa,	1. Univ. of the Ryukyus, Nakagami District, Japan 2. Princeton University, Princeton, USA 3. Nagoya University, Nagoya, Japan	1. Northwestern University, Evanston, USA 2. Northwestern University, Evanston, USA 3. Purdue University, Lafayette,	1. Univ. of Utah, Salt Lake City, USA 2. University College Cork, Cork, Ireland 3. Univ. of Groningen, Groningen, Netherlands	1. Univ. of the Ryukyus, Nakagami District, Japan 2. University of Ontario Oshawa, Canada 3. Aalborg Univ., Aalborg,

	Canada		USA		Denmark

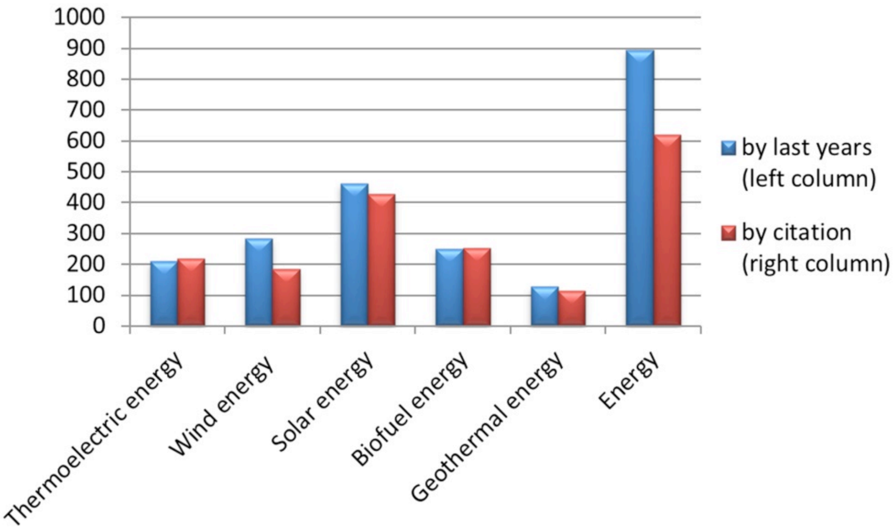
Moreover, a difference of Thermoelectric Energy from Solar Energy can be explained by the prospects of thermoelectricity. But thermoelectric converters may not always be independent sources of electricity; often they are additional or auxiliary to improve the environmental situation [50]. Only thermoelectric energy conversion is used in practice much less often than photovoltaic one. Accordingly, the number of published works on the tag "Thermoelectric Energy" is 12% (Fig. 1, b).

Much fewer works relate to Biofuel Energy (4%), Geothermal Energy (4%), Hydro Energy (3%). But there is a rather powerful practical implementation. That is, there are a large number of players on the market that commercially implement these trends, with great support at the state level and using their natural and productive potential. Therefore, the impact of this small percentage of publications is rather high (Fig. 1, a).

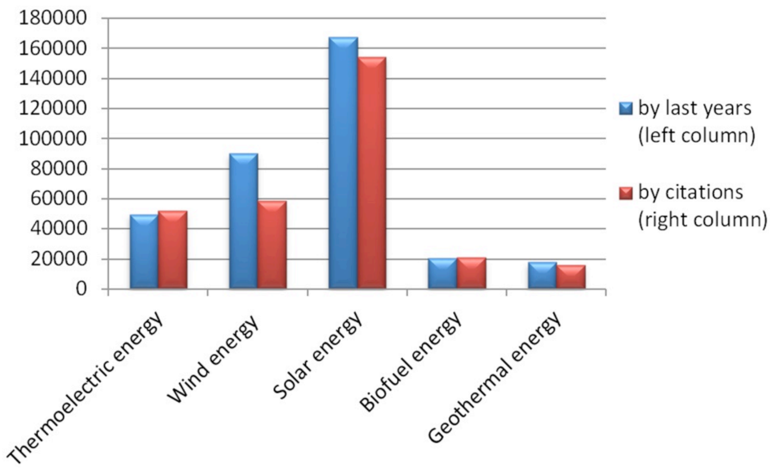
Given the relevance of quotes in the directions (Table 2) and multiplying this value by the values of the h-index and the number of publications, we obtain certain normalized values of these parameters (Figure 2). We do not do this for the tag "Energy" in order to adequately compare individual types of renewable energy. As can be seen in Fig. 2, the data are fully consistent with the above mentioned conclusions and assumptions.

It is interesting to note the fact that the normalized value of the number of publications indicates a greater number of papers published in recent years than papers that have high links only for the term "Thermoelectric Energy" (Fig. 2b). It means that there are quite new publications in this area, as well as an increase in interest in this topic in recent years.

Part of statistical data on publications is given in Table 2. Analysis of this table shows us that the United States and China are leaders in energy-related publications, including renewable energy. Also we can see that there are countries with national energy priorities. They occupy different positions in this table, depending on a certain type of renewable energy. This is often due to the geographical location of the country or its own state policy. Both the United States and China are geographically located in different geographic zones, and each of these states has powerful research centers. Therefore, their 1st and 2nd positions are obvious. Germany, UK, India, Japan, Canada, Italy, France are countries that have chosen energy security as their national interest.



a)



b)

Fig. 2. Normalized values of the h-index (a) and the number of publications (b) in scientific areas.

For example, India declared a transition to 100% renewables by 2022. The basis of renewable energy in India will be solar power. Therefore, India ranked 3rd in the world by the number of publications in solar energy. The same is true in the production of solar electricity. China (52 GW), the United States (12.5 GW) and India (9 GW) are leading in the development of solar energy [30].

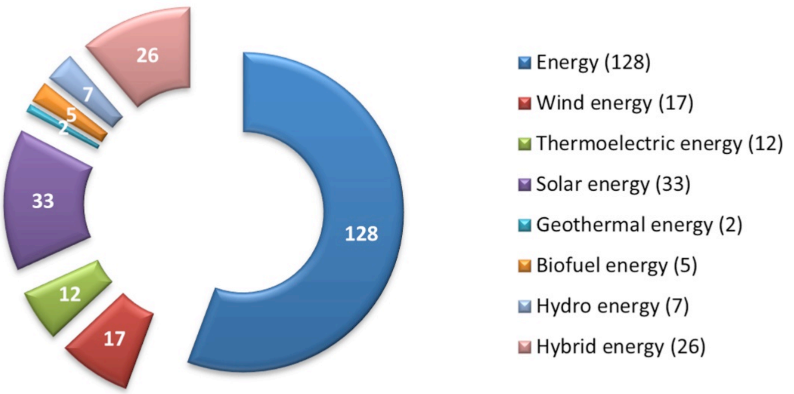
The situation with research centers that occupy leading positions in the number of publications is slightly different from the ranking by state. There are centers that, as it turned out, are explicit leaders in energy research. Moreover, this can simultaneously be the development of a policy on the environmental norms of energy sources, and the development of fundamentally new materials and devices. That is, there are organizations that have gained an undeniable positive reputation (Table 2, Line 2): CNRS, University of Tokyo, UC Berkeley, MIT, NASA Goddart Space Flight Center, National Renewable Energy Laboratory, California Institute of Technology, Tsinghua University, Technical University of Denmark, etc.

But even more interesting is the third line, which lists the centers that are the most cited in their industry. Selection was carried out on the most cited researchers from these centers (affiliation of the most recognized scientists is given). In thermoelectricity, the first two positions are occupied by the same university: Northwestern University (USA). In other directions, the listed institutions are not included in the list of organizations from line 2. The total number of publications of the authors from the institutions indicated in line 3 is smaller, but they are the flagships, i.e., those who are a "trendsetter".

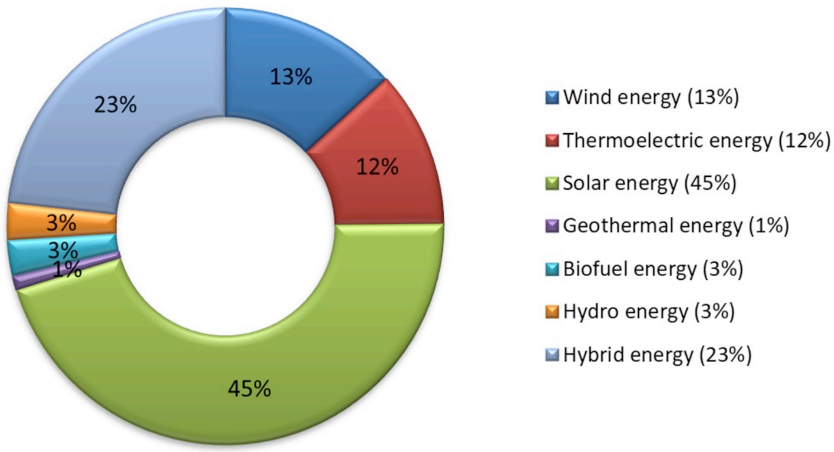
And it turns out that these "trendsetters" present organizations not only from the USA, Canada, Japan, Germany, India, but also from Switzerland, Norway, Denmark, the Netherlands, which are not included in the list of states in line 1. That is, if a certain state is not included in the list of those states that publish the largest number of publications, nevertheless, researchers from them can claim the highest positions in the rank of world scholars. And secondly, it was very interesting to find a certain "bias" in those organizations where the most cited researchers work, towards the Scandinavian states. On the other hand, the states listed in line 3 have the largest number of Nobel laureates. This confirms once again that the statistics on open data of international scientific and metrological databases give a possible result and contributes to providing reliable conclusions.

3.2. Renewable energy state in Ukraine

Similar studies have been carried out for publications by researchers from Ukraine (Fig. 3).



a)



b)

Fig. 3. The total h-index (a) and the total number of Ukrainian publications in percent (b) related to energy in general and individual renewable energy sources.

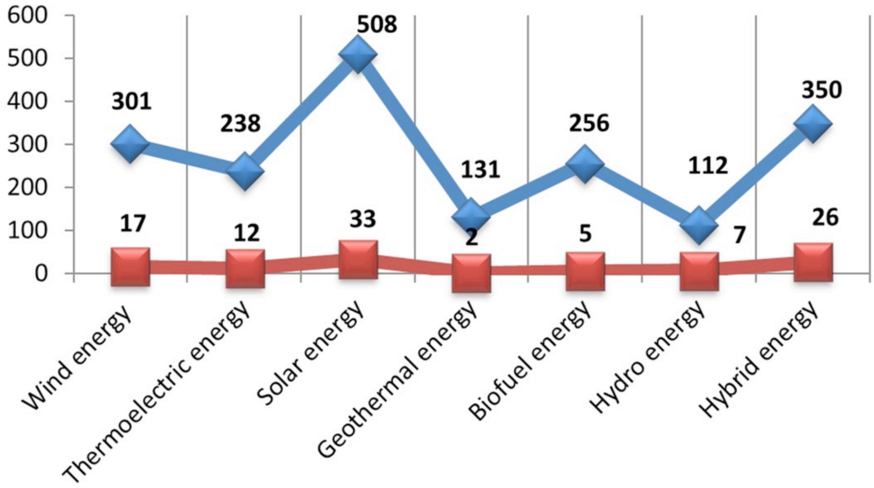


Fig. 4. Comparison of the total h-indices of publications in different directions of renewable energy to the h-index of publications of Ukrainian researchers in the same directions.

Fig. 4 shows a comparison of h-indices of publications in different directions for Ukrainian researchers to the world's ones. We can see that the general character for most tags is retained. However, there are some significant differences that need to be analyzed in detail.

It is clear that the direction "Geothermal Energy" has a significantly smaller number of publications, as well as citation indices. Considering the geographical location of Ukraine, this is not surprising, as the country does not have powerful geothermal sources, and launching the mass production of heat pumps requires significant financial costs. Therefore, despite the existence of individual companies that have their own elaborations [51], their use is not as massive as the purchase of well-known international brands. However, the availability of a number of patents and tested prototypes show technical potential in the presence of appropriate investments.

Ukraine is characterized by continental climate. It borders on European countries that are characterized by different climatic zones [52]. This is an important reason for the emergence of stable wind streams near the climatic zones and, accordingly, a positive factor for the development of wind energy stations.

Three largest trends that exist in the research market of Ukraine are the same as in the world, but with a slightly different distribution of priorities. The h-indices of the publications of researchers for which the host university is located in Ukraine are significantly lower than the h-indices that are analyzed here as the Global energy state of art (Fig. 3a). The number of publications with the tag "Solar Energy" is higher in Ukraine (45% in Ukraine versus 38% in the world). For "Wind Energy", this value is lower for Ukraine (13% vs. 20% in the world). Also, it is interesting that the tag "Thermoelectric Energy" has the same percentage (12%). Similarly, "Biofuel Energy" (3%) and "Hydro Energy" (4%) remain practically unchanged in percentage terms.

A good trend is increasing of this percentage for "Hybrid Energy" (up to 23% compared to 19% in the world). This means that technically Ukrainian scientists are more likely to create new systems based on modern technological solutions.

The largest number of publications in Ukraine on the tag "Energy" refers to such areas as Physics, Materials Science, Engineering, and Chemistry. That is, it is mainly high-tech results (almost 80% of all publications), while around 40% of the publications on the tag "Energy" are found in the world, while the rest is related to device engineering, environmental issues, economics, etc. It can be concluded that there are far fewer studies in Ukraine that justify economic forecasting on the appropriateness of certain research areas, the social sphere of adaptation of the final product (feasibility of researching technologies or materials that, for example, contain environmentally hazardous substances), and meet its national market's needs. Ukrainian researchers can receive extremely important and relevant results in high-tech areas. But the lack of a material base is a barrier that hinders their industrial application.

In order to better demonstrate the relation between Ukrainian achievements and the current state of publications in the world, diagrams were developed. They show relative values of h-indices and the number of publications (Figures 5, 6). In these diagrams, the lowest values show the highest potential of Ukrainian researchers' achievements (inverse character).

We consider the directions in which values shown in Fig. 5 and Fig. 6 are the lowest and which, with high probability, can be attributed to high tech, and analyze the most interesting publications to see the difference in the obtained results between the leading researchers in the world and in

Ukraine. These directions are "Solar Energy" and "Thermoelectric Energy".

For "Solar Energy", as already mentioned above, the most cited are studies on the properties of TiO_2. A lot of other publications also relate to photovoltaic material science, but there is one trend – the most popular publications are the papers devoted to new materials that can be effective and cheap at the same time. These are, for example, polymer-based materials [53-58] or hybrid and nanostructured materials of different composition [59-61]. Significantly fewer works refer to constructive solutions or signal conversion and measurement systems.

The most cited publication with the participation of Ukrainian researchers concerns the development of a new type of photovoltaic cell - a hybrid photovoltaic cell, which will use excessive heat in its work. This idea solves several problems. It increases the efficiency of the photocell (30-40% as indicated in this work) and the life of the operation, as conventional photocells over time reduce their efficiency due to constant heating. Other publications in the field of photoelectric material science also show high modern achievements. This is, in particular, the development of cheaper and more efficient thin-film photocells [62-69]. It is important that most publications have the nature of fundamental research in the physics of semiconductors, as well as final practical application in the way of testing obtained parameters to work as a photocell. Such semi-empirical approaches that combine research in materials science, elaboration of technology for obtaining low-dimensional structures and showing the prospect of use are a feature of Ukrainian scientists. The lack of mass high-tech production in the country does not allow the production of industrial designs. Therefore, the output is laboratory testing, which often did not have the opportunity to be implemented. Though this trend was the only one in the period 1990-2010, recently situating has been changed. One of the reasons is that very often representatives of major scientific centers are in co-authorship with Ukrainian scientists. Due to this, there was a possibility to launch such developments on the market. But still, it has not become a mass phenomenon. And developments in the field of Solar Energy, which are continuing in Ukraine today, still require extensive international cooperation.

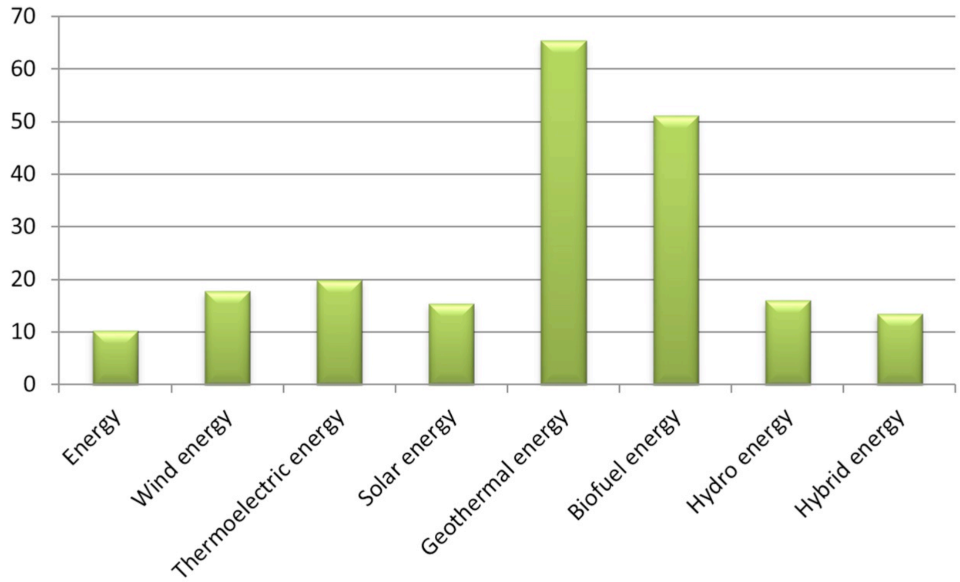


Fig. 5. The ratio of h-indices by directions (hglob/hukr)

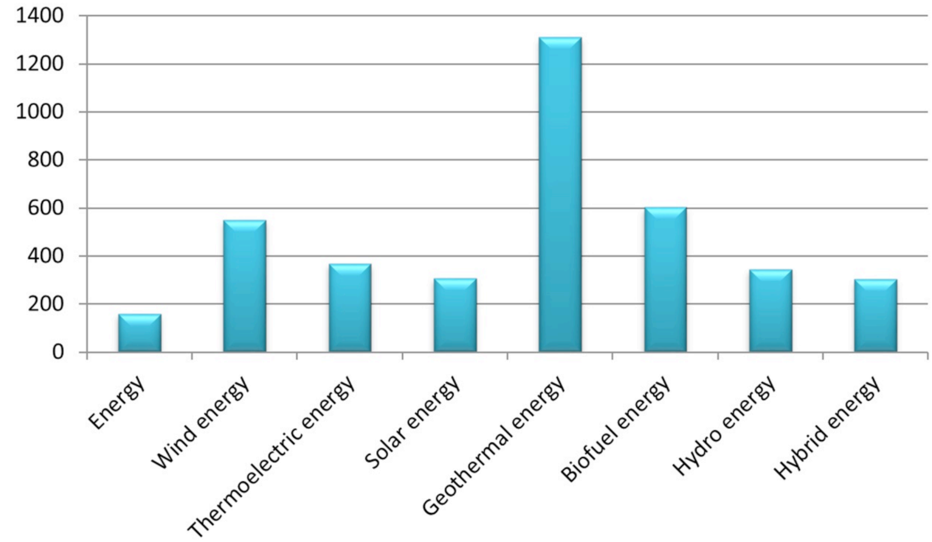


Fig. 6. The ratio of the number of publications by directions (Nglob/Nukr).

The most cited publication in the world within the tag "Thermoelectric Energy" is research paper [50]. This is review in which an analysis of modern thermoelectric materials for their use as n- and p-type elements of the thermoelectric module has been done. For a wide range of temperatures, materials with the highest values of dimensionless thermoelectric quantum well ZT as the main indicator of the quality of the material for thermoelectric application are determined. Among commercial materials, PbTe-based compounds (medium temperature range), Bi_2Te_3 (low and room temperatures) and SiGe (high temperatures) are the most appropriate. Also new and economically feasible materials such as half-Heusler alloys, skutterudites ($CoSb_3$-based materials), cobaltite oxides ($NaxCoO_2$ and others like those based on the Ca-Co-O system) and Zintl compounds (Zn-Sb-based materials) were studied.

However, materials with microstructural inclusions of the type LAST (PbAgSbTe), TAGS (GeAgSbTe) are determined as the most industrially important materials. The following citation applies to thin film thermoelectric refrigeration units [70]. In particular, it has been shown that the transition to superlattice materials causes a significant increase in thermoelectric characteristics compared to bulk materials. Among other highly cited publications, we should mention a group of papers [71-75], where the authors substantiate the importance of research and show the effectiveness of the practical application of systems based on low-dimensional thermoelectric materials. The papers study not only the perspective of superlattice, as in the previous work [70], but also such approaches as the influence of the oscillation of thermoelectric parameters and the consideration of quantum-dimensional effects [74, 75]. Another part of the publications [76-80] deals with new multicomponent semiconductor materials for thermoelectricity.

These are materials with nanoinclusions, and materials in which the efficiency is regulated through the control of the composition of the final compound and the development of technologies for the synthesis of these materials and the methods of forming individual thermoelements. Moreover, the number of publications on the study of nanostructured materials for thermoelectricity is increasing every year, which was 2.4% of the total number of publications in 1996, 14.4% in 2006, and 39.1% in 2016 [81]. Considering the value of ZT as the efficiency of thermoelectric materials, the highest values for $AgPb_mSbTe_{2+m}$ are 2.2 [76], 1.7 [82] or 1.5 [83]. That is, the PbTe-based materials have a stable high value of ZT today. Other materials have not yet reached such values. ZT directly influences on the efficiency of the terminal thermoelectric converter [50].

As for the research of Ukrainian scholars, despite a much smaller number of publications, two main directions can be distinguished: thermoelectric material science [84-86] and thermoelectric devices [87-89]. The world thermoelectric community is also actively involved in the development of thermoelectric devices. In the world, there are much more large manufacturing companies, which specialize in producing ready-made TEG (thermoelectric generators) than in Ukraine. However, the percentage of publications on topics is much higher in Ukraine. This can be caused by a number of large industrial centres, the leading of which is the company ALTEK (Chernivtsi). It operates on the basis of the Institute of Thermoelectricity. Other research centers are located at universities and do not have manufacturing facilities. However, the obtained results commensurate with the world's ones. Thus, in [90], the value $ZT \sim 2.2$ for $Pb_{18}Ag_2Te_{20}$ was obtained. The creation of conducting nano-channels around macroscopic grains for increasing of the thermoelectric parameters in pressed bulk materials was implemented by the first time in [91]. The first studies of quantum-dimensional effects in PbTe-type binary materials were studied jointly in Kharkiv Polytechnic Institute (Ukraine) and MIT (USA) [85] or for multicomponent LATT compounds (Pb-Ag-Sn-Te) in recent paper [92].

Therefore, we see that scientists from Ukrainian universities are gaining significant results in thermoelectricity, which cannot always be practically applied. One of the possible solutions is close cooperation with researchers from other countries. In particular, the formation of large consortia, for example within the Horizon 2020 program, will facilitate an efficient and fast process of commercialization of the results. These consortia include both research centers and industrial companies that are an impetus for the development of new technologies.

As for other areas (tags) "Bioenergy'" is becoming more popular and promising in Ukraine. Although a number of publications in this area are rather low, the simultaneous analysis of h_{glob} / h_{ukr} and N_{glob} / N_{ukr} indicates a lack of a high h-index, but at the same time, there is the growth in the number of publications in recent years. There are two important reasons for this: a lot of agricultural enterprises want to use waste (I) and the need and state support for the most extensive renewable energy (II). In addition, the issue of rational nature use in growing and using resources for bioenergy is important for Ukraine.

Regarding the world's leading research in the field of Bioenergy, development of biofuels is the most crucial, since today biofuels give 10% of the world's energy from renewable sources [93]. The analysis of publications shows that from the point of view of renewable energy, "Bioenergy" includes primarily "Biofuels" as a study of the possibilities of obtaining various types of fuel through the cultivation of certain crops, as well as the receipt of fuel as a result of waste processing, including, agricultural [94-103]. However, there are publications dealing with high-tech industries for biofuels, for example, methods and approaches to chemistry, biochemistry and biotechnology [104-106], as well as general questions on the policy of biofuel development in the world, regulation of legislation and improvement of the environmental situation [108-110].

The most cited publications with the participation of Ukrainian researchers, as well as the most recent publications concern the development of "general rules" in the international market for renewable energy and climate change [111-114]. There are fewer publications on Biofuel Energy prospects [115]. However, for Ukraine, the efficient use of agricultural resources, including biomass, is a very important issue [116]. Most of the publications on the narrower direction of "Biofuel Energy" are rather new, from 2016-2017. It indicates the novelty and relevance of this issue in Ukraine. Rational use of biomass potential is a viable alternative to solving food and energy security problems in the face of unlimited demand for food and energy in today's society. After the analysis of publications we see that legislative initiatives that must be in line with international requirements for emissions or utilization of agricultural wastes are already actively implemented by large-scale agricultural companies. However, in Ukraine, the bioenergy market is only being formed and legal norms are just being established. Therefore, there is a scientific problem that needs to be solved. It deals with international acts that should be in line with existing internal regional agreements. They have to take into account the different regional peculiarities. Therefore, there is also the need to establish international contacts between scientists, but unlike thermoelectricity, such cooperation should primarily concern the practical implementation in the Ukrainian market, as one of the world's largest agricultural markets.

The same conclusions are also followed if we introduce a certain normalized h-index of publications by Ukrainian researchers $h = 10 \cdot h_{ukr} / h_{global}$. Here the result is multiplied by 10, because the analysis of share is less perceptible than units (Fig. 7).

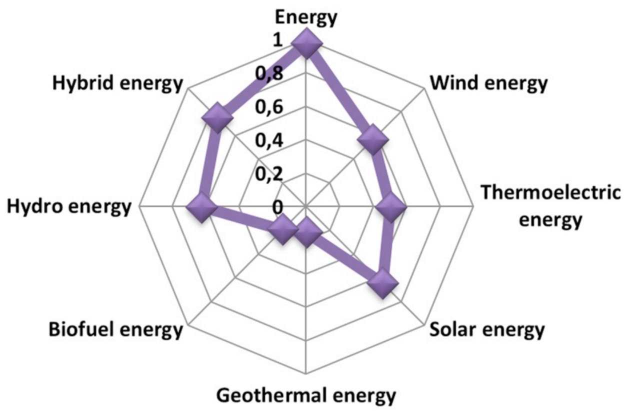


Fig. 7. Normalized h-index of publications of Ukrainian researchers ($10 \cdot h_{ukr} / h_{global}$).

Figure 7 illustrates the need to start new research with good scientific background. The closer the curve is to zero, the greater need is for qualitative research for Ukraine. First of all, as a priority, national research centers need to focus on "Biofuel Energy" as a promising industry with a clear lack of a scientific component. Such recommendations for the structures that form the state policy of Ukraine (the National Academy of Sciences of Ukraine, the Ministry of Education and Science of Ukraine, as well as the National Science Foundation, which is currently being formed) have to be taken into account. But, we must remember that the balance should be kept. If there are significant scientific results in any other field, the international cooperation is to be established and results have to be brought to the market.

4. Conclusions and Policy Implications

If we want to adequately predict the development of renewable energy, it is necessary to take into account a number of factors simultaneously. This is not only the price or the availability of the systems themselves. These factors are derived from the basic ones, the main for which is the state of art of research achievements. But not only will the results of specific research be decisive for the development of entire industries. It is necessary to take into account the dynamics of obtaining such results, their quality and the possibility of dissemination. That is why, the multifactorial analysis of scientific publications, as the main method of dissemination of scientific research results, comes to the fore. Regarding the various factors that follow from the statistics of scientific publications, the main factor is index of the perception of research results by the scientific community, or, as it is often called, the index of quotes, as well as the number of publications by year and by sector. It is expedient to use a variety of coefficients to determine the relationship between the quality and quantity of publications, or the correlation between quality or quantity of publications in the world and in a particular country, like Ukraine.

In the field of renewable energy, such an analysis needs to be carried out in the same way as for publications under the basic tags "Energy" or "Renewable Energy", as well as in the main directions, which includes the above-mentioned more general tags: "Solar Energy", "Wind Energy", "Geothermal Energy", "Biofuel", "Thermoelectric Energy". In order to determine the prospects for the development of renewable energy in a particular region, for example Ukraine, it is necessary to carry out the entire spectrum of research on the overall state of development of renewable energy in the world, as well as for its state in Ukraine. However, the same method can be successfully transferred to any other state. This makes this approach sufficiently versatile and realistic.

From this paper one can draw a number of conclusions:

1. The amount of scientific publications on the subject of renewable energy is directly determined by the economic state of the country in which the research is carried out. The quality of scientific publications or their citation also depends on the level of research funding. Publications of researchers from economically less powerful states may also have competitive scientific results. However, due to the lack of "open access", which often requires additional funding, such publications are less well-known to scholars from other countries, and therefore their "visibility" is lower for both the scientific community and for manufacturing companies as potential future donors

2. Studies on renewable energy in Ukraine correspond to the same laws as research in the world as a whole. This shows the possibility of a successful transfer of the methodology for studying the status of similar studies in any other country. However, quantitatively, such studies are significantly inferior to research in other countries. Given the fact that Ukraine has a sufficiently high scientific potential, i.e. a large number of universities and research institutes of the National Academy of Sciences, in quantitative terms such studies are determined primarily by the level of funding, not the number of institutions.

3. A qualitative analysis of renewable energy research in Ukraine shows a high scientific potential in the following renewable energy sectors, which are primarily related to materials science: Solar Energy, Thermoelectricity, medium potential in the direction of Wind Energy and low research potential in other directions. The economic potential of Ukraine points to high energy production needs from renewable sources. The most favorable directions for investors are "Biofuel" and "Wind Energy". Other areas are relevant because of the existence of a "feed-in tariff" ("Solar Energy") and the need to address the environmental demands for heat recovery ("Thermoelectricity").

4. The methodology proposed in this paper may be the basis for future research on specific areas of renewable energy. The analysis of the quality of published research results is unified source of information for compiling professional business plans for large companies that want to enter new markets or startups during implementation of new ideas in the sphere of renewable energy. In order for publications to have a positive impact on economic development for countries such as Ukraine, they must be accessible to the R&D community as much as possible. As one of the most effective options, it may be collaborative international research with resulting review papers.

Acknowledgements

This work was performed under the Laboratory of Physical and Technical Department and Department of Management and Business Administration of the Vasyl Stefanyk Precarpathian National University in Ivano-Frankivsk, Ukraine, Laboratory of Material Technologies for Industry University of Rzeszow and Subcarpathian Renewable Energy Cluster, Poland.

Publications are based on the research provided by the grant support of the Ministry of Education and Science of Ukraine (State registration No 0117U002409).

References

[1] L. Gibson, E.N. Wilman, W.F. Laurance, "How Green is 'Green'Energy?", Trends in ecology & evolution, DOI: 10.1016/j.tree.2017.09.007, Vol. 32, pp. 922–935, 2017.

[2] J.M. Tour, C. Kittrell, V.L. Colvin, "Green carbon as a bridge to renewable energy", Nature materials, DOI: 10.1038/nmat2887, Vol. 9, pp. 871–874, 2010.

[3] B. Johansson, "Security aspects of future renewable energy systems – A short overview", Energy, DOI: 10.1016/j.energy.2013.09.023, Vol. 61, No 1, pp. 598–605, 2013.

[4] D. Timmons, J.M. Harris, B. Roach, "The economics of renewable energy. Global Development and Environment Institute", Tufts University, 2014 (book).

[5] G. Heal, "Reflections – The Economics of Renewable Energy in the United States", Review of Environmental Economics and Policy, DOI: 10.1093/reep/rep018, Vol. 4, No 1, pp. 139–154, 2010.

[6] N. Apergis, D. Danuletiu, "Renewable energy and economic growth: Evidence from the sign of panel long-run causality", International Journal of Energy Economics and Policy, Vol. 4, No. 4 pp. 578–587, 2014.

[7] A. Šimelytė, G. Dudzevičiūtė, "Consumption of renewable energy and economic growth. In Contemporary issues in business, management and education'2017", In: 5th international scientific conference, Vilnius Gediminas Technical University: VGTU Press, p. 1–10, 2017.

[8] L. Freris, D. Infield, "Renewable energy in power systems", John Wiley & Sons, 2008 (book).

[9] A. Tokarcik, M. Rovnak, M. Lechwar, G. Wisz, „Zarządzanie energią w jednostkach samorządu terytorialnego wybrane modele – możliwości, ograniczenia, rekomendacje", CeDeWu, Warszawa, 2017 (book).

[10] Energy DG, European Commission. EU, energy in figures, statistical pocketbook 2017. Brussels: Publications Office of the European Union, DOI: 10.2833/80717, 2017, 265 p.

[11] A.Z. Amin, 2013. IRENA. Renewable power generation costs in 2012: an overview. Abu Dhabi: International Renewable Energy Agency (book).

[12] S. Jacobsson, A. Bergek, D. Finon, V. Lauber, C. Mitchell, D. Toke, A. Verbruggen, "EU renewable energy support policy: Faith or facts?", Energy policy, 10.1016/j.enpol.2009.02.043, Vol. 37, No 3, pp. 2143-2146, 2009.

[13] Z. Guo, X. Xiao, D. Li, "An assessment of ecosystem services: water flow regulation and hydroelectric power production", Ecological Applications, DOI: 10.1890/1051-0761(2000)010[0925:AAOESW]2.0.CO;2, Vol. 10, No 3, pp. 925-936, 2000.

[14] M. Dresselhaus, I. Thomas, "Alternative energy technologies", Nature, DOI: 10.1038/35104599, Vol. 414, pp. 332–337, 2001.

[15] A. Becke, "Density-functional thermochemistry. III. The role of exact exchange", The Journal of chemical physics, DOI: 10.1063/1.464913, Vol. 98, No. 7, pp. 5648–5652, 1993.

[16] G. Kresse, J. Furthmüller, "Efficient iterative schemes for ab initio total-energy calculations using a plane-wave basis set", Physical review B, DOI: 10.1103/PhysRevB.54.11169, Vol. 54, No 16, p. 11169, 1996.

[17] A. Becke, "Density-functional exchange-energy approximation with correct asymptotic behavior", Physical review A, DOI: 10.1103/PhysRevA.38.3098, Vol. 38, No. 6, p. 3098, 1988.

[18] J.P. Perdew, K. Burke, M. Ernzerhof, "Generalized gradient approximation made simple", Physical review letters, DOI: 10.1103/PhysRevLett.77.3865, Vol. 77, No 18, p. 3865, 1996.

[19] P. Hohenberg, W. Kohn, "Inhomogeneous electron gas", Physical review, DOI: 10.1103/PhysRev.136.B864, Vol. 136, No 3B, B864, 1964.

[20] B. O'regan, M. Grätzel, "A low-cost, high-efficiency solar cell based on dye-sensitized colloidal TiO_2 films", Nature, DOI: 10.1038/353737a0, Vol. 353, pp. 737–740, 1991.

[21] R. C. Duncan, C. Thompson, "Formation of very strongly magnetized neutron stars-Implications for gamma-ray bursts", The Astrophysical Journal, DOI: 10.1086/186413, Vol. 392, No 1, pp. L9–L13, 1992.

[22] P. Goldreich, S. Sridhar, "Toward a theory of interstellar turbulence. 2: Strong alfvenic turbulence", The Astrophysical Journal, DOI: 10.1086/175121, Vol. 438, No 2, pp. 763–775, 1995.

[23] B. Kang, G. Ceder, "Battery materials for ultrafast charging and discharging", DOI: 10.1038/nature07853, Nature, Vol. 458, pp. 190–193, 2009.

[24] A. Platis, S.K. Siedersleben, J. Bange, A. Lampert, K. Bärfuss, R. Hankers, B. Cañadillas, R. Foreman, J. Schulz-Stellenfleth, B. Djath, T. Neumann, S. Emeis, "First in situ evidence of wakes in the far field behind offshore wind farms", Scientific reports, DOI: 10.1038/s41598-018-20389-y, Vol. 8, p. 2163, 2018.

[25] Z. Hajej, N. Rezg, M. Bouzoubaa, (2017, November). "An integrated maintenance strategy for a power generation system under failure rate variation (case of wind turbine)", In Renewable Energy Research and Applications (ICRERA), 2017 IEEE 6th International Conference, DOI: 10.1109/ICRERA.2017.8191175, pp. 76-79, IEEE, 2017.

[26] S. Janhunen, A. Grönman, K. Hynynen, M. Hujala, M. Kuisma, P. Härkönen, "Audibility of wind turbine noise indoors: Evidence from mixed-method data", In Renewable Energy Research and Applications (ICRERA), 2017 IEEE 6th International Conference, DOI: 10.1109/ICRERA.2017.8191260, pp. 164-168, IEEE, 2017.

[27] S.H. Vega, A. Mandel, "Technology Diffusion and Climate Policy: A Network Approach and its Application to Wind Energy", Ecological Economics, DOI: 10.1016/j.ecolecon.2017.11.023, Vol. 145, pp. 461-471, 2018.

[28] M.Z. Jacobson, M.A. Delucchi, M.A. Cameron, B.V. Mathiesen, "Matching demand with supply at low cost in 139 countries among 20 world regions with 100% intermittent wind, water, and sunlight (WWS) for all purposes", Renewable Energy, DOI: 10.1016/j.renene.2018.02.009, Vol. 123, pp. 236–248, 2018.

[29] "GWEC. Global Wind Statistics 2016" [accessed 10 Feb. 2017], Global Wind Energy Council, 2017 (book).

[30] "IRENA, Renewable Power Generation Costs in 2017", Abu Dhabi: International Renewable Energy Agency, 2018 (book).

[31] M. Hassanalian, D. Rice, A. Abdelkefi, "Aerodynamic performance analysis of fixed wing space drones in different solar system bodies", In: 2018 AIAA Aerospace Sciences Meeting, DOI: 10.2514/6.2018-1533, p. 1533, 2018.

[32] C.H. Trisos, G. Amatulli, J. Gurevitch, A. Robock, L. Xia, B. Zambri, "Potentially dangerous consequences for biodiversity of solar geoengineering implementation and termination", Nature Ecology & Evolution, DOI: 10.1038/s41559-017-0431-0, Vol. 2, pp. 475–482, 2018.

[33] M.A. Green, Y. Hishikawa, W. Warta, E.D. Dunlop, D.H. Levi, J. Hohl-Ebinger, A.W. Ho-Baillie, "Solar cell efficiency tables (version 50)", Progress in Photovoltaics: Research and Applications, DOI: 10.1002/pip.2909, Vol. 25, No 7, pp. 668–676, 2017.

[34] R. Ehrlich, H.A. Geller, Renewable Energy, Second Edition: A First Course. CRC Press, 2017, 490 p. (book).

[35] P. Collins, K. Bradley, M. Ishigami, D. Zettl, "Extreme oxygen sensitivity of electronic properties of carbon nanotubes", Science, DOI: 10.1126/science.287.5459.1801, Vol. 287, No. 5459, pp. 1801-1804, 2000.

[36] D.M. Rowe, "Thermoelectrics, an environmentally-friendly source of electrical power", Renewable energy, DOI 10.1016/S0960-1481(98)00512-6, Vol. 16, No 1-4, pp. 1251–1256, 1999.

[37] C. Wood, "Materials for thermoelectric energy conversion", Reports on progress in physics, DOI:

10.1088/0034-4885/51/4/001, Vol. 51, No 4, p. 459, 1998.

[38] D.M. Rowe, "Handbook of thermoelectrics", CRC press, 1995, 720 p. (book).

[39] E.P. Odum, H.T. Odum, J. Andrews, "Fundamentals of ecology" 3rd Edition, W.B. Saunders Company, Philadelphia-London-Toronto, 1971 (book).

[40] M.T. Iqbal, "Modeling and control of a wind fuel cell hybrid energy system", Renewable energy, DOI: 10.1016/S0960-1481(02)00016-2, Vol. 28, No 2, pp. 223–237, 2003.

[41] S. Ashok, "Optimised model for community-based hybrid energy system", Renewable energy, DOI: 10.1016/j.renene.2006.04.008, Vol. 32, No. 7, pp. 1155-1164, 2007.

[42] S. R. Alvarez, A. M. Ruiz, J. E. Oviedo, "Optimal design of a diesel-PV-wind system with batteries and hydro pumped storage in a Colombian community", In Renewable Energy Research and Applications (ICRERA), 2017 IEEE 6th International Conference, DOI: 10.1109/ICRERA.2017.8191272, pp. 234-239, IEEE, 2017.

[43] G. Omer, A. H. Yavuz, R. Ahiska, "Heat pipes thermoelectric solar collectors for energy applications", International Journal of Hydrogen Energy, DOI: 10.1016/j.ijhydene.2017.01.132, Vol. 42, No 12, pp. 8310-8313, 2017.

[44] R. Asahi, T. Morikawa, T. Ohwaki, K. Aoki, Y. Taga, "Visible-light photocatalysis in nitrogen-doped titanium oxides", Science, DOI: 10.1126/science.1061051, Vol. 293, pp. 269–271, 2001.

[45] M.K. Nazeeruddin, A. Kay, I. Rodicio, R. Humphry-Baker, E. Müller, P. Liska, N. Vlachopoulos, M. Grätzel, "Conversion of light to electricity by cis-X2bis (2, 2'-bipyridyl-4, 4'-dicarboxylate) ruthenium (II) charge-transfer sensitizers (X= Cl-, Br-, I-, CN-, and SCN-) on nanocrystalline titanium dioxide electrodes", Journal of the American Chemical Society, DOI: 10.1021/ja00067a063, Vol. 115, No 14, pp. 6382–6390, 1993.

[46] A. Hagfeldt, G. Boschloo, L. Sun, L. Kloo, H. Pettersson, "Dye-sensitized solar cells", Chemical reviews, DOI: 10.1021/cr900356p, Vol. 110, No 11, pp. 6595–6663, 2010.

[47] F. Blaabjerg, R. Teodorescu, M. Liserre, A. Timbus, "Overview of control and grid synchronization for distributed power generation systems", IEEE Transactions on industrial electronics, DOI: 10.1109/TIE.2006.881997, Vol. 53, No. 5, pp. 1398–1409, 2006.

[48] J. Carrasco, L. Franquelo, J. Bialasiewicz, E. Galván, R. PortilloGuisado, M. Prats, J. Leon, N. Moreno-Alfonso, "Power-electronic systems for the grid integration of renewable energy sources: A survey", IEEE Transactions on industrial electronics, DOI: 10.1109/TIE.2006.878356, Vol. 53, No. 4, pp. 1002–1016, 2006.

[49] I. K. Buehring, L. L. Freris, "Control policies for wind-energy conversion systems". In IEE Proceedings C-Generation, Transmission and Distribution, DOI: 10.1049/ip-c.1981.0043, Vol. 128, No. 5, pp. 253-261, 1981.

[50] G.J. Snyder, E.S. Toberer, "Complex thermoelectric materials", Nature materials, DOI: 10.1038/nmat2090, Vol. 7, pp. 105–114, 2008.

[51] E.S. Shchuchuk, I.M. Romanyuk, S.A. Tsuryk, S.A. Kukhtarov, "Heat Pump Senso 1.06", Patent of Ukraine #112388, IPC F25B 30/02 (2006.01), 2016.

[52] A. Malvaldi, S. Weiss, D. Infield, J. Browell, P. Leahy, A. M. Foley, "A spatial and temporal correlation analysis of aggregate wind power in an ideally interconnected Europe", Wind Energy, DOI: 10.1002/we.2095, Vol. 20, No 8, pp. 1315-1329, 2017.

[53] G. Li, V. Shrotriya, J. Huang, Y. Yao, T. Moriarty, K. Emery, Y. Yang, "High-efficiency solution processable polymer photovoltaic cells by self-organization of polymer blends", Nature materials, DOI: 10.1038/nmat1500, Vol. 4, pp. 864–868, 2005.

[54] W.U. Huynh, J.J. Dittmer, A.P. Alivisatos, "Hybrid nanorod-polymer solar cells", Science, DOI: 10.1126/science.1069156, Vol. 295, No 5564, pp. 2425–2427, 2002.

[55] C. Brabec, N. Sariciftci, J. Hummelen, "Plastic solar cells", Advanced functional materials, DOI: 10.1002/1616-3028(200102)11:1%3C15::AID-ADFM15%3E3.0.CO;2-A, Vol. 11, No. 6, pp. 15–26, 2001.

[56] B.C. Thompson, J.M. Fréchet, "Polymer–fullerene composite solar cells", Angewandte chemie international edition, DOI: 10.1002/anie.200702506, Vol. 47, pp. 58–77, 2008.

[57] Y. Liang, Z. Xu, J. Xia, S.T. Tsai, Y. Wu, G. Li, C. Ray, L. Yu, "For the bright future— – bulk heterojunction polymer solar cells with power conversion efficiency of 7.4%", Advanced Materials, DOI: 10.1002/adma.200903528, Vol. 22, No 20, pp. E135–E138, 2010.

[58] G. Li, R. Zhu, Y. Yang, "Polymer solar cells", Nature photonics, DOI: 10.1038/nphoton.2012.11, Vol. 6, pp. 153–161, 2012.

[59] M.M. Lee, J. Teuscher, T. Miyasaka, T.N. Murakami, H.J. Snaith, "Efficient hybrid solar cells based on meso-superstructured organometal halide perovskites", Science, DOI: 10.1126/science.1228604, Vol. 338, No 6107, p. 1228604, 2012.

[60] M. Law, L.E. Greene, J.C. Johnson, R. Saykally, P. Yang, "Nanowire dye-sensitized solar cells", Nature materials, DOI: 10.1038/nmat1387, Vol. 4, pp. 455–459, 2005.

[61] B. Tian, X. Zheng, T.J. Kempa, Y. Fang, N. Yu, G. Yu, J. Huang, C.M. Lieber, "Coaxial silicon nanowires as solar cells and nanoelectronic power sources", Nature, DOI: 10.1038/nature06181, Vol. 449, pp. 885–889, 2007.

[62] G. Khrypunov, A. Romeo, F. Kurdesau, D.L. Bätzner, H. Zogg, A.N. Tiwari, "Recent developments in evaporated CdTe solar cells", Solar energy materials and solar cells, DOI: 10.1016/j.solmat.2005.04.003, Vol. 90, No 4, pp. 664–677, 2006.

[63] V.G. Litovchenko, N.I. Klyui, "Solar cells based on DLC film–Si structures for space application", Solar

energy materials and solar cells, DOI: 10.1016/S0927-0248(00)00345-7, Vol. 68, No 1, pp. 55–70, 2001.

[64] I. V. Horichok, L. I. Nykyruy, T. O. Parashchuk, D. Bardashevska, M. P. Pylyponuk, "Thermodynamics of defect subsystem in zinc telluride crystals", Modern Physics Letters B, DOI: https://doi.org/10.1142/S0217984916501724, Vol. 30, No 16, p.1650172, 2016.

[65] L.A. Kosyachenko, M.P. Mazur, "Hot-carrier far infrared emission in silicon", Semiconductors, DOI: 10.1134/1.1187660, Vol. 33, No 2, pp. 143–146, 1999.

[66] V. Brus, "On quantum efficiency of nonideal solar cells", Solar Energy, DOI: 10.1016/j.solener.2011.12.009, Vol. 86, No. 2, pp. 786–791, 2012.

[67] Y.P. Saliy, L.I. Nykyruy, R.S. Yavorskyi, S. Adamiak, "The Surface Morphology of CdTe Thin Films Obtained by Open Evaporation in Vacuum", Journal of Nano- and Electronic Physics, DOI: 10.21272/jnep.9(5).05016, Vol. 9, No 5, p. 05016, 2017.

[68] A. N. Shimko, G. E. Malashkevich, D. M. Freik, L. I. Nykyruy, and V. G. Lytovchenko, "Effect of Thermal Treatment of PbTe Films on their IR Spectra and Surface Structure", Journal of Applied Spectroscopy, DOI: 10.1007/s10812-014-9871-3, Vol. 80, No. 6, pp. 950-953, 2014.

[69] G. Wisz, I. Virt, P. Sagan, P. Potera, R. Yavorskyi, "Structural, Optical and Electrical Properties of Zinc Oxide Layers Produced by Pulsed Laser Deposition Method", Nanoscale Research Letters, DOI: 10.1186/s11671-017-2033-9, Vol. 12, pp. 253–259, 2017.

[70] R. Venkatasubramanian, E. Siivola, T. Colpitts, B. O'quinn, "Thin-film thermoelectric devices with high room-temperature figures of merit", Nature, DOI: 10.1038/35098012, Vol. 413, pp. 597–602, 2001.

[71] J. Coleman, M. Lotya, A. O'Neill, S. Bergin, P. King, U. Khan, I. Shvets, "Two-dimensional nanosheets produced by liquid exfoliation of layered materials", Science, DOI: 10.1126/science.1194975, Vol. 331, No. 6017, pp. 568–571, 2011.

[72] B. Poudel, Q. Hao, Y. Ma, Y. Lan, A. Minnich, B. Yu, ... & X. Chen, "High-thermoelectric performance of nanostructured bismuth antimony telluride bulk alloys", Science, DOI: 10.1126/science.1156446, Vol. 320, No 5876, pp. 634–638, 2008.

[73] A.I. Hochbaum, R. Chen, R.D. Delgado, W. Liang, E.C. Garnett, M. Najarian, ... & P. Yang, "Enhanced thermoelectric performance of rough silicon nanowires", Nature, DOI: 10.1038/nature06381, Vol. 451, pp. 163–167, 2008.

[74] L.D. Hicks, M.S. Dresselhaus, "Effect of quantum-well structures on the thermoelectric figure of merit", Physical Review B, DOI: 10.1103/PhysRevB.47.12727, Vol. 47, No 19, p. 12727, 1993.

[75] M. Dresselhaus, G. Chen, M. Tang, R. Yang, H. Lee, D. Wang, ... & P. Gogna, "New directions for low-dimensional thermoelectric materials", Advanced materials, DOI: 10.1002/adma.200600527, Vol. 19, No. 8, pp. 1043–1053, 2007.

[76] K. Hsu, S. Loo, F. Guo, W. Chen, J. Dyck, C. Uher, ... & M. Kanatzidis, "Cubic $AgPb_mSbTe_{2+m}$: bulk thermoelectric materials with high figure of merit", Science, DOI: 10.1126/science.1092963, Vol. 303, pp. 818–821, 2004.

[77] J. Heremans, V. Jovovic, E. Toberer, A. Saramat, K. Kurosaki, A. Charoenphakdee, ... & G. Snyder, "Enhancement of thermoelectric efficiency in PbTe by distortion of the electronic density of states", Science, DOI: 10.1126/science.1159725, Vol. 321, No 5888, pp. 554–557, 2008.

[78] B.C. Sales, D. Mandrus, R.K. Williams, "Filled skutterudite antimonides: a new class of thermoelectric materials", Science, DOI: 10.1126/science.272.5266.1325, Vol. 272, No 5266, pp. 1325–1328, 1996.

[79] Y. Pei, X. Shi, A. LaLonde, H. Wang, L. Chen, G.J. Snyder, "Convergence of electronic bands for high performance bulk thermoelectrics", Nature, DOI: 10.1038/nature09996, Vol. 473, pp. 66–69, 2011.

[80] H. Mamur, R. Ahiska, "A review: Thermoelectric generators in renewable energy", International Journal of Renewable Energy Research (IJRER), Vol. 4, No 1, pp. 128-136, 2014.

[81] W. Liu, J. Hu, S. Zhang, M. Deng, C.G. Han, Y. Liu, "New trends, strategies and opportunities in thermoelectric materials: a perspective", Materials Today. Physics, DOI: 10.1016/j.mtphys.2017.06.001, Vol. 1, pp. 50–60, 2017.

[82] H. Lin, E.S. Božin, S.J.L. Billinge, E. Quarez, M.G. Kanatzidis, "Nanoscale clusters in the high performance thermoelectric $AgPb_mSbTe_{m+2}$", Physical Review B, DOI: 10.1103/PhysRevB.72.174113, Vol. 72, No 17, p. 174113, 2005.

[83] M. Zhou, J.F. Li, T. Kita, "Nanostructured $AgPb_mSbTe_{m+2}$ system bulk materials with enhanced thermoelectric performance", Journal of the American Chemical Society, DOI: 10.1021/ja7110652, Vol. 130, No 13, pp. 4527–4532, 2008.

[84] E.I. Rogacheva, O.N. Nashchekina, A.V. Meriuts, S.G. Lyubchenko, M.S. Dresselhaus, G. Dresselhaus, :Quantum size effects in n-PbTe⁄ p-Sn Te⁄ n-PbTe heterostructures", Applied Physics Letters, DOI: 10.1063/1.1862338, Vol. 86, p. 063103, 2005.

[85] E.I. Rogacheva, T.V. Tavrina, O.N. Nashchekina, S.N. Grigorov, K.A. Nasedkin, M.S. Dresselhaus, S.B. Cronin," Quantum size effects in PbSe quantum wells", Applied physics letters, DOI: 10.1063/1.1469677, Vol. 80, pp. 2690–2692, 2002.

[86] M. Gürth, G. Rogl, V.V. Romaka, A. Grytsiv, E. Bauer, P. Rogl, "Thermoelectric high ZT half-Heusler alloys $Ti_{1-x-y}Zr_xHf_yNiSn$ ($0\leq x\leq 1$; $0\leq y\leq 1$)", Acta Materialia, DOI: 10.1016/j.actamat.2015.11.022, Vol. 104, No 1, pp. 210–222, 2016.

[87] H. Scherrer, L. Vikhor, B. Lenoir, A. Dauscher, P. Poinas, "Solar thermolectric generator based on skutterudites", Journal of Power Sources, DOI: 10.1016/S0378-7753(02)00597-9, Vol. 115, No 1, pp. 141–148, 2003.

[88] L.N. Vikhor, L.I. Anatychuk, "Generator modules of segmented thermoelements", Energy Conversion and Management, DOI: 10.1016/j.enconman.2009.05.020, Vol. 50, No 9, pp. 2366–2372, 2009.

[89] L. Anatychuk, R. Kuz, "Thermoelectric generator for trucks", Journal of thermoelectricity, No. 3, pp. 40–45, 2016.

[90] I. Horichok, R. Ahiska, D. Freik, L. Nykyruy, S. Mudry, O. Matkivskiy, T. Semko, "Phase Content and Thermoelectric Properties of Optimized Thermoelectric Structures Based on the Ag-Pb-Sb-Te System", Journal of Electronic Materials, DOI: 10.1007/s11664-015-4122-9, Vol. 45, No 3, pp. 1576–1583, 2016.

[91] M. O. Haluschak, S. I. Mudryi, M. A. Lopyanko, S. V. Optasyuk, T. O. Semko, L. I. Nikiruy, I. V. Horichok, "Phase composition and thermoelectric properties of materials in Pb-Ag-Te system", Journal of thermoelectricity, No 3, pp. 34-39, 2016.

[92] L.I. Nykyruy, M.A. Ruvinskiy, E.V. Ivakin, O.B Kostyuk, I.V. Horichok, I.G. Kisialiou, Y.S. Yavorskyy, A.B. Hrubyak, "Low-Dimensional Systems on the Base of PbSnAgTe Compounds for Thermoelectric Application", Physica E: Low-dimensional Systems and Nanostructures, DOI: 10.1016/j.physe.2018.10.020, Vol. 106, pp. 10-18, 2019.

[93] H. Kopetz, "Renewable resources: build a biomass energy market", Nature, DOI: 10.1038/494029a, Vol. 494, pp. 29–31, 2013.

[94] E. Gnansounou, A. Dauriat, J. Villegas, L. Panichelli, "Life cycle assessment of biofuels: energy and greenhouse gas balances", Bioresource technology, DOI: 10.1016/j.biortech.2009.05.067, Vol. 100, No 21, pp. 4919–4930, 2009.

[95] D. Tilman, R. Socolow, J.A. Foley, J. Hill, E. Larson, L. Lynd, ... & R. Williams, "Beneficial biofuels – the food, energy, and environment trilemma", Science, DOI: 10.1126/science.1177970, Vol. 325, No 5938, pp. 270–271, 2009.

[96] A. Demirbas, "Biofuels securing the planet's future energy needs", Energy Conversion and Management, DOI: 10.1016/j.enconman.2009.05.010, Vol. 50, No. 9, pp. 2239–2249, 2009.

[97] R. Slade, A. Bauen, "Micro-algae cultivation for biofuels: cost, energy balance, environmental impacts and future prospects", Biomass and bioenergy, DOI: 10.1016/j.biombioe.2012.12.019, Vol. 53, pp. 29–38, 2013.

[98] J. Hill, E. Nelson, D. Tilman, S. Polasky, D. Tiffany, "Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels", Proceedings of the National Academy of sciences, DOI: 10.1073/pnas.0604600103, Vol. 103, No 30, pp. 11206–11210, 2006.

[99] A. Demirbas, "Competitive liquid biofuels from biomass", Applied Energy, DOI: 10.1016/j.apenergy.2010.07.016, Vol. 88, No. 1, pp. 17-28, 2011.

[100] M.E. Himmel, S.Y. Ding, D.K. Johnson, W.S. Adney, M.R. Nimlos, J.W. Brady, T.D. Foust, "Biomass recalcitrance: engineering plants and enzymes for biofuels production", Science, DOI: 10.1126/science.1137016, Vol. 315, No 5813, pp. 804–807, 2007.

[101] J. Goldemberg, P. Guardabassi, "Are biofuels a feasible option?", Energy Policy, DOI: 10.1016/j.enpol.2008.08.031, Vol. 37, No 1, pp. 10–14, 2009.

[102] A. V. Bridgwater, "The technical and economic feasibility of biomass gasification for power generation", Fuel, DOI: 10.1016/0016-2361(95)00001-L, Vol. 74, No 5, pp. 631-653, 1995.

[103] P.S. Nigam, A. Singh, "Production of liquid biofuels from renewable resources", Progress in energy and combustion science, DOI: 10.1016/j.pecs.2010.01.003, Vol. 37, No 1, pp. 52–68, 2011.

[104] L.R. Lynd, M.S. Laser, D. Bransby, B.E. Dale, B. Davison, R. Hamilton, ... & C.E. Wyman, "How biotech can transform biofuels", Nature biotechnology, DOI: 10.1038/nbt0208-169, Vol. 26, pp. 169–172, 2008.

[105] A. Raheem, W.W. Azlina, Y.T. Yap, M.K. Danquah, R. Harun, "Thermochemical conversion of microalgal biomass for biofuel production", Renewable and Sustainable Energy Reviews, DOI: 10.1016/j.rser.2015.04.186, Vol. 49, pp. 990–999, 2015.

[106] Y. Ulusoy, A. H. Ulukardesler, R. Arslan, Y. Tekin, "Energy and emission benefits of chicken manure biogas production – A case study", In Renewable Energy Research and Applications (ICRERA), 2017 IEEE 6th International Conference, DOI: 10.1109/ICRERA.2017.8191140, pp. 648-652, IEEE, 2017.

[107] V. M. Yakubiv, N. I. Horohotska, R. D. Yakubiv, "Administrative model of ensuring the development of agricultural enterprises through diversification processes implementation", Actual Problems in Economics, Vol. 170, pp. 58-65, 2015.

[108] R. Quadrelli, S. Peterson, "The energy–climate challenge: Recent trends in CO_2 emissions from fuel combustion", Energy policy, DOI: 10.1016/j.enpol.2007.07.001, Vol. 35, No 11, pp. 5938–5952, 2007.

[109] D. Pimentel, T.W. Patzek, "Biofuels, solar and wind as renewable energy systems", Benefits and risks, New York: Springer, 2008 (book).

[110] R.H. Wijffels, M.J. Barbosa, "An outlook on microalgal biofuels", Science, DOI: 10.1126/science.1189003, Vol. 329, No 5993, pp. 796–799, 2010.

[111] H. Böttcher, P. Verkerk, M. Gusti, P. HavlÍk, G. Grassi, "Projection of the future EU forest CO_2 sink as affected by recent bioenergy policies using two advanced forest management models", Gcb Bioenergy, DOI: 10.1111/j.1757-1707.2011.01152.x, Vol. 4, No. 6, pp. 773–783, 2012.

[112] Y. Ulusoy, A. H. Ulukardesler, "Biogas production potential of olive-mill wastes in Turkey", In Renewable Energy Research and Applications (ICRERA), 2017 IEEE 6th International Conference, DOI: 10.1109/ICRERA.2017.8191143, pp. 664-668, IEEE, 2017.

[113] R. Bun, M. Gusti, L. Kujii, O. Tokar, Y. Tsybrivskyy, A. Bun, "Spatial GHG inventory: analysis of uncertainty sources. A case study for Ukraine", Water, Air, & Soil Pollution: Focus, DOI: 10.1007/s11267-006-9116-4, Vol. 7, No. 4-5, pp. 483–494, 2007.

[114] N. Hurmak, V. Yakubiv, "Efficiency of intermediary activity of agricultural enterprises: Methods and assessment indicators", Bulgarian Journal of Agricultural Science, Vol. 23, No 5, pp. 712–716, 2017.

[115] V. Pidlisnyuk, T. Stefanovska, E.E. Lewis, L.E. Erickson, L.C. Davis, "Miscanthus as a productive biofuel crop for phytoremediation", Critical reviews in plant sciences, DOI: 10.1080/07352689.2014.847616, Vol. 33, No 1, pp. 1–19, 2014.

[116] V. Yakubiv, O. Zhuk, I. Prodanova, "Model of region's balanced agricultural development using the biomass energy potential", Economic Annals-XXI, Vol. 3-4, No 1, pp. 86–89, 2014.