TRENDS IN SCIENTIFIC RESEARCH ON TECHNOLOGICAL ASPECTS OF GREEN ENERGY TRANSITION

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Abstract

The significant potential of renewable energy sources (RES) in Azerbaijan served as the basis for the green energy transition (GET) and the integration of renewable energy into the country's energy supply system. A bibliometric analysis of trending scientific research issues on the technological aspects of GET was carried out using the metadata of publications indexed in the Web of Science (WoS) Core Collection abstract database over the past 4 years using the VOSviewer program. As a result of the analysis, four main directions of scientific research were identified: optimization of energy resource consumption; the impact of renewable energy sources on sustainable development; the environmental benefits of the energy transition; and technological innovation. The publications of the first cluster mainly address the problems of optimizing energy generation from renewable sources, primarily solar and wind energy, as well as issues of storage, distribution, and energy consumption. The second cluster presents an empirical analysis of the impact of renewable energy consumption on carbon dioxide emissions and, as a consequence, on environmental sustainability, considering energy consumption and cointegration. In the works of the third cluster, environmental sustainability is assessed as a key priority of modern energy policy in light of the need for an energy transition from traditional energy to the use of renewable energy sources and the fight against climate change. Research in the fourth cluster reflects the benefits of using floating solar power plants. The results can serve as a basis for developing efficient government strategies for GET.

Keywords: green energy transition, renewable energy, VOSviewer program

I. Introduction

The modern global energy system is undergoing a socio-technical transformation called the "energy transition" or "green energy transition" (GET), which involves the use of renewable energy sources (RES) to replace fossil fuels and nuclear energy [1]. The GET has two goals: expanding sources of RES, increasing the share of their use, and reducing greenhouse gas emissions [2]. Globally, consumers spent nearly 20% more on energy in 2022 than the previous five-year average [3]. Almost one in ten people out of 40 million in the European Union could not provide sufficient heat in their homes [4, 5]. Therefore, energy transition issues are the center of attention for the world community. The most common and used renewable energy sources are hydropower, solar, wind, bioenergy, geothermal, and tidal. According to the International Energy Agency (IEA), for 2023, the share of energy production from renewable energy sources in countries that are members of the agency was 30.2% [6]. As follows from Fig. 1, the share of solar and wind energy capacity is increasing, while hydropower is decreasing. According to IEA forecasts, the commissioning of green energy capacity will steadily increase and should reach

more than 40% by 2030 [7]. For Azerbaijan, the share of RES in the country's energy balance is 18%. By 2030, it is planned to increase this figure to 30%, by 2050, it will be more than 40% [8].

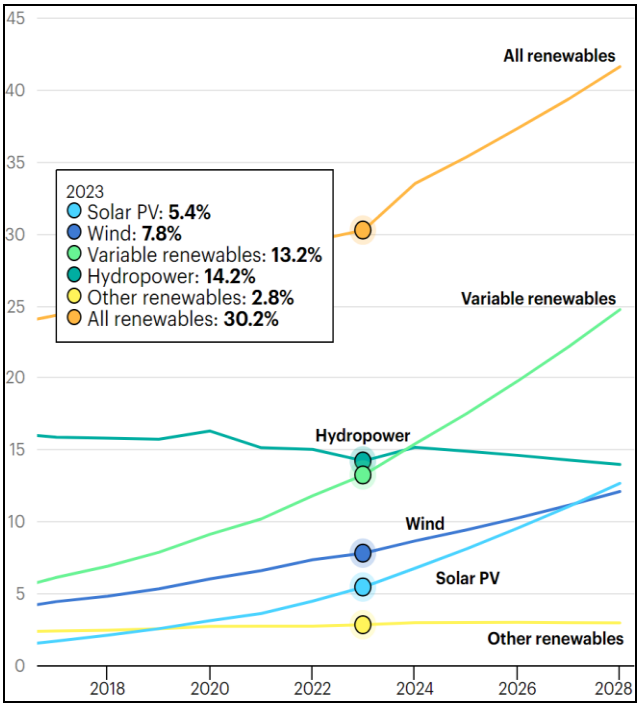

Figure 1: *Renewable electricity generation by segment (https://www.iea.org/reports/renewables-2024/executive-summary)*

For a long time, in the development of the national economy of Azerbaijan, the main driver of growth was the extraction and export of fossil energy resources, which led to risks of environmental degradation and imbalance of the ecosystem. The year 2024 in Azerbaijan was declared the "Year of Solidarity for the Green World" (https://azertag.az/ru/xeber/azerbaidzhan_lider_v_regione_po_perehodu_na_zelenuyu_energiyu_2882779), which involves the introduction of green energy technologies, environmentally friendly waste processing, the introduction of environmentally friendly production with zero greenhouse gas emissions, and the implementation of measures to restore contaminated areas [9, 10]. The significant potential of Azerbaijan's renewable energy sources served as the basis for their successful integration into the country's energy supply system: the technical potential of green energy (GE) on land is 135 GW, and on the shelf of the Caspian Sea,- 157 GW [11]. Since 2021, the Karabakh region of the country has been declared a "Green Energy Zone," and corresponding creative work is underway. The region's energy supply is planned to be fully provided by green energy [12]. In international projects on green energy and the energy transition implementation, Azerbaijan works with Norway, Great Britain, the United Arab Emirates, and Slovakia [13]. The scale of Azerbaijan's development in GET makes it relevant to study promising scientific research and international experience in using green energy.

The purpose is to identify trending research tasks on the technological aspects of countries' transition to green energy, analyze foreign experience in introducing various types of green energy, and forecast potential areas for green energy development.

II. Methods

To study the scientific field of GET, this study applies the publication analysis methodology by using keywords for scientific articles in the WoS database [14,15]. Keywords are a mandatory

and important informative component of each article [16,17]. If the author does not give the keywords, they are assigned by the WoS database. To analyze the topic of GET and determine the main trends in scientific research, the tools of the VOSviewer 1.6.20 program were used. The keywords used in the search were: green technologies, renewable energy, alternative energy, low-carbon energy, environmentally friendly energy, sustainable energy, technology, sustainable energy transition, low-carbon transition, transition to renewable energy sources, and decarbonization. The initial query to the WoS database was carried out on May 16, 2024, and 7244 scientific publications were identified for 2021–2024. To narrow the scope of research, scientific articles from the WoS Categories section were selected from this number, and the section "Green sustainable scientific technologies" was selected (Table 1). The remaining 894 publications are downloaded from the WoS database as a tab-delimited file in Full Record format. Next, in the VOSviewer program, select the data type: - Creating a map using bibliographic data. The program then reads data from the downloaded WoS files. As a type of analysis of keywords, their co-presence in publications is selected, and the calculation method is complete (Table 2).

Table 1: *Data collection process [18,19]*

Data	Line search - Search string
Topic	Green energy transition
Added keywords	green technologies renewable energy, alternative energy, low-carbon energy, environmentally friendly energy, sustainable energy, technology
Timesp a n	2021-2024
Sources	
Types of articles	Review article, Open access, Early access, Enriched cited references, Open publisher-invited reviewers
Initial results	7244 publications
WoS category	Green Sustainable Science technology
End results	894 publications
Records were exported to	Tab to limited file
Record content as	Full record and cited references

Table 2: *Chosen command parameters of tabs on VOSviewer*

Choose data source	Read data from bibliographic database files
Choose type of data	Create a map based on bibliographic data
Select files	WoS Core Collection files
Choose type of analysis and counting method 1. Type of analysis 2. Unit of analysis 3. Counting method	 1. Co-occurrence 2. All keywords - Author keywords and keywords plus 3. Full counting
Choose threshold: Of the 4981 keywords, 107 meet the threshold with minimum number of occurrences of keywords	11

III. Results and discussion

Energy transition means the transition from energy systems based on fossil fuels, such as oil,

natural gas, and coal, to systems based on renewable energy sources, such as solar energy, wind, and biofuels. Azerbaijan's policy shift towards renewable energy sources was accelerated after 2020 with the return of 20% of its territory. In 2023, during COP-28, President I. Aliyev formulated strategies for the country's energy transition, promoting carbon neutrality. Therefore, there is an urgent need for large-scale research to increase the use of cleaner energy sources. This bibliometric review analyzes research on the technical aspects of countries' energy transitions over the past four years and identifies future promising research [21, 22]. By mapping the keywords of scientific publications on the energy transition, this study uses bibliometric software such as VOSviewer to display the research results of scientific publications listed on the Web of Science in 2021-2024. Analysis of research shows that aspects such as climate change, alternative energy, green energy management approaches, and emissions reduction are becoming increasingly important. Additionally, areas requiring future research include the development of policy frameworks, energy infrastructure (storage and transmission), renewable energy ecosystems, GE adaptation, economic analysis of clean energy, and impact assessments for a timely energy transition around the world [23, 24]. Therefore, cooperation between countries and research institutions should be promoted, with a special focus on the development of clean technologies and knowledge transfer for a rapid energy transition around the world.

From the metadata of the downloaded 894 publications, the VOSviewer program identified 4981 keywords. With a minimum number of co-present keywords of 11, 107 words were involved in constructing the map. Of these, the 20 most frequently used keywords with co-presence frequency and full degree of connections are shown in Fig. 2, these are mainly the terms and phrases of the authors themselves.

Create Map

Verify selected keywords

Keyword	Occurrences	Total link strength
renewable energy	190	810
co2 emissions	72	391
sustainability	91	376
energy	105	375
transition	85	372
impact	75	368
consumption	67	350
energy transition	83	293
innovation	61	281
economic-growth	47	256
growth	53	249
policy	57	249
china	55	242
emissions	56	236
performance	68	227
sustainable development	52	210
efficiency	44	197
circular economy	46	183
electricity	33	165
system	41	162

Figure 2: *20 top keywords*

In the 894 publications reviewed, the most frequently used terms were renewable energy, carbon dioxide emissions, impact, energy consumption, economic growth, optimization,

productivity, sustainability, generation, management, system, power, China, energy transition, etc.

The 107 words selected by the program are grouped into 4 clusters and indicated in different colors (Fig. 3):

1st cluster - red - 37 terms on optimization of energy resources;

2nd cluster - green - 33 terms on renewable energy sources and sustainable development;

3rd cluster - blue - 30 terms on environmental benefits of the energy transition;

4th cluster - yellow - 7 terms on technological innovations.

The publications of the first cluster mainly address the problems of optimizing the generation of energy from renewable sources, mainly focusing on solar and wind energy, as well as issues of energy storage and distribution [25]. In [6], the energy sector is presented as the core of the global goal of reducing carbon dioxide emissions, and renewable energy sources are becoming an increasingly preferred source of energy generation throughout the world, and their use leads to decarbonization of the energy sector.

According to the publication, generated in the second cluster, the energy transition to the predominant use of green energy is an integral component of the strategy of states on the path to sustainable development. The publications provide an empirical analysis of the impact of renewable energy consumption on carbon dioxide emissions and, as a consequence, on environmental sustainability, considering energy consumption and cointegration. The articles [16] examine the relationship between renewable energy consumption and economic growth using the concept of the environmental Kuznets curve. Based on the analysis of empirical data, strategies are proposed for an effective energy transition aimed at reducing greenhouse gas emissions and promoting environmental sustainability (Fig. 4).

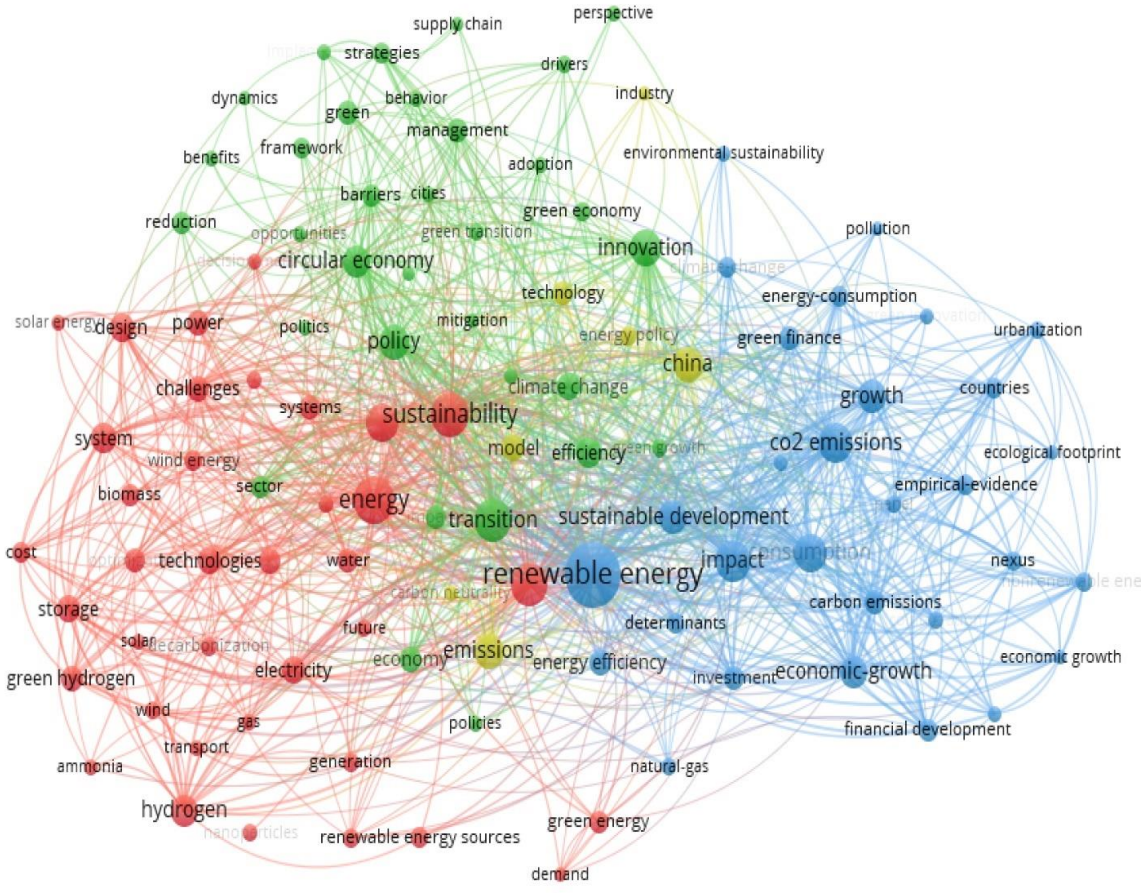

Figure 3: *Clustering of co-occurrence of all keywords (Author KW + KW Plus)*

In the works of the third cluster, environmental sustainability is assessed as a key priority of modern energy policy in light of the need for an energy transition from traditional energy to the use of renewable energy sources and the fight against climate change [1]. Article [26] analyzes the factors influencing the achievement of carbon neutrality, based on the concepts of energy efficiency and the use of innovative technologies. [9] examines the role of public energy policy in promoting environmental sustainability and achieving the energy transition. Based on an analysis of current trends and best practices, recommendations are offered for the development of strategies aimed at promoting sustainable development and reducing negative impacts on the environment. The environmental disadvantages of green energy are studied in [24]:

-for hydroelectric power plants (HPP)- flooding of territories during construction; construction is only possible nearby rivers and large reservoirs; not suitable for construction in northern regions; changes in the microclimate around hydroelectric power stations lead to changes in flora and fauna, changes in river beds and, as a consequence, ecosystem body of water;

-for solar power plants- environmental pollution is observed during the extraction of the main element for the production of solar panels - silicon; environmental pollution occurs during the disposal of solar panels and batteries due to the high cost of processing elements;

-for wind power plants- environmental pollution during the disposal of wind generator blades; high-noise wind generators; low-frequency vibrations cause soil corrosion.

The publications in the fourth cluster discuss Floating Solar Power Plants (FSPPs). The energy efficiency of FSPP is up to 10 % higher than ground-based ones. FSPP can occupy unused space in water bodies, including reservoirs at hydroelectric dams, other than those intended for drinking water supply. FSPP often requires fewer materials than a similarly sized above-ground project, less maintenance, and less cleanup since the panels are typically located away from potential sources of debris.

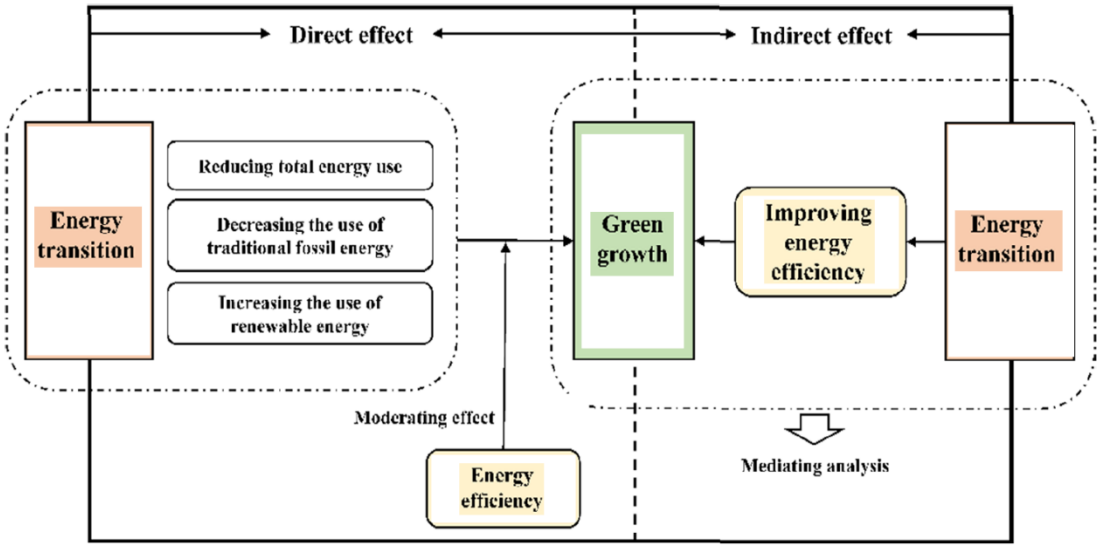

Figure 4: *The theoretical link between energy transition and sustainable development [6]*

IV. Conclusion

The "green" energy transition is a global economic policy trend that entails the need for a radical restructuring of many industries, primarily energy, construction, and transport, to achieve carbon neutrality. The study of the scientific field of "energy transition" in the context of modern global energy policy is a topical issue, the focus of which is the replacement of traditional energy resources with renewable energy sources. An analysis of 894 scientific publications selected by the

VOSviewer program using metadata analysis methodology revealed the main trends and prospects for this scientific area of research (Fig. 5): this is primarily a solution to the problems of optimal sustainable energy consumption. The results obtained indicate significant interest in the optimization of energy resources, the development of renewable energy, and sustainable environmental development [25]. Four key clusters have been identified, which examine aspects of the optimization of energy resources, the use of renewable energy sources, and their impact on the environment. This study highlights the importance of the transition to sustainable energy sources, in the context of combating climate change and achieving environmental sustainability. The results, based on the analysis of current trends and practices, can serve as the basis for the development of effective government strategies and programs aimed at achieving sustainable development and reducing the negative impact on the environment in the energy sector [26].

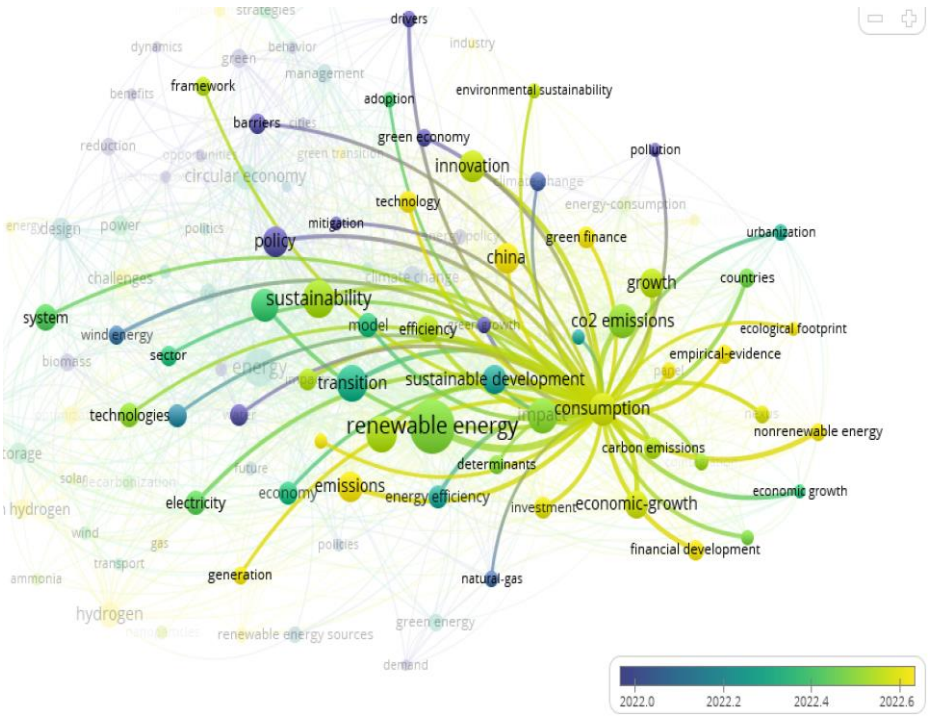

Figure 5: *Emerging research topics*

In Azerbaijan, renewable energy generation is at the beginning of its development. To achieve the results planned by 2030, not only government support is required, but also the formation and development of the entire production chain- from research and development to the creation of our industry for the production of equipment for renewable energy sources. Because the renewable energy sector is one of the most innovative, its development will be quite significant for the country's economy, both in terms of the creation of new high-tech products and in terms of the creation of new high-tech industries.

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