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THE EVOLUTION AND IMPACT OF BIOGAS RESEARCH IN MITIGATING CLIMATE CHANGE: A BIBLIOMETRIC APPROACH

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Abstract

As a solution to mitigate the effects of climate change, scientists have been looking for more environmentally friendly energy production alternatives, so, since the 2000s, renewable energy production has increased across Europe. Climate change has a negative impact on our planet, with increased emissions of greenhouse gases contributing to global warming. In this context, biogas has become a promising solution for reducing greenhouse gas emissions and improving environmental quality. The purpose of the study is to review the evolution of research and development in this field, identify trends and gaps in existing knowledge, and assess the impact and significance of published research. In this sense, a bibliometric analysis was carried out, based on the topics "renewable energy" and "biogas", in which VosViewer software was used to create maps. The research results show that existing policies worldwide encourage transfer and synergy between researchers from different countries, achieving important results. Practically, researches and examples of good practise show that biogas can be a viable solution to mitigate the effects of climate change, and in the coming decades, under the conditions of the population growth estimates materialization, we will most likely witness an intensification of agriculture to ensure the population's food needs.

Key words**:** *renewable energy, biogas, bibliometric analysis, climate change*

INTRODUCTION

Lately, researchers around the world have focused their research on protecting the environment by finding innovative solutions for alternative energy sources. This approach has been determined by significant increases in average temperatures over the past 150 years, driven by rising greenhouse emissions, and it is estimated that by the end of 2100, these temperatures will rise between 1.8^{o} C and 4^{o} C [24]. Rising average temperatures have led to the impairment of many natural systems, including glacial lakes or lakes and river temperatures, with the effects of climate change becoming increasingly pronounced over the past 30 years [6]. Practically, climate change is negatively affecting natural systems, human populations, and regions (Figure 1).

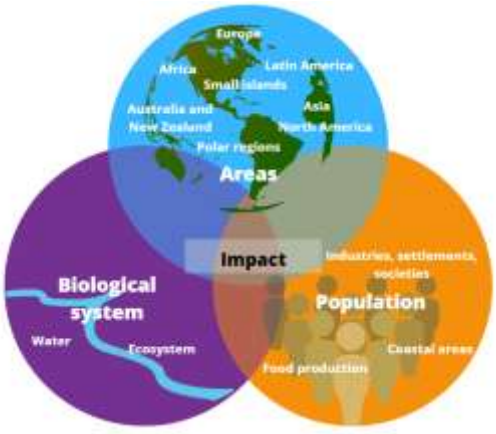


Fig. 1. Perspectives of the global warming impact
Source: [16].

As a solution to mitigate the effects of climate change, scientists and practitioners alike have been looking for more environmentally friendly alternatives, so that, since the 2000s, renewable energy production has increased across Europe [4]. Mutaqin [23] notes that the demand for renewable energy has been on an upward trend so far, which is due to both the decrease in fossil fuel reserves and the public's awareness on the effects of climate change, and thus, the need to use more environmentally friendly energy sources. This process is increasingly present in developing countries (e.g. Indonesia), where this type of energy is having a positive impact on the whole society. Fossil fuels are present in few geographic areas and are limited resources, making countries outside these areas dependent on imports. In order to prevent an energy crisis like that in the 1970s, global efforts have focused on trying to replace fossil fuels with renewable ones, increasing interest in biogas.

Biogas is a good source of renewable energy, offering the possibility of recycling various agricultural residues and secondary agricultural products, industrial and domestic wastewater, sewage sludge, and its production is sustainable and environmentally friendly.

Only 40 million ha of the EU surface could be used for producing biogas and the largest amount of wastes used in biogas production come from the urban areas [11].

Alternative forms of energy largely contribute to sustainable rural and regional development Renewable energy can be seen as a way to improve the economic situation of farms, and in addition can help develop other companies involved in agro-bio-energy plants [25].

Climate change has a negative impact on our planet, with increasing greenhouse gas emissions contributing to global warming [5]. In this context, biogas has become a promising solution for reducing greenhouse gas emissions and improving environmental quality. By converting organic residues into energy, biogas can be used to generate electricity and heat, thus reducing dependence on fossil energy sources [26].

Looking for a healthier food production and to mitigate the impact of climate change, new sustainable energy options have been developed.

Of the total methane gas produced by human activities, 30% is carried out by livestock. Also, the use of chemical fertilizers increases emissions as well as the greenhouses polluting effects.

Biogas is an alternative to reduce the dependence of producers to oil and optimize agricultural production systems, helping the reduction of the environmental impact of human activities [28].

Organic waste is an environmental problem that society is facing more and more [2] and, as a result, sustainable waste management, is a major policy priority for many countries around the world, which can make an important contribution to joint efforts to reduce pollution, GHG and climate change impacts [29].

Although biogas combustion releases carbon dioxide, the difference from fossil fuels is the origin of the carbon in biogas, which has a closed cycle in a very short period of time [15]. Biogas production through anaerobic digestion also contributes to reducing methane and nitrous oxide emissions resulting from the storage and use of manure as fertiliser, with a much higher greenhouse potential compared to carbon dioxide [13].

Biogas production is a sustainable process used to simultaneously generate renewable energy and to treat organic waste. The growing interest in using biogas as a substitute for natural gas or exploiting it for transport fuel has opened new perspectives in the development of biogas upgrading techniques [1].

Biogas production primarily involves a well-established technology for renewable energy generation and also, for the organic residues' valorisation. Biogas and digestate are the final products of a biologically mediated process, so-called anaerobic digestion, in which a multitude of microorganisms follow various metabolic pathways to decompose organic matter. Therefore, biogas being a combustible gas, it can be used for the production of heat

and electricity, and the decomposed substrate i.e., digestate, it can utilised in agriculture as fertiliser due to its richness in macronutrients and micronutrients, that are essential for plants growth.

In a circular economy, the biogas production can play an important role in, since a renewable fuel can be produced from organic waste. Therefore, resource-efficient biogas production must consider both biological and energy performance [21, 30].

Biogas, in addition to being able to contribute to improving the country's energy balance, helps to conserve natural resources and to improve environmental conditions. On top of this, it has numerous benefits for the farmers involved in its production.

The aim of the study is to examine the evolution of research and development in this field, identifying trends and gaps in existing knowledge, and to assess the impact and importance of published researches, in the same field. The study also provides a general review of the most important attainments and issues biogas's use as a source of renewable energy, thus easing the ways to develop the energy production solutions and strategies.

Review of the scientific literature

One of the most important issues that society is facing today is climate change, with negative impacts on people's lives and on the environment. Massive greenhouse gas emissions are the main cause of global warming, and this has led to an urgent need for solutions to reduce their negative impact. Climate change has an important effect on ecosystems and the environment. As shown in the study published by Chen (2017), climate change has a major effect on thermal changes and environmental and soil changes around the world [9, 18].

Biogas can be seen as an important solution in this context as it converts organic waste into energy, reduces greenhouse gas emissions and contributes to the conservation of natural resources. The biogas production process is based on the fermentation of organic materials such as agricultural and household waste, thus producing electricity and heat.

Also, to add at the environmental benefits, biogas is also a resource to elevate the energy efficiency and to decrease reduce the costs for consumers. For example, biogas can be used in thermal power stations or even biogas-powered vehicles, which can reduce dependence on fossil fuels and contribute to sustainable economic development.

Biogas is a cleaner and less polluting option than other fuels, especially compared to fossil fuels. An article published by Mitsui [22] reveals that biogas is a clean fuel and therefore significantly reduces emissions of greenhouse gases and pollutants that affect air quality.

The authors Lanzerstorfer and Jager [19] found, from their analysis, an increase in the number of biogas power stations as well as in their size and also appreciated that the raw material mainly used for biogas production is renewable organic material. In addition, older biogas power station use mainly organic waste, while larger stations built in recent years use organic material. Petersson [27] states that biogas contains not only methane, carbon dioxide, and water, but also other impurities, which can affect equipment for biogas use through corrosion and mechanical wear.

Biogas digestion has experienced a quick development due to its unique characteristics in dealing with energy shortages and environmental pollution, asserts Chen [8] in his paper titled "History of Biogas Production in China". He also said that small farms in China are becoming larger and larger while developing biogas plants.

The standardisation of biogas technology is extremely important to promote the biogas industry worldwide. China has built a comprehensive biogas standard system, which involves common standards, household biogas, biogas digester for household wastewater treatment, production utilization and service system standards. The potential problems and barriers to biogas standardisation in China are analysed and reduced to slow standards, overlapping standards, government-dominated standards and lagging international standards; therefore,

all potential biogas standards should be evaluated and placed under the same department in the company [20].

Benato [3] states that Italy occupies an important position in the ranking of biogas producing countries. Agricultural, storage, sewage and manure substrates through anaerobic digestion, are transformed into biogas and after into heat and electricity through internal combustion engines that are properly adapted. Thus, in the study cited above [3, 17], after overviewing the European context, the authors present the stage of the Italian biogas sector, in regard to the trends and factors development that favour/block the expansion of biogas production and use. Even if biogas is a renewable gas and involves a consolidated technology usage, it is necessary to examine the real costs, the composition of biogas and the combustion products of engines. Analysis of biogas production shows an increasing growth rate until the end of 2012, due to generous government subsidies, while, after the reduction of support, a continuous reduction of biogas installations was observed. Actual on-site measurements have demonstrated the variable composition of biogas, while engine emissions remain comparable to natural gas.

Biogas has many different ways that can be used: direct combustion with only heat production, combined heat and power (CHP) generation, or it can be transformed into biomethane and subsequently used for vehicles as a fuel or injected into the natural gas grid. The question arises: what is the most feasible way to use biogas? Assessing the feasibility and performance of a single modality cannot be based solely on economic criteria, such as costs and related economic benefits [12].

The purpose of the study is to review the evolution of research and development in this field, identify trends and gaps in existing knowledge, and assess the impact and significance of published research. In this sense, a bibliometric analysis was carried out, based on the topics "renewable energy" and "biogas", in which VosViewer software was used to create maps.

MATERIALS AND METHODS

In order to identify the direction of the biogas production segment in recent years, data were collected from the Eurostat platform, starting with year 2014, which was the beginning of a new programming period focused even more on climate change mitigation [16].

Next, through the Web of Science platform, publications with "renewable energy" and "biogas" as the main topic were collected and then entered into the Vosviewer software in order to generate maps showing the link between the topics.

In this respect, by the end of 2022, 158,577 results had been generated on the topic 'renewable energy', while the topic 'biogas' generated 31,644 results.

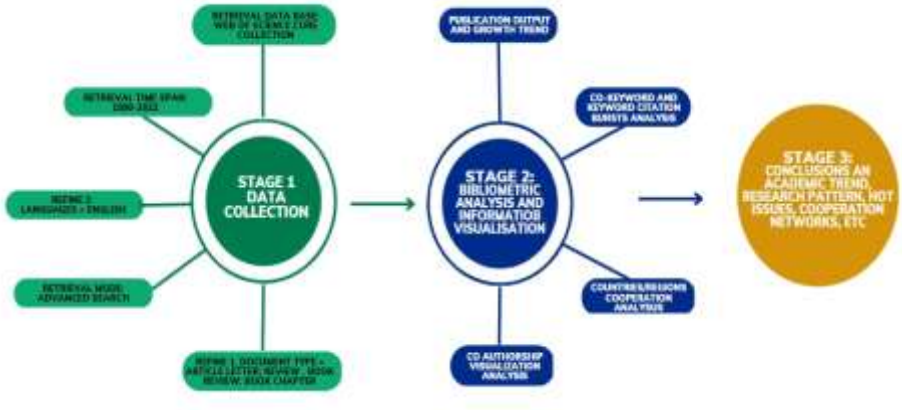


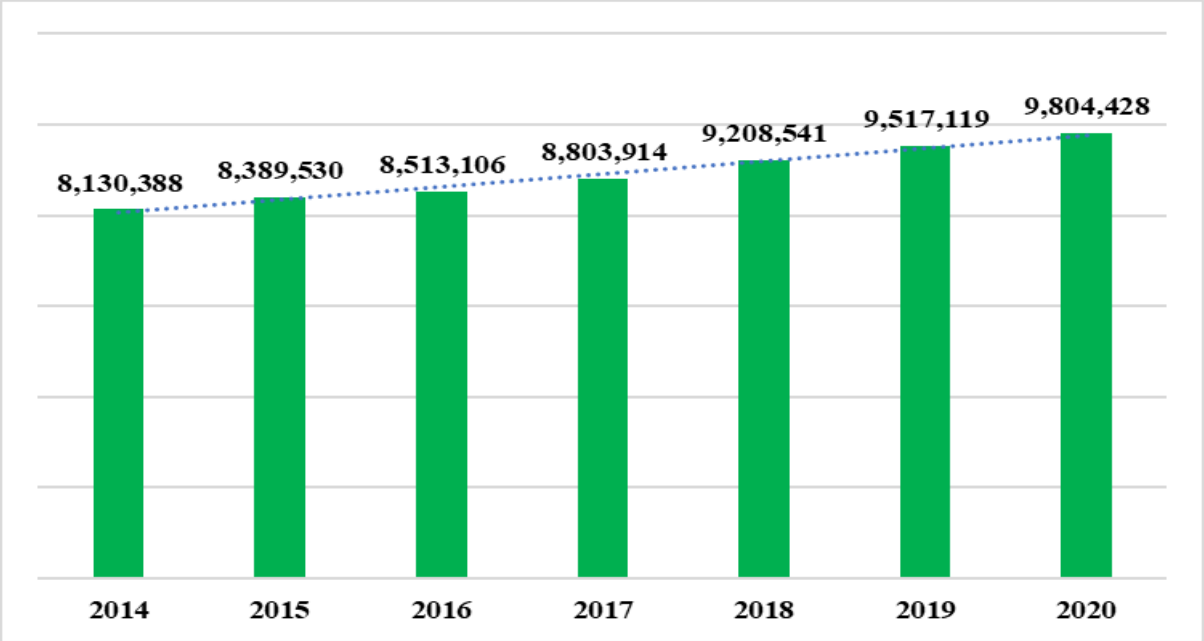
Fig. 2. Steps in data collection and analysis.
Source: processing after [16] using Canva [6].

Scientometrics is seen as a particularly important scientific discipline, representing an informational process that quantitatively analyses a specific scientific field. Thus, the aim of the process is to provide an objective picture through which science develops over a period of time, from the assessment of timeliness, through the generation of the main topics of interest for academic activity, to the optimal organisation of research systems and activities [16].

Alan Pritchaed used the term bibliometrics for the first time, as early as year 1969, as a statistical and mathematical method whose field of applicability are books and publications [16]. Using VOSsviewer software (Centre for Science and Technology Studies, Leiden University, Leiden, The Netherlands), once the data have been entered, keyword-based maps of existing publications in the Web of Science are generated, thus producing unique results. Basically, this type of analysis involves three steps, as shown in Figure 2.

RESULTS AND DISCUSSIONS

The main energy production from renewable sources and biofuels has a continuous increasing trend in the European Union, therefore by comparing the production from year 2020 to one in year 2014, there is an increase of 20.6% (Figure 3).



Fig, 3. Primary energy production from renewable sources and biofuels in the EU-27 (terajoule)
Source: Processing of the Eurostat database, Accessed 20.01.2022 [14].

It is worth noting that Germany, France, and Italy are among the top "green" energy producing countries, each producing more than 1 million terajoules, and are also the largest energy consuming countries. This is driven by the need of these highly industrialised countries to secure their domestic needs and limit their dependence on energy from conventional sources. At the same time, the last year of analysis (2020) shows a decrease in consumption of total energy caused by the temporary closure of industrial centres due to the Covid-19 pandemic (Figure 3).

Regarding the use of energy from gasification installations for biogas, there was a decrease of 8.5% in 2018 compared to the previous year. However, these decreases are driven by high production costs, which result in higher prices compared to other production sources (Figure 4). This segment is fully covered by only three countries: Germany (95% of use), Hungary, and Croatia.

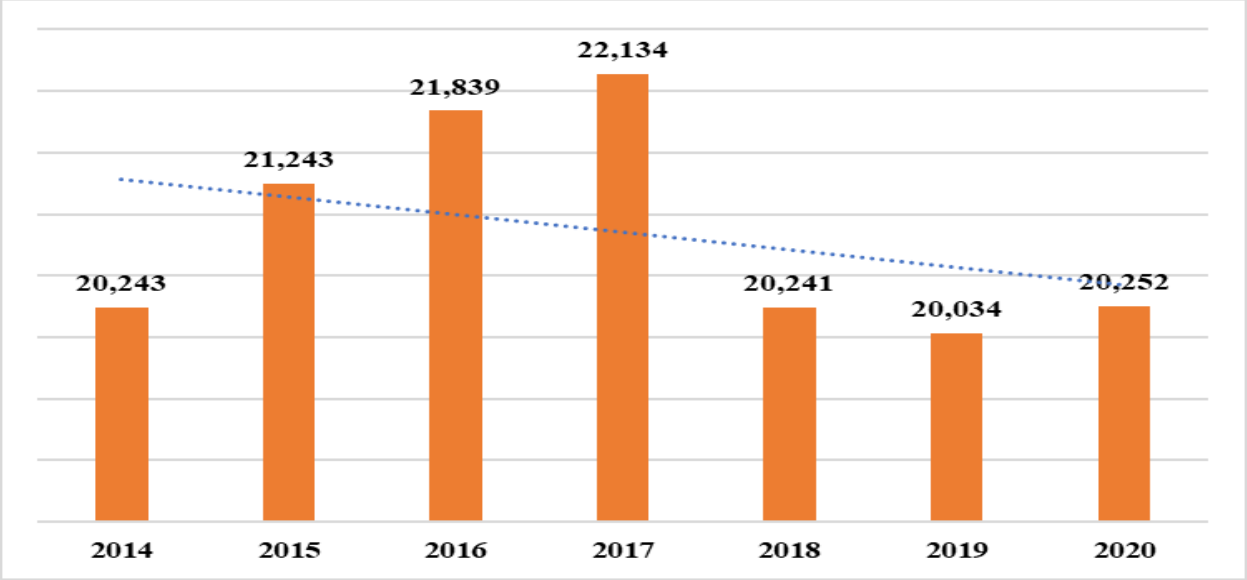


Fig. 4. Energy use from gasification installations for biogas at EU level (terajoules)
Source: Processing of the Eurostat database, accessed 20.01.2022 [14].

The following presents the information obtained from the bibliometric analysis, which is used to measure the impact and quality of research on the topics mentioned, as well as to identify trends, and is of particular importance in terms of resource allocation and identifying opportunities for collaboration.
Thus, by collecting data from the Web of Science database, a total of 158,577 papers on the topic "renewable energy" were identified between 1990 and 2022, while the topic "biogas" recorded a total of 31,644 publications. According to Figure 5, a continuous upward trend in the number of publications in these fields can be observed, except for the year 2022, when a slight decrease was recorded due to the energy instability in the world. This reality has led to a moderation of the measures regarding the implementation and use of renewable sources, through which the European Union can ensure its energy security (Figure 5).

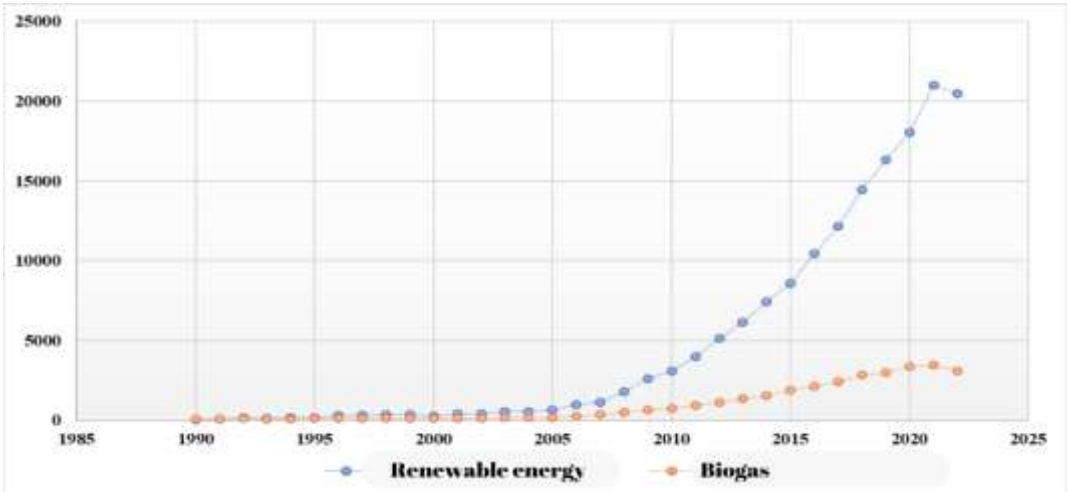


Fig. 5. Evolution of the number of articles published in the Web of Science Core Collection according to the analysed fields
Source: own processing, [10] Accessed 08.01.2023.

The main terms related to the research topic "renewable energy" are: wind energy, solar energy, wave energy, geothermal energy, energy security, energy consumption, energy poverty, environment, economy, energy reuse technologies, feed-in tariff, eco-innovation,

energy policy, clean energy, grouped in four clusters (Figure 6). Basically, the analysis shows the most widely used renewable energy sources and their implications for the environment and the economy.

The first cluster includes terms such as biomass, biogas, hydrogen, energy mix, energy efficiency, renewables, energy security, energy consumption, energy poverty, environment, economy, integration, penetration, optimisation, power generation, planned energy, photovoltaics, solar, heat (Figure 6). This cluster group studies in less researched than well-known areas such as biomass and biogas with a focus on energy efficiency and process optimisation with the aim of becoming a viable alternative in all respects.

The second cluster refers to capacity, resources, system, investment in the project, innovation, determination, barriers, strategies, development, wind power, energy reuse technologies, feed-in tariff, Eco innovation, energy policy, geothermal energy, promotions, implementation, impact, sustainability, policy (Figure 6.). Like any relatively new or emerging field, it faces certain challenges, so this cluster groups terms related to investment sources and existing policies.

The third cluster interconnects our research topic with energy consumption, carbon emissions, cointegration, impact, consumption, oil price, carbon, cooperation, dynamics, non-renewable energy consumption, evidence of economic growth, non-renewable energy, unit root test, clear energy, new evidence, linkages, panel data analysis (Figure 6). This group can be said to bring together positive evidence on the use of energy from renewable sources compared to the use of energy from conventional sources.

The fourth cluster refers to terms such as wind energy, solar energy, wave energy, geothermal energy, renewable biomass energy, tri-energy, hydropower, sustainable energy, bioenergy, hydropower, future (Figure 6). Finally, the last cluster covers the most widely used sources of green energy, which is considered the future of energy production.

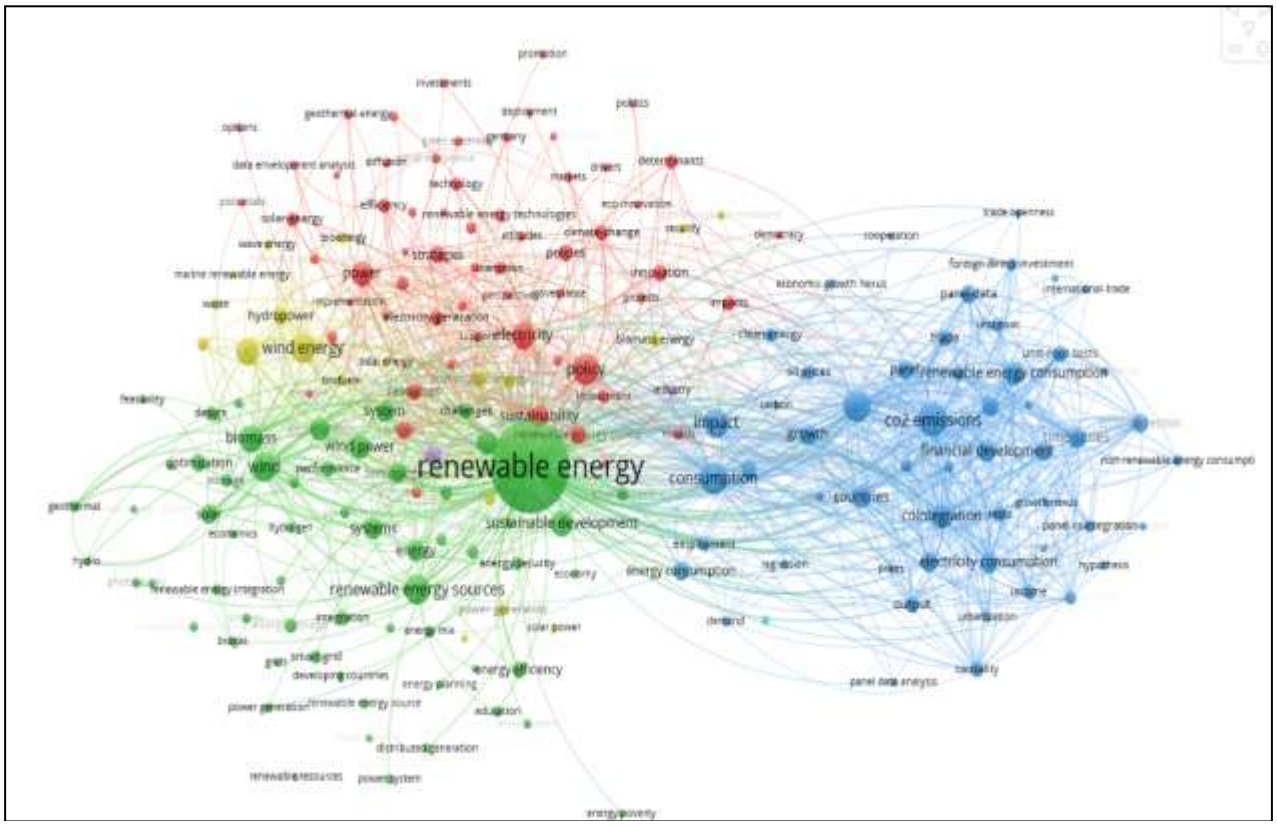


Fig. 6. Link between renewable energy and other related terms
Source: own processing based on WoS[10] results using VOSviewer [31].

Analysing the keywords by year, it can be seen that in 2014, 2015 and 2016 researchers were concerned with: renewable energy sources such as biomass, biogas, hydrogen, energy mix, energy efficiency, renewables, energy security, energy consumption, energy poverty, environment, economics, integration, penetration, optimisation, power generation, planned energy, wind power, energy reuse technologies, feed-in tariff, eco-innovation, energy policy, geothermal energy, promotions, implementation, sustainability, policy, employees. The evolution identified in the graphical representation highlights the steps taken by this topic to identify alternative sources of green energy and quantify the results through the implementation of these sources, as a result of investment measures driven by governments around the world, in the desire to limit the effects of climate change and to try to reduce energy dependence on conventional sources, concentrated in certain countries. In 2017-2018, the focus was on impact, consumption, solar energy, cointegration, foreign direct investment, outputs, panel data, growth, countries, impact, innovation, oil price, industry, models (Figure 7) direction driven by the investment impact assessment made in this sector.

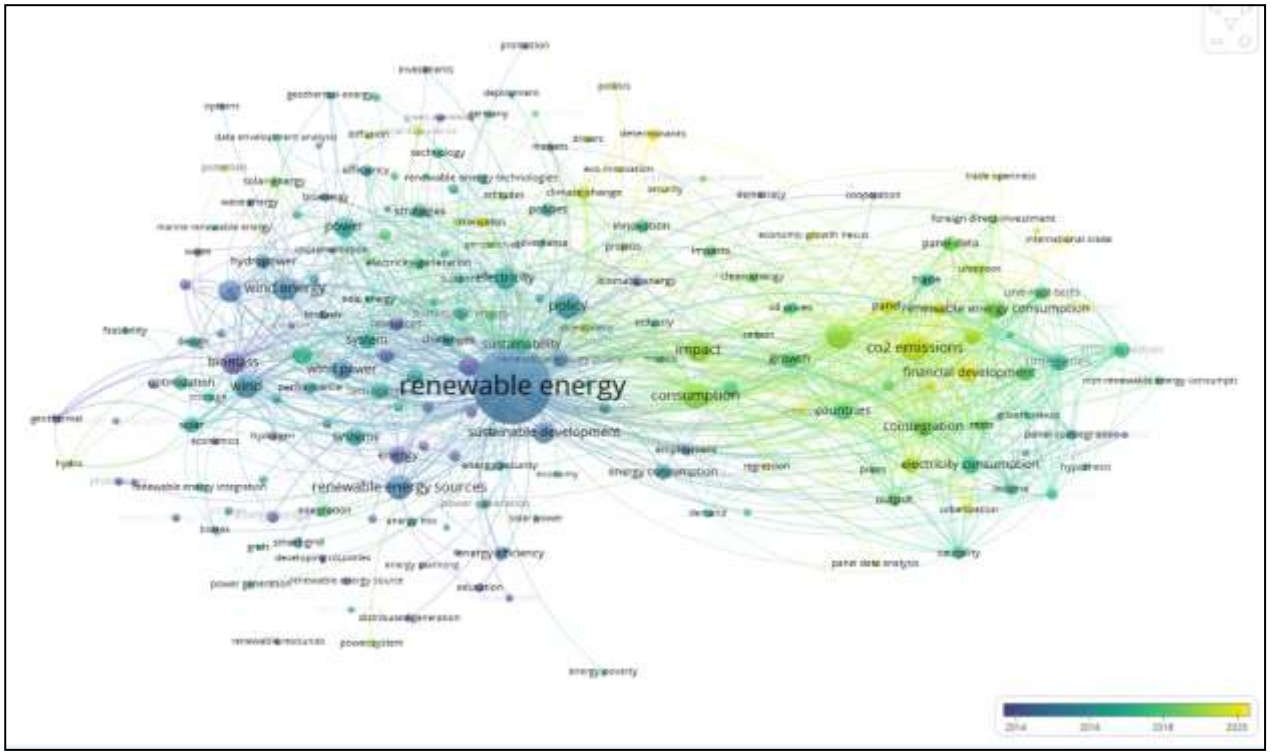


Fig. 7. Relationship between renewable energy and other related terms by year
Source: own processing based on WoS results using VOSviewer [10, 31].

In 2019 and 2020 the main topics were consumption, carbon emissions, renewable energy, economic growth, financial development, determination, security, politics, international trade and urbanisation (Figure 7).

Analysing the link between the co-author countries, it can be seen that countries such as China, Turkey and the United States of America give particular importance to the subject, while China, Denmark, India and the United States of America are in close cooperation. Also, countries in the European Union such as Germany, Belgium, Finland, Italy, and the Netherlands are in close contact and approach research in a different direction compared to the other countries presented above (Figure 8). Basically, the countries that pollute the environment the most, mostly due to their high degree of industrialisation, allocate significant funds to research to identify and optimise green energy sources,

also determined by the international agreements they have to take into account. At the same time, the European Union's policy, through the required research programmes, encourages collaboration between member countries on renewable energy sources, perhaps the most important objective set at EU level.

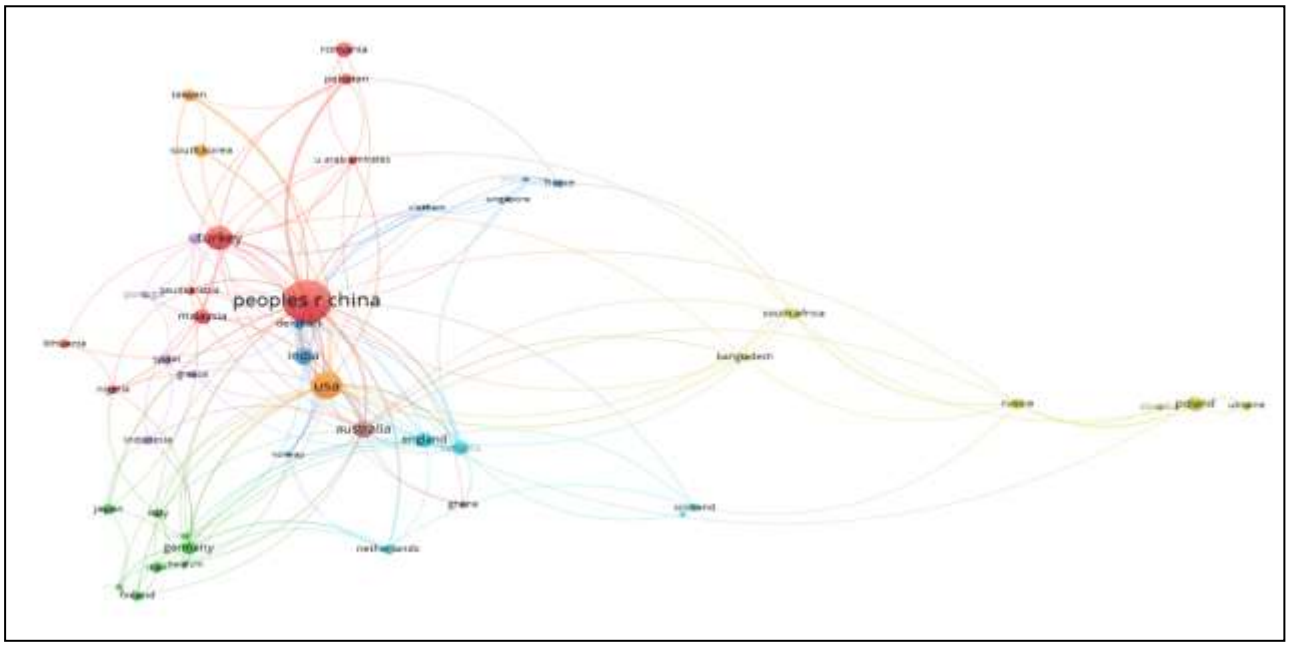


Fig. 8. Link between co-author countries (renewables and other related terms)
Source: own processing based on WoS results using VOSviewer [10, 31].

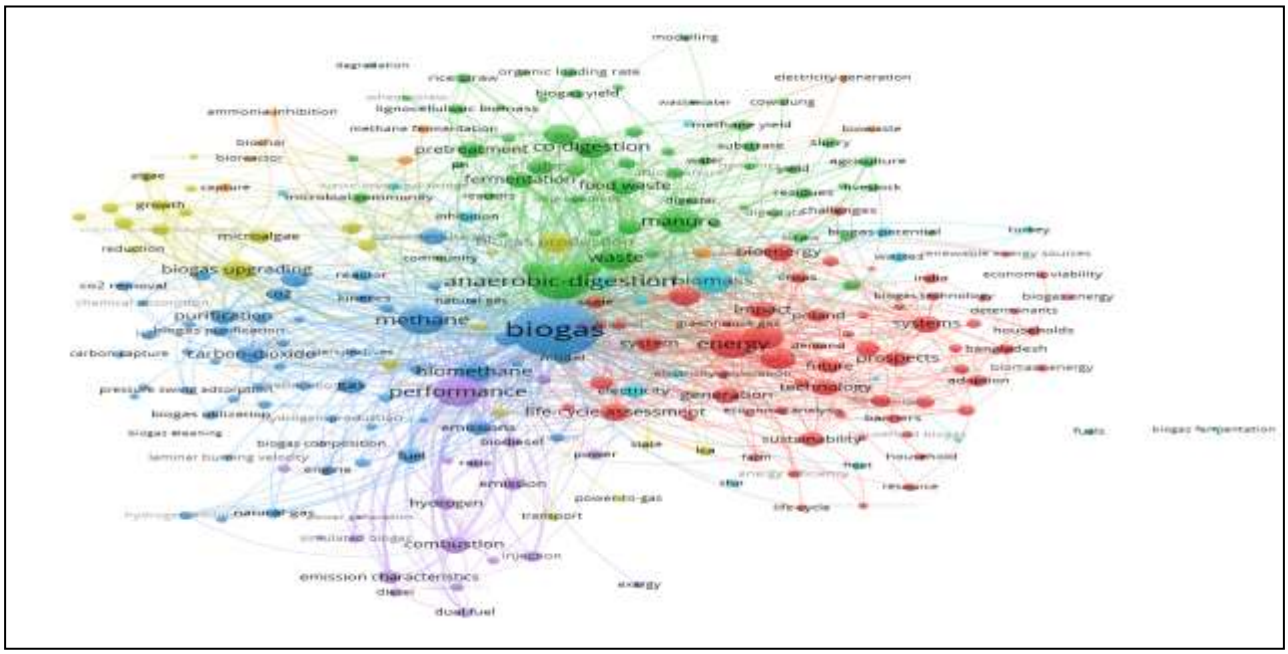


Fig. 9. Link between biogas and related terms
Source: own processing based on WoS results using VOSviewer [10, 31].

The main terms related to biogas are biodiesel, biomass, bioenergy, energy, waste, emissions, biogas use, pre-treatment, anaerobic digestion, fermentation, purification, biogas upgrading, life cycle allocation, technology, electricity, economic analysis, sustainability, etc. (Figure 9). The graphical representation on this more specific biogas segment reflects an in-depth analysis of process optimisation for biogas**.**

Unlike the general topic shown in Figure 6 on renewable energy, this topic and related terms are grouped into five clusters. The first cluster refers to the chemical compounds of biogas, such as carbon dioxide, methane, carbon dioxide removal, carbon capture, natural gas, hydrogen production, but also other terms such as inhibition, kinetics, pressure fluctuation, fuel, biogas cleaning, sludge, spent activated sludge, sewage sludge, reactor, design (Figure 9.).

The second cluster is interlinked with terms such as anaerobic digestion, waste, garbage, food waste, water waste, residues, water, surface, agriculture, livestock, household, biogas yield, sludge, straw, rice straw, fermentation, pre-treatment, organic loading rate, substrate, dynamics, upgrading. Cluster number 3 covers terms such as energy, biogas energy, biogas technology, greenhouse gases, technology, system, generation, adaptation, economic viability, harvests, sustainability, farms, resources, barriers, future, demand, challenges, life cycle allocation, life cycle, prospect. Cluster number four covers performance, biodiesel, hydrogen, emissions, fuels, dual fuels, biogas stimulation, emissions characteristics, power generated. The fifth cluster interconnects biogas with biogas production, biogas upgrading, algae, microalgae, growth, conversion, wastewater treatment, transport, gas power (Figure 9). In contrast to the general term renewable energy, this topic is mainly approached from the perspective of the chemical processes involved in the biogas process, with a lack of links to economic efficiency or special policies to encourage biogas production. Thus, until as much analysis as possible is carried out on the chemical processes, other associations are premature.

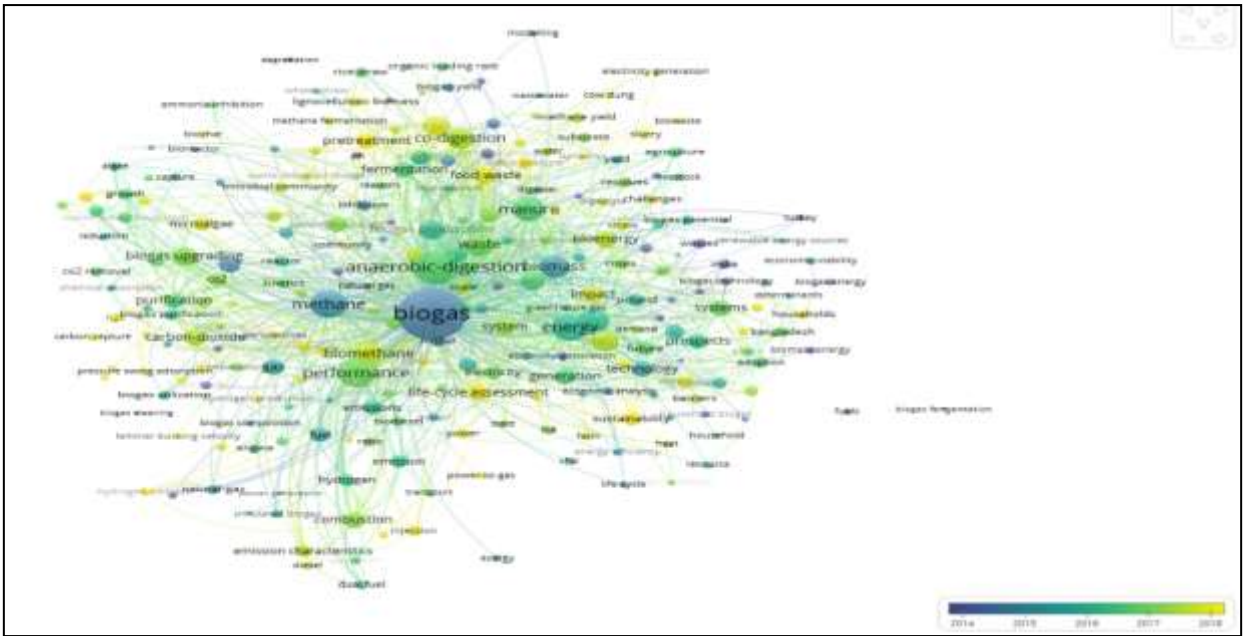


Fig. 10. Relationship of keywords used by year between biogas and related terms
Source: own processing based on WoS results using VOSviewer [10, 31].

Figure 10 shows, by year, the terms related to biogas, also grouped into clusters. Thus in 2014 - 2015, researchers were concerned with biomass, methane, natural gas, economic analysis, biogas technology, waste, biogas yield, degradation, bioreactor, electricity generation, fuel, design. In the next 2 years, 2016 and 2017, the main topics were biomass, energy, adaptation, emissions, fermentation, biogas purification, biogas use, hydrogen, natural gas, algae, anaerobic digestion, waste, purification, biogas upgrading, fuel growth, electricity, systems, agriculture, adaptation, sludge, sewage sludge, fermentation. Later in 2018, researchers paid attention to terms such as life cycle allocation, biomethane, sustainability, farms, carbon capture, pre-treatment, sludge, food waste, biomethane

fermentation, straw, challenges, biowaste, households (Figure 10). Overall, research in recent years has focused on the chemical aspects of biogas, driven by the novelty of the field under consideration.

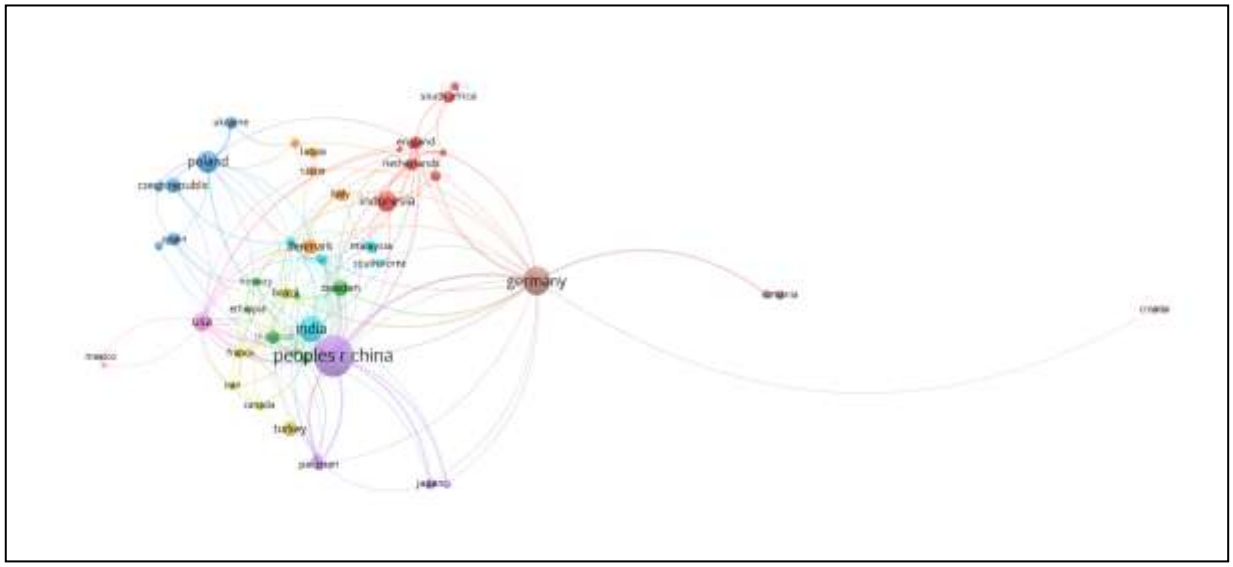


Fig. 11. Link betweenco-authorcountries (biogasandrelatedterms)
Source: ownprocessingbased on WoSresultsusingVOSviewer [10, 31].

Analysing the frequency of co-authors according to country of origin, we can see the degree of relationship between the countries interested in this research. Large nodes represent countries with increased interest in the topic of our study, with connections between nodes representing cooperative relationships between institutions. The distance between nodes and the thickness of connections represent the level of cooperation between countries, and the diversity of colours on the map indicates the diversification of research directions. Thus China, Germany and Indonesia are particularly interested in biogas, with Romania closely linked to Germany (Figure 11). The issues presented in Figure 8 are also reflected in Figure 11, where the countries that have paid particular attention to renewable energy research are basically the highly industrialised and polluting countries of the world, which are constrained in finding innovative solutions.

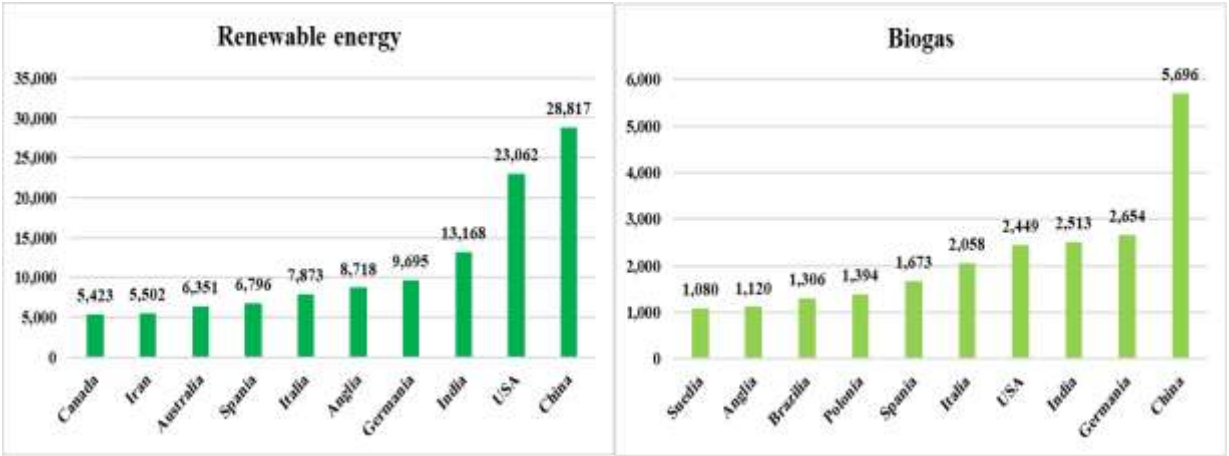


Fig. 12. Top countries ranked by number of publications on "renewableenergy" and "biogas" topics
Source: ownprocessingbased on WoSresultsusingVOSviewer [10, 31].

China has by far the highest number of publications in both the "renewable energy" and "biogas" fields. This is driven by a growing appetite for the field, fuelled by sustained economic growth, innovation and research. It is worth noting that the top countries are mainly countries that are dependent on imported conventional energy (Figure 12).

CONCLUSIONS

The field of renewable energy and biofuels plays an important role in the context of the energy security of the need to improve the European Union, offering the possibility of a variety of original approaches. Based on the huge potential of biogas in the RES sphere, the research undertaken is important in identifying the most feasible combinations or portfolio of biogas options and other related terms.

Addressing the two topics of "renewable energy" and "biogas", even if the former includes the latter term, significant differences in the state of the research process are highlighted. The importance of the first topic is already quite far back in time, and the need to identify 'green' sources has resulted in one of the many options being researched, including biogas.

Clearly, the results of the analysis show that there is a great deal of academic activity on renewable energy, given the large number of publications and the many links between this topic and other related terms. Clearly, existing policies worldwide encourage transfer and synergy between researchers in different countries, thus achieving important results. Awareness of the effects of global warming contributes to important research in the identification and analysis of different sources of green energy. Despite the importance and high potential of this field, the topic of biogas is in an early stage of development and has not been explored by researchers around the world. Most existing researches focus on understanding the chemical mechanisms that take place in the biogas production process. It is likely that as time goes by, this topic will be approached and investigated in a similar way to the generalist topic, "renewable energy".

In practical terms, biogas may be a viable solution to mitigate the effects of climate change, especially since the raw material comes from the agricultural sector, and expectations of population growth will most likely lead to an intensification of agriculture in the desire to provide food for the population, with more by-products expected to be produced suitable for biogas. However, the sector needs continuous funding to develop further and to be economically and energetically competitive with non-renewable energy sources.

REFERENCES

[1]Angelidaki, I., Treu, L., Tsapekos, P., Luo, G., Campanaro, S., Wenzel, H., Kougias, P., 2018, Biogas upgrading and utilization: Current status and perspectives. Biotechnology Advances, 36(2), 452-466. https://doi.org/10.1016/j.biotechadv.2018.01.011

[2]Banzhaf, E., Anderson, S., Grandin, G., Hardiman, R., Jensen, A., Jones, L., Knopp, J., Levin, G., Russel, D., Wu, W., 2022, Urban-Rural Dependencies and Opportunities to Design Nature-Based Solutions for Resilience in Europe and China. Land, 11, 480. https://doi.org/10.3390/land11040480

[3]Benato, A., Macor, A., 2019, Italian Biogas Plants: Trend, Subsidies, Cost, Biogas Composition and Engine Emissions. Energies 2019, 12, 979. https://doi.org/10.3390/en12060979

[4]Biesbroek, G.R., Swart, R.J., Carter, T.R., Cowan, C., Henrichs, T., Mela, H., Morecroft, M.D., Rey, D., 2010, Europe adapts to climate change: Comparing National Adaptation Strategies. Glob. Environ. Change-Hum. Policy Dimens., 20, 440–450. https://doi.org/10.1016/j.gloenvcha.2010.03.005

[5]Campos, I., Vizinho, A., Coelho, C., Alves, F., Truninger, M., Pereira, C., Santos, F., Penha-Lopes, G., 2016, Participation, scenarios and pathways in long-term planning for climate change adaptation. Plan. Theory Pract., 17, 537–556. https://doi.org/10.1080/14649357.2016.1215511

[6]Canva, https://www.canva.com/ro_ro/, Accessed on July 5, 2023

[7]Carrico, A.R., Truelove, H.B., Vandenbergh, M.P., Dana, D., 2015, Does learning about climate change adaptation change support for mitigation? J. Environ. Psychol, 41, 19–29. https://doi.org/10.1016/j.jenvp.2014.10.009

[8]Chen, B., Hayat, T., Alsaedi, A., 2017, History of Biogas Production in China. In: Biogas Systems in China. Springer, Berlin, Heidelberg. https://doi.org/10.1007/978-3-662-55498-2_1

[9]Chen, W., 2017, Global Climate Change and Its Impacts on Environmental and Soil Pollution. Journal of Cleaner Production, 161, 1160–1167. https://doi.org/10.1016/j.jclepro.2017.06.063
[10]Clarivate, Web of Science Core Collection, https://clarivate.com/products/scientific-and-academic-research/research-discovery-and-workflow-solutions/webofscience-platform/web-of-science-core-collection/, Accessed on July 5, 2023
[11]Dumitru, M., 2015, Development trends in biogas, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol.15(1), 165-160.
[12]Dzene, I., Romagnoli, F., Seile, G., Blumberga, D., 2014, Comparison of different biogas use pathways for Latvia: biogas use in CHP vs. biogas upgrading, The 9th International Conference "Environmental Engineering" 22–23 May 2014, Vilnius, Lithuania, http://dx.doi.org/10.3846/enviro.2014.017
[13]Eriksen, S.H., Nightingale, A.J., Eakin, H., 2015, Reframing adaptation: The political nature of climate change adaptation. Glob. Environ. Change, 35, 523–533. https://doi.org/10.1016/j.gloenvcha.2015.09.014
[14]Eurostatdatabase, Renewable energy statistics, https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Renewable_energy_statistics Accessed on 20.01.2022.
[15]Flach, C., Conti, F., Bayraktar, A., Goldbrunner, M., 2022, Direct Methanation and Storage Concepts for the Flexibilization of Biogas Plants. Chemical Engineering & Technology. https://doi.org/10.1002/ceat.202200239
[16]Iancu, T., Tudor, V.C., Dumitru, E.A., Sterie, C.M., Micu, M.M., Smedescu, D., Marcuta, L., Tonea, E., Stoicea, P., Vintu, C., Jitareanu, A.F., Costuleanu, L.C., 2022, A Scientometric Analysis of Climate Change Adaptation Studies. Sustainability, 14, 12945. https://doi.org/10.3390/su141912945
[17]Iglinski, B., Buczkowski, R., Iglinska, A., 2012, Agricultural biogas plants in Poland: Investment process, economical and environmental aspects, biogas potential, Renewable and Sustainable Energy Reviews Vol. 16(7), 4890-4900, https://doi.org/10.1016/j.rser.2012.04.037
[18]Kougias, P., Angelidaki, I., 2018, Biogas and its opportunities—A review, Front. Environ. Sci. Eng., Vol. 12 (30):14, DOI: 10.1007/s11783-018-1037-8
[19]Lanzerstorfer, C., Jäger, A., 2008, Decentralized integrated biogas and bioethanol production, Zuckerindustrie. Sugar industry 133(133):642-45.
[20]Li, C.J., Liao, Y.C., Wen, X.X., Wang, Y.F., Yang, F., 2017, The development and countermeasures of household biogas in northwest grain for green project areas of China. Renewable & Sustainable Energy Reviews, 44, 835-846. https://doi.org/10.1016/j.rser.2015.01.027
[21]Lindkvist, E., Karlsson, M., 2018, Biogas production plants; existing classifications and proposed categories, Journal of Cleaner Production Vol.174, 10 February 2018, pp.1588-1597, https://doi.org/10.1016/j.jclepro.2017.10.317
[22]Mitsui, M., 2019, The potential of biogas as a renewable and clean fuel. Applied Energy, 242, 1163–1177. https://doi.org/10.1016/j.apenergy.2019.02.092
[23]Mutaqin, M. I., Widyarani, U., Hamidah, S. A., Janetasari, Muchlis, Sintawardarni, N., 2019, Biogas Consumption Pattern in Indonesia: (A Case Study of Sumedang Community Biogas Plant, Indonesia), International Conference on Sustainable Energy Engineering and Application (ICSEEA), 2019, 113-118, doi: 10.1109/ICSEEA47812.2019.8938624.
[24]Neset, T.-S., Opach, T., Lion, P., Lilja, A., Johansson, J., 2016, Map-Based Web Tools Supporting Climate Change Adaptation. Prof. Geogr, 68, 103–114. https://doi.org/10.1080/00330124.2015.1033670
[25]Palkova, S., Palko, M., 2017, Green energies for agriculture; comparation study for Slovakia and the Netherlands, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol.17(2), 269-274.
[26]Panda, A., 2018, Transformational adaptation of agricultural systems to climate change. WIREs Clim. Change, 9, e520. https://doi.org/10.1002/wcc.520
[27]Petersson, A., 2013, Biogas cleaning. Biogas Handbook: Science, Production and Applications, 52, 329-341. https://doi.org/10.1533/9780857097415.3.329
[28]Saborio Viquez, C., 2013, Biogas as an alternative energy source to promote indigenous communities development, Scientific Papers Series Management, Economic Engineering in Agriculture and Rural Development, Vol.13(1), 345-352
[29]Stadler, F., Houghton, L., 2019, Breathing life into climate change adaptation. J. Ind. Ecol., 24, 400–409. https://doi.org/10.1111/jiec.12922
[30]Sturmer, B., Leiers, D., Anspach, V., Brugging, E., Scharfy, D., Wissel, T.,2021, Agricultural biogas production: A regional comparison of technical parameters, Renewable Energy Vol. 164, Fe. 2021, 171-182. https://doi.org/10.1016/j.renene.2020.09.074
[31]VoSViewer, Visualizing scientific landscapes, https://www.vosviewer.com/, Accessed on July 10, 2023.