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BIBLIOMETRIC ANALYSIS OF BIOMETHANE

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Abstract. *Given the emerging demand for eco-friendly energy and the increasing recognition of the significance of ecological sustainability, a bibliometric investigation was undertaken to assess potential pathways for enhancing the attributes, physical traits, classification, manufacture, and global market scope of renewable natural gas (biomethane/biogas). Sustainable fuel alternatives have garnered heightened attention as feasible substitutes for fossil fuels owing to their renewable essence and their capacity to curtail greenhouse gas emissions. Within this context, advancements in characterizing these sustainable gases are deliberate, emphasizing the identification of impurities and pollutants alongside analytical methodologies ensuring adherence to the quality and safety benchmarks stipulated by national and international regulations. In essence, this inquiry provides a comprehensive outlook on plausible technological advancements, market prospects, and economic hurdles linked with renewable natural gas (biomethane/biogas). These burgeoning energy reservoirs hold the potential to assume a pivotal role in the shift toward a cleaner, more sustainable, and economically viable energy framework, thereby contributing to diminished environmental footprints and a more resilient energy prospectus*

Keywords: *biomethane, biogas, renewable natural gas, Sustainable fuel.*

1. INTRODUCTION

For a cleaner and healthier planet, industries must decarbonize and move away from linear “take-make-waste” economies towards circular economies, in order to maximize value and minimize negative environmental impact. . (SHARMA et al., 2022)

Resource depletion and climate change due to human activities and excessive burning of fossil fuels are the main factors for exploring alternative clean energy resources. (FAISAL et al., 2022)

Due to the increase in energy consumption, the search for new energy sources and the decrease in the use of fossil fuels due to CO2 and greenhouse gas emissions, many studies have emerged looking for new alternative renewable energy sources. (HENROTIN; HANTSON; DEWASME, 2023)

Some measures are necessary to promote renewable energy sources and emphasize energy recovery from the recovery and reuse of waste, aiming to mitigate emissions resulting from human activities related to fossil fuels (CALISE et al., 2023) Biogas (biomethane) and natural gas (methane) are taking centre stage among renewable fuels due to their environmental compatibility; these gaseous fuels have significant environmental advantages over conventional petroleum-based or fossil fuels (MEMETOVA et al., 2022). For this reason, biomethane is an example of a biofuel that is currently attracting interest due to its possible use as a substitute for natural gas and for its generation in a “power to gas” production scheme. (SÁNCHEZ NOCETE; PÉREZ RODRÍGUEZ, 2022).

Every year, more than 2 billion tons of organic waste are generated in the production of renewable energy, including biofuels, and much more specifically biogas (biohydrogen and biomethane) by anaerobic digestion.(LICZBIŃSKI; BOROWSKI; CIECIURA-WŁOCH, 2022) .

A large number of scientific publications with a wide variety of topics has increased the need for review articles in the last decade (DALDRUP-LINK, 2018). In the last twenty years, there has been a large amount of literature on how to improve methane production performance, but few systematic reviews have been conducted (WANG; MAIYALAGAN; WANG, 2012). However, there is a lack of practical research on new standards, engine performance and costs for low carbon intensity (DOS SANTOS; DA SILVA; SERRANO, 2022). The overview of limitations and perspectives highlights a number of opportunities for research areas that can further contribute to increasing sustainability in biofuel production and thus to achieving the SDGs (sustainable development), since there is little work assessing the actual impact of biofuels on sustainable development (NAZARI et al., 2021). Renewable energy gases such as biomethane are expected to replace natural gas, provided they strictly comply with the quality standards for natural gas, which prescribe maximum levels for various trace chemicals (LECHARLIER et al., 2022).

Biogas is considered one of the most promising alternative renewable fuels, but the raw biogas must be upgraded before it can be used in vehicles or injected into the natural gas grid, and the resulting biomethane must be liquefied to be transported to distant locations (KHAN et al., 2022). However, in order to sustainably integrate these gases into the current energy mix, their quality must be controlled in terms of their major, minor and trace components

in order to maintain the integrity of the infrastructure in which they are burned, transported or stored (LECHARLIER; CARRIER; LE HÉCHO, 2022).

Biomethane (BM) is a highly competitive bioenergy alternative to reduce dependence on fossil fuels worldwide. Biogas is a cornerstone of a clean and sustainable energy portfolio, while hydrogen production from biogas is a key enabler for methane conversion and carbon dioxide valorisation to mitigate greenhouse gas emissions stove. (ABD et al*.,* 2023)

Anaerobic digestion technology is a well-established technology for energy generation, as well as an efficient and economical solution. (NAUMAN et al., 2023)

Adopting anaerobic digestion of lignocellulosic biomass to produce biomethane is an effective approach to meet the urgent demand for clean and sustainable energy in the energy transition (MA et al., 2022)

Conventional energy processes remain crucial and will continue to be essential for a long time if they are based on renewable and clean sources. (CORIGLIANO et al., 2023). Anaerobic digestion (AD) of different organic wastes is a promising technique to increase the production of clean energy (bioenergy) and manure (slurry), reducing stress on the environment. (NOOR et al., [s.d.]) (AGRAWAL; CHAUDHARI; GHOSH, 2023). Anaerobic digestion is one of the routes available to recover energy from waste through the production of biogas, while reducing organic load and pollutants in the environment (MESSINEO; MANISCALCO; VOLPE, 2020), (AD) has attracted the scientific community for its simplicity and ease of handling, and has the potential to use any type of organic waste to produce a mixture of combustible gases, that is, biogas and digested leachate, which has other applications in agriculture, solid biofuels and purification (DHULL et al., 2023).

A study investigates the effect of specially designed adsorptive packed column system (APCS) on improving biogas quality up to biomethane purity (PIECHOTA, 2021). The production of biogas from food waste with AD process and co-digestion process achieved high purity of biogas (DEVI et al., 2023). A study points to the need for complete cleaning of Renewable Natural Gas (RNG) before its injection into the Natural Gas (NG) network (ZHAO et al., 2020).

The expected increase in the proportion of biomethane in NG networks could increase fluctuations in the composition of the NG-biomethane mixture in amplitude and frequency (CARVALHO et al., 2023). The degree of substitutability of current impure fuels and the net greenhouse gas emissions avoided by using this biomethane are assessed for three different end-use scenarios: electricity production, cooking and road transport (DEY; THOMSON, 2022).

The injection of biomethane into the existing gas infrastructure is a fundamental opportunity to be promoted, but one that leads to increasing complexity in the management of natural gas networks (CAVANA; LEONE, 2022). The same study evaluated the role of line-pack in determining the absorption capacity of the gas network and tested the smart management of pressure set points and injection flow to minimise the reduction of biomethane.

In the present study, a bibliometric study was conducted to analyse possible scenarios to improve the quality, physical properties, characterisation, production and global market of renewable natural gas (biomethane/biogas).

2. BIBLIOMETRIC DATABASE

The evaluation of combinations of renewable natural gas and biomethane represents a promising approach to improving the quality of fuels used in various sectors, including transportation, industry and power generation. Given that such mixtures of these renewable gases with natural gas, currently widely used in industrial processes and in many other activities, can vary in their proportions, the opportunity arises to adjust their characteristics according to the specific needs of each application. In this context, the continuous advancement of production, storage and distribution technologies is crucial to establish synergies between renewable gases. To begin building a database, it was essential to clearly outline the scope of the topic. In this case, the research focused on identifying studies that addressed technical, production and configuration data relevant to this area. Additionally, the prospects for the consumer market for renewable natural gas or biomethane were examined. The research process began with the identification of the most relevant keywords on the Scopus platform. A bibliometric analysis was carried out in the Scopus database, searching for the expressions "renewable natural gas" or "biomethane" in titles and articles. Initially, 1,376 references were found containing the selected keywords.Figure 1. Considering that the main objective is to show current scenarios, new philtres were applied to improve and select articles according to the expected perspectives. We first included the words “mixture|” or “blend” in the search to select articles specifically dealing with these topics, as one of the objectives of this research is also the analysis of blends containing renewable natural gas/biomethane, then the following philtres were selected, to obtain a result with high search relevance selection of the last 10 years of publication, then topics were selected from the subjective area of publication, type of documents, articles or literature reviews, disregarding books or conferences, and finally we restricted to articles published in English, Table 1.

These documents were ordered chronologically according to the most recent year of publication, taking into account the last 10 years Figure 2, since articles with more than 30 years of publication appeared in this study and the current scenarios are very different, whereupon the articles with the highest number of citations but more recent publications were also taken into account. This information was essential for carrying out several bibliometric

analyses. The information contained in these articles was extracted in CSV format (comma separated values) from the Scopus database,

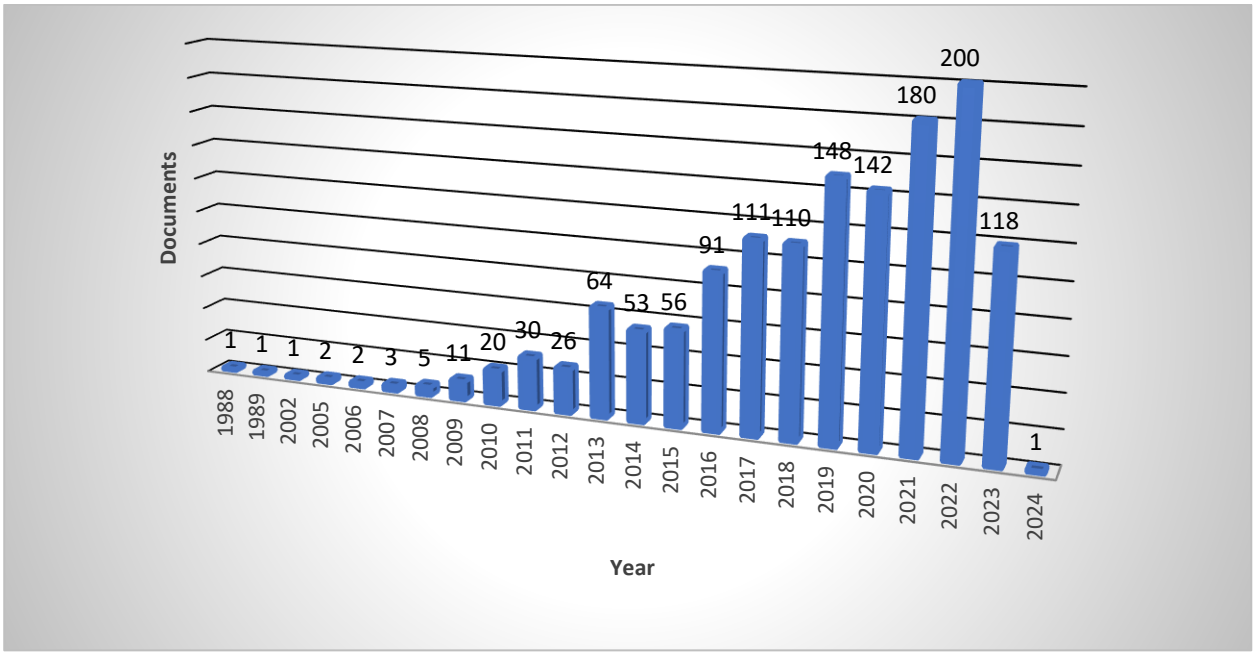

Figure 1 Number of publications per year considering the first stage of researched articles, based on data from the Scopus platform, until July 2023

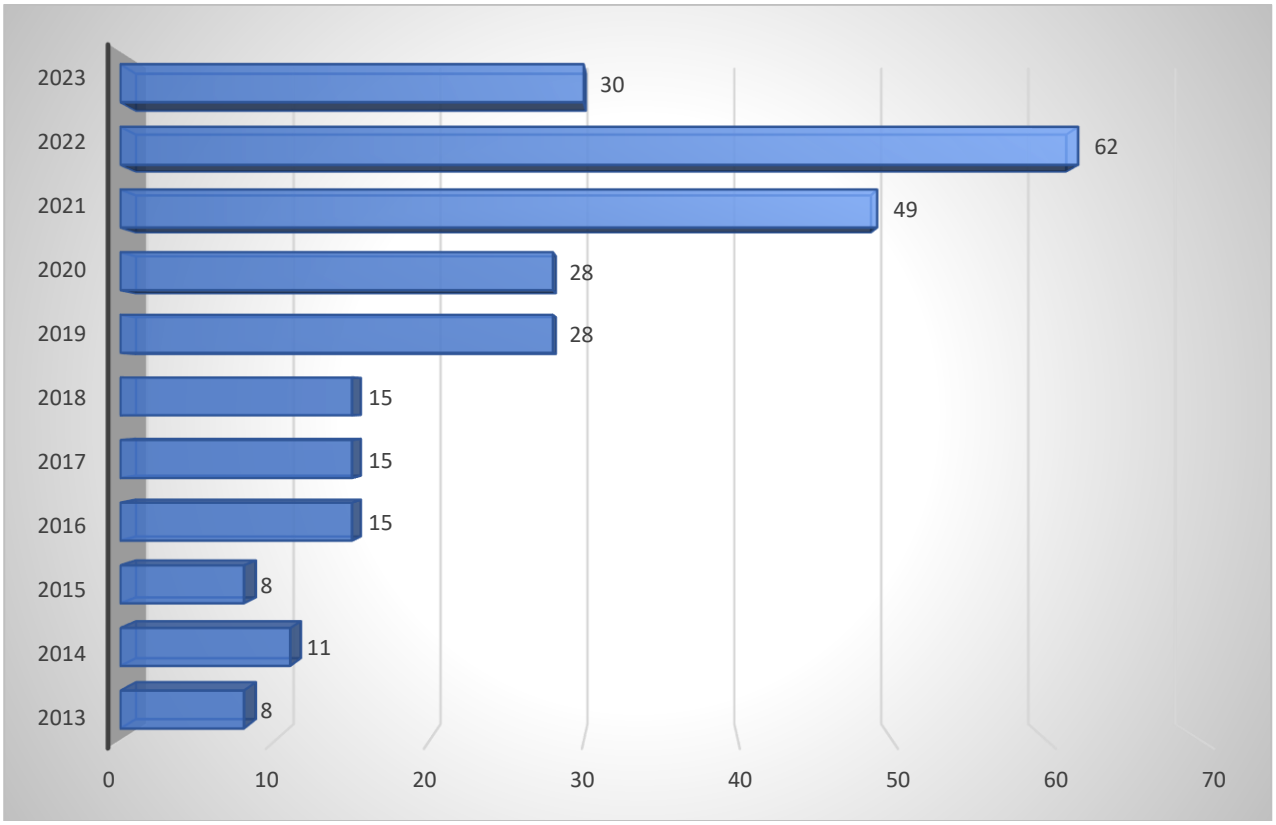

Figure 2 Number of publications per year considering the last 10 years, based on data from the Scopus platform, until July 2023.

3. RESULTS AND DISCUSSION

From here onwards, the entire discussion of bibliometric analysis is based on the 269 selected articles. The number of articles published by the authors were analysed, and the 10 authors with the highest number of publications were selected Table 1. To ensure the quality of this information, records with inconsistent data were removed from the current analysis.

The bibliometric searches were carried out using chains linking topics across the title field of articles published up to July 2023. After applying these philtres, 269 articles Table 1 and Table 2 were selected for a more detailed reading selection and the start of the research, initially considering the most recent and most cited for conducting this bibliometric analysis.

Highly cited publications can be considered as references to provide perspective on a topic or provide a solution to a problem.

According to this analysis, in the last 10 years, the topic with renewable fuels, especially blends between natural gas and biomethane, has gained considerable attention, as the large number of publications has increased, especially since 2019, as shown in Figure 3.

Table 1 - Advanced Boolean search queries performed on the Scopus database.

Campo de Busca	Consulta de pesquisa avançada booleana	Refinações	Resultados Scopus (julho de 2023)
		-	
ArticleTitle	TITLE ("renewable natural gas" OR "biomethane")	-	1376
"mixture" or "blend"	(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend)	-	340
Year	(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend) AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2013))	2013 -2023	332
Subject area	(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend) AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "CHEM"))	Energy; Environmental Science; Chemistry; Engineering; Chemical Engineering	304
Document type: Article; Review	(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend) AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "CHEM") OR LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re"))		273
Source type	(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend) AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "CHEM")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re"))	Journal	273
language	(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend) AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "CHEM") OR LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English"))	English	269

Table 2 Boolean advanced search query details based on scopus data.

Pesquisa Boleana Avançada	Resultados Scopus
(TITLE ("renewable natural gas" OR "biomethane")) AND (mixture OR blend) AND (LIMIT-TO (PUBYEAR , 2015) OR LIMIT-TO (PUBYEAR , 2014) OR LIMIT-TO (PUBYEAR , 2023) OR LIMIT-TO (PUBYEAR , 2022) OR LIMIT-TO (PUBYEAR , 2021) OR LIMIT-TO (PUBYEAR , 2020) OR LIMIT-TO (PUBYEAR , 2019) OR LIMIT-TO (PUBYEAR , 2018) OR LIMIT-TO (PUBYEAR , 2017) OR LIMIT-TO (PUBYEAR , 2016) OR LIMIT-TO (PUBYEAR , 2013)) AND (LIMIT-TO (SUBJAREA , "ENER") OR LIMIT-TO (SUBJAREA , "ENVI") OR LIMIT-TO (SUBJAREA , "CENG") OR LIMIT-TO (SUBJAREA , "ENGI") OR LIMIT-TO (SUBJAREA , "CHEM") OR LIMIT-TO (SUBJAREA , "BUSI")) AND (LIMIT-TO (DOCTYPE , "ar") OR LIMIT-TO (DOCTYPE , "re")) AND (LIMIT-TO (SRCTYPE , "j")) AND (LIMIT-TO (LANGUAGE , "English"))	269 (julho 2023)

Figure 3. Then, an analysis was carried out containing the highest number of citations. of the authors with the highest number of publications (Figure 3 and Figure 4). This article argues that the relevance of a publication is associated with the timeliness of the publications and the significant numbers of citations it receives. Therefore, the year of publication and number of citations was used as an important weighted indicator of relevance.

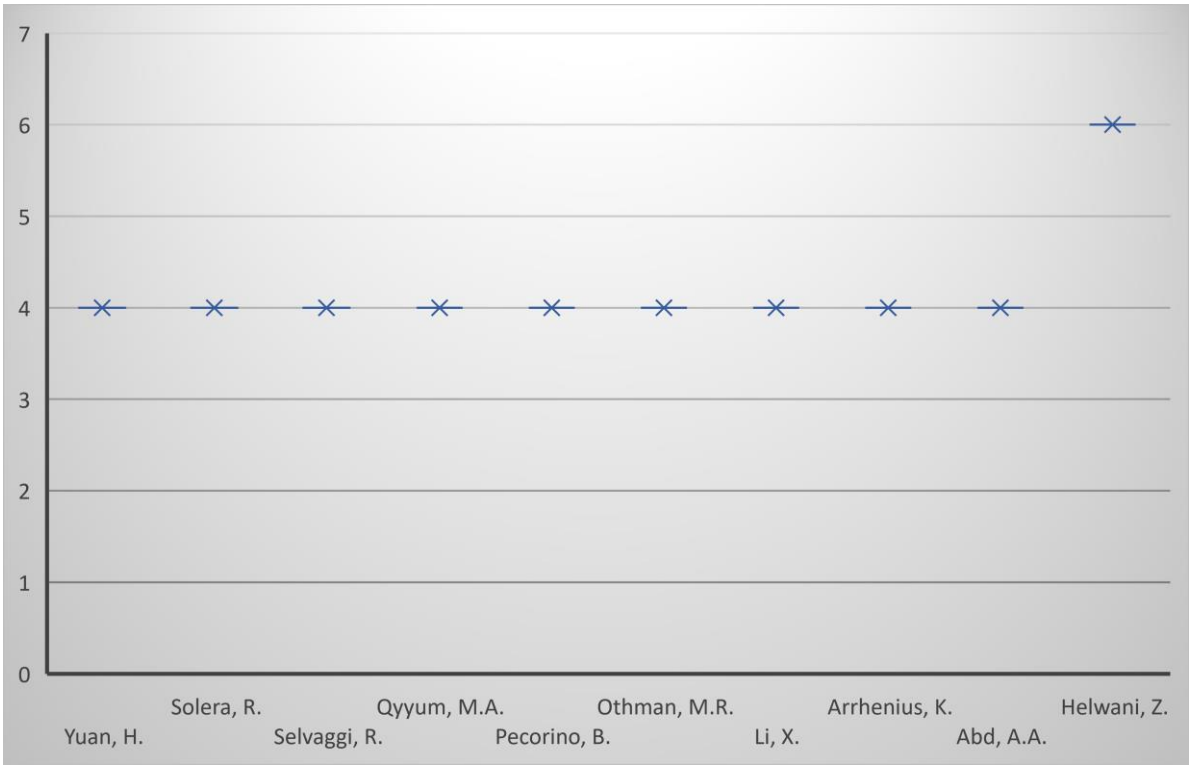

Figure 3 Number of documents published by author based on the selection of articles carried out in the Scopus database.

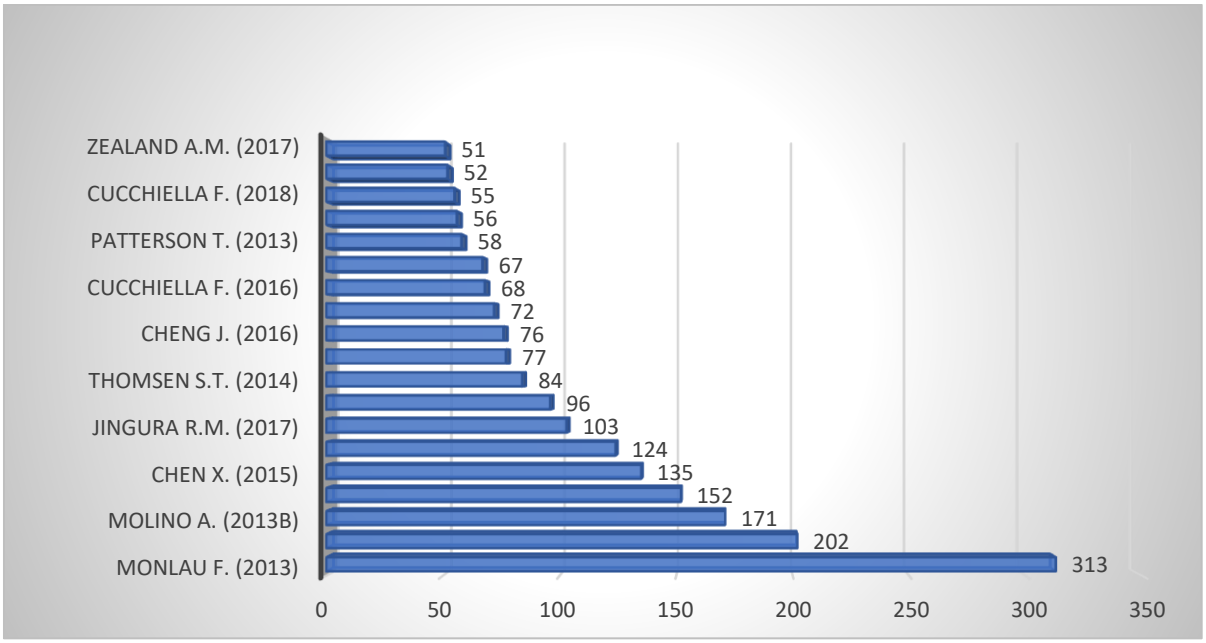

Figure 4 Number of Citations per author based on the selection of articles carried out in the Scopus database.

It is also important to highlight that the thematic areas of Energy, Chemistry, Environmental Sciences, Engineering and Chemical Engineering, which are areas that are directly correlated to the development of techniques that allow the use of renewable gases or biomethane in industrial processes, or even areas that are linked to sustainable development, as shown in Figure 5.

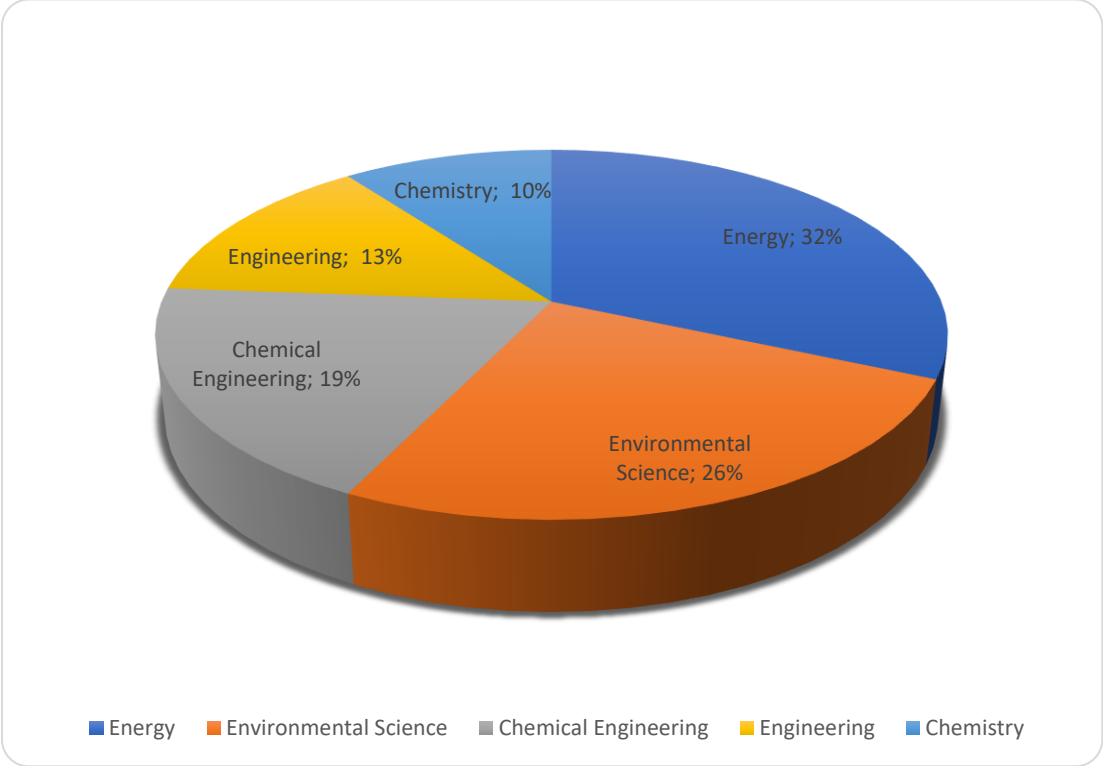

Figure 5 Distribution of scientific publications by thematic area, based on the selection of articles carried out in the Scopus database.

One of the selection topics was determined by type of publication, with only works published in article format and in review format being selected, considering the last 10 years of research on the topic, the majority of works were published in article form, representing a total of 92% of the results presented by the Scopus platform, only 8% were reviews, as shown in Figure 6

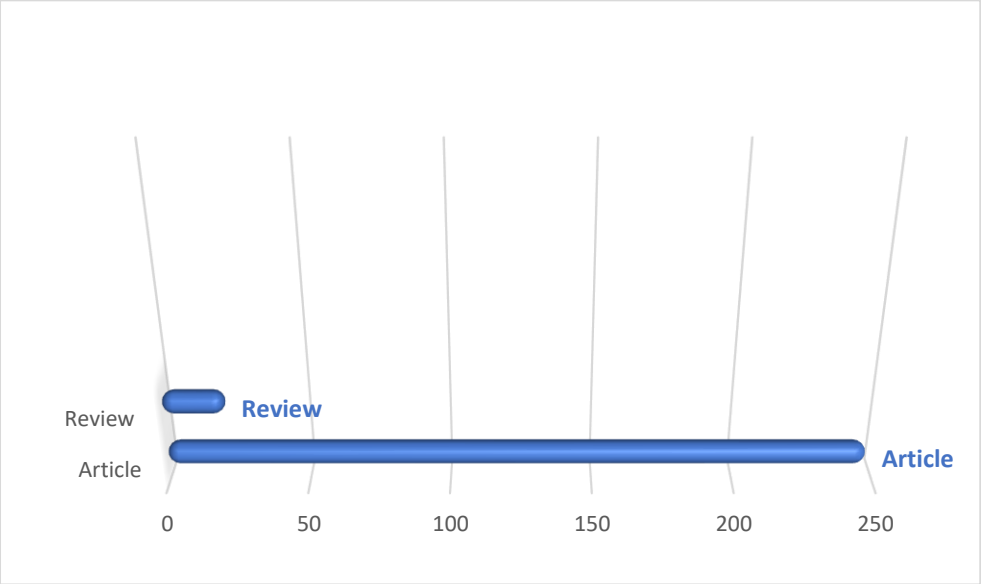

Figure 6 Distribution of scientific publications by thematic area, based on the selection of articles published in the Scopus database. Last 10 years.

In terms of circulation, these articles can be found in more than 140 different journals. However, 19% of the published articles are found in ten of these journals, with the journal of Anna University of India being the one that published the most articles in the 10-year period, with 7 articles. The journals Chiang Mai University, from Thailand, Universiti Sains Malaysia, from Malaysia, Jiangsu University, Beijing University of Chemical Technology, both from China, Universitas Riau, from Indonesia and Al-Qasim Green University, from Iraq, appear in succession with 6 publications each, as shown in Figure 7; the other journals contain between 5 and 4 publications Figure 7.

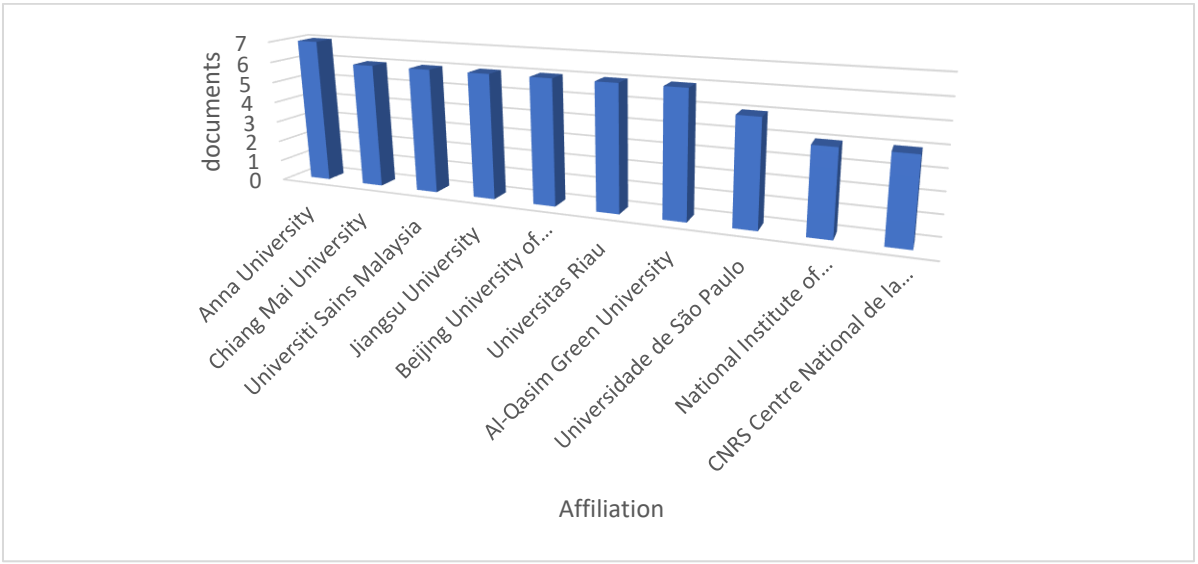

Figure 7 Number of publications by periodicals with more than 4 publications, based on the selection of articles carried out in the Scopus database. Period considered 2013-2023.

These results demonstrate that on all continents there is broad interest in research on renewable natural gas/biomethane, and this research is being published in large university centers. The largest numbers of publications are concentrated in Asia, India, the United States and Brazil presents a considerable number of publications, Figure 8 which facilitates access to a reasonable number of researchers, and there is still a lot to be researched in this area, since mixtures containing This type of fuel can be applied in many commercial, industrial and domestic sectors.

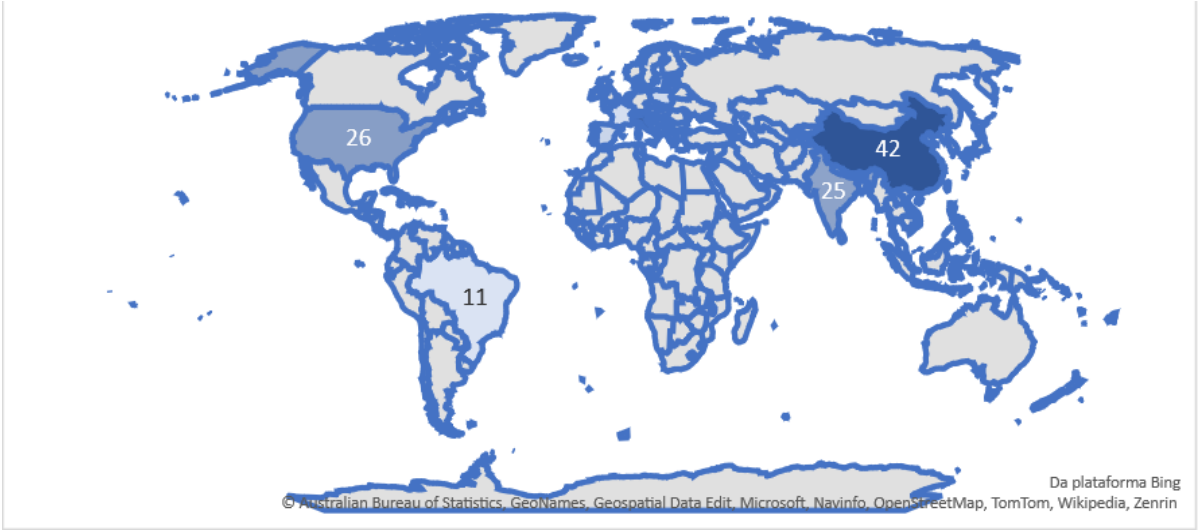

Figure 8 Number of Publications by countries based on the selection of articles carried out in the Scopus database. Period considered 2013-2023.

The countries that feature the most publications on the topic are China first with 16%, followed by Italy with 15%, the United States with 10%, India with 9% and finally Brazil with 4%,. These five countries represent 54% of publications on the selected topic Figure 9.

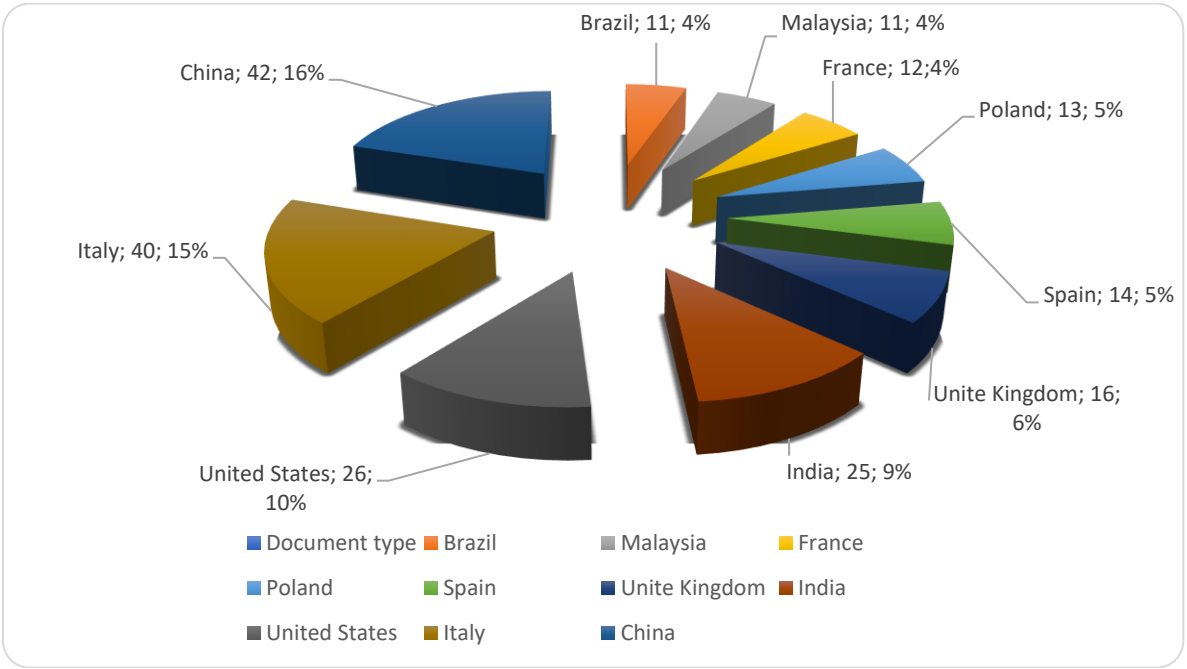

Figure 9 Percentage of publications by countries based on the selection of articles carried out in the Scopus database. Period considered 2013-2023.

A network graph containing the main highlights of keywords was constructed to identify trends in the use of biomethane and to understand the relationship between the techniques developed for gas mixtures using fuels produced from renewable sources. To build this map a dictionary of keywords extracted from articles in the Scopus database was applied, and pre-treatment of this data was carried out so that there were no repetitions of keywords with the same meaning (for example: gas and gases, fuel and fuels) are written in slightly different ways.

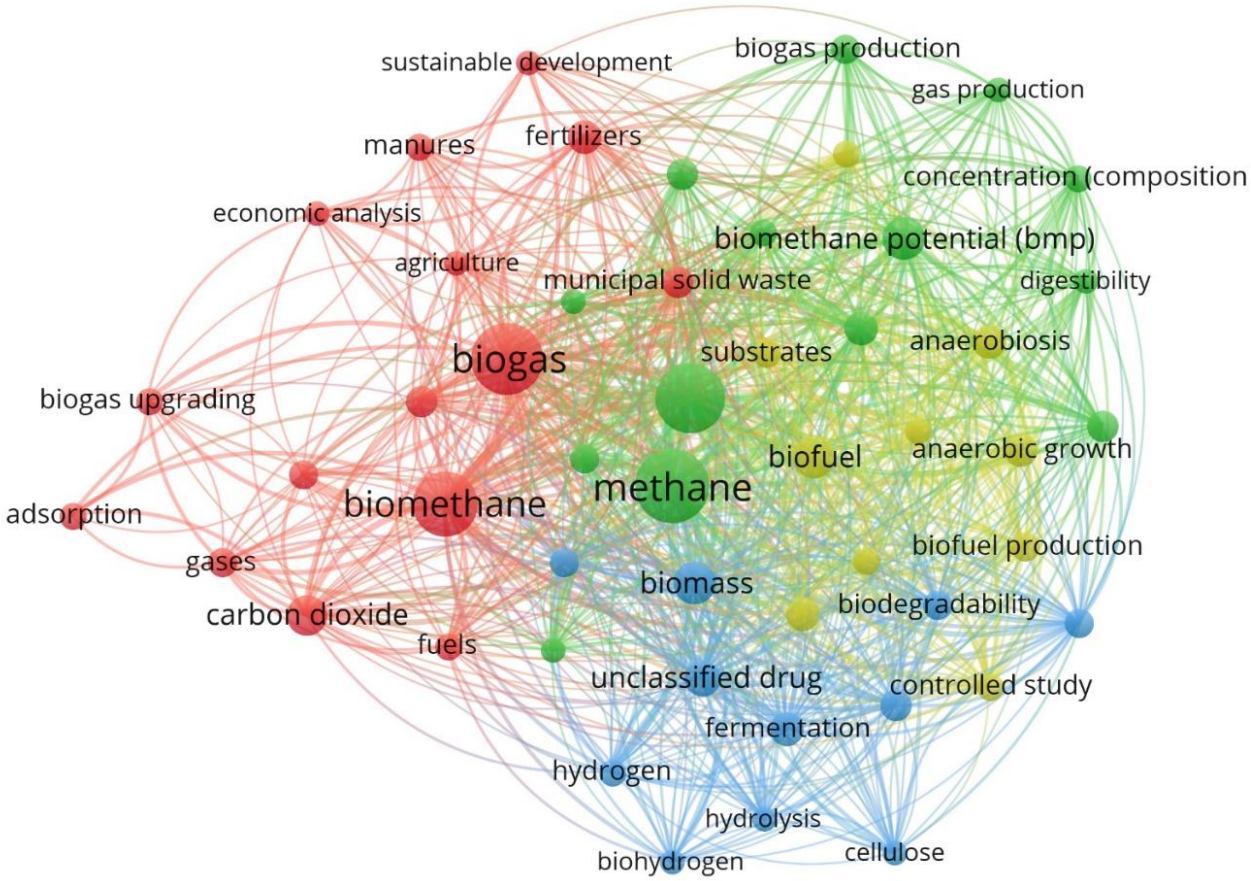

Figure 10 Co-occurrence network of keywords (minimum of five occurrences), parents based on the selection of articles carried out in the Scopus database and VOSviewer as bibliometric mapping software. Period considered 2013-2023.

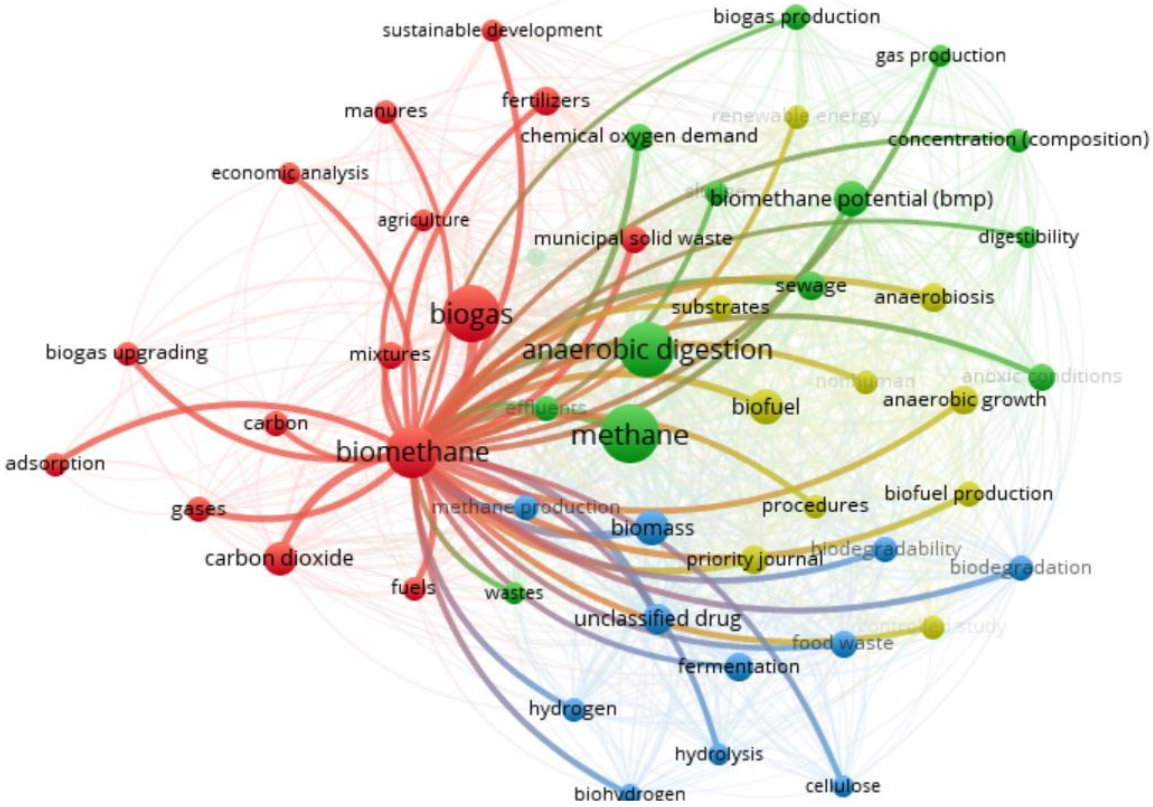

Figure 11 Details of the keyword co-occurrence network (minimum of five occurrences) showing the links between the keyword biomethane and the other clusters, information based on the selection of articles carried out in the Scopus database and VOSviewer as bibliometric mapping software. Period considered 2013-2023.

After the necessary executions of this pre-treatment, four main keyword network clusters were created, red, green, blue and yellow. As expected, biogas, biomethane, methane, biofuels, biofuel production, biogas production, carbon dioxide, are keywords that are most prominent. The four clusters substantially present the highlighted keywords of this study. The focus of the research is that biomethane is interconnected with the other clusters Figure 11, interacting mainly with the production of biofuels, biomass, biogas production, biogas, sustainable development, fuels, carbon dioxide, among others.

4. CONCLUSION

The production and use of mixtures of renewable natural gas or biomethane as an alternative to fossil fuels presents itself as a promising and sustainable option in the energy field. The introduction and improvement of these combinations represent a crucial step towards a more resilient and sustainable energy matrix. Technological advances, which include improvements in the production, storage and distribution of biomethane, make these energy sources more effective and accessible. Additionally, the expansion of raw material sources, such as organic and animal waste, is expanding the potential for generating these renewable gases. With continuous technological progress, strategic investments and policies aimed at sustainable development, these energy sources have the potential to play a significant role in building a more promising future for future generations. Therefore, it is essential that governments, industry and society in general persist in supporting and promoting the development and implementation of these technologies.

5. REFERENCES

ABD, A. A. et al. Green route for biomethane and hydrogen production via integration of biogas upgrading using pressure swing adsorption and steam-methane reforming process. **Renewable Energy**, v. 210, p. 64–78, 1 jul. 2023.
AGRAWAL, A. V.; CHAUDHARI, P. K.; GHOSH, P. Effect of mixing ratio on biomethane potential of anaerobic co-digestion of fruit and vegetable waste and food waste. **Biomass Conversion and Biorefinery**, 2023.

CALISE, F. et al. Dynamic Simulation and Thermoeconomic Analysis of a Novel Hybrid Solar System for Biomethane Production by the Organic Fraction of Municipal Wastes. **Energies**, v. 16, n. 6, 1 mar. 2023.
CARVALHO, F. S. DE et al. Substitution of Natural Gas by Biomethane: Operational Aspects in Industrial Equipment. **Energies**, v. 16, n. 2, 1 jan. 2023.
CAVANA, M.; LEONE, P. Smart Gas Network with Linepack Managing to Increase Biomethane Injection at the Distribution Level. **Energies**, v. 15, n. 21, 1 nov. 2022.
CORIGLIANO, O. et al. Enhancing Energy Processes and Facilities Redesign in an Anaerobic Digestion Plant for Biomethane Production. **Energies**, v. 16, n. 15, 1 ago. 2023.
DALDRUP-LINK, H. E. Writing a review article-Are you making these mistakes? **Nanotheranostics**, v. 2, n. 2, p. 197–200, 2018.
DEVI, M. K. et al. A comprehensive review on current trends and development of biomethane production from food waste: Circular economy and techno economic analysis. **Fuel**, v. 351, 1 nov. 2023.
DEY, A.; THOMSON, R. C. India's biomethane generation potential from wastes and the corresponding greenhouse gas emissions abatement possibilities under three end use scenarios: electricity generation, cooking, and road transport applications. **Sustainable Energy and Fuels**, v. 7, n. 1, p. 209–241, 8 nov. 2022.
DHULL, P. et al. Anaerobic Digestion: Advance Techniques for Enhanced Biomethane/Biogas Production as a Source of Renewable Energy. **Bioenergy Research**, 2023.
DOS SANTOS, V. A.; DA SILVA, P. P.; SERRANO, L. M. V. **The Maritime Sector and Its Problematic Decarbonization: A Systematic Review of the Contribution of Alternative Fuels**. **Energies**MDPI, , 1 maio 2022.
FAISAL, S. et al. Enhanced waste hot-pot oil (WHPO) anaerobic digestion for biomethane production: Mechanism and dynamics of fatty acids conversion. **Chemosphere**, v. 307, 1 nov. 2022.
HENROTIN, A.; HANTSON, A. L.; DEWASME, L. Dynamic modeling and parameter estimation of biomethane production from microalgae co-digestion. **Bioprocess and Biosystems Engineering**, v. 46, n. 1, p. 129–146, 1 jan. 2023.
KHAN, J. et al. Reduction in Specific Energy Consumption of Overall Biogas Upgrading and Biomethane Liquefaction Process: Energy and Exergy Analysis. **Energy Conversion and Management**, v. 271, 1 nov. 2022.
LECHARLIER, A. et al. Novel field-portable high-pressure adsorbent tube sampler prototype for the direct in situ preconcentration of trace compounds in gases at their working pressures: application to biomethane. **RSC Advances**, v. 12, n. 16, p. 10071–10087, 30 mar. 2022.
LECHARLIER, A.; CARRIER, H.; LE HÉCHO, I. **Characterization of biogas and biomethane trace compounds: A critical review of advances in in situ sampling and preconcentration techniques**. **Analytica Chimica Acta**Elsevier B.V., , 9 out. 2022.
MA, S. et al. **Features of single and combined technologies for lignocellulose pretreatment to enhance biomethane production**. **Renewable and Sustainable Energy Reviews**Elsevier Ltd, , 1 set. 2022.
MEMETOVA, A. et al. **Porous carbon-based material as a sustainable alternative for the storage of natural gas (methane) and biogas (biomethane): A review**. **Chemical Engineering Journal**Elsevier B.V., , 15 out. 2022.
MESSINEO, A.; MANISCALCO, M. P.; VOLPE, R. **Biomethane recovery from olive mill residues through anaerobic digestion: A review of the state of the art technology**. **Science of the Total Environment**Elsevier B.V., , 10 fev. 2020.
NAUMAN, M. et al. Designing and performance evaluation of continuously stirring anaerobic batch reactor for biomethane production from biowaste. **Biomass Conversion and Biorefinery**, 2023.
NAZARI, M. T. et al. **Biofuels and their connections with the sustainable development goals: a bibliometric and systematic review**. **Environment, Development and Sustainability**Springer Science and Business Media B.V., , 1 ago. 2021.
NOOR, R. S. et al. Enhanced biomethane production by 2-stage anaerobic co-digestion of animal manure with pretreated organic waste. [s.d.].
PIECHOTA, G. Multi-step biogas quality improving by adsorptive packed column system as application to biomethane upgrading. **Journal of Environmental Chemical Engineering**, v. 9, n. 5, 1 out. 2021.
SHARMA, I. et al. Exploring the potential for biomethane production by the hybrid anaerobic digestion and hydrothermal gasification process: A review. **Journal of Cleaner Production**, v. 362, 15 ago. 2022.
WANG, H.; MAIYALAGAN, T.; WANG, X. Review on recent progress in nitrogen-doped graphene: Synthesis, characterization, and its potential applications. **ACS Catalysis**, v. 2, n. 5, p. 781–794, 4 maio 2012.
ZHAO, L. et al. Pollutant Formation during Utilization of Renewable Natural Gas Containing Trace Ammonia Impurities. **Industrial and Engineering Chemistry Research**, v. 59, n. 43, p. 19177–19184, 28 out. 2020.

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