PROJECT DEVELOPMENT METHODOLOGIES APPLIED TO CAPITAL PROJECTS FOCUSED ON NON-RENEWABLE AND RENEWABLE ENERGY SOURCES: BIBLIOMETRIC ANALYSIS

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RESUMO

Esse artigo tem por objetivo demonstrar os principais resultados da análise bibliométrica relacionados as atuais publicações que divulgam a transição energética da fonte fóssil, prioritariamente do gás natural, para as renováveis; as que envolvem a produção de combustíveis gasosos como o biogás, biometano, gás sintético natural e o gás de síntese provenientes da biomassa; e, ainda, como esses se relacionam com os mais recentes conceitos de organização econômica, como a Economia Circular, a Ecologia Industrial, a *Short Supply Chain*, etc. Não distante disso, também estão expostas as metodologias sob o ponto de vista técnico, econômico e financeiro de desenvolvimento de projetos de capital para este setor, amplamente utilizadas pelo setor acadêmico de pesquisa e desenvolvimento, mas que não necessariamente estejam alinhados com as práticas estabelecidas pelo mercado.

Palavras-chave: Projeto de capital; Análise bibliométrica; Análise financeira; Análise econômica; Análise técnica.

ABSTRACT

This article aims to demonstrate the main results of bibliometric analysis related to current publications that disclose the energy transition from fossil sources, primarily natural gas, to renewable sources. It also covers publications involving the production of gaseous fuels such as biogas, biomethane, synthetic natural gas, and synthesis gas derived from biomass. Additionally, it explores how these topics relate to recent economic organization concepts, such as Circular Economy, Industrial Ecology, Short Supply Chain, etc. Notably, the article presents methodologies from a technical, economic, and financial perspective for the development of capital projects in this sector. These methodologies are widely used in academic research and development but may not necessarily align with established market practices.

Keywords: Capital project; Bibliometric analysis; Financial analysis; Economic analysis; Technical analysis.

1. INTRODUCTION

The growing global energy demand, along with various environmental impacts associated with it, has exerted pressure on the social, political, economic, and technological restructuring of consumption. This is aimed at diversifying the current energy matrix by increasing the share of sources with low or zero carbon emissions, such as biomass, wind, and solar. This shift addresses the various challenges that the current fossil-based economy has propagated in a detrimental manner (CULABAL et al., 2022; NEWMAN, 2019; PAUNA et al., 2021; VELVIZHI et al., 2022).

In order to design, construct, and operate the necessary infrastructure for such diversification, industrial project engineering is directly linked to all phases of project development and operations, from strategic planning to implementation. Due to this, not only is the public sector exposed to uncertainties and investment risks associated with projects aimed at addressing or mitigating energy demand and its social and environmental issues upon implementation, but also the private sector. This is because these projects aim to either maintain or financially enhance capital over time (MERROW, 2011; NEWMAN, 2019; TOWLER et al., 2008).

Thus, various methodologies and indicators have been suggested for the assessment and development of capital projects, both by the private sector and academia. However, currently, there is limited published information on this subject, especially concerning capital projects aimed at producing biogas, biomethane, and hydrogen. In order to explore this frontier and propose a new perspective for capital project development, this article employs bibliometric analysis as a method of literature research to qualitatively and quantitatively delineate all formally documented knowledge in the literature (DONTHU et al., 2021; HADDOW, 2018).

Therefore, bibliometric analysis was chosen due to a methodological exclusion adopted as a justification criterion. Meta-analysis is typically applied when the research has a homogeneous character with an extensive sample population of articles (e.g., >200), and systematic literature review is employed when the research is specific with a smaller sample database of references (e.g., approximately 40). Given that the research is multidisciplinary and involves interaction with various themes, it exhibits heterogeneity across a diverse and extensive sample population. This characteristic allows for determining the current state of the art in the knowledge areas that intersect with industrial project engineering. Thus, justifying the application of bibliometric analysis as advocated by Donthu et al. (2021).

2. METHODOLOGY

The bibliometric mapping technique was adopted to conduct quantitative and qualitative metric analyses to comprehend the interrelationships and the current stage of the topics studied in this research, which consists of five stages, according to the Figure 1.

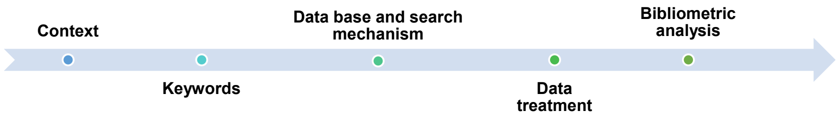

Figure 1 - Structure of the general bibliometric analysis method

2.1 Context, problem, and the main objective

The context of this research is based on recurrent observations in the field of capital project development regarding the market opportunities for the establishment of transformation industries using renewable energy sources, as outlined below, but not limited to:

- Expansion of the industrial production concept through Circular Economy, aiming to meet the indicators established by the United Nations (UN) 2030 agenda for Sustainable Development Goals (SDGs).
- Restriction on the flow and utilization of natural gas near the coastal producing regions in Brazil due to the limited pipeline infrastructure, except along GasBol.
- Opportunities, growth, and market penetration facilitated by the maturation of technologies (digestion, carbonization, gasification, and electrolysis) for the production of biogas, biomethane, synthetic natural gas, synthesis gas, and hydrogen from agricultural, industrial, and urban waste.
- Establishment of public policies and pricing mechanisms for products derived from renewable sources.

Thus, the issue lies in the inefficiency and/or lack of methodology and tools for the holistic planning of the implementation of capital projects. This planning should enable the development and exploration of regional resources with energy value, providing the means to secure large-scale investments in various regions of Brazil. As can be observed in Figure 2, there is a high concentration of natural gas processing facilities and its distribution along the Brazilian coast, with limited access to this resource in the interior of the country.

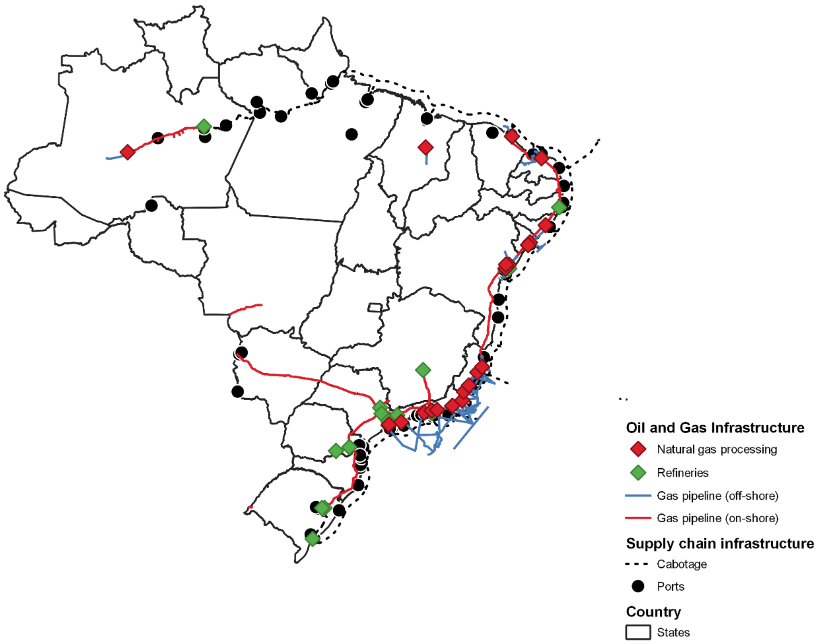

Figure 2 - Existing and projected infrastructure for the transport and treatment of natural gas in Brazil

With the suggestion of developing a tool based on a multidisciplinary methodology, there is a possibility of better directing investments toward capital projects in the energy and transformation sector. This tool would assess regional resources to meet the needs of both the public and private sectors. It has the potential to maximize the financial return margin with optimal geographic distribution for the implementation of production units for biogas, biomethane, synthetic natural gas, and hydrogen, as analyzed thus far.

2.1.1 Scope

According to Haddow (2018) and Treinta et al. (2013), the first step of bibliometric analysis is to determine the context and scope (Figure 3), the problem, and the questions to be addressed in the research. These aspects guide the subsequent step, which is related to the selection of keywords that best fit the theme.

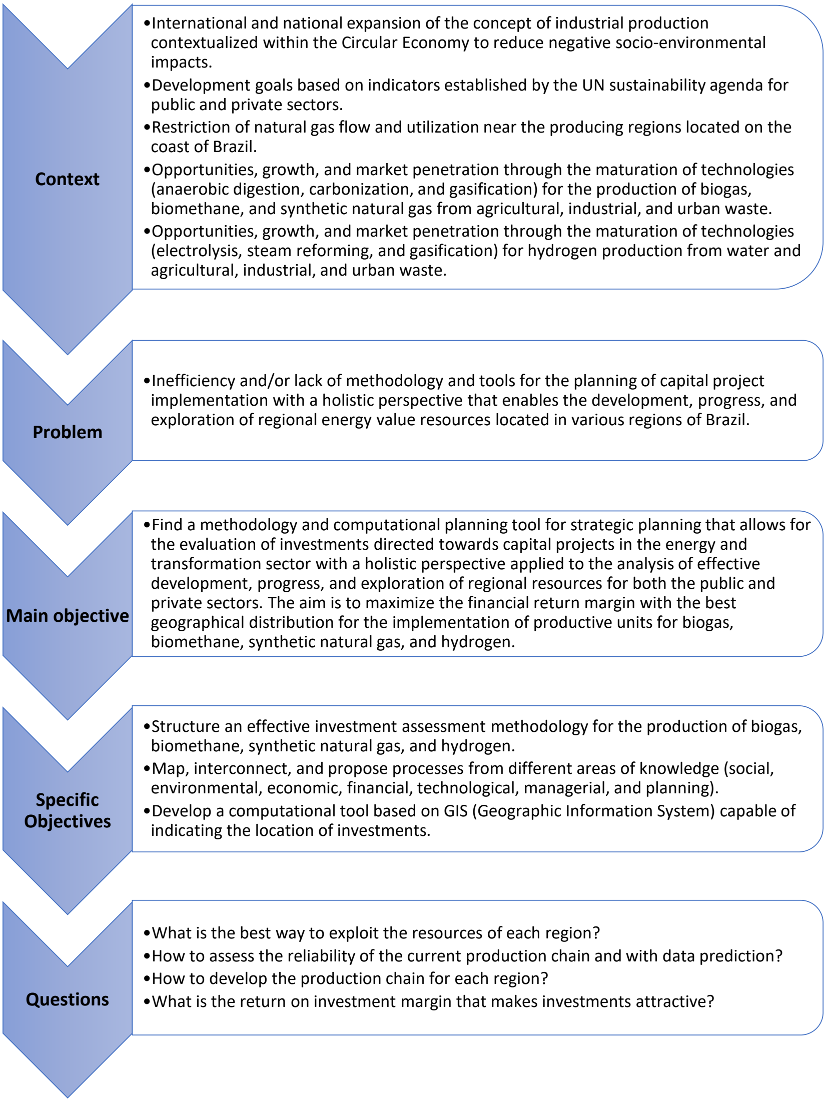

Figure 3 - Thematic synthesis of the research

2.2 Keywords definition

The keywords were separated into groups related to fossil or renewable sources and into themes that describe methodological contexts, as depicted in Figure 4 and Table 1.

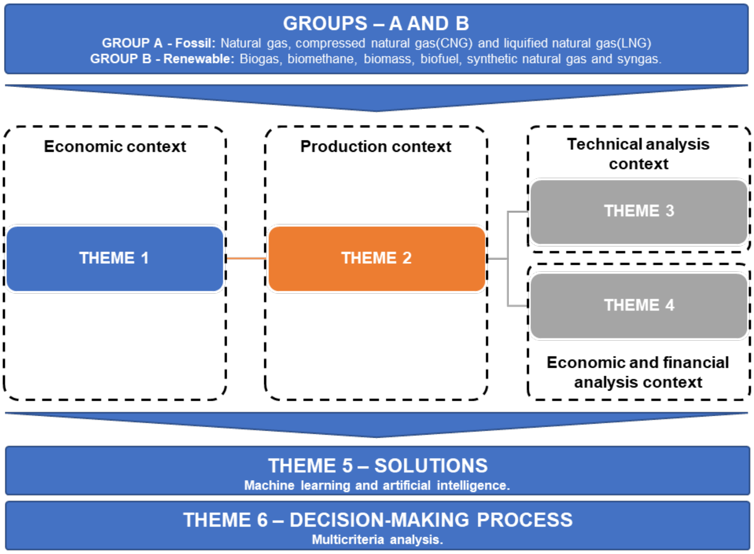

Figure 4 - Branching structure or themes of keyword identification

Table 1 - Division of keyword groups

Item	Keywords	Subject
	Group	
A	"Natural gas" OR "compressed natural gas" OR "cng" OR "liquified natural gas" OR "lng"	Economy and market
B	"Biogas" OR "biomethane" OR "biomass" OR "biofuel" OR "biofuels" OR "synthetic natural gas" OR "sng" OR "syngas"	Economy and market
	Theme	
Theme 1	"Capital project" OR "capital projects"	Economy and market
Theme 2	"Circular economy" OR "industrial ecology"	Economy and market
Theme 3	"Techno-economic analysis" OR "techno-economic assessment" AND ("geoprocessing" OR "GIS" OR "Geographic Information System" OR "material flow analysis" OR "mfa" OR "life-cycle assessment" OR "life-cycle analysis" OR "lca" OR "lcia" OR "supply chain" OR "process systems design" OR "process integration" OR "pinch analysis" OR "water pinch analysis"	Methodology
Theme 4	"Techno-economic analysis" OR "techno-economic assessment" AND ("Capital expenditure" OR "Capex" OR "operational expenditure" OR "Opex" OR "internal rate return" OR "irr" OR "minimum attractive rate" OR "MAR" OR "net present value" OR "npv" OR "ebitda" OR "risk assessment")	Methodology
Theme 5	"Machine Learning" OR "Artificial Intelligence"	Methodology
Theme 6	"Multicriteria Analysis" OR "decision-making process"	Methodology

2.3 Database and search mechanism

For analysis, scientific publication databases found in the SCOPUS (SCO) and Web of Science (WOS) platforms were utilized. The search mechanism employed the "advanced search" feature for the inclusion of relevant research groups, associating them in the following manner: Themes 1 or 2 with an analysis theme (3, 4, or 5), and the decision-making process Theme 6, as illustrated in Figure 4 and Table 1.

The variable used in synthesizing the SCO base was TITLE-ABS-KEY, which searches for terms entered in the title, abstract, and keywords fields. As for WOS, the variable TS was used, which is equivalent to the one used for the SCO base (Table 2).

Table 2 - Database search synthesis

Item	Base	DATABASE SEARCH SYNTHESIS
1A	SCO	TITLE-ABS-KEY(A AND TEMA 1 AND NOT B)
	WOS	TS=(A AND TEMA 1)
1B	SCO	TITLE-ABS-KEY(B AND TEMA 1 AND NOT A)
	WOS	TS=(B AND TEMA 1)
2A	SCO	TITLE-ABS-KEY(A AND TEMA1 AND TEMA 2 AND TEMA 6 AND NOT B)
	WOS	TS=(A AND TEMA 1 AND TEMA 2 AND TEMA 6)
2B	SCO	TITLE-ABS-KEY(B AND TEMA1 AND TEMA 2 AND TEMA 6 AND NOT A)
	WOS	TS=(A AND TEMA 1 AND TEMA 2 AND TEMA 6)
3A	SCO	TITLE-ABS-KEY(A AND TEMA1 AND TEMA 3 AND TEMA 6 AND NOT B)
	WOS	TS=(A AND TEMA 1 AND TEMA 3 AND TEMA 6)
3B	SCO	TITLE-ABS-KEY(B AND TEMA1 AND TEMA 3 AND TEMA 6 AND NOT A)
	WOS	TS=(A AND TEMA 1 AND TEMA 3 AND TEMA 6)
4A	SCO	TITLE-ABS-KEY(A AND TEMA1 AND TEMA 4 AND TEMA 6 AND NOT B)
	WOS	TS=(A AND TEMA 1 AND TEMA 4 AND TEMA 6)
4B	SCO	TITLE-ABS-KEY(B AND TEMA1 AND TEMA 4 AND TEMA 6 AND NOT A)
	WOS	TS=(A AND TEMA 1 AND TEMA 4 AND TEMA 6)
5A	SCO	TITLE-ABS-KEY(A AND TEMA1 AND TEMA 5 AND TEMA 6 AND NOT B)
	WOS	TS=(A AND TEMA 1 AND TEMA 5 AND TEMA 6)
5B	SCO	TITLE-ABS-KEY(B AND TEMA1 AND TEMA 5 AND TEMA 6 AND NOT A)
	WOS	TS=(A AND TEMA 1 AND TEMA 5 AND TEMA 6)

2.4 Database treatment

The database was treated by excluding incomplete records, such as those lacking author information, title, publication year, keywords, and abstract. This same method was suggested by Treinta et al. (2013), as it complicates information traceability. Furthermore, the database improvement considered adherence through the analysis of titles and abstracts to the research theme and the exclusion of publications that could be duplicates due to the use of two databases. Conference papers and book chapters not associated with scientific journal publications were also excluded, as they are often not subjected to peer review (GARRIDO et al., 2020).

The Microsoft Excel version 365 software was used to compile and process the data. For the mapping analysis, the VOSviewer software version 1.6.18 was utilized. The temporal analysis factor was delimited by the date of the database query creation on April 15, 2023, excluding articles published in 2023 to avoid quantitative distortions.

3. RESULTS AND DISCUSSION

3.1 Analysis and quantitative reduction of articles regarding the lack of data

Upon compiling the two databases, 13,778 articles were found. After exclusion as described in section 2, 3,585 unique records remained, as shown in Table 3.

Table 3 - Total number of articles published by Group and Theme

Theme	Groups [un.]						Distribution [%]					
	A1	A1	A2	B	B1	B2	A	A1	A1	B	B1	B2
1	4	0	0	3	0	0	0.11	0	0	0.08	0	0
2	0	1	84	0	6	1,433	0	0.03	2.34	0	0.17	39.97
3	0	0	60	0	1	252	0	0	1.67	0	0.03	7.03
4	0	0	34	0	1	168	0	0	0.95	0	0.03	4.69
5	0	5	269	0	5	1,259	0	0.14	7.50	0	0.14	35.12
Total	4	6	447	3	13	3,112	0.11	0.17	12.46	0.08	0.37	86.61

Regardless of Group "A" or "B," the other themes associated with Theme 1 yielded a few published articles. However, these were excluded after applying the mentioned filters, leading to the insertion of a suffix denoted by the number 1 in the established synthesis in Table 2 to identify the research item without the use of Theme 1. This resulted in the themes described in Table 1. Similarly, when the groups and themes were associated with Theme 6, although in some cases, a few articles were returned, a suffix with the number 2 was added to indicate the results that excluded Theme 6 from the search synthesis.

3.2 Analysis between themes related to the quantity of publications

The quantity of publications analyzed from Table 1, and plotted in Figure 5, draws special attention to the difference between the number of articles published with Theme 2B and Theme 5B compared to the others. Among these, 87% of articles published between 1990 and 2022 belong to these themes. These articles pertain to products or inputs obtained from renewable sources combined with concepts associated with circular economy, industrial ecology, and analysis techniques involving machine learning and artificial intelligence concepts (Table 1 and Table 2).

The low number of publications found with the term "capital project" combined with the defined keywords in the research could be related to the following hypotheses:

- Divergence in the specific technical terminology used in the market and academia.
- The term "capital project," widely employed in private project management institutions (e.g., Project Management Institute - PMI and the International Project Management Associate - IPMA), in economics, finance, or even in engineering focused on financial analysis, may be primarily associated with publications in books and conference papers or in scientific journals outside the utilized database.
- Possible lack of interest in academia to address the topic directly focusing on capital valuation.
- The term "capital project" might be indirectly included under the term "techno-economic analysis" used in academic research.
- Strong inclination towards simplified studies of capital and operational costs that use only the payback criterion as the investment decision-making criteria, without addressing more complex analyses related to the quality of investment through net present value (NPV), internal rate of return (IRR), minimum attractive rate of return (MARR), and break-even.

These factors more accurately and precisely constitute the economic and financial analysis of the project and the company, typically adopted by the market.

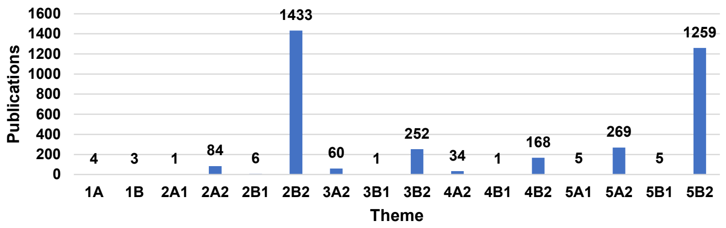

Figure 5 - Publications by theme

Based on the data shown in Figure 5, which illustrates the quantity of publications by themes, it is evident that researchers tend to align with the criteria established by the United Nations regarding sustainability by reorganizing productive sectors in order to:

- Decarbonize or "defossilize" industrial sectors by reducing the consumption of raw materials and inputs.
- Make supply chains and production processes more efficient.
- Reuse by-products, waste, or effluents within the production chain.

Moreover, there is a difference in the quantity of articles that use Theme 6 or not. By not utilizing decision-making methods considering multiple criteria (Theme 6), solutions presented in the articles may lack a systemic business perspective and only address criteria defined by an organization in a bottom-up manner. This means they only consider indicators relevant to operational and managerial viewpoints, such as quantity, operational parameters, socio-environmental impact, financial return, etc. This approach may not encompass a top-down perspective, i.e., a strategic business viewpoint developed by a specific group within a company. This group requires a comprehensive set of financial information such as NPV, IRR, payback, break-even, pricing, along with data related to other indicators like socio-environmental impacts, stakeholder and shareholder acceptance, associated public policies, technical performance, etc.

Still, when analyzing Figure 5 concerning published articles, there is a highlight for themes involving the context of machine learning and artificial intelligence, grouped in Theme 5. Of the total articles published during the period, around 35% are from this theme applied to the assessment of renewable resources, and only 7.64% for fossil sources.

However, when observing themes related to technical analyses (Theme 3) and economic analyses (Theme 4), deviations between them are also demonstrated. Comparing articles published with Theme 5 (machine learning and artificial intelligence), only 14.4% are associated with publications with Themes 3 and 4. For either of the associated groups, A or B, the technical theme slightly shows more interest due to the number of publications. This greater number of publications indicates the normal flow of technological development, as it is necessary to demonstrate technical feasibility before economic feasibility. However, this does not dismiss the possible lack of interest or synchronization between the Research and Development (R&D) sector, mainly concentrated in academia and the private sector. The latter requires technical and economic analyses to be aligned and linked to technological development for investment attractiveness to emerges.

To support this perspective on the distance between academia and the private sector in the context of capital projects, the article published by Nsanzumuhire et al. (2020) can be cited. In this article, the authors conduct a systematic review of 68 articles addressing the university-industry interaction. They indicate that, for both the university and industry, among the indicators analyzed, the commercial relationship between these two institutions—the financial return from the partnership, particularly for developing countries—is the one with the lowest value and/or attractiveness. This relationship is mainly influenced by socio-political aspects.

3.3 Evolution of themes over the years

According to the database treated in the context of the research (Figure 6), the first publication for Theme 5 associated with Group B occurred in 1991. In this article, the authors (KIMES et al., 1991) used artificial intelligence to determine phenotypic characteristics of vegetation. As for Group A, the first publication took place in 1998 for the same Theme 5. Li et al. (1998) describe a control system for pigging-assisted pipeline inspection using artificial intelligence to assess the instrument inside the pipeline.

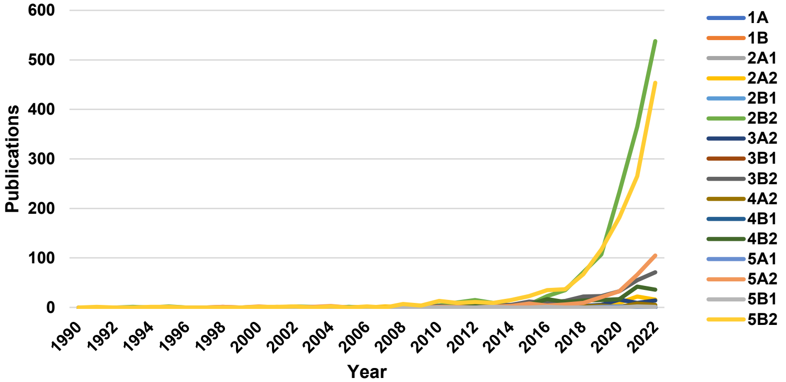

Figure 6 - Number of annual publications in a historical series by theme

As shown in Figure 6 there are intervals during the publication years that involve the defined themes. Although some articles on the themes have been published since 1985, such as the emergence of Industrial Ecology in 1989 by Frosch et al. (1989), and Circular Economy in 1991 by Pearce et al. (1991), it was only in 2014 that all five themes emerged simultaneously for Group A and, in 2017, for Group B (Table 4 and Table 5).

Table 4 - Number of publications per theme per year

Year	Theme									Total
	1A	2A1	2A2	3A1	3A2	4A1	4A2	5A1	5A2	
2014	1	0	5	0	2	0	1	0	3	12
2015	0	0	1	0	2	0	1	0	8	12
2016	0	0	2	0	3	0	4	0	4	13
2017	0	0	10	0	4	0	3	1	6	24
2018	0	0	2	0	3	0	2	0	9	16
2019	0	1	5	0	5	0	4	1	21	37
2020	1	0	9	0	16	0	1	2	33	62
2021	0	0	22	0	9	0	8	0	66	105
2022	1	0	16	0	14	0	5	0	105	141
Year	**1B**	**2B1**	**2B2**	**3B1**	**3B2**	**4B1**	**4B2**	**5B1**	**5B2**	**Total**
2014	0	0	2	0	5	0	1	0	15	23
2015	0	0	6	0	12	0	6	0	23	47
2016	0	0	23	0	9	0	17	1	35	85
2017	1	1	35	0	13	0	11	0	37	98
2018	0	1	71	0	22	0	14	0	67	175
2019	0	0	107	1	23	0	15	0	117	263
2020	0	1	233	0	33	1	17	0	182	467
2021	0	1	365	0	55	0	42	2	265	730
2022	0	2	538	0	71	0	36	1	454	1,102

This demonstrates the growing interest and a greater trend towards publications related to sustainability, more efficient production methods, and analysis methods involving artificial intelligence, followed by subjects containing techno-economic analyses applied to various production situations. Finally, financial analyses and decision-making methods are nearly nonexistent.

Similarly, when observing the start of discussions on more efficient production methods and the emergence of concepts such as Circular Economy and Industrial Ecology (1989 and 1990) and comparing them with the current discussions in the public and private sectors of the economy, it can be emphasized how these sectors are lagging behind. There is an approximately 30-year difference between the maturation of proposals and their actual application.

Although a simple numerical analysis leads to this assertion, it can be justified as the market exhibits a conservative behavior regarding new ways of structuring and how and when to implement and/or deploy new production technologies. This is because it needs to protect itself from unnecessary exposure to the risks of financial resource loss associated with high investments in unknown subjects, as mentioned by Krugman et al. (2015) and Towler et al. (2008).

This analysis is supported by the suggested contingency of 50%, reserved to mitigate risks related to the learning curve, implementation, and operation during the capital project development phase that utilizes technologies not yet fully mastered by the market. This can be compared with the contingency practiced around 5 to 15% for technologies already known and mastered by the sectors, as explained by Towler et al. (2008).

Nevertheless, other themes combined with the term "capital project" did not achieve a representation equivalent to the number of publications when compared to others. This may indicate little interest in developing a holistic and more complex project analysis structure and/or methodology with greater applicability to the public and private sectors. Publications have sought more in-depth exploration of specific subjects or theoretical application in case studies for analysis with limited multidisciplinary interaction, especially those related to capital valuation.

3.4 Analysis of themes by occurrence and association of keywords

By inputting the data into the VOSViewer software, an analysis of keyword occurrences was conducted to visualize how they interrelated. It can be observed in both Table 5 and Figure 7(a) that three clusters were formed (Figure 7(b), (c) e (d)) based on the strength of the connections between the words and separated by colors, following the approach of Tamala et al. (2022).

Table 5 - Compilation of themes for occurrence analysis

Keywords	Cluster	Strenght	Occurence
Biomass	3	11,327	958
Biofuel	2	5,167	274
Circular economy	1	5,073	568
Biofuels	2	4,949	298
Machine learning	3	4,803	694

Table 5 - Compilation of themes for occurrence analysis (cont.)

Keywords	Cluster	Strenght	Occurence
Economic analysis	2	4,456	313
Anaerobic digestion	1	4,305	298
Biogas	1	4,289	322
Sustainable development	2	3,874	287
Life cycle	2	3,669	240

The most frequent occurrence is related to the word "biomass," which becomes the central term for the entire holistic analysis and is connected to all the main terms of the other clusters, as shown in Figure 7(a). This same word is strongly linked to other themes: circular economy, biofuels, and machine learning.

Thus, as suggested by Ampah et al. (2021), based on the data presented in Table 4 and Table 5, it is possible to indicate that when the context is to develop a methodology that analyzes the renewable biofuel production market using geoprocessing and considering financial aspects of investment, research tends to focus more on studying biofuel production processes under organizational aspects suggested by the circular economy. This aims to meet sustainable development through economic analyses using machine learning, as outlined in Table 5.

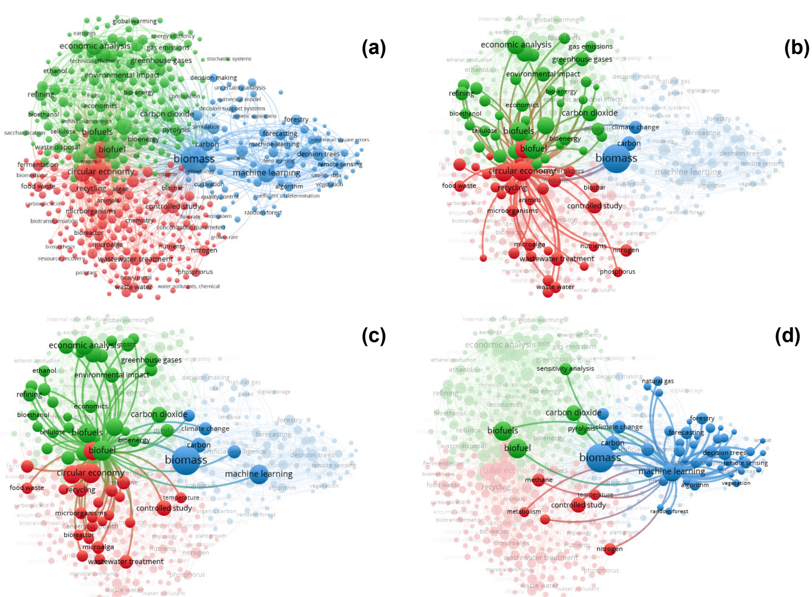

Figure 7 - Network of total keywords by occurrence for the research and main interaction networks between clusters

Although the analyses have shown a strong technical-economic focus in publications, there is a weak connection, representing low occurrence, between economic terms and the keyword network. Terms such as "capital expenditure (CAPEX)" and its possible derivations do not appear, and there is no connection between "operational expenditure (OPEX)" and the central terms or even a direct link between the latter and CAPEX.

At this point, there is a divergence between academia and the market. In the market, during economic feasibility studies that underpin the go/no-go decision for a project, values obtained for CAPEX and OPEX are always developed and used as parameters. The aim is to formulate economic and financial indicators such as NPV, IRR, and payback. These, along with the Minimum Attractive Rate (TMA), defined by the company's strategic planning, assist in the decision-making process of whether to proceed with the investment or not.

3.4.1 Analysis by occurrence and association of keywords: Cluster 1

Cluster 1 is defined by the main term "Circular Economy," as shown in Figure 7(b). The Circular Economy has a strong connection with these top 10 terms: anaerobic digestion, biogas, controlled study, economic aspect, recycle, effluent treatment, methane, nitrogen, microalgae, and fermentation.

There is an indication that in this context, the Circular Economy may be directed towards the creation of biorefineries or increased biogas (methane) production through fermentative processes (anaerobic digestion) by cultivating microalgae in effluent treatment. Analyzing the key articles that appear in the database with a connection strength greater than 100, Stiles et al. (2018) propose that the proper management of organic waste and effluents can be optimized by producing microalgae for subsequent processing in biorefineries to obtain inputs for feed, biofuels, biofertilizers, and high-value-added chemical compounds due to European restrictions in nitrate-vulnerable areas.

On the other hand, Mishra et al. (2019) emphasize that the establishment of biorefineries using microalgae as raw material is not yet economically viable. To address this, the author suggests reducing, recycling, and reusing residues from microalgae processing for biofuel production and high-value-added chemical compounds, especially through life cycle analysis. Alternatively, Al-Jabri et al. (2021) highlight in their article that industrial and municipal effluents are contaminated with a high load of dissolved nitrogen and phosphorus in the environment. According to the authors, with improved effluent treatment, microalgae could be used to optimize the contaminant removal process and recover their energy value through the production of chemicals and biofuels.

Wainaina et al. (2020) conduct a systematic review of the main technological routes involving anaerobic digestion for biogas production and high-value-added chemical compounds, including nitrogen recovery and fixation. Finally, Kumar et al. (2021) analyze the use of biochar from residues produced in the food industry as an additive to increase biogas production via anaerobic digestion.

3.4.2 Analysis by occurrence and association of keywords: Cluster 2

Cluster 2 is defined by the main term "Biofuels," as shown in Figure 7(c). The term biofuels has a strong connection with the following top 10 terms: economic analysis, sustainable development, life cycle (life cycle analysis), carbon dioxide, techno-economic analysis, environmental impact, waste management, greenhouse gases, biofuel production, and refining.

There is an indication that the term biofuel in this context is directed towards techno-economic analyses that aim for biofuel production, focusing on the product life cycle with the goal of reducing greenhouse gas emissions (carbon dioxide). This, consequently, reduces environmental impacts through proper waste management to meet the criteria established for sustainable development.

Similarly to the analysis in section 3.4.1, when examining the main articles in the database Klein-Marcuschamer et al. (2012) analyze the contribution of enzyme costs in ethanol production from corn, as well as a sensitivity analysis on raw material prices and the fermentation process itself. Venkata Mohan et al. (2016) address the biofuel topic associated with sustainable development in a holistic manner, presenting a study focused on the development of biorefineries that use waste as raw material in different technologies to produce biomaterials and biocompounds through the circular economy as a context, comparing these with the substitution of the same products from fossil sources.

Liska et al. (2009) perform a life cycle analysis of corn-produced ethanol in the United States by transforming the plant into a biorefinery through the inclusion of anaerobic digestion in the process. The authors conclude that this production system can mitigate greenhouse gas emissions not only in the industry but also in the agricultural inventory, consequently reducing the importation of oil for conversion into fuels used in the transportation sector.

3.4.3 Analysis by occurrence and association of keywords: Cluster 3

Cluster 3 is defined by the main term "Biomass," as shown in Figure 7(d). The term "biomass" has a strong connection with these top 10 terms: machine learning, carbon, decision tree, artificial intelligence, climate change, prediction, learning systems, forest, optimization, and neural networks.

With the synthesis of these key terms, the database indicates that Ali et al. (2015) conducted a review of the main machine learning techniques associated with predicting biomass production through spatial analysis via satellite by quantifying and qualitatively interpreting soil moisture and biophysical aspects of crops. Maimaitijiang et al. (2017) similarly analyze soybean production, but with some specificities, using spatial information provided via satellite (images and thermal information) to predict productivity, utilizing biochemical data to determine aspects of the crop both under and above the soil cover.

In contrast, with a weaker connection to the term "biomass" the main studies for biomass production appear in the article by Antwi et al. (2017) in which, through a neural network, the prediction of biogas and methane production is analyzed using UASB reactors with effluents from the potato processing industry. Wang et al. (2020) apply the same prediction process to different biomass types in biogas production to analyze reactor operational parameters and determine production yields. On the other hand, De Clercq et al. (2020) focuses on predicting biogas production by applying the random forest technique in the food industry, evaluating co-digestion.

3.5 Analysis of themes by countries

Relating the publications by origin, the 10 most representative countries in terms of the number of publications and consequently having a greater interest in the entire context defined in section 2.1, are highlighted in Figure 8. Brazil is in 8th place, with 3.43% of the publications.

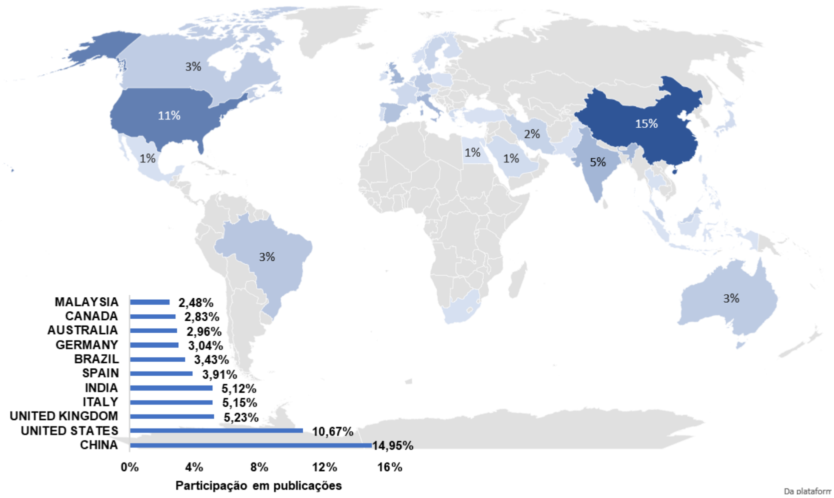

Figure 8 - Global representation percentage regarding the theme

3.6 Research development perspectives and technological advancement

In addition to the occurrence analyses presented in sections 3.4.1, 3.4.2 and 3.4.3, another analysis determined by the bibliographic review of the most recent articles (2022) that adhere to the research context and are chosen by the number of citations can demonstrate the frontier of technological advancement and highlight the gaps that still need to be filled for capital projects related to energy transition to be better implemented in the industry.

Taking a top-down approach to the organization of the economic production sector, Hoang et al. (2022) start with the use and management of urban solid waste in the production of chemical compounds and fuels. Unlike other articles, the authors not only emphasize technological aspects but also address economic cost criteria (implementation and operation) by suggesting supply chain and distribution organization and discuss how this can impact the local economy.

In a complementary analysis to the aforementioned article, Dar et al. (2022) evaluate primary sources of renewable energy through GDP and CO_2 emissions as common aspects for comparison with fossil energy sources. The authors employ various causality assessment techniques to establish balance and comparison of indicators, resulting in the suggestion of various long-term public policies for energy transition. To complement these studies, Culaba et al. (2022) focus on the application of artificial intelligence in analyzing economic aspects in creating biorefineries under the Circular Economy context.

As a transition and connection between publications that highlight the economic organization of the energy sector, the article by Aghnashlo et al. (2022) critically analyzes the current methodologies used for studies, such as techno-economic analysis, life cycle analysis, emergy analysis, energy, and exergy analysis. In this article, the authors highlight the advantages and disadvantages of each and proposes their interrelation to provide more accurate results.

From a productive perspective, three articles stand out for the number of citations. The first of these was published by Seo et al. (2022), in which the authors discuss the use of lignocellulosic biomass as promising raw materials to replace fossil sources by developing biorefineries. This article focuses on the advantages and disadvantages of using thermochemical technologies for biomass conversion into higher value-added chemicals, considering future technological prospects, including optimizing these processes by associating them with artificial intelligence algorithms. Chilakamarry et al. (2022) address the use of agricultural residues in biochemical (fermentative) processes in biofuel production and how this process can act in remediation to reduce effluents and contaminants under the Circular Economy context. Similarly, analyzing both thermochemical and biochemical processes, Velvizhi et al. (2022) propose that all projects for the production of chemicals from lignocellulosic materials should be analyzed from the perspective of energy integration, recovering and providing inputs inherent to the production stages with the aim of reducing energy consumption, inputs, and raw materials. Finally, Chen et al. (2022) highlight an extremely important step in the conversion chain of lignocellulosic materials, pre-treatment. In his article, the authors describe the procedural characteristics, influencing factors, techno-economic aspects, and challenges that this step still faces.

Making the analysis even more profound from the perspective of production prediction methodologies, Wang et al. (2022) propose the use of artificial intelligence to predict aspects of production processes that use biomass in the production of chemical compounds and fuels. Through a critical analysis, the authors demonstrate the pros and cons, highlighting the limitations of using different artificial intelligence techniques. On the other hand, Andrade Cruz et al. (2022) apply artificial intelligence algorithms to understand the aspects influencing biogas production by anaerobic digestion.

Therefore, it can be noted that with the sample of publications used, there are concentrations of research that address macroeconomic aspects, productive aspects, and a few economic aspects. It is important to note that the way of organizing, developing, and evaluating projects is different from that applied in the market. The interdisciplinary correlation, information generation, financial indicators, and decision-making aspects are quite different from those demonstrated in the analyzed articles.

Of all the articles, only one publication demonstrated a critical analysis proposing an interconnection between different analysis techniques, developing a methodology for projects, which, even so, is far from the working structure adopted in engineering consulting companies responsible for developing these types of projects in the market. In publications that proposed some kind of economic analysis, CAPEX might have been applied within some other term, or OPEX might have been developed simplistically for determining operational costs as an aid to pricing definition.

Once again, terms like IRR, NPV, TMA, and EBITDA or break-even were not even mentioned, and these are the most important financial aspects used by the industry to evaluate the project and identify whether to proceed with strategic investments or not. Another aspect that cannot be assessed, as there are almost no publications in this context, is analytical methodologies to aid decision-making, such as multi-criteria analysis (MCA), in addition to risk analyses.

In conclusion, it is possible to say that there is a lack of organizational development that seeks to concatenate a holistic methodology for project evaluation, considering methods widely adopted in the market and suggesting new ones from academia to improve performance and results during development. This can bring greater security to investments made by the public and private sectors.

4. CONCLUSION

Although these analyses play an important role in research to demonstrate the advancement of the knowledge frontier, one point to highlight is the potential flaw in the applied methodology. For example, the researched authors may have used various means of technical or financial determination, but when suggesting keywords, they might have chosen another term that represented the researched topics, and these terms might not accurately reflect the exposed data.

In any case, it is important to emphasize that financial and economic indicators that were used in this analysis are commonly employed in the market, following established criteria of good practice that better guide investment decisions. Therefore, it is crucial for academia, in its research endeavors, to align with these practices. This alignment ensures the provision of more accurate and practical insights while adhering to a scientific methodology that is replicable and verifiable. This approach enhances the reliability of the information, a factor often lacking in market data that may not disclose the method behind information determination.

Nevertheless, it was possible to verify that research aiming to optimize the productive sector using biomass as a raw material began around 1991 with publications involving artificial intelligence techniques. This suggests a temporal lag of 30 years concerning current socio-political and market discussions on these topics.

When comparing energy sources like fossil and renewable, there is a significant difference in the number of publications, about 74.5% between them. Approximately 87% pertain to topics involving renewable sources, while only 13% pertain to fossil sources. Furthermore, there is a trend for researchers over the years to investigate analysis techniques involving the concept of artificial intelligence.

The formation of clusters demonstrated the correlation between different topics, suggesting that the central theme interconnecting the entire research revolves around the term "biomass." Notably, financial indicators demonstrating business profitability are not addressed, implying that research is primarily dedicated to developing technical analyses that evaluate productive aspects. There was an insignificant number of published articles using decision-making methodologies, such as multi-criteria analysis, which was also evident when analyzing the co-occurrence of terms in the formed clusters.

Thus, there may be a gap in the research sector suggesting a methodology and development tool focused on strategic planning for market development with a holistic view. This would enable the correct exploration of regional resources with energy value, providing security for large-scale investments.

The development of this methodology and tool could allow for an evaluation of investments directed towards capital projects in the energy and transformation sector. It would assess regional resources for both the public and private sectors, aiming to maximize the financial return margin with the best geographical distribution for the implementation of biogas, biomethane, synthetic natural gas, and hydrogen production units at a top-down evaluation level.

Otherwise, the dynamics of academic publications often do not prioritize the analysis of economic feasibility. This is partly due to the nature of research, which frequently explores topics distant from advanced stages, such as pilot units or practical demonstrations. A complementary approach to assessing the impact of these publications would be to link them to the Technology Readiness Levels (TRLs) of the addressed technologies. It can be observed that publications with more citations are often associated with technologies in more immature stages, reflecting significant interest in the scientific community even before the practical implementation phase.

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