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**Environmental Technology**

# Scientific production on biogas from cassava processing waste in Brazil: characteristics and approaches

## Produção científica sobre o biogas dos resíduos do beneficiamento da mandioca no Brasil: características e abordagens

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## ABSTRACT

The presented research proposes an investigation on how scientific production has been carried out regarding biogas produced from cassava processing residues in Brazil. In this direction, a Systematic Literature Review (SLBR) was carried out, inspired by the principles of the methodology proposed by Tranfield *et al*. (2003). Data was extracted from the articles according to: a) Characterization of publications; and b) Research approach. Thus, it was found that 2018 was the year with the largest scientific publication on the subject; the formation of the main authors is concentrated in the field of Engineering; and publications are especially focused on the state of Paraná. The predominant methodological approach was the Experimental, which prioritized research with the objective of verifying the Efficiency in the production of biogas, according to: a) Co-digestion, inoculum and alkalinizing strategies; b) Performance of operational parameters; and c) Reactor design performance. It was also verified that most articles do not consider the issue of production scale in their research, and when this parameter was considered, it met the large scale of production. Although the Brazilian cassava crop and its processing are marked by a mostly small-scale production, carried out by family farming and destined for internal trade, it appears that this reality was not addressed in any of the articles analyzed.

**Keywords**: Biogas; Cassava; Waste

## RESUMO

A pesquisa apresentada propõe uma investigação sobre como tem sido feita a produção cientifica a respeito do biogas produzido a partir dos resíduos do beneficiamento da mandioca no Brasil, Nessa direção foi feita uma Revisão Bibliográfica Sistemática da Literatura (RSB) inspirada nos princípios da metodologia proposta por Tranfield *et al*. (2003). Os dados foram extraídos dos artigos segundo: a) Caracterização das publicações; e b) Abordagem das pesquisas. Assim, foi verificado que 2018 foi o ano com maior publicação cientifica sobre o tema; a formação dos autores principais concentra-se na área das Engenharias; e as publicações concentram-se especialmente no estado no Paraná. A abordagem metodológica predominante foi a Experimental, que priorizou pesquisas com o objetivo de verificar a Eficiência na produção de biogás, segundo: a) Estratégias de codigestão, inoculos e alcalinizantes; b) Desempenho de parâmetros operacionais; e c) Desempenho do desenho dos reatores. Também foi verificado que a maioria dos artigos não considera a questão da escala de produção em sua pesquisa, e quando esse parâmetro foi considerado atendeu a larga escala de produção. Apesar da cultura brasileira da mandioca e seu beneficiamento serem marcados por uma produção de escala majoritariamente pequena, protagonizada pela agricultura familiar e destinada ao comercio interno, verifica-se que essa realidade não foi contemplada em nenhuma dos artigos analisados.


**Palavras-chave**: Biogás; Mandioca; Resíduo

# 1 INTRODUCTION

Given the growing international commitment to reducing greenhouse gases (GHG); preserving the environment; and producing clean energy[1], anaerobic digestion has gained the attention of the world as an alternative to achieve these goals. Milanez (2018) highlights that such attention is especially related to its “negative carbon footprint”, since anaerobic digestion is applied as a solution for treating waste from human activities, potential pollutants to the environment, and at the same time it captures methane gas[2] for energy use from the biogas produced.

Among these residues, those from agro-industrial activities are responsible for three quarters of the potential of raw materials to be explored for the production of biogas (MILANEZ *et al*., 2018). In this scenario, the research work presented consists of a Systematic Literature Review (SLR) on the production of biogas from cassava processing residues in Brazil. The proposed reflection is

[1] Expressed especially in the implementation of international agreements on climate change
[2] Methane gas was considered a GHG by the Kyoto Protocol, with a global warming potential 21 times higher than carbon dioxide. Annually, the natural biodegradation of organic matter under anaerobic conditions releases between 590 million and eight hundred million tons of methane into the atmosphere (MILANEZ *et al*., 2018).

introduced with an overview of the origins of cassava cultivation, production, trade and consumption from the roots in the world, in Latin America and in Brazil. Thus, the panorama presented starts from the taxonomy, characteristics and origins of root culture, based especially on the work of Antônio Allem (2002), who explores the botanical, historical and geographic factors that drew the dynamics of plant dissemination for over 100 producing countries in the world today.

Then, the publications of the United Nations Food and Agriculture Organization (FAO, 2013; 2018); and the International Center for Tropical Agriculture (CIAT, 2014) demonstrate the conditions that promoted the accelerated growth of production, verified in the last three decades. In this sense, there is the dynamics of production, commercialization and particular consumption of the cassava crop, marked by the insertion of the root and its derivatives as commodities in the international market, especially in Southeast Asia.

At the same time, it is also recognized for its importance as a food base for around 800 million people in the world; in the development of peripheral local economies; in rural development; and in food security, where smallholder farmers in sub-Saharan Africa and Latin America predominantly do root production and processing.

The panorama presented also zooms in on the scenario of production, processing, trade and consumption patterns in Brazil, with the potential for biogas production from cassava processing waste. This task was especially supported by secondary data from the Brazilian Institute of Geography and Statistics (IBGE); Department of Rural Economy of the Secretariat of Agriculture and Supply of the Government of the State of Paraná (DERAL); Food and Agriculture Organization (FAO); International Center for Tropical Agriculture (ICTA); and the work developed by Peres *et al* (2019).

Given the assumption, the methodology used to carry out the SLBR guided by the contributions of Tranfield *et al*. (2003), with the objective of identifying, systematizing and analyzing relevant information from scientific publications; and the respective methodological approaches used in research on the subject.

### 1.1 Panorama on cassava cultivation

Researching the origins and taxonomy of cassava, Antônio Allem (2002) identifies the culture as an ancestral practice, cultivated over 9,000 years ago by pre-Colombian Amerindians due to its starch-rich roots. Cassava (*Manihot esculenta Crantz*) is one of the 100 species of the genus Manihot, classified as a woody perennial shrub that grows up to 5 meters in height, found from northern Argentina to the southern United States of America.

The origin of one of the oldest cultures in the world is in South America, Mesoamerica and the Caribbean islands, where the root was already cultivated in the pre-Columbian era, until the arrival of Portuguese and Spanish invaders on the continent, who took the plant to the Atlantic coast of Africa. Thus, during the 19th century, the plant's cultivation spread geographically along the east coast of Africa and South Asia, expanding considerably in the 20th century, when it emerged as an important component of food culture in sub-Saharan Africa, India, Indonesia and the Philippines (ALLEM, 2009).

Due to its sensitivity to frost and nearly a year's growth phase, agricultural cultivation of the plant currently takes place in tropical and subtropical regions in over 100 countries, under a variety of local names such as cassava in Brazil, yuca in Honduras, ketela pohon in Indonesia, mihogo in Kenya, akpu in Nigeria and sắn in Vietnam (FAO, 2013).

In the report published by the International Center for Tropical Agriculture (CIAT) in 2014, with an analysis of the advances and possibilities for an “eco-efficient agriculture”, cassava is recognized as the third most important source of dietary energy in the world, after corn and rice (CIAT, 2014).

Mainly due to the high concentration of starch in its roots; at wide range for harvesting; the ease and accessibility of cultivation; and its tolerance to adverse conditions, the plant is considered one of the most reliable food security crops in the world. In many sub-Saharan African countries, root is the most affordable source of available calories, as well as containing significant amounts of vitamin C, thiamine, riboflavin and niacin[3] (FAO, 2013).

The root makes up the food base of about 800 million people in the world, cultivated largely by small, low-income farmers; it is one of the few staple crops produced efficiently on a small scale, without the need for mechanization or the acquisition of inputs, in marginal areas with poor soils and unpredictable rainfall (FAO, 2013). In addition to being a rich source of energy for food, starch from roots can also be used widely in industry including food processing, pharmaceuticals, textiles, plywood, adhesive paper and as a raw material for biofuel ethanol production.

Some characteristics of the cassava crop make it especially attractive to small producers who, using little or no input, can count on abundant root crops where other crops would probably fail (CIAT, 2014). Among them, FAO (2013) especially points out the efficient use of water and soil nutrients made by the plant; its high tolerance to adverse conditions such as lack of rain and acidic soils; and resistance to attacks from sporadic pests and predators[4].

Thus, in addition to consuming or selling fresh roots, many small producers supply the market with a wide variety of products derived from cassava. However, the International Center for Tropical Agriculture (ICTA) points out that a challenge for producers is the variety of pests and diseases that can attack cassava

[3] In some countries, its leaves are also consumed, which contain about 25% of protein of their dry weight (FAO, 2013).
[4] In addition to showing high tolerance to acidic soils, it forms a symbiotic association with fungi that help the roots to absorb phosphorus and micronutrients. Under conditions of water stress, leaf production on the plant is reduced until the next rain occurs. Meanwhile, most of the nutrients absorbed by the soil during plant growth are found in its upper portion of the plant, above ground, so recycling this part of the plant into cultivation promotes the maintenance of soil fertility. To discourage its herbivorous predators, its leaves produce two glycosides that when digested are metabolized to highly toxic hydrogen cyanide (FAO, 2013).

throughout its long growing cycle (CIAT, 2014). In this sense, ICTA identified advances in research and practices for biological pest control; genetic improvement and resistance to diseases and pests; crop management; and starch quality, in the last three decades, following the market's interest in the root and the increase in world production.

Between the 1980s and 2011, the world's cassava cultivation area increased from 13.6 million hectares to 19.6 million, with an increase of 44%, representing the highest growth among the five main food crops in the world. Still, in the same period, the world production of cassava rose from 124 million tons per year in 1980 to about 252 million tons per year in 2011, representing a 51% increase in production since 2000. This increase was concentrated especially in Asia, with the increased demand for dry cassava and starch for use in cattle feed and industrial applications; and in Africa, with the expansion of the urban market for food products derived from cassava (FAO, 2013).

Another trend verified by FAO (2013) was the increase in cassava productivity per planted area, from 10.4 tons per hectare in 2000 to 12.8 tons per hectare in 2011, representing an average increase in productivity of 1.8% per year. However, a study by ICTA (2014) indicates that cassava productivity is still well below its potential, since with soil management and the use of higher yielding and more resistant varieties, cassava crops could produce an average of 23.2 tons of roots per hectare. Meanwhile, FAO (2013) indicates that under optimal conditions, cassava productivity can reach 80 tons per hectare, increasing by 6.25 times its current average production of 12.8 tons per hectare.

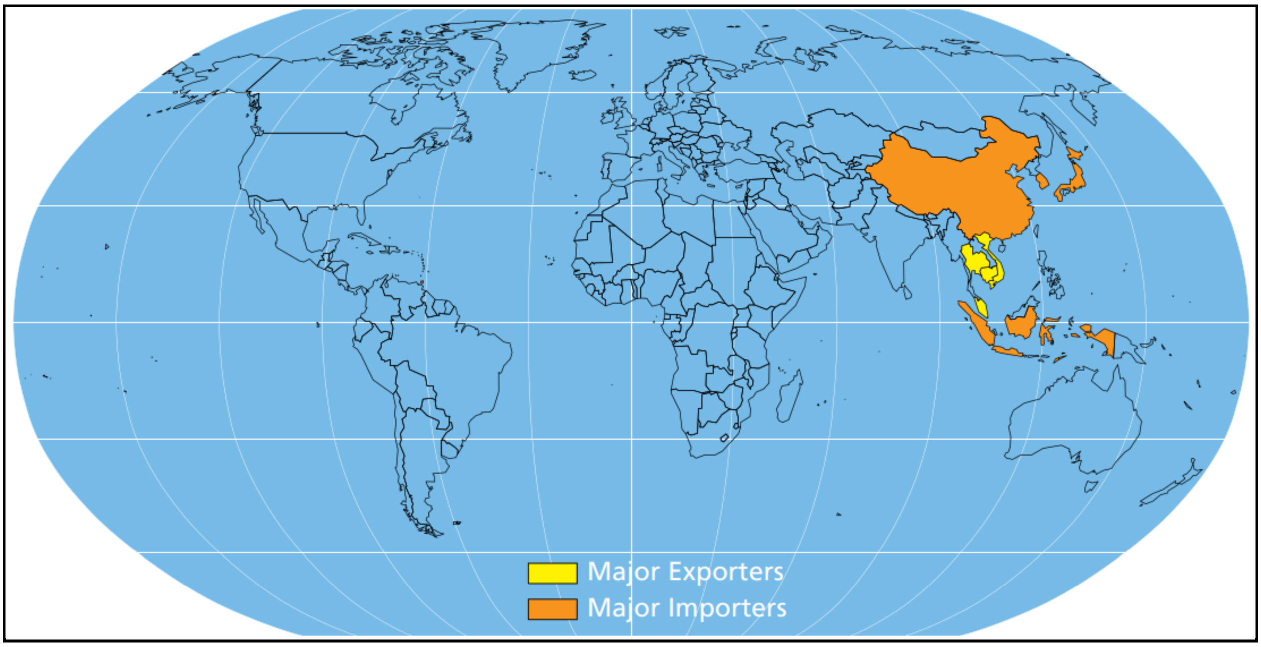
Inspired by the potential of cassava production in the world, FAO produced in 2013 a guide for the “sustainable intensification of cassava production” based on the “save and grow” agriculture model proposed by the institution, specific for small farmers and family systems. On this occasion, the FAO also points out that cassava has gone from “food of the poor to a multipurpose crop and a trend in the

21st century global economy", meeting the priorities of developing countries, trends in the global economy and the challenges of climate change.

In this context, the *Annual Report on Global Food Markets*, published by FAO in 2018, provides a deeper analysis of the development of cassava markets (FAO, 2018), also indicating how the "geography of cassava" clarify the demand and supply demands on global market, with its various forms of use, oriented by the "*Food Empires*" of modern society (PLOEG, 2008).

Although root consumption as food is its main use, its use as animal feed, industrial use and energy source also has a prominent place in the global agricultural economy, as well as in regional and local markets. In this "*cassava geography*", it is possible to see how the flow of international trade in cassava is concentrated in Southeast and East Asia, as illustrated in Figure 1, where the commodity sectors [5]meet the high demand of the energy, food and industrial sectors of China, responsible for more than two-thirds of world imports (FAO, 2018).

Figure 1 – Largest cassava exporters and importers in the world

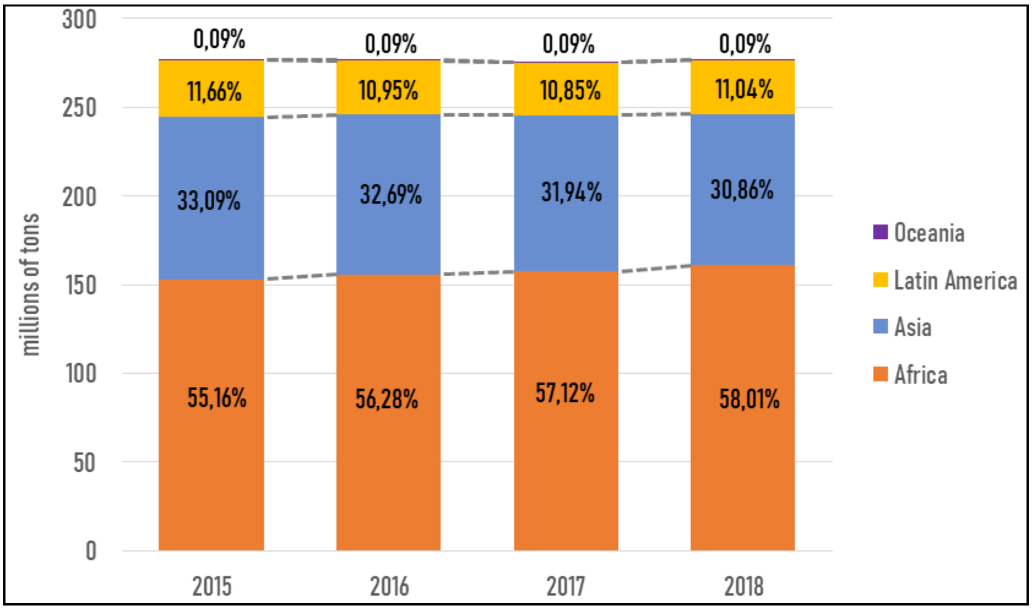



Source: FAO, 2018

[5] Marketed in natura or processed into chips, pellets, flour and starch, mainly by Thailand, and to a lesser extent by Vietnam and Cambodia (FAO, 2018)

East and Southeast Asia play a leading role in international trade, especially represented by China and Thailand. However, some of the largest cassava producers in the world, located in Africa and Latin America, as represented in Figure 2, do not appear in the "geography of cassava" (represented in Figure 1), showing that production in these countries is primarily intended for domestic consumption.

Figure 2 – World production of cassava




Source: Organized by the authors with data from FAO, 2013

It appears that the world production of cassava is concentrated in the four largest producers in the world, responsible for 45.18% of the world production, they are: Nigeria (56 million tons per year); Thailand (27.24 million tons per year); Brazil (20.94 million tons per year); and Indonesia (21 million tons per year).

Cassava is most important in the diet in the tropical regions where it is grown, particularly in Sub-Saharan Africa and South America, where it is widely consumed both as a fresh root, as well as in its processed fermented, unfermented, granulated and flour products. In this scenario, the sector has been promoting incentives for rural development and poverty reduction with initiatives to add value to the cassava food chain, with a view to promoting the rural economy and meeting food security[6].

However, it appears that since the 1990s there has been a significant shift towards more intensive and larger-scale production, especially in southern Brazil, where crops destined for the flour, starch, cardboard and textile industries are mainly processed. In the state of Paraná, they reach 40 tons/ha, with 70% of the production being made by small farmers (FAO, 2013).

Cassava planting is present in practically all Brazilian municipalities, but its concentration continues in the North (34.5%) and South (24.8%) regions of the country, followed by the Northeast (23.6%), Southeast ( 10.5%) and the Midwest with 6.6% (IBGE, 2019). The exploration of cassava in the Midwest region is the most recent, as several entrepreneurs migrated from Paraná in search of new horizons, attracted by the offer of land of lesser value than in their state of origin (DERAL, 2020).

It is also verified that the Brazilian culture of cassava is marked by a production made mainly by small farmers and family agriculture, and its consumption and derivatives primarily supply the domestic market. Family farming is responsible for the production of 69.56% of cassava in Brazil, while 50.02% of Brazilian agribusinesses are destined to the production of cassava flour or tapioca gum. In Goiás, 21.40% of agribusinesses are destined to the production of cassava flour or tapioca gum, with 82.35% of these industries being family farming and 17.81% of small and medium rural producers (IBGE, 2019). Starch, for example, is basically intended for consumption in the domestic market, while a small portion (around 1%) is exported to other countries (DERAL, 2020).

According to research published by the Department of Rural Economy of the State of Paraná (DERAL), the Brazilian production of cassava starch in 2018 was

[6] Nigeria, for example, encourages the processing of cassava flour as a substitute for wheat in bread production, in an effort to reduce the country's high dependence on imported wheat into the country. In the same direction, Ghana's proposal to introduce a mandatory 10% proportion of cassava flour in the mixture with wheat flour has been gaining momentum due to the low quantities of wheat imported by the country today (FAO, 2018).

536,611 tons, with the highest concentration of these industries in the State of Paraná, which accounts for about 59% of the total starch factories operating in the country, with a production of approximately 14,000 tons of root per day (DERAL, 2020).

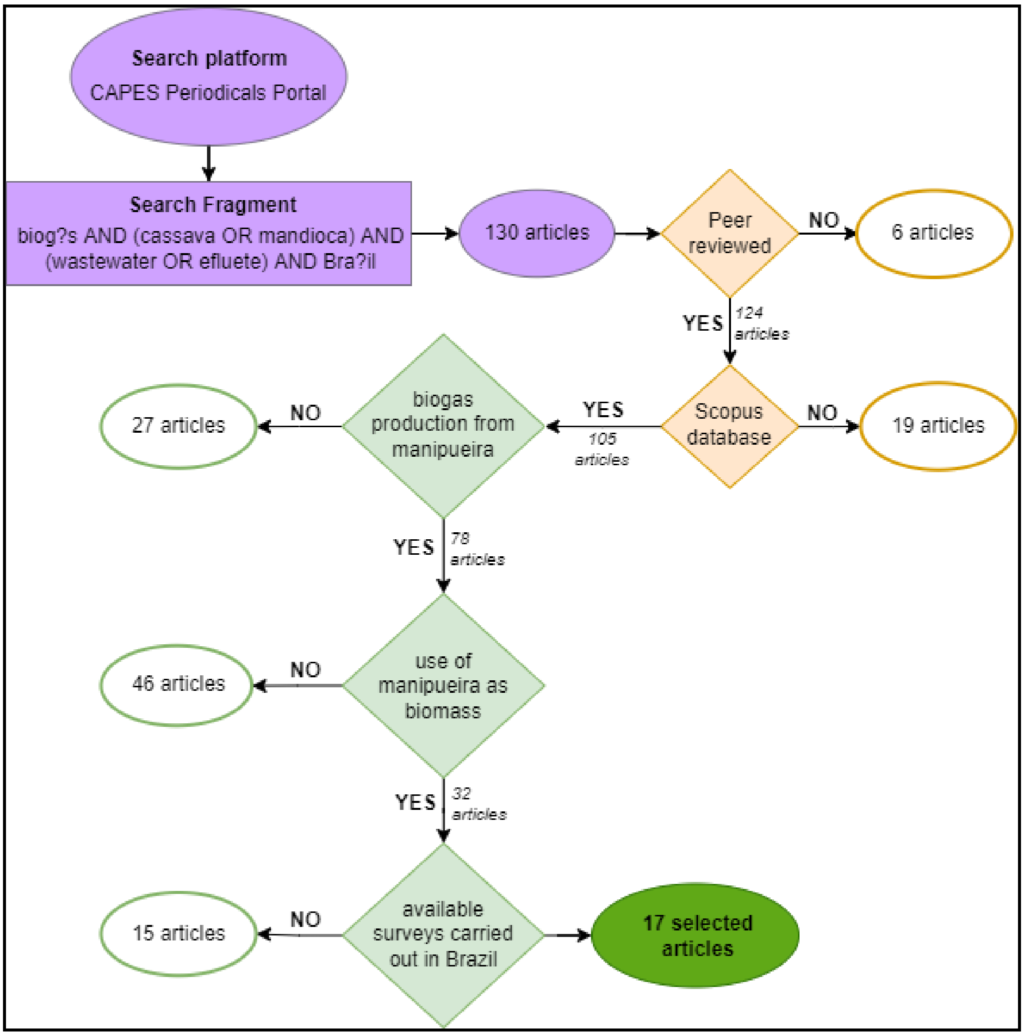
Given the patterns of production, processing, trade and consumption of the root in Brazil, Peres *et al*. (2019) points out that manipueira can be used in the production of biogas both in large-scale agro-industries and in small rural properties. The latter, which process cassava for the production of flour, starch and derivatives, with the implementation of small systems, designed to meet domestic consumption and to dry the flour in production, resulting in financial and environmental gains, in addition to promote the diversification of the energy matrix in the production of family farming. It is important to highlight that family farming establishments represent 77% of agricultural establishments, occupying 23% of the total area of Brazilian agricultural establishments (IBGE, 2019).

From this scenario, the exploration of this work was dedicated to investigating the characteristics of publications and their approaches in scientific production on the energy use of biogas production, from the effluent of the cassava processing process in Brazil. Thus, the objective has been to identify which types of approaches have been used in scientific production on the subject. The Systematic Literature Review (RBS) of the literature on the subject was formulated using the method proposed by Tranfield *et al*. (2003).

## 2 METHODOLOGY

The Systematic Literature Review (SLR) is a type of literature review that presupposes a series of methods, search criteria and analysis of bibliographic sources, so that other researchers can replicate it. In this direction, Tranfield *et al*. (2003) proposes a method for carrying out the SLR, consisting of three stages in order to reach the results of the step-by-step review. Considering the authors' contribution, the methodology presented in this work was inspired by the guidelines of Tranlield, Denyer and Smart (2003), as presented in the prepared review script in Figure 3.

Figure 3 – Systematic literature review script




Source: Own authorship

As illustrated in Figure 3, the research was carried out on Periodical Portal from Coordination for the Improvement of Higher Education Personnel (CAPES), with remote access via the Federated Academic Community (CAFe), in order to identify the approaches of scientific production on the energy use of biogas production from effluent from the cassava processing process in Brazil. In this way, the search and selection of articles (Figure 3) was performed in three main stages:

a) Research on the CAPES/CAFe platform with the search feature for "Subject", without specifying the period of the research, but applying filters to peer-reviewed journals, based on the search fragments defined as “*biog?s AND (cassava OR mandioca) AND (wastewater OR effluent) AND Bra?il”*, which resulted in the survey of 130 articles, in English and Portuguese.
b) Refine the peer-reviewed articles available in the Scopus database, which resulted in 105 articles.
c) Reading the title and abstract of 105 articles selected for scientific publications on the subject of biogas production from cassava in Brazil. This step resulted in a selection of 17 articles. Among the 88 articles discarded for not meeting the selection criteria defined in the protocol, there are:
    - 27 articles that did not directly address the issue of biogas production from manipueira (wastewater or effluent), with contributions especially on the production of energy from biomass in agriculture; sustainability; and other questions about cassava and its processing, such as the nutritional value of manipueira for raising sheep or fertilizing the soil;
    - 46 articles dealing with the production of biogas from another type of biomass, such as vinasse, urban solid waste and domestic effluents; and still
    - 15 articles dealing with studies carried out in other countries, such as Thailand, India, China, Nigeria and Ghana; or were not available.

The 17 selected articles are presented in Table 1, systematized by title, authors' names; journal; and publication date.

Table 1 – Articles selected by the Systematic Literature Review

Continuation

| | TITLE | AUTHORS | JOURNAL | DATE |
|---|---|---|---|---|
| **1** | Ecological analysis of hydrogen production via biogas steam reforming from cassava flour processing wastewater | Jonni Guiller F. Madeira; Ronney Arismel Mancebo Boloy; Angel Ramon Sanchez Delgado; Flavia Renata Lima; Elua Ramos Coutinho; Ricardo de Castro P. Filho | Journal of Cleaner Production | 2017 |
| **2** | Using dolomitic limestone to replace conventional alkalinization in the biodigestion of rapid acidification cassava processing w astewater. | Denise Palma; Lucas Tadeu Fuess; Adriana Neres de Lima-Model; Ketllin Zanella da Conceiçao; Marney Pascoli Cereda; Maria Hermínia F. Tavares; Simone D. Gomes | Revista Ceres | 2018 |
| **3** | Biorefinery integration of microalgae production into cassava processing industry: Potential and perspectives | Júlio Cesar de Carvalho; Ivo Alberto Borghetti; Liliana Carrilo Cartas; Adenise Lorenci Woiciechowski; Vanete Thomaz Soccol; Carlos Ricardo Soccol | Bioresource Technology | 2018 |
| **4** | Strategies to improve the biohydrogen production from cassava wastewater in fixed-bed reactors. | Shaiane D.M.L. Corbari ; Cristiane L. Andreani; Douglas G.B. Torres; Felipe Eng; Simone D. Gomes | International Jornal of Hydrogen Energy | 2019 |
| **5** | Hydrogen production from cassava processing wastewater in na anaerobic fixed bed reactor with bamboo as a support material | Cristiane L. Andreani; Douglas G. B. Torres; Leonardo Schultz; Karina Q. de Carvalho; Simone D. Gomes | Revista Engenharia Agricola | 2015 |
| **6** | Anaerobic reactors with biofilter and different diameter-length ratios in cassava starch industry wastewater treatment | Kathia R. Kunzler; Simone D. Gomes; Pitágoras A. Piana; Douglas G. B. Torres; Marcio A. Vilas Boas; Maria H. F. Tavares | Revista Engenharia Agricola | 2013 |
| **7** | Anaerobic co-digestion of crude glycerin and starch industry effluent Codigestão anaeróbia de glicerina bruta e efluente de fecularia | Andrea C. Larsen; Benedito M. Gomes; Simone D. Gomes; Dilcemara C. Zenatti; Douglas G. B. Torres | Revista Engenharia Agricola | 2014 |
| **8** | Exergetic and economic evaluation of incorporation of hydrogen production in a cassava wastewater plant. | Jonni Guiller Ferreira Madeira; Angel Ramon Sanchez Delgado; Ronney Arismel Mancebo Boloy; Eluã Ramos Coutinho; Carla Cristina Almeida Loures | Applied Thermal Engineering | 2017 |
| **9** | Effects of stirring on cassava effluent treatment in an anaerobic horizontal tubular pilot reactor with support medium – A Review | Osvaldo Kuczman; Maria Hermínia Ferreira Tavaresa; Simone Damasceno Gomesa; Luciana Pagliosa Carvalho Guedesa; Geovane Grisottib | Renewable and Sustainable Energy Reviews | 2017 |

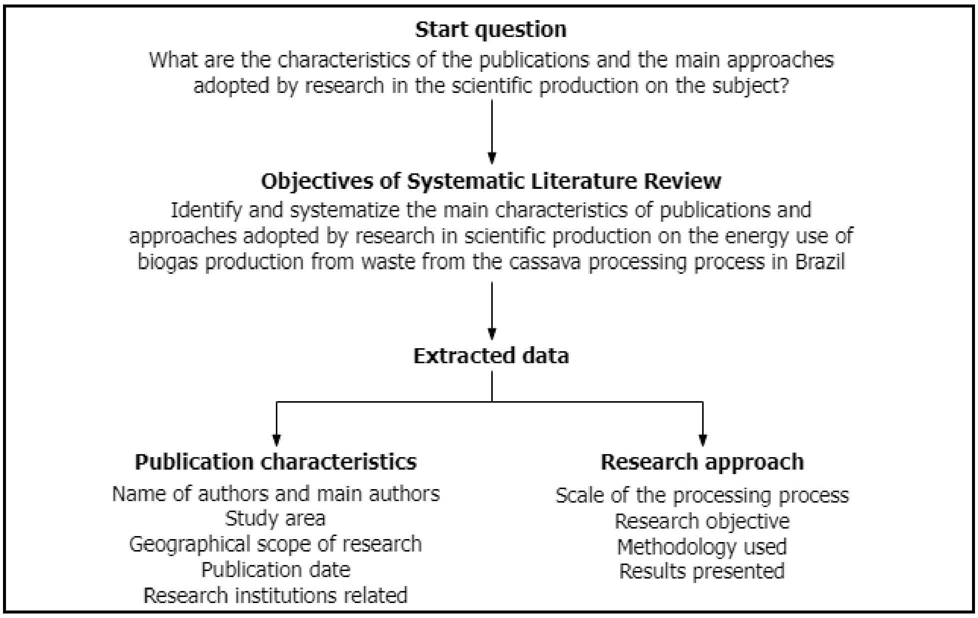
Table 1 – Articles selected by the Systematic Literature Review

Conclusion

| | TITLE | AUTHORS | JOURNAL | DATE |
|---|---|---|---|---|
| **10** | Cassava wastewater (manipueira) treatment using a two-phase anaerobic biodigestor | Ana Claudia Barana; Marney Pascoli Cereda | Food Science and Technology | 2000 |
| **11** | Cassava starch extraction effluent treatment in a one phase tubular horizontal pilot reactor with support médium | Osvaldo Kuczman; Maria H. F. Tavares; Simone D. Gomes; Luciana P. C. Guedes; Geovane Grisotti | Revista Engenharia Agricola | 2014 |
| **12** | Anaerobic biodegradation of cassava wastewater under different temperatures and inoculums. | Miriam Cleide C. de Amorim; Paula Tereza de S. Silva; Patricia Silva Barbosa; Nayara Evelyn Montefusco | Comunicata Scientiae | 2019 |
| **13** | Anaerobic Digestion Process for the Production of Biogas from Cassava and Sewage Treatment Plant Sludge in Brazil | Sergio Peres; Marina Monteiro; Micheline Ferreira; Adalberto Nascimento Junior; Maria Los Angeles Perez Fernandez Palha | BioEnergy Research | 2018 |
| **14** | Specific biogas production from manipueira at one-phase reactor | Osvaldo Kuczman; Simone D. Gomes; Maria H. F. Tavares; Douglas G. B. Torres; Michael S. Alcântara | Revista Engenharia Agricola | 2011 |
| **15** | Performance Study of a Microturbine System for Cogeneration Application Using Biogas from Manipueira | Yasmim Aparecida de Oliveira Chaves; Marcus Val Springer; Ronney Arismel M. Boloy; Orlando Manuel C. F. Soares; Jonni Guiller F. Madeira | BioEnergy Research | 2020 |
| **16** | The effect of methanogenesis inhibition, inoculum and substrate concentration on hydrogen and carboxylic acids production from cassava wastewater | Norma C. S. Amorim; Eduardo Lucena Cavalcante de Amorim; Mario T. Kato; Lourdinha Florencio; Savia Gavazza | Biodegradatio n | 2018 |
| **17** | Pretreatment on anaerobic sludge for enhancement of biohydrogen production from cassava processing wastewat er | Franciele do Carmo Lamaison; Rafael Fragata, Regina Vasconcellos Antônio, Edna Regina Amante, Valeria Reginatto | Acta Scientiarum | 2014 |

The selected articles were read and systematized according to the data extracted, differentiated into two strands of analysis motivated by the generating questions of the research, as illustrated in Figure 4: (i) Characterization of publications and (ii) Approach to research.

Figure 4 – Methodological conception of systematic literature review




Source: Own authorship

## 3 RESULTS AND DISCUSSIONS

As proposed in the methodology, the data extracted from the 17 selected articles, were systematized and analyzed based on the two questions raised in the research (i) Publications characteristics and (ii) Research approach (Figure 4).

The first question, *Publications characteristics*, revealed that two researchers stood out in the main authorship of the articles, and the Engineering area as the main thematic area. It was also verified that the concentration of publications were from the southern region of the country, especially in the State of Paraná, from the year 2000, with the highest concentration in the year 2018. Seven research institutions linked to the realization of the systematized searches were identified, with the State University of West Paraná (UNIOESTE) having the largest number of publications. Given this scenario, the contributions of Mariani (2018) and Bley Junior (2015) are presented with an overview of the conditions that delineated the scientific production on biogas from effluent from cassava processing in Brazil.

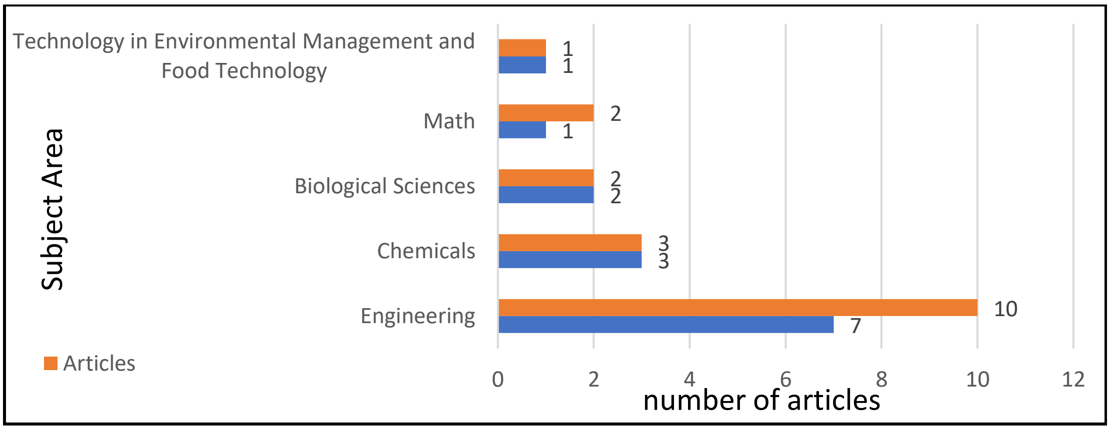
Regarding the second question, *Research approach*, it was found that most publications do not indicate or specify the production scale of the cassava processing establishments; it was also observed that the main methodology used in the research was the experimental one, with the development of experiments in the laboratory; and that the main objective of the research was to study the efficiency of biogas production.

Next, a more detailed systematization of the analyzed aspects is presented, with a synthesis of the main contributions of the publications, according to the two guiding questions proposed:

### 3.1 Publications characteristics

As registered in Appendix I, two authors stand out in the number of publications: one author, responsible for the main authorship of four of the selected articles; and the second prominent author has authorship of two of the articles. The other articles are distributed with different authorships.

Figure 5 – Subject Area from main authors and concentration of articles



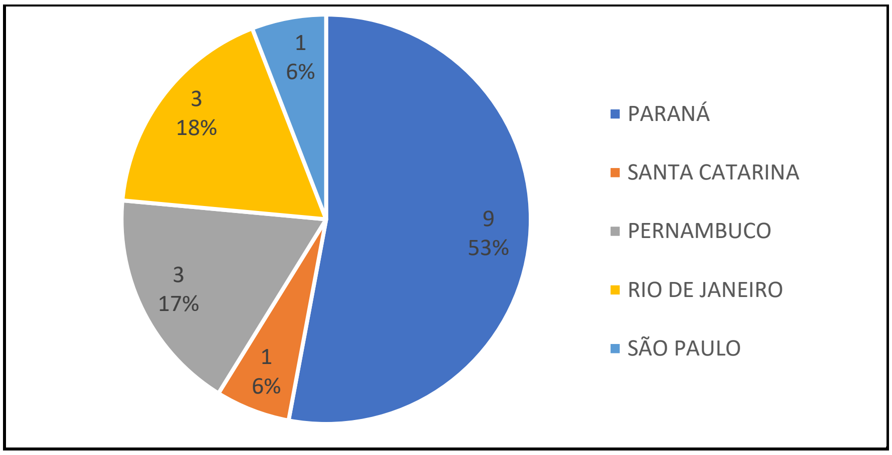

Source: Own authorship

It is also verified that seven authors have training in the field of Engineering, distributed in: Chemical, Civil, Mechanical, Food and Agricultural Engineering. While 3 authors are trained in Chemistry or Industrial Chemistry; 2 authors with a background in Biological Sciences; 1 author in Mathematics and 1 author in Environmental Management Technology and Food Technology, as illustrated in the graph in Figure 5.

The graph in Figure 6 illustrates how the geographic scope of the surveys is concentrated in the state of Paraná, with 9 surveys carried out; followed by Rio de Janeiro and Pernambuco, tied with 3 of the surveys in each state; and São Paulo and Santa Catarina, with 1 survey in each state.

It appears that the concentration of research in Paraná is consistent with the state's potential in the starch industry, which represents the highest concentration of starch factories in activity, with about 59% of national industries and a daily production of approximately 14,000 tons of root (DERAL, 2020).

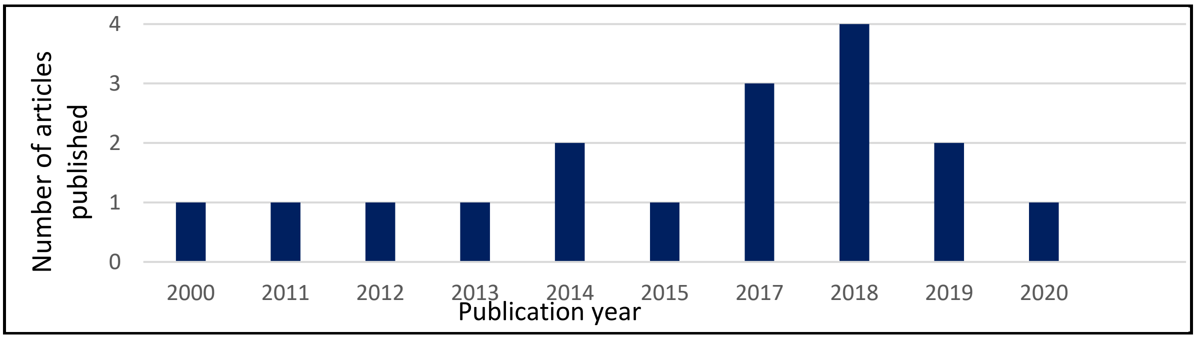
Figure 6 – Geographical distribution of analyzed publications




Source: Own authorship

Regarding the period of publications on the subject, these are relatively recent, with the first article published in 2000. After a gap of 10 years, it appears that 58.82% of the articles published are concentrated between 2017 and 2020, according to what is illustrated in Figure 7.

Figure 7 – Publication year distribution of the analyzed articles

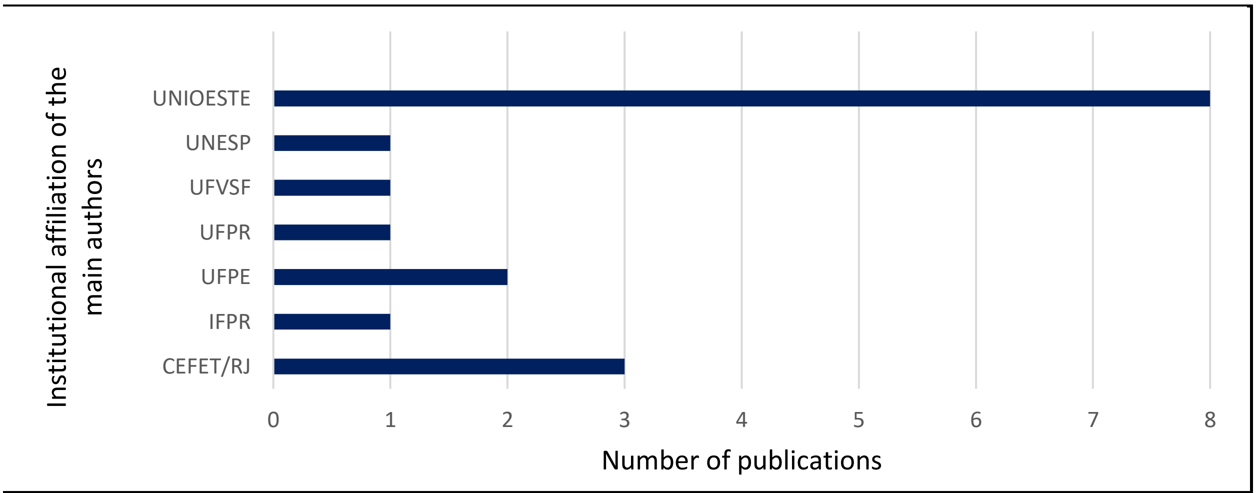



Source: Own authorship

The initiatives to use biogas technology in Brazil can be understood from three fundamental moments, which resulted from their respective motivations: a) the price of oil and fossil fuels; b) international measures to reduce GHGs[7] and; c) diversification of energy sources and development of a new production chain in the economy (BLEY JÚNIOR, 2015).

As for the institutions related to the articles, it appears that the analyzed research were produced in seven national Research Centers, located in the South, Southeast and Northeast regions of the country, as illustrated in the graph in Figure 8.

Figure 8 - Publications by research institution




Source: Own authorship

[7] With the projects inserted in the context of the Clean Development Mechanism (CDM) and the respective sale of generated carbon credits, established by the Kyoto Protocol in 1997.

Figure 8 shows the graph of publications by institution, which shows a concentration of 10 publications in the South region, of which 8 are from the State University of West Paraná (UNIOESTE). Three out of four publications from the Southeast region are from the Federal Center for Technological Education of Rio de Janeiro (CEFET/RJ), and the other one from the State University of São Paulo (UNESP). Two out of three publications from the Northeast region are from the Federal University of Pernambuco (UFPE) and the other one from the Federal University of Vale do São Francisco (UFVSF).

It appears that the concentration of Research Centers identified in the South and Southeast regions is in accordance with the survey carried out by Mariani (2018), with the CNPq Directory of Research Groups in Brazil, which identified 86 research groups related to biogas themes in 2015, as shown in Figure 9. In addition to the regional concentration of Research Centers, the survey carried out also highlights the leading role of Engineering as the main area of training, as verified in this review and shown previously in the graph in Figure 9.

Given the concentration of publications in Research Centers in the South, Southeast and Northeast, it is interesting to examine the scenario of initiatives in Research and Development Projects on biogas in Brazil. In this sense, among the first initiatives are the public calls published by the Basic Sanitation Research Program (Prosab) between 1995 and 2000. It appears that the production of biogas was not the main axis of the program, which was guided by the perspective of solutions in basic sanitation. However, among the products delivered by the cooperative research network of the program, a volume was published on “Anaerobic digestion of solid organic waste and use of biogas” (CASSINI *et al*., 2003).

At the same time, the performance of the National Biomass Reference Center (CENBIO), created in 1996 within the scope of the Institute of Electrotechnics and Energy (IEE) of the University of São Paulo (USP), strengthened the more specific shared research initiatives on the subject, especially with the publication of the Atlas of Bioenergy in Brazil (COELHO *et al*., 2008).

Figure 9 - Location of CNPq's biogas, biodigesters and biodigestion research groups in 2015


Source: Mariani, 2018

It appears that research on the subject continued to the south, encouraged by the technical cooperation agreement between Itaipu Binacional and Companhia Paranaense de Energia (Copel) for the implementation of biogas production demonstration units in western Paraná. Such Initiatives fostered research and extension projects, partnerships and agreements with universities in the region, especially with UNIOESTE - as also verified in the SLR results presented (see Figures 6 and 8) -, whose Center for Exact Sciences of the University was installed at the Itaipu Technological Park (ITP) in 2006 (ITAIPU BINACIONAL, 2008)

In this regard, ANEEL's initiatives for the sector are also noteworthy, particularly in the context of Call nº 014/2012: “Strategic Project: Technical and Commercial Arrangements for Insertion of Electric Energy Generation from Biogas from Waste and Effluents Liquids in the Brazilian Energy Matrix”, launched in July 2012. As a result of the work of Itaipu Binacional aiming at strengthening the sector in the country, the International Center for Renewable Energies - Biogas (CIBiogás) was created in May 2013. From the 2000s onwards, there has been a strengthening of partnerships between research centers, power plants, institutions and states, as can also be seen in the directions and approximation of the Organization of United Nations for Industrial Development (UNIDO) with the sector.

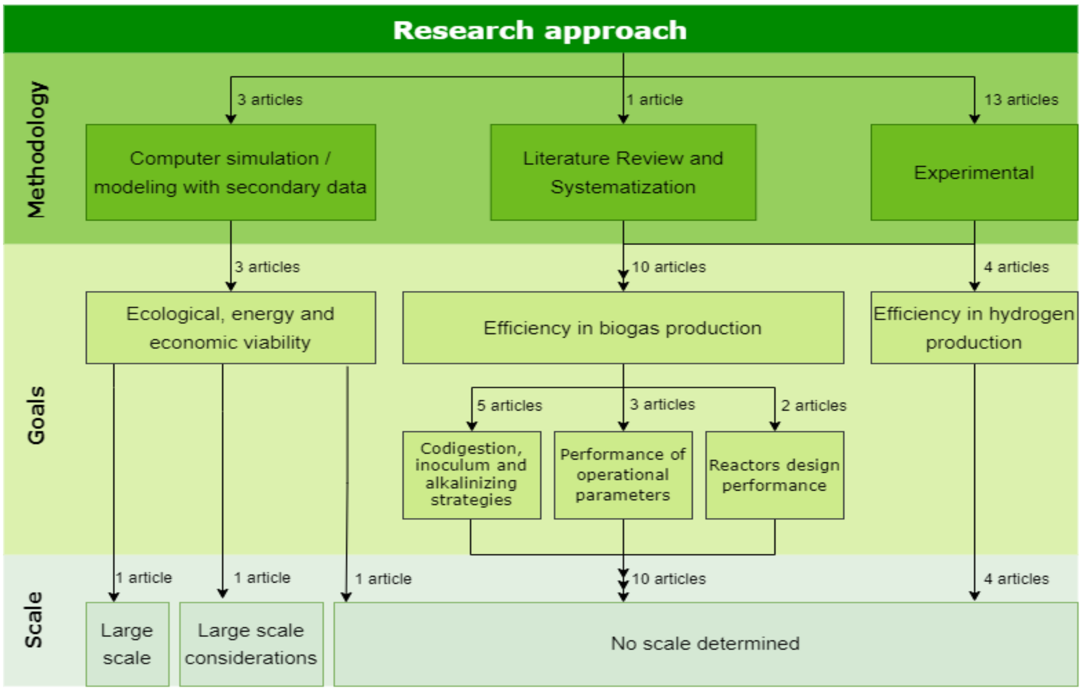
In this scenario, several initiatives emerge in Brazil from the partnership between institutions[8] that have been promoting local and federal actions to encourage the integration of biogas into the Brazilian production chain. Among these most recent initiatives is the *Tropicalization Program* led by the Global Fund for the Environment (GEF), published in March 2021, with the main objective of implementing actions to encourage economic development and technological innovation aimed at the biogas value chain in Brazil (GEF BIOGÁS BRAZIL, 2021)

### 3.2 Research approach

From the analysis of the selected articles, after the adopted protocol, the 17 were classified according to the approach (research focus): (i) methodology; (ii) research objectives carried out; and (iii) the production scale of the cassava processing projects. The results were summarized in the summary table shown in Figure 10.

[8] Such as the Coordination for the Improvement of Higher Education Personnel (Capes); German Academic Exchange Service (DAAD); German Agency for International Cooperation (GIZ); Global Fund for the Environment (GEF); International Energy Center Renewable Biogas (CIBiogás); Brazilian Association of Biogas (ABiogás); among others.

Figure 10 – Systematization of Research Approach aspects




Source: Own authorship

It appears that the identified methodologies can be systematized into three categories: *Computational simulation / modeling with secondary data; Literature review and systematization of secondary data;* and *Experimental,* which concentrated most of the research. In this approach, according to its objectives, the selected publications can also be arranged in three main groups, as illustrated in Figure 10, as detailed below:

*3.2.1 Ecological, energetic and economic viability*

The three articles that make up this group differ, especially by the non-experimental approach of the research carried out, sharing analytical approaches on the feasibility of anaerobic digestion, based on simulations and mathematical models, whether in the context of economic, energy or ecological feasibility (CHAVES *et al*., 2020; MADEIRA *et al*., 2017a, 2017b). Among the three articles on ecological, energetic and economic themes, a single publication was identified that dealt with large-scale agroindustries; an article that made considerations about large-scale (industrial) enterprises; and an article that did not consider the production scale in the research.

### *3.2.2 Efficiency in biogas production*

The articles identified in this group have the common objective of evaluating alternatives to increase the efficiency of biogas production from manipueira, making up the most extensive group, consisting of eleven articles, which were distributed into three subgroups according to the type of alternatives evaluated in the respective surveys:

- *Co-digestion, inoculum and alkalinizing strategies:* includes five articles, dedicated to evaluating the efficiency of co-digestion strategies, application of inoculum and alkalizing in the production of biogas from the cassava plant. Among them are the comparison between the performance of inoculation with cattle and goat manure; sludge from sewage treatment plants; textile industry effluents and bacterial and microalgae cultures. There is also the co-digestion of manipueira with glycerin and the use of dolomitic limestone as an alkalizing agent (C. LARSEN *et al*., 2013; DE AMORIM *et al*., 2019; DE CARVALHO *et al*., 2018; PALMA *et al*., 2018; PERES *et al*., 2019).

- *Performance of operational parameters:* The second subgroup consists of three articles, dedicated to evaluating the performance of different operating parameters in the efficiency of biogas production, such as different organic loads, feed volumes and Hydraulic Detention Time (HDT) (BARANA; CEREDA, 2000; KUCZMAN *et al*., 2011, 2014).

- *Reactor design performance:* Kuczman *et al*. (2011) point out that the manipueira biodigestion process has a tendency to acidify, due to the concentration of starch in its composition. Given the assumption, the articles identified in this subgroup are dedicated to study design alternatives to anaerobic reactors, such as phase separation (acidogenic and methanogenic); agitation systems; use of support means; and reactor dimensions, which promote the maintenance of optimal conditions for anaerobic digestion within reactors with greater efficiency in biogas production (KUCZMAN *et al*., 2017; KUNZLER *et al*., 2013).

*3.2.3 Efficiency of hydrogen production*

Anaerobic treatment of manipueira often produces methane and carbon dioxide as the main end-products of biogas (SÁNCHEZ *et al*., 2017). However, Kuczman *et al*. (2011) pointed out that some recent research on carbohydrate-rich effluents has studied the conditions of anaerobic biodigestion for the priority production of hydrogen, since this gas is considered a cleaner energy source and its production takes place in the first stages of biodigestion (hydrolysis and acidogenesis stages). Thus, the efficiency of hydrogen production from a mixed culture of bacteria requires the maintenance of conditions that inhibit the bacteria responsible for the last stages of anaerobic digestion (acetogenesis and methanogenesis) and those that consume hydrogen inside the reactor (LAMAISON *et al*. , 2014).

In this direction, pre-treatment and inoculation strategies in reducing competition between hydrogen-producing and hydrogen-consuming bacteria were rated, in addition to support media efficiency; operational conditions such as organic loading rate (TCO) and hydraulic detention time (TDH); and the composition of the substrate (AMORIM *et al*., 2018; ANDREANI *et al*., 2015; CORBARI *et al*., 2019; LAMAISON *et al*., 2014).

## 4 FINAL CONSIDERATIONS

In view of the results presented, it is important to recognize the limitations of the adopted methodology. Despite being a useful tool in the selection of articles relevant to the topic under study, possibly it did not include several other articles that may be relevant, especially because they are not indexed in the search platform and database used, in addition to others that may not have been properly covered by the delimited search string. In this sense, another limitation verified by the research was the delimitation of the term (wastewater OR effluent) in the composition of the search string, which possibly did not include in its results other residues from the cassava processing process that can be used as biomass in the production of biogas, like the bark of the root. In exploratory research, it was found that most research on the subject is concentrated in Brazil; followed by the other two largest cassava producers in the world: Thailand and Nigeria; by the largest importer of cassava and its derivatives: China; and followed by South Africa.

Taking that into account, the main results achieved on the Publications Characteristics carried out verified an emergence of scientific production from the 2000s onwards, concentrated in the southern region of the country, especially in the state of Paraná, mostly within the field of Engineering. These characteristics were justified in the literature, especially by the flow of public and private initiatives in research and development on the subject in the country; as well as the distribution and characteristics of the national agro-industry for the production and processing of cassava. Thus, scientific production on the subject in Brazil is recent, inspired by public and private initiatives in research and development that have reached the country in recent decades, especially in the southern region, which also has the largest number of starch factories operating in the country.

The results on the Research Approaches revealed that most of the research developed on the subject is Experimental, dedicated to investigate alternatives to increase Efficiency in the production of biogas. It was also found that most research does not consider the scale of production studied, while only one article specifically dealt with large-scale projects.

In an exploratory research, no research on the topic dedicated to small or medium-scale agribusinesses was found, signaling the lack of representativeness of these aspects on the issue. Considering that 78% of the biogas production plants in operation in the country are small, driven predominantly by agricultural activity residues; and that family farming is responsible for the production of 69.56% of cassava in the country, as pointed out by the literature presented, the consistency in contextualizing scientific research to the Brazilian reality is highlighted. In this sense, the proposed reflection suggests that scientific production on the subject should be attentive to the issue, seeking to consider the particular aspects of the small-scale production of family farming in future research.

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