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# Barriers to the adoption of energy-efficient technologies in the building sector: A survey of Brazil

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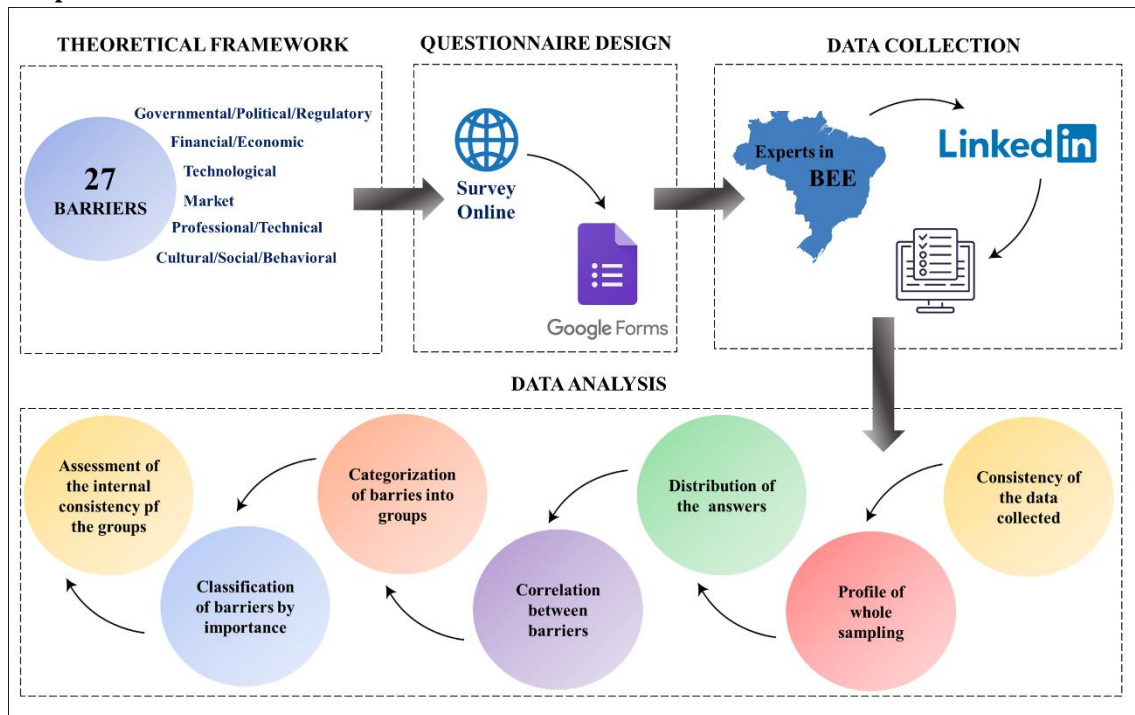
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## Graphical abstract



## Highlights

- The 27 barriers to BEE technologies classified into six categories.
- Survey is conducted with one thousand Brazilian experts.
- The cluster and factor analysis ratified the theoretical classification.
- The factor analysis ranked the barriers categories by importance.
- Barriers related to government and financial aspects are considered the most important.

**Abstract** The building sector is responsible for 51% of electricity consumed in Brazil, and about 10% of total greenhouse gas emissions. These numbers continue to grow consistently, despite significant efforts done by the government to promote the adoption of building energy efficiency (BEE) technologies, which have not been widely adopted due to barriers. A systematic literature review revealed 27 barriers, classified

into six categories, as the responsible for hindering the adoption of energy-efficient technologies. This article aimed to verify whether such barriers make sense for the Brazilian reality. In order to accomplish such a goal, a survey among Brazilian specialized professionals was carried out. The results were analysed by two multivariate techniques, cluster and factor analysis, validating these barriers as well as the proposed taxonomy for Brazil. The results also showed that the two most important categories of barriers are the Governmental/Political/Regulatory and Financial/Economic, showing that the Brazilian society has high expectations about the government will be more active in this matter. In addition, the respondents gave insights into important points concerning with technology, education, etc. that should be verified in a timely manner. These findings can assist government agencies, researchers, and experts to develop guidelines/strategies to overcome such barriers.

**Keywords** Energy efficiency · Energy-efficient technologies · Building sector · Barriers · Brazil · Survey study · Descriptive statistic · Clustering analysis · Factor analysis

## 1. Introduction

Energy is one of the most important factors for social, economic, and technological development worldwide, that is why the energy demand has been increasing over the last decades [1-6]. However, the high-energy consumption brings with itself several concerns like the uncertainty on available resources, the increase of greenhouse gas emissions, etc. [6-8]. Therefore, such a picture made of reducing the energy consumption, without affecting the economic growth, a strategic target of energy policies worldwide.

For many years, the industrial sector was the target of energy efficiency policies, since it had been the main responsible for the greatest part of the energy consumption [9]. However, in recent years, researchers have become increasingly interested in the building sector [6,10], since there was a significant increase in the energy consumption of such a sector. According to Ding and Zhou [11] the building sector represents 36% of the overall end-use energy consumption worldwide and it is responsible for 28% of global energy-related CO<sub>2</sub> emissions.

In Brazil, between the years 2005-2018, the energy consumption of this sector increased from 30.7 million to 37.8 million toe, representing an annual growth of 2%. Nowadays, the primary energy consumption accounts for about 16% of the total, while the electricity consumption is approximately 51% of all electricity consumed in the country [12-16].

Consequently, energy consumption reduction has been a strategic target of the Brazilian government [17], which has been encouraging the adoption of building energy efficiency (BEE) technologies [18,19]. A number of studies worldwide have reported that new buildings that adopted BEE technologies achieved an energy saving of up to 50%, while existing buildings approximately 30%. Furthermore, such technologies provide thermal, visual, and acoustic comfort for the occupants [20-27].

However, despite the benefits, the BEE technologies have not been widely adopted, so the potential reduction of energy consumption has not been achieved, creating an energy-efficient gap [28-29]. Such a phenomenon has received a lot of research attention and several studies have shown that it is due to barriers that act as inhibiting mechanisms that hinder the adoption of the BEE technologies. In order to overcome such obstacles, firstly, it is necessary to know them. Therefore, an enormous amount of research has been conducted around the world, to identify and classify such obstacles over the years [30-41]. The most recent systematic literature review, carried out over 450 articles [42], identified 27 barriers classified into six categories: financial/economic, market, cultural/social/behavioural, professional/technical, governmental, and technological.

Therefore, there are several barriers coexisting and producing a cumulative effect. Thus, in order to understand the interaction between such barriers as well as the underlying mechanisms hindering the adoption of the BEE technologies a model is necessary. However, the formulation of such a theoretical model requires a suitability check of these barriers to the reality where this model is supposed to be applied. Only a limited number of countries like China [6,30,36,43-45], New Zealand [46], Italy [26], Australia [46,47], Finland [35], Ghana [37,38], Norway [48,49], Russia [50], Cambodia [51], the United Kingdom [52,53], Germany [48,49] and the United States [54] carried out such a check.

Regardless of the fact that Brazil is among the eight largest consumers of primary energy, and among the ten greatest electricity consumers, in the world, no study has been published considering such barriers in light of the Brazilian scenario.

Therefore, in order to bridge this gap, this paper aims to verify the relevance of the 27 barriers and the respective taxonomy reported by Cristino et al. [42] to the Brazilian reality as well as the existence of unpublished obstacles, besides ranking the groups of barriers according to their importance.

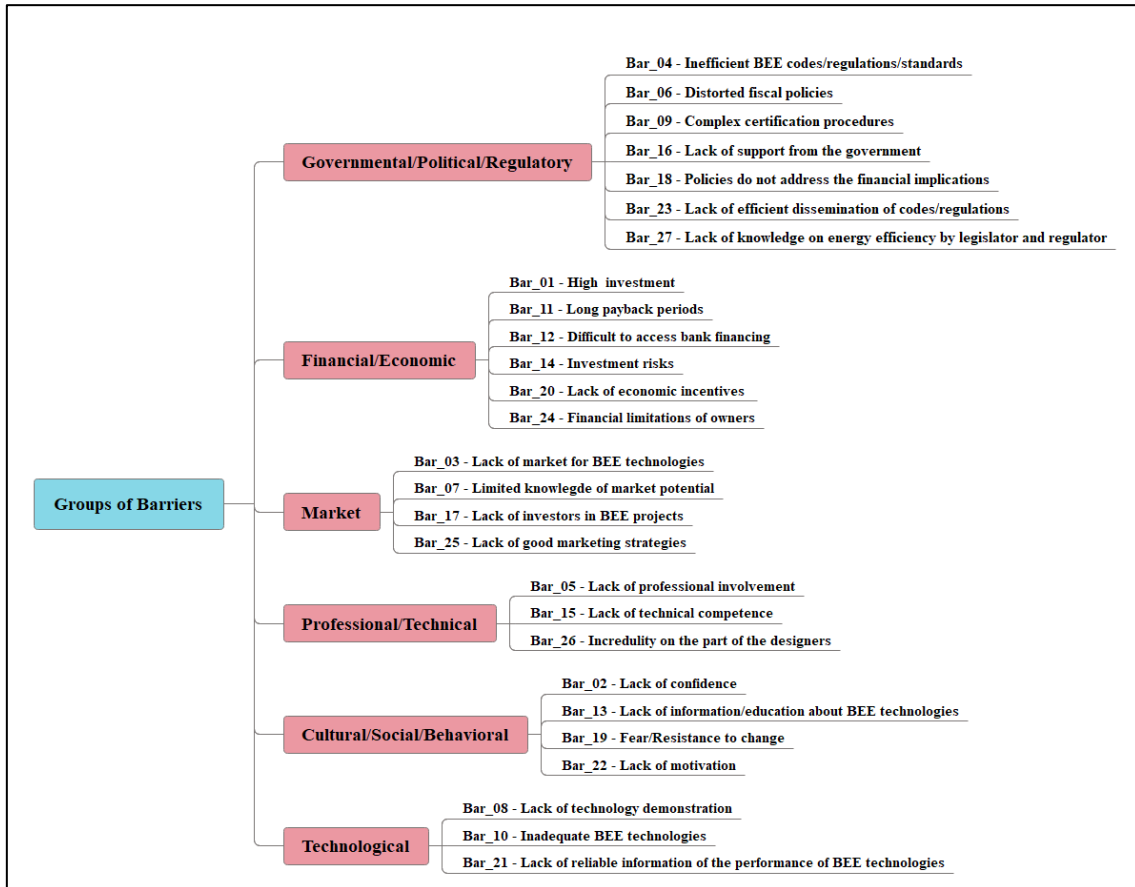
The results of this research mainly contribute to a broader understanding of the inner mechanisms of the barriers to the adoption of BEE technologies and the interrelationships between the several knowledge areas involved with BEE, providing insights on the contextual requirements faced in implementing such technologies.

The findings of this research will assist energy efficiency experts, government policymakers and academics in discovering effective strategies to encourage the adoption of BEE technologies, and therefore reducing the energy efficiency gap.

The remaining of this article is organized as follows: Section 2 provides an overview of the barriers to the adoption of BEE technologies reported by Cristino et al. [42]. Section 3 presents an extensive description of the methodological approach adopted in this study. Section 4 discusses the results of the research. And, the article concludes with Section 5, discussing the main conclusions of this research.

## **2. Theoretical Framework**

The research presented in this paper is a part of a larger investigation effort aimed to gather information about the barriers hindering the adoption of BEE technologies, especially in the light of Brazilian reality. Thus, the first step of this investigation was to identify and classify the barriers to BEE technologies through a comprehensive literature review based on the characteristics of the building sector and energy-saving technologies. This part of the study was published by Cristino et al. [42] and, as result, 27 barriers hindering the adoption of BEE technologies were identified in 450 articles published between 2000-2018. Furthermore, a new taxonomy was proposed by Cristino et al. [42] and such barriers were classified into six groups (*Financial/Economic, Market, Cultural/Social/Behavioral, Professional/Technical, Governmental/Political/Regulator*) as depicted in Fig. 1.



**Fig. 1** Barriers to the adoption of BEE technologies identified by [42].

### 2.1 Governmental/Political/Regulatory barriers

According to Zhang and Wang [6], Hirst and Brown [33] the government has provided greater support for energy production than for energy efficiency, with both tax policies and support for R&D. In general, the governments all around the world have been providing large subsidies to energy-supply industries through federal tax breaks while for energy-efficiency industries they have been minimal, what can be characterized as a lack of support from the government [36,38,55,56].

In general, codes and standards are drivers and not obstacles, since they are capable to improve the level of efficiency of several devices [8,29,57]. However, the process of setting and revising standards and codes is slow, puzzling and many times dominated by special interests, resulting in inefficient codes and regulations implemented after a long process [21,37,52,58]. Because of that, they, sometimes, inhibit innovation, recommending obsolete technologies. According to Djokoto et al. [38], the particular interests explain why there are several different and complex code specifications that fragment the market and contribute to manufacturing inefficiencies. Hirst and Brown [33], Bruce et al. [59], and Hopkins [60] states that the standards and codes covering materials and equipment are mostly concerned with safety, reliability and health rather than with energy efficiency.

The distorted fiscal policies are another barrier to the adoption of BEE technologies. According to Hirst and Brown [33] it can be exemplified by the pricing policies for fossil fuels. The prices paid by the consumers for fuels do not take into account the social and environmental costs associated with fuels production, conversion, transportation and use [39,61]. As highlighted by Hirst and Brown [33] the costs of acid rain and global warming are not incorporated in the prices of fossil fuels and electricity which will certainly raise their prices, reflecting their full costs, making investing in BEE technologies more attractive. According to Alanne and Saari [62] for electricity, the situation is further complicated because of the way the electricity price is set. Usually, prices reflect the average cost of producing electricity, even if the costs to build and operate future power plants are larger than the current average. Based on that, consumers will invest less in BEE technologies than would be optimal because of the environmental costs of electricity production that are not included in the final electric energy prices [51,63].

One of the arguments in favour of the adoption of BEE technologies is that such technologies increase the market value of real estate [57]. A way to highlight this potential advantage is by means of the energy-efficiency label. However, as reported by Alam et al. [64] and Li et al. [65], the certification procedures are too complex and inefficient. Currently, the guidelines describing the procedures are fuzzy, difficult to understand and use [51]. It is important to make labelling procedures as transparent as possible, providing simple procedures, good examples, documented reports and education [50].

Obviously, the financial implications of energy efficiency are the most important reason for owners, investors and building constructors to consider the BEE technologies in their purchasing decision [66]. However, according to Chmutina et al. [67] it is difficult to find such implications documented by available policies and codes. As established by Adeyeye et al. [58], the energy policy ought to create better investment conditions, which to some extent means that such policies should help consumers to undertake these investments more easily. Such a goal is accomplished by providing the consumers with reliable data on building energy use as well as the financial implications in terms of cost savings and asset values [58,67].

The impact of energy-efficiency policy and legislation on the environment as well as the stakeholder engagement is well known for a reduced number of people. Many citizens remained unaware of the benefits afforded them by the legislation due to a lack of efficient dissemination of codes/regulations. Therefore, “regulations and standards ought to be developed with a clearer definition of the importance of energy efficiency actions in buildings” [52].

The lack of knowledge on energy efficiency by regulator and legislator seems to be a key point when discussing energy efficiency legislation and rules in the building sector. It is fair to say that the policymakers

have to improve their knowledge in this field [68]. Otherwise, their vague idea about the theme can lead them to misinterpretations of the main issues, resulting in mistakes in the policies formulated by them [67].

## *2.2 Financial/Economic barriers*

According to Hirst and Brown [33], Zhang et al. [36], Goodier and Chmutia [52], Du et al. [57] BEE technologies requires high investments. Usually BEE technologies are more expensive than their inefficient counterparts are [6,29,38,44,45,50,69]. Additional money to pay the incremental capital costs of efficiency improvements can be a problem, since the financial limitations of owners are the major obstacle for low-income households [58,61].

Interesting to note that, in general, consumers adopt high discount rates in making tradeoffs between higher initial investments and reduced operating costs [10,39,46,70]. These high discount rates lead to long payback periods and gives rise to a phenomenon called the payback gap, which means the difference between investment criteria for BEE technologies versus energy-production investments [35,44,71]. Such a difference in implicit discount rates yields larger investments in producing energy than in BEE technologies [51,59,72,73].

To decision-makers, investing in BEE Technologies is risky. They are uncertain about the long-term savings in operating costs as well as whether the new devices will last as long as predicted. Besides, some entrepreneurs are unsure how the new technologies will affect their operations [38,67].

According to Persson and Grönkvist [8], Gupta et al. [21], and Durdyed et al. [51] financial incentives are vital for energy conservation in the building sector. However, many building contractors and owners claim that there is a lack of economic incentives for those who really shell out for investments in BEE technologies. Although there is the expectation that such investments can raise the sale value of the real state, a large part of the financial benefits resulting from the adoption of BEE technologies will be enjoyed only by the building occupants, by means of lower bills [55,69,74]. Therefore, the investors claim some kind of subsidy, without which, they question the viability of such investments [5,29,37,75].

It is well known that the BEE technologies are more expensive than their inefficient counterpart. There are situations that the adoption of such technologies is incredibly expensive, requiring financing. However, according to Gupta et al. [21], Zhang and Zhou [29], it is difficult to access bank financing since, most of the time, the financial savings resulting from the adoption of energy-efficient technologies have not been clearly established because there is not a “historical tracking of savings. In such cases, the lenders treat energy savings projections sceptically and refuse to include funds for energy-efficient technologies when



calculating loan size for constructing or refurbishing a building”. According to Palmer et al. [28], Häkkinen and Belloni [71], the lenders approach such cases focusing on construction costs without considering the potential cost savings as well as environmental benefits after adopting the BEE technologies. As stated by Jafarzadeh and Utne [15], Addy et al. [37], the long payback period is another point that difficulty obtaining financing for projects involving energy efficiency, since, in general, the lenders expect the investment return within a few years.

### 2.3 Market barriers

According to Zhou et al. [63] most investors “do not care about the energy performance of a building”. Furthermore, most of the owners show some resistance in adopting BEE technologies for several reasons like high investments, financing difficulties, uncertainty results, etc [75]. These reasons lead to a lack of market demand for BEE technologies [38,76].

As highlighted to Chian et al. [77] the market demand is a significant factor in determining the level of adoption and development of the BEE technologies, since it directly affects the costs and supply of such technologies. When occurs a lack of market demand the investors’ questions the feasibility of their business and this refrain the adoption of BEE technologies [37]. Du et al. [57] claims that the lack of market demand for efficient technologies is mainly explained by the lack of awareness of the benefits brought by such technologies.

As reported by Addy et al. [37] the energy efficiency market offers a profitable future from a long-term perspective. However, there is a general lack of investors in BEE technologies due to “the long innovation and development cycles in this domain, which are incompatible with the structure of the investment market” [74]. The investors prioritise the financial returns rather than social and environmental benefits.

The energy efficiency market offers a profitable future, even from a long-term perspective, since there are sufficient possibility and potential for the building sector for investment in this field. However, there is still a lack of investors willing to pay for energy-efficient buildings [74].

As stated by Shukla et al. [78] the knowledge of the market potential for energy conservation is limited, which means that no one knows the exact potential of reduction of GHG emissions and energy consumption whether the BEE technologies were adopted. In general, such figures are underestimated, as well as the costs due to the adoption of energy-efficient technologies that are, in general, overestimate. According to Goodier and Chmutia [52], if the real potential market were known, it would work as a driver for the adoption of BEE technologies.

According to Dadzie et al. [69] marketing strategies are concerned with providing consumers and investors with information on the energy-saving potential of specific technologies. Thus, as stated by Gliedt and Hoicka [39] and Dadzie et al. [69], marketing strategies and the adoption of such technologies are correlated. Therefore, the lack of good marketing strategies leads to poor adoption of BEE technologies.

#### *2.4 Professional/Technical barriers*

From the point of view of Hirst and Brown [33], Travezan et al. [79], and Wilson et al. [80] there is a lack of technical competence in this field of knowledge, since there are few trained professionals in engineering, operations, and maintenance to develop and deploy new energy technologies. Energy issues are not priority components of the engineering curricula. In addition, companies that deal with BEE technologies provide limited training to keep their employees informed of the recent technological breakthroughs [38,44,53,81,82].

According to Holloway and Parrish [9], Kangas et al. [35], Häkkinen and Belloni [71], Ding et al. [83] energy-efficient buildings can be hindered by a lack of common involvement or interest of professionals about energy efficiency. Djokoto et al. [38] claims that “while designers demonstrate confidence in their ability to access and use knowledge in general, this confidence falls when energy efficiency building issues are addressed”. In fact, installing BEE technologies requires new competencies and knowledge. It seems, until now, that those involved with energy-efficient buildings do not have the necessary experience and commitment to meet such a challenge. Williams and Dair [53] established that such professionals not only ought to be fully acquainted with the energy-efficiency principles, but to “form a team comprising the developer/owner, project manager, contractor, architect, services engineer, structural engineer, civil engineer, environmental engineer, landscape consultant, cost planner, and building surveyor what seems not to be the case”.

Zhou et al. [63] points out the incredulity on the part of the professionals involved with building construction as a significant barrier to the adoption of the BEE technologies. Such an incredulity comes from the limited information on energy-saving technologies as well as the lack of experience of the professionals involved with such a topic [60]. This lack of information leads designers and other professionals not to believe in the technical and economic benefits resulting from the adoption of such technologies while reducing the environmental impact [57,63].

## *2.5 Cultural/Social/Behavioural barriers*

Because of the invisible and automatic nature of the use of energy, the final consumer understands only a little about the amount of information concerned with energy efficiency [10,38,76]. Aggravating this situation is the fact that utility bills do not allow the consumers to identify the energy consumption of different pieces of equipment [44,62,79,81,82]. This lack of information on energy use, energy-saving, and BEE technologies available difficult decisions on energy-efficiency improvements [33,41,58,84].

As established by Stevenson and Baborska-Narozny [76] end-users are not motivated to invest in BEE technologies because they have limited information and knowledge about building's energy consumption and its effects on the environment. In addition, the uncertainties concerned with energy prices contribute to improving this lack of motivation [55,82]. Even potential users that are aware of the BEE technologies and their benefits do not feel motivated to adopt them, because of some of their requirements, like maintenance, cleaning, and training [74].

As reported by Zhang et al. [36], Chan et al. [77], Caputo and Pasetti [81] the owners, building constructors, occupants, and investors are naturally resistant to change from traditional non-efficient technologies to energy-efficient ones, because their negative perception concerned with energy efficiency. According to Goodier and Chmutia [52], Hopkins [60], Alam et al. [64], Ruiz [82] such behaviour is explained by the numerous unsuccessful programs; the not clear demonstrations of the benefits from the adoption of the BEE technologies as well as many other factors associated with other barriers.

There is a lack of confidence in BEE technologies, which comes from disbelief that such technologies cannot accomplish the benefits advertised at the costs informed. The end-users do not trust in the information provided by the manufacturers and government [33,74]. Besides, in general, those who would pay and use them are deeply rooted in the traditional technologies because there is a strong belief that energy-efficient technologies are too complex to use and difficult to obtain [67].

## *2.6 Technological barriers*

As claimed by Hirst and Brown [33], Tuominen et al. [41] there is a lack of reliable information on the performance of BEE technologies. This is critical to those who decide on the deployment and market penetration of new technologies. According to Persson and Grönkvist [8], Ruiz [82], Ding et al. [83] information regarding the economic and technical viability of the BEE technologies under real-world conditions is scarce because there is a lack of government-supported demonstrations of BEE technologies [73].

As stated by Hirst and Brown [33], Amoruso et al. [49], Williams and Dair [53] architects, engineers decide the energy-efficiency of buildings and their equipment without direction from the owners and occupants, resulting many times in the adoption of inadequate BEE technologies. According to Addy et al. [37], Castleberry et al. [54] the choice of the technologies to be adopted emphasizes the first cost rather than the life-cycle cost, even though the focus on life-cycle cost would increase the energy conservation. This is an obstacle to the adoption of BEE technologies, since they have higher first costs but lower life-cycle costs than conventional technologies [21,29].

### 3. Methodological approach

Fig. 2 presents the followed to carry out this research. These steps range from the theoretical framework to the data analysis.

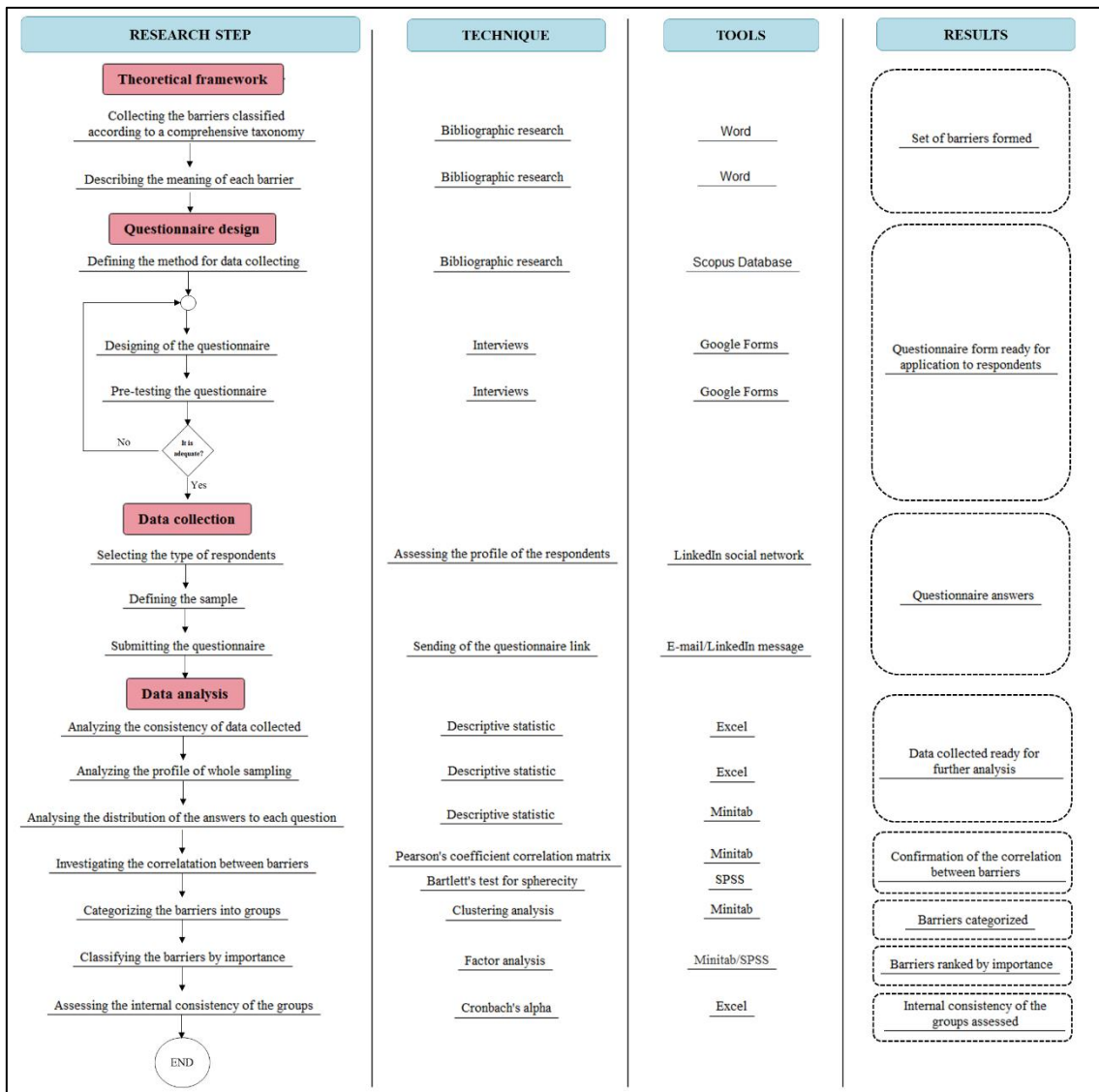


Fig. 2 Research methodological flow.

### 3.1 Theoretical Framework

As mentioned previously, this research is a part of a larger investigation effort. Thus, the 27 barriers identified by means of a comprehensive literature review and categorized into 6 groups by Cristino et al. [42] were summarized in the theoretical framework, since the aim of this study is to know the relevance/importance of such barriers and the respective taxonomy proposed by Cristino et al. [42] for the Brazilian scenario.

### 3.2 Questionnaire Design

The structured questionnaire was used to collect the perception of Brazilian experts about the importance/relevance of the barriers gathered from the literature for the Brazilian scenario. Such an approach allowed for a broad exploration of the subject and offered the possibility to perform statistical analysis of the data collected.

The questionnaire was designed in Google Forms, a free online tool to create surveys, and was segmented into three parts. Firstly, the theme was contextualized by the following introductory text:

*“Electricity consumption has been steadily increasing over the years, worrying the government about the scarcity of primary energy resources, leading to the search for alternative sources of energy. Nowadays, public, commercial, and residential buildings are responsible for 36% of total energy consumption and 40% of total greenhouse gas emissions. Therefore, it is necessary to reduce the consumption of electricity. However, such a reduction must be made without decreasing the building occupant’s welfare. This aim can be achieved by the adoption of building energy efficiency (BEE) technologies. Although there are consolidated technology options in the market, their adoption is still timid. Recent research listed the following items as the main barriers to the adoption of BEE technologies”.*

Next, the kernel of the questionnaire presented the 27 barriers, found by Cristino et al. [42], to the respondents. In this part, the respondents were invited to indicate, according to their perception, the importance of each of the 27 barriers to the Brazilian reality. Fig. 3 presents this part of the structured questionnaire.

Indicate, according to your perception, the relevance to the Brazilian reality, of each of the barriers below, on the scales from 0 (not important) to 10 (very important).

Implementation of energy-efficient technologies requires high capital investments	0	1	2	3	4	5	6	7	8	9	10
Lack of confidence, by owners and occupants, on the information disseminated by the government and/or market concerned with the building energy-efficient technologies	0	1	2	3	4	5	6	7	8	9	10
Lack of a market for building energy-efficient technologies	0	1	2	3	4	5	6	7	8	9	10
Ineffective building energy efficiency codes/regulations/standards	0	1	2	3	4	5	6	7	8	9	10
Lack of confidence of the specialized professionals, in the results claimed by energy-efficient technologies	0	1	2	3	4	5	6	7	8	9	10
Lack of subsidies or other policy interventions that reduces energy prices	0	1	2	3	4	5	6	7	8	9	10
Limited knowledge of market potential	0	1	2	3	4	5	6	7	8	9	10
Complex energy efficiency certification procedures	0	1	2	3	4	5	6	7	8	9	10
Inadequate building energy-efficient technologies for Brazilian reality	0	1	2	3	4	5	6	7	8	9	10
Long payback periods	0	1	2	3	4	5	6	7	8	9	10
Lack of technology demonstration	0	1	2	3	4	5	6	7	8	9	10
Difficult access to financing building energy-efficient projects	0	1	2	3	4	5	6	7	8	9	10
Lack of knowledge on the benefits associated with building energy efficiency by owners and occupants	0	1	2	3	4	5	6	7	8	9	10
High investment risks	0	1	2	3	4	5	6	7	8	9	10
Lack of technical competence	0	1	2	3	4	5	6	7	8	9	10
Lack of government support	0	1	2	3	4	5	6	7	8	9	10
Lack of investors in building energy-efficient projects	0	1	2	3	4	5	6	7	8	9	10
Policies do not address the financial implications	0	1	2	3	4	5	6	7	8	9	10
Fear/Resistance to change by the owners and occupants	0	1	2	3	4	5	6	7	8	9	10
Lack of information on technologies available in the Brazilian market	0	1	2	3	4	5	6	7	8	9	10
Lack of economic incentives	0	1	2	3	4	5	6	7	8	9	10
Lack of motivation of owners and occupants to develop building energy-efficient actions	0	1	2	3	4	5	6	7	8	9	10
Lack of efficient dissemination of codes/regulations/policies, by the government, concerned with building energy efficient	0	1	2	3	4	5	6	7	8	9	10
Financial limitation of the owners	0	1	2	3	4	5	6	7	8	9	10
Lack of good marketing strategies to promote the building energy-efficient technologies	0	1	2	3	4	5	6	7	8	9	10
Incredulity on the part of the architects and engineers	0	1	2	3	4	5	6	7	8	9	10
Lack of knowledge on energy efficiency by legislators and regulators	0	1	2	3	4	5	6	7	8	9	10
Is there another barrier that you would like to add to the above list?											

**Fig. 3** The kernel of the questionnaire.

The structured questionnaire was presented to the respondents in the Portuguese language version, faithfully maintained the meaning intended by Cristino et al. [42].

The choice of the response scale is generally the most important decision to ensure the reliability of the data collected with the application of a questionnaire [85-88]. This choice depends on some criteria, as, for example, the facility for the respondents to adjust the subjectivity of their answers to questions and the adequacy of the data analysis techniques to be employed [89].

The use of a larger scale, besides being more understood and interpreted, provides the respondents with significantly more flexibility to express their opinion than a smaller scale one [90,91]. In addition, longer scales show increased variability in responses what makes them more suitable for data analysis techniques based on advanced statistics [89,91].

As can be seen in Fig. 3, an 11-point response scale was chosen. Thus, the respondents could indicate how important, or relevant, a barrier was, ranging from 0 (not important) to 10 (very important). Furthermore, if respondents felt that there was still a particular barrier that was not listed, they could include them in the blank below the scale.

The final part of the questionnaire, as can be seen in Fig. 4, aimed to know the respondents such as their academic formation, the type of company they are employed in, and also their experiences and knowledge in the BEE area.

<p>What is your academic education?</p> <input type="checkbox"/> Architecture <input type="checkbox"/> Civil Engineering <input type="checkbox"/> Electrical/ Electronics Engineering <input type="checkbox"/> Mechanical Engineering <input type="checkbox"/> Certificate Programs <input type="checkbox"/> Other: _____	<p>You have gained your knowledge of building energy efficiency by means of:</p> <input type="checkbox"/> Conferences <input type="checkbox"/> Training Programs <input type="checkbox"/> Technical Journals <input type="checkbox"/> Magazines <input type="checkbox"/> Books <input type="checkbox"/> Internet <input type="checkbox"/> During the school <input type="checkbox"/> Other: _____
<p>What type of company do you work for?</p> <input type="checkbox"/> Architecture/Engineering Office <input type="checkbox"/> Construction Company <input type="checkbox"/> Engineering Department <input type="checkbox"/> Government <input type="checkbox"/> Research Center <input type="checkbox"/> University <input type="checkbox"/> INMETRO Accredited Organization <input type="checkbox"/> Other: _____	<p>You have gained your knowledge of building energy efficiency by means of:</p> <input type="checkbox"/> Conferences <input type="checkbox"/> Training Programs <input type="checkbox"/> Technical Journals <input type="checkbox"/> Magazines <input type="checkbox"/> Books <input type="checkbox"/> Internet <input type="checkbox"/> During the school <input type="checkbox"/> Other: _____
<p>When was the last time you read or studied about building energy efficiency?</p> <input type="checkbox"/> Less than 6 months <input type="checkbox"/> From 6 months to 1 year <input type="checkbox"/> From 1 year to 5 years <input type="checkbox"/> Greater than 5 years	<p>Which of the following groups of technologies has the greatest adoption potential in Brazil?</p> <input type="checkbox"/> Technologies related to building envelope <input type="checkbox"/> Technologies related to thermal comfort of the occupants <input type="checkbox"/> Use of alternative energy sources in buildings <input type="checkbox"/> Technologies related to indoor/outdoor lighting <input type="checkbox"/> Energy-efficient appliances <input type="checkbox"/> Other: _____
<p>When was the last time you read or studied about building energy efficiency?</p> <input type="checkbox"/> Less than 6 months <input type="checkbox"/> From 6 months to 1 year <input type="checkbox"/> From 1 year to 5 years <input type="checkbox"/> Greater than 5 years	

**Fig. 4** Questions to characterize the respondents.

A pilot study was conducted prior to pretest the comprehensibility and suitability of the questionnaire. The pilot study involved 20 respondents. After each interview, if necessary, the questions were modified until they reach their final writing as presented in Fig. 3.

### 3.3 Data collection

Survey participants were sampled among professionals subscribed to the LinkedIn social network. The selected participants were those with some professional experience or academic education related to BEE in the areas of architecture, civil engineering, electric/electronic engineering, mechanic engineering, etc.

A link to the online survey available on Google Forms was sent out to a sample of 3,506 participants from November 2019 to December 2019 by means of the LinkedIn message tool. The invite informed them of the purpose of the research, the positive impact of their participation could have on this research, and the confidentiality of their responses.

The online survey was self-administrated and available on Google Forms from December 2019 to May 2020. During this period, a total of 1,236 responses were collected from the online survey available on Google Forms.

### *3.4 Data Analysis*

Before proceeding with the data analysis, all the questionnaires were checked for inconsistencies and only the good ones were considered for further analysis. The questionnaires that presented the same score for all the answers were considered inconsistent and, therefore, discarded. Thus, 1,000 questionnaires were properly responded to, corresponding to a response rate higher than 25%, which, according to Adetia et al. [92] and Fervaha and Remington [93], is typical for online surveys.

Subsequently, the responses were analysed and the most and less important barriers to the Brazilian reality, according to the respondents' perceptions, were identified.

The Pearson's coefficient correlation matrix was computed in order to measure the degree of relationship between the 27 barriers. The correlation matrix was submitted to Bartlett's test for sphericity, which stated that the correlations were statistically significant [94-96].

The result of Bartlett's test indicated that the barriers were connected to one another by means of underlying factors indicating that multivariate statistical techniques, like clustering and factor analysis, could be applied to build an underlying factor model.

Therefore, the barriers were submitted to a hierarchical clustering algorithm using the correlation matrix as a matrix of similarity. The result was presented under the form of a clustering tree whose numbers of groups and the barriers within each group were presented.

Afterward, factor analysis was carried out, to confirm the results of the clustering analysis, and classify the groups of barriers according to the importance ascribed by the Brazilian experts. Finally, the internal consistency of the groups was assessed by Cronbach's Alpha.

No need to say that the profile of the respondents was richly addressed by means of several descriptive statistics.



## 4. Results

### 4.1 Data collecting analysis

Table 1 presents the information about the data collecting by means of a structured questionnaire sent to the Brazilian experts.

**Table 1** - The results of data collection.

<b>Structured Questionnaires</b>	<b>Total</b>
Sent Questionnaires	3,506
Answered Questionnaires	1,236
Discarded questionnaires	236
Validated questionnaires	1,000
Response rate (%)	28.5

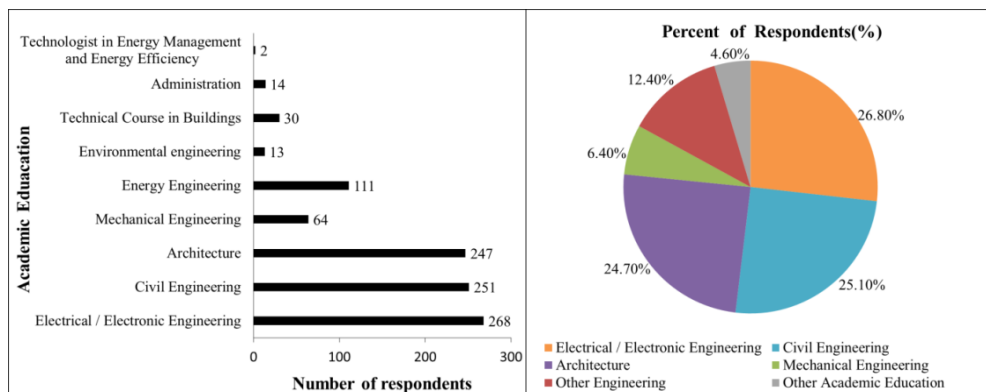
The questionnaire link was sent to 3,506 professionals subscribed to the LinkedIn social network, by means of the message tool. A total of 1,236 responses were collected from the online survey available on Google Forms. However, 236 questionnaires presented the same score for the answers were considered inconsistent, and, thus, discarded.

Thus, from this total, 1,000 questionnaires were considered valid. This number leading to a net response rate of 28.5%.

### 4.2 Analysis of the respondents' profile

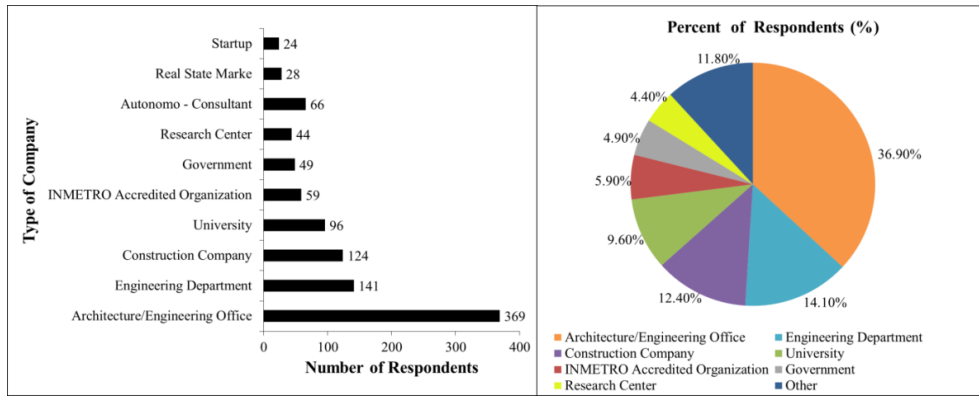
The sample of the respondents was selected from a population of professionals involved with BEE in the areas of architecture, civil engineering, electric/electronic engineering, and mechanical engineering subscribed to the LinkedIn social network.

The education profile of the respondents is presented in Fig. 5. More than 75% of the respondents have a degree in Electrical/Electronic or Civil Engineering, or Architecture.



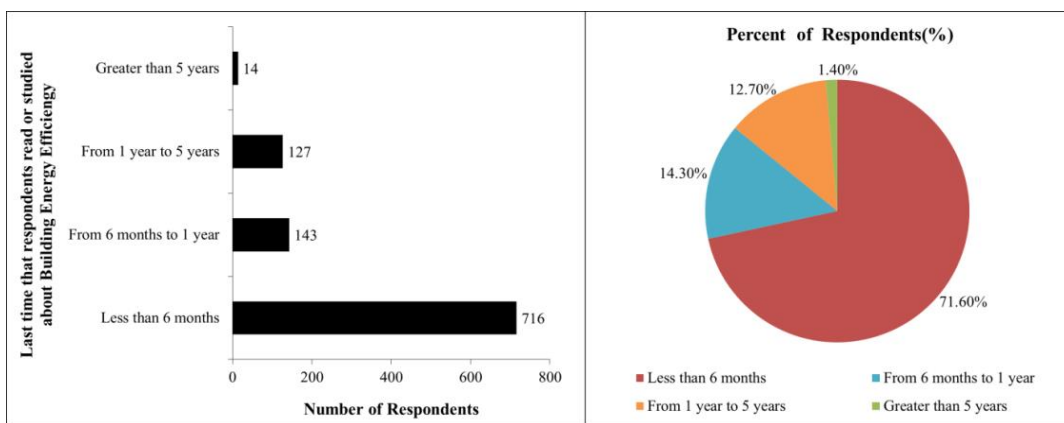
**Fig. 5** Academic education of the survey respondents.

About 63.5% of respondents work in companies that deal, directly or indirectly, with BEE, as illustrated in Fig. 6.



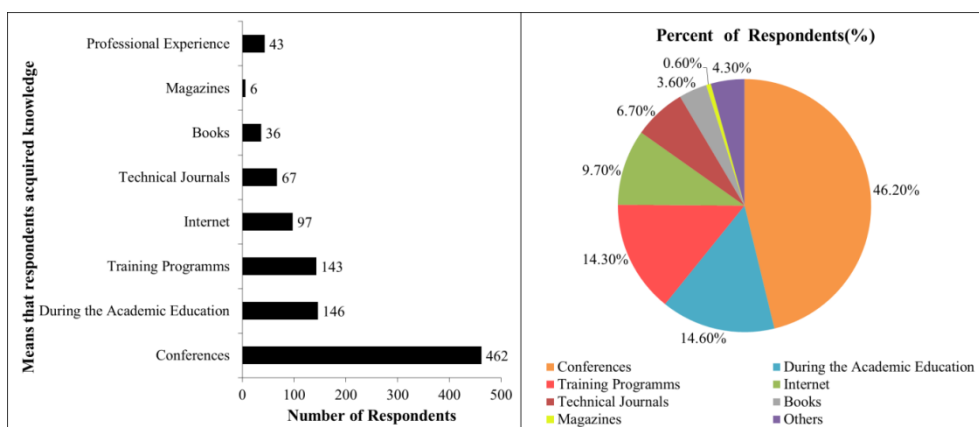
**Fig. 6** Occupation profile of the survey respondents.

According to Fig. 7, the respondents are updated with the subject, since 71.6% of the respondents were involved in knowledge acquisition activities within the last six months.



**Fig. 7** Distribution of the survey respondents according to the last time they were involved information acquirement on BEE.

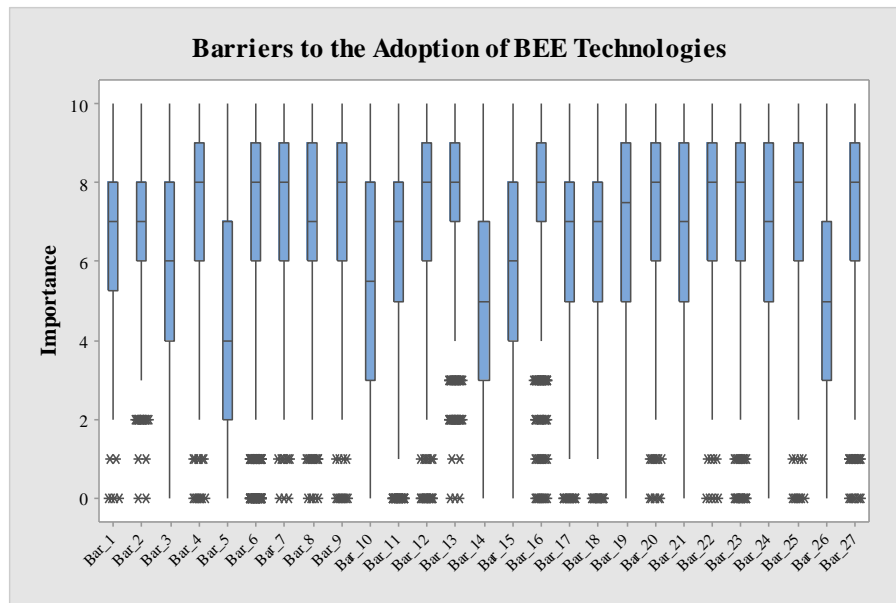
Conferences are the main source of acquiring knowledge in BEE, followed by formal academic education and training programs as can be seen in Fig. 8.



**Fig. 8** Knowledge source used by the respondents.

### 4.3 Distribution of the responses for each barrier

Fig. 9 shows the distributions of the responses for each barrier.



**Fig. 9** Distribution of the responses for each barrier.

The following points are remarkable:

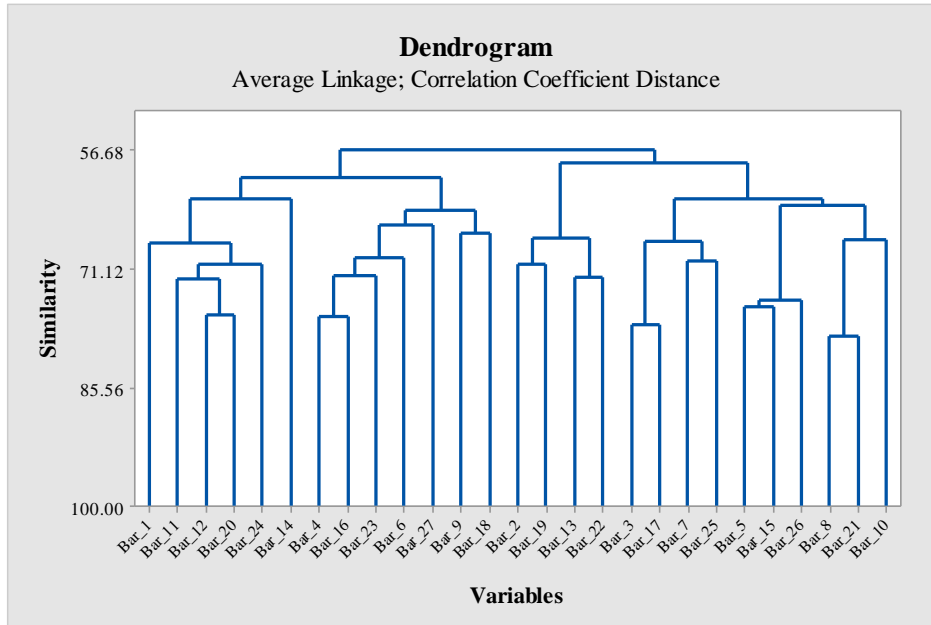
- Some of the barriers similar distributions like Bar\_4, Bar\_6, Bar\_7, Bar\_9, Bar\_12, Bar\_20, Bar\_22, Bar\_23, Bar\_25, and Bar\_27);
- The vast majority of the barriers were considered relevant according to the experts, since most of the distributions (14 out of the 27 barriers) showed that 75% of the grades assigned by the respondents are higher than six;
- The barriers whose distributions showed more than 50% of the scores assigned lower than six were considered fewer importance barriers: Bar\_5, Bar\_10, Bar\_14, Bar\_15, and Bar\_26. It is worth noticing the large variability in the assessment of such barriers, which demonstrates the high degree of uncertainty involving such barriers.
- Three barriers presented the lowest interquartile range (Bar\_2, Bar\_13, and Bar\_16) higher than six. It means that there were few doubts about the relevance of such barriers.

Before proceeding with the analysis it is interesting to investigate the correlation between the barriers. If the barriers are not correlated, the analysis cannot go beyond the descriptive statistics presented; otherwise, a wide range of possibilities is open.

Appendix A.1 presents the correlation matrix of the barriers followed by Appendix A.2 that presents Bartlett's test of sphericity.

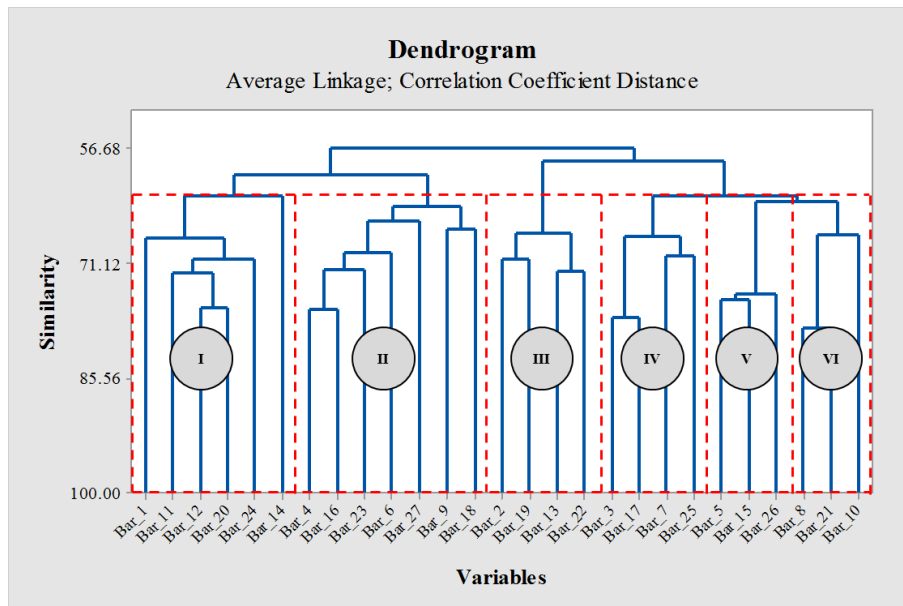
#### 4.4 Variable clustering analysis

Since the importance assigned to each barrier by the respondents are significantly correlated (see Appendix A.2), the correlation matrix can be used as a similarity measure and submitted to a hierarchical clustering algorithm, which resulted in the dendrogram shown in Fig. 10.



**Fig. 10** Clustering tree.

From Fig. 10 is easy to group the 27 barriers into the six groups shown in Fig. 11. The barriers within each group are equally important according to the perception of the specialists.



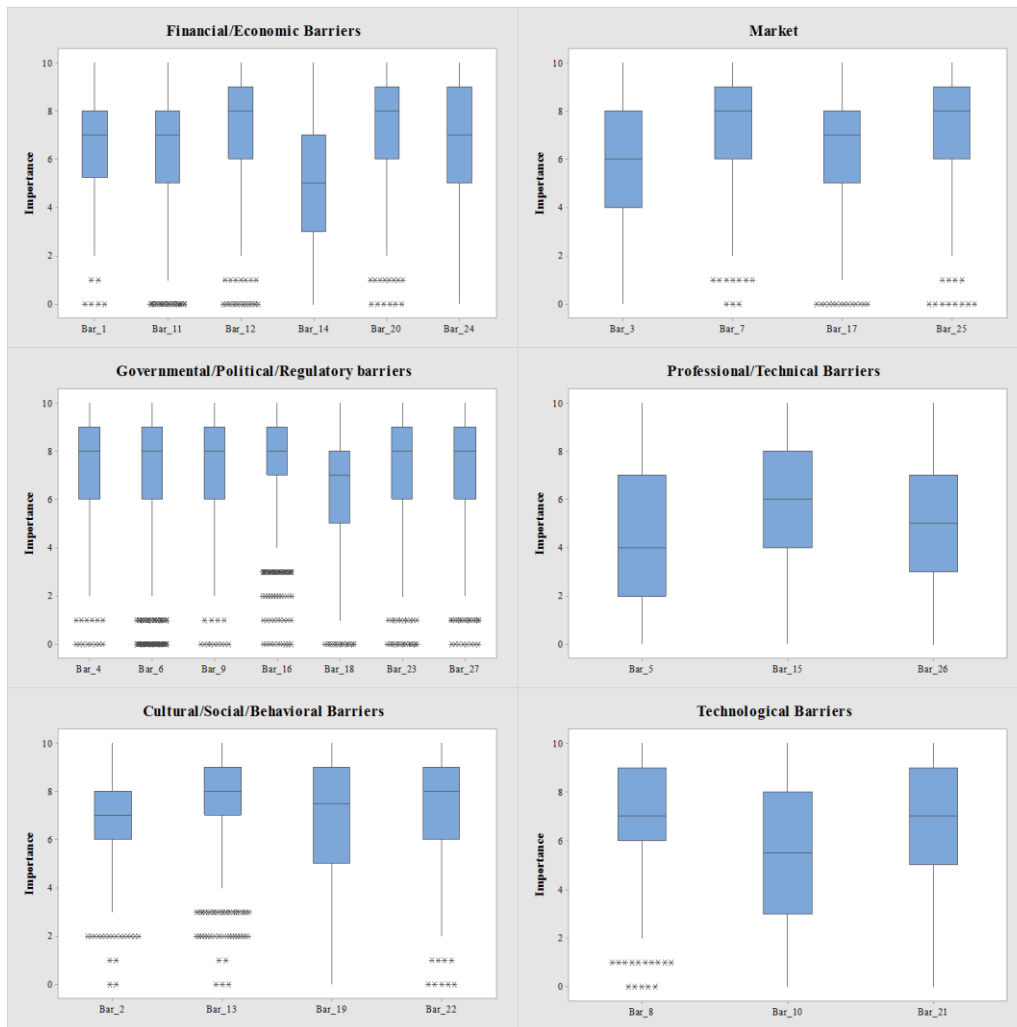
**Fig. 11** Groups formed in clustering analysis.

The first finding resulting from this analysis was that the clusters are seen in Fig. 11 match the same groups proposed by Cristino [42], as shown in Table 2.

**Table 2 -** Categorization of the barriers according to their importance.

<b>Cluster number</b>	<b>Cluster Name</b>	<b>Variable code</b>	<b>Name of barriers represented by the variable</b>
I	Financial/ economic barriers	Bar_11	Long payback periods
		Bar_01	High investment
		Bar_12	Difficult to access bank financing
		Bar_24	Financial limitations of the owners
		Bar_14	Investment risks
		Bar_20	Lack of economic incentives
II	Government/ political/ regulatory barriers	Bar_04	Ineffective BEE codes/regulations/standards
		Bar_16	Lack of support from the government
		Bar_23	Lack of efficient dissemination of codes/regulations
		Bar_06	Distorted fiscal policies
		Bar_27	Lack of knowledge on energy efficiency by legislator and regulator
		Bar_09	Complex certification procedures
		Bar_18	Policies do not address the financial implications
III	Cultural/social/ behavioral barriers	Bar_02	Lack of confidence
		Bar_19	Fear/Resistance to change
		Bar_13	Lack of information/education about the BEE technologies
		Bar_22	Lack of motivation
IV	Market barriers	Bar_03	Lack of a market demand for BEE technologies
		Bar_17	Lack of investors in BEE projects
		Bar_07	Limited knowledge of market potential
		Bar_25	Lack of good marketing strategies
V	Professional/ technical barriers	Bar_05	Lack of professional involvement
		Bar_15	Lack of technical competence
		Bar_26	Incredulity on the part of the designers
VI	Technological barriers	Bar_08	Lack of technology demonstration
		Bar_21	Lack of reliable information of the performance of BEE technologies
		Bar_10	Inadequate BEE technologies

In order to better describe the nature of the members of each cluster, Fig. 12 presents the respective distributions.



**Fig. 12** Distribution of the barriers for each cluster formed in clustering analysis.

The barriers concerned with Financial and Economic affairs form Cluster I. It is possible to infer from the distributions that the most important barriers in this group are Bar\_12 (“difficult access to financing BEE projects”) and Bar\_20 (“lack of economic incentives”), since 75% of the grades assigned to them by the experts is higher than six. In the opposite way is Bar\_14 (“high investment risks”).

Cluster II gathers the barriers related to the category named Governmental/Political/Regulatory. It can be considered that the respondents assigned to this group great importance scoring nearly equally all the barriers, notice that the five out of the seven barriers have nearly the same distribution. While Bar\_16 (“lack of government support”) seems to be the most important, Bar\_18 (“policies do not address the financial implications”) is slightly less important than the others.

Cluster III groups the barriers concerned with Cultural, Social, and Behavioral aspects. The respondents assigned great importance to this group since nearly 75% of them assigned a score greater than six to the importance of such barriers. Bar\_13 (“lack of knowledge about the BEE technologies”), seems to be the most important within this group since 75% of the respondents assigned seven to their relevance.

Cluster IV gets together the barriers associated with Market issues. The most important barriers within this group are Bar\_7 (“limited knowledge of market potential”) and Bar\_25 (“lack of good marketing strategies”).

Cluster V gathers the three barriers related to Professional and Technical aspects. Such group was considered the less important according to the perception of the experts based on the same criterion used above.

Three barriers concerned with Technology form Cluster VI. According to the respondents, Bar-10 (“inadequate BEE technologies for the Brazilian scenario”) is the less relevant barrier within this group and one of the less important considering all barriers.

Although the results from the clustering analysis ratified the taxonomy proposed in Section 2, it was not possible to sort these groups by importance. However, as stated in Appendix A.1, the correlation matrix of the barriers is suitable to factor analysis.

#### *4.5 Factor analysis*

The essential motivation of factor analysis is to describe the correlation relationships among several variables in terms of a few underlying, but not observable, quantities called factors, underlying variables, or constructs [97]. An underlying factor model is based on the possibility that the variables can be grouped by their correlations, i.e., all variables within a particular group are highly correlated among themselves, but weakly correlated with the variables in other groups [97]. Therefore, it is plausible that each group of variables represents a single underlying factor (or construct), that is responsible for the observed correlations [97].

Recall that this research has identified 27 barriers, in the literature, that hinder the adoption of the BEE technologies and has proposed a taxonomy in which such barriers were grouped into six categories. Such a structure suggests a model in which each category represents a construct and the barriers within each group are possibly highly correlated, and weakly correlated with the others.

Thus, the factor analysis, in the scope of this research, aims to verify whether the underlying factor model, obtained from the perception of the Brazilian experts, confirms the previous clustering analysis, ultimately whether it is consistent with the proposed taxonomy. Additionally, the factor analysis classifies such groups by the importance assigned to them by the experts.

The starting point of the factor analysis is the correlation matrix of the variables. Although, the Bartlett’s test for sphericity assured that the correlation matrix is suitable to factor analysis, it is usually double-

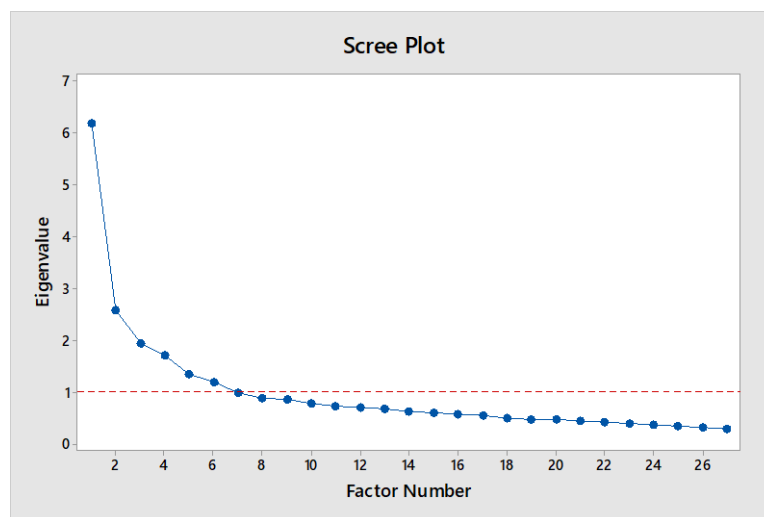
checked such adequacy by means of the computation of the Kaiser-Meyer-Olkin measure of sampling adequacy, which value, in this case, is 0.851, which is very good according to Jain and Raj [96], Phogat and Gupta [98]. See Appendix A.2.

Since the factors (or constructs) extracted from the correlation matrix are a linear combination of the variables, there are as many factors as variables. Each factor is capable to explain a portion of the variance of the raw data, in such a way that all of them together are capable to explain almost 100% of the data variability.

Using all the factors to represent the data is not a great deal. Instead, the underlying factor model intends to use a minimal number of factors to summarize all variables into latent factors. The number of factors must be such, that they are capable to explain a significant amount of the variability in the data.

There are several criteria to determine the minimal number of factors (or the most important) to be extracted from the correlation matrix [97]. The most important factors are those with a high variance, since the eigenvalues of the correlation matrix equal the variance of each factor, a common criterion is to include the factors with an eigenvalue above 1 [95].

A common way to assess factor eigenvalues is by mean of the scree plot (Fig. 13), which displays the number of factors against its corresponding eigenvalue.



**Fig. 13** Scree Plot.

According to Fig. 13, the six first eigenvalues are greater than 1, thus the minimal number of Factors to be extracted from the correlation matrix should be six as well [97]. It is interesting to notice that six also is the number of categories into which the barriers were formerly grouped during the clustering analysis and is the number of categories of the proposed taxonomy as well.



The next step is to determine which of the six factors have the greatest influence on each variable. This can be reached by examining the correlation between observed variables and latent common factors (constructs). Such a correlation can be directly observed through a parameter known as factor loading [97]. The examination of the loading pattern determines the factor that has the greatest influence on each variable. Obviously, the loadings range from -1 to 1. Thus, loadings close to  $\pm 1$  indicate that the factor strongly influences the variable. Loadings close to zero indicate that the factor has a weak influence on the variable.

It is worth mentioning that the statistical significance of the loading is related to the size of the sample, thus according to Jain and Raj [96] for a sample size larger than 350, factor loadings higher than 0.3 are considered significant.

Table 3 presents the loadings for the six factors extracted from the correlation matrix.

**Table 3** – Loading for the six factors extracted from the correlation matrix.

Variable	Factor1	Factor2	Factor3	Factor4	Factor5	Factor6	Communality
Bar_16	<b>0.789</b>	0.104	-0.128	0.033	0.025	-0.077	0.657
Bar_4	<b>0.695</b>	0.145	-0.074	-0.061	0.099	0.033	0.525
Bar_6	<b>0.684</b>	0.136	0.026	0.101	-0.028	0.042	0.500
Bar_23	<b>0.680</b>	0.014	-0.206	0.125	0.009	-0.190	0.557
Bar_18	<b>0.520</b>	0.230	0.187	-0.010	0.213	-0.243	0.463
Bar_27	<b>0.484</b>	0.050	-0.251	0.151	0.234	0.008	0.378
Bar_9	<b>0.400</b>	0.161	0.015	0.079	0.119	-0.398	0.365
Bar_11	0.071	<b>0.742</b>	-0.063	0.143	-0.039	-0.137	0.600
Bar_1	0.072	<b>0.696</b>	-0.050	-0.040	-0.020	0.026	0.495
Bar_24	0.175	<b>0.653</b>	-0.209	0.087	0.056	0.025	0.513
Bar_12	0.293	<b>0.626</b>	-0.168	-0.017	0.064	-0.048	0.513
Bar_14	-0.022	<b>0.583</b>	0.310	-0.015	0.310	-0.101	0.543
Bar_20	0.478	<b>0.541</b>	-0.177	0.130	-0.023	-0.120	0.584
Bar_7	-0.004	0.065	<b>-0.690</b>	-0.058	0.294	-0.161	0.596
Bar_25	0.184	0.065	<b>-0.612</b>	0.208	0.163	-0.066	0.487
Bar_3	0.133	0.265	<b>-0.566</b>	0.330	0.002	-0.075	0.523
Bar_17	0.160	0.232	<b>-0.531</b>	0.321	0.087	-0.153	0.496
Bar_5	0.061	0.108	0.003	<b>0.803</b>	0.087	-0.135	0.687
Bar_26	0.033	-0.021	-0.208	<b>0.740</b>	0.224	-0.030	0.643
Bar_15	0.154	0.027	-0.239	<b>0.720</b>	-0.032	-0.188	0.636
Bar_19	0.076	0.028	-0.009	0.181	<b>0.714</b>	-0.019	0.550
Bar_2	0.145	0.109	-0.009	0.009	<b>0.683</b>	-0.053	0.502
Bar_22	0.049	0.031	-0.252	0.129	<b>0.665</b>	-0.050	0.528
Bar_13	0.025	-0.060	-0.386	-0.077	<b>0.646</b>	-0.073	0.581
Bar_21	0.142	0.009	-0.386	0.174	0.081	<b>-0.717</b>	0.720
Bar_10	0.010	0.133	0.115	0.402	-0.052	<b>-0.694</b>	0.677
Bar_8	0.084	0.016	-0.422	-0.025	0.159	<b>-0.667</b>	0.656
Variance	3.220	2.798	2.476	2.324	2.281	1.875	14.974
% Var	0.119	0.104	0.092	0.086	0.084	0.069	0.555

Table 3 showed the variables sorted based on their factor loadings. Thus, those variables more correlated with Factor 1 come first, followed by the ones more correlated with the second factor, and so on.

The last column of Table 3 presents the communality for each variable, which is the proportion of variability that is explained by the factors. The closer the communality is to 1, the better the variable is explained by the factors [95,99]. Thus, for instance, Bar\_21 is the variable whose variability is the best explained by this set of factors while Bar\_9 is just the opposite.

At the bottom of Table 3, it can be seen the percentage of the variance in the data explained by each factor. Recall that the higher is the % Var, the more important is the factor. Thus, Factor 1, explains by itself almost 12% of the total variability, and all the factors together explain more than 55% of the total variability.

Fig. 14 presents the Underlying Factor Analysis model, showing which barriers are affected by which factors as well as the loadings. The picture also allows the reader to identify the most important factors. The bidirectional edges connecting the factors represent the weak correlation between them, as expected. It is worth mentioning that correlations below 0.1 were not represented.

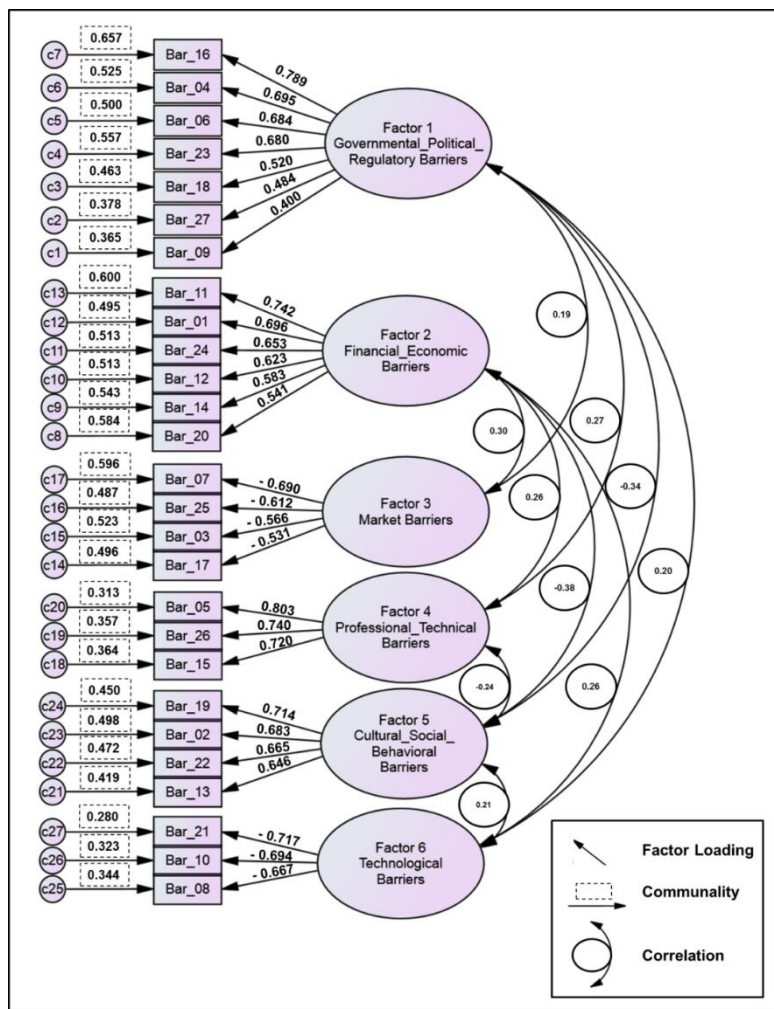


Fig. 14 Categorization of the barriers according their importance.

Before relying on the results from Factor Analysis it is important to verify the internal consistency of each group of barriers by means of the Cronbach's Alpha. The Cronbach's Alpha measures how well the set of barriers are correlated one to another within the same group, how well each of them fits the category. Table 4 shows the Cronbach's Alpha for each Factor and their respective 95% confidence interval.

**Table 4 - Internal consistency (Factor Cronbach's alpha coefficient).**

Factors	Items	Number of Respondents	Cronbach's $\alpha$ coefficient (95% CI)	$\begin{cases} H_0: \alpha \geq 0.700 \\ H_1: \alpha < 0.700 \end{cases}$	P-value
1	7	1000	$0.756 \leq 0.774 \leq 0.792$	$> 0.700$	$< 0.001$
2	6	1000	$0.746 \leq 0.765 \leq 0.783$	$> 0.700$	$< 0.001$
3	4	1000	$0.703 \leq 0.727 \leq 0.750$	$> 0.700$	0.032
4	3	1000	$0.729 \leq 0.752 \leq 0.774$	$> 0.700$	$< 0.001$
5	4	1000	$0.675 \leq 0.701 \leq 0.726$	$< 0.700$	
6	3	1000	$0.644 \leq 0.674 \leq 0.702$	$< 0.700$	

According to Jain and Raj [96], it is desirable that the Alpha coefficient is greater than 0.7. Then, Alpha's value can be considered greater than 0.700 for Factors 1-4, with the respective P-values showed in the last column of Table 6. The Alpha's values for Factors 5 and 6 are slightly lower than 0.700. It does not seem to be a great deal, since many authors consider 0.6 acceptable.

Comparing Fig. 2 with Table 4 (clustering) and Fig. 1 (proposed taxonomy) it can be seen that the Brazilian experts' perception led to the same classification as the Taxonomy proposed by [42].

#### 4.5. New barriers added by the respondents

After assessing the importance of the 27 barriers, the respondents could fill a blank with other barriers they considered important and were not listed and submitted to their assessment. The participants suggested around 40 barriers. Although this is a small number of suggestions, devoid of statistical significance, considering that more than 1000 questionnaires were processed, it is worth analyzing them in order to see whether valuable insights come from them, justifying deeper research.

According to a few numbers of respondents (Table 5) the Brazilian industries are not capable to develop high-quality BEE technologies, thus it is necessary to import them. However, some of the imported products are of poor quality as well as many of them do not take into account the regionality. Comparing such statements with the Technological Barriers, from the proposed taxonomy, they can be summarized into the barrier "*Inadequate BEE technologies*".

**Table 5** – New barriers, added by the respondents, related to “Inadequate BEE technologies”.

STATEMENT	#RESPONDENT
<i>"Lack of national technologies"</i>	#360
<i>"Low development of new national technologies"</i>	#923
<i>"Lack of development of national technologies to compete with imported technologies"</i>	#668
<i>"Few national manufacturers of energy-efficient technologies"</i>	#327
<i>"Restricted national technologies"</i>	#415
<i>"Most of the technologies used to improve BEE are imported"</i>	#200
<i>"Poor quality of many imported technologies"</i>	#418
<i>"Difficulty importing efficient technologies"</i>	#904
<i>"Lack of technologies aimed at different regions of the country"</i>	#216

A small number of respondents (Table 6) were concerned with the purchasing power of lower classes.

A careful analysis of such statements shows that they can be included into the barrier “**Financial limitations of the owners**”.

**Table 6** – New barriers, added by the respondents, related to “Financial limitations of the owners”.

STATEMENT	#RESPONDENT
<i>"The middle and lower classes do not have access to BEE technologies"</i>	#81
<i>"Lack of cost-effective efficiency solutions for the most vulnerable class"</i>	#20
<i>"Available technologies do not include differences in social and regional classes"</i>	#21
<i>"Little disclosure about energy-efficient technologies for different social classes in the country"</i>	#863
<i>"There are no technologies available for the different popular strata, especially for the middle and lower classes of the country"</i>	#761
<i>"The low purchasing power of the middle and lower classes"</i>	#710
<i>"The low incentive for popular devices for the middle and lower classes"</i>	#278

Other respondents make statements related to the certification procedures (Table 7) that recall the barrier entitled **Complex energy efficiency certification procedures**.

**Table 7** – New barriers, added by the respondents, related to “Complex energy efficiency certification procedures”.

STATEMENT	#RESPONDENT
<i>"Bureaucratic processes with the concessionaire and the government are longer. Even with the technology already ready to be used, the time required for its adoption to be released can take months or even almost 1 year"</i>	#226
<i>"Bureaucratic processes for adopting new technologies are time-consuming, which makes the market unstable"</i>	#20

A great part of the respondents suggested that the main barriers to the adoption of BEE technologies are concerned with academic education in Building Energy Efficiency (Table 8). Thus, the suggestions given by the respondents must be included into the barrier “**Lack of technical competence**”.

**Table 8** – New barriers, added by the respondents, related to “Lack of technical competence”.

STATEMENT	#RESPONDENT
<i>"Lack of incentives from universities and a research centers to train specialists in the field of energy efficiency"</i>	#10
<i>"Lack of academic guidance on BEE for undergraduate students"</i>	#16
<i>"Lack of education on energy efficiency technologies at universities"</i>	#32
<i>"Lack of undergraduate student training"</i>	#47
<i>"There are no specific disciplines that address the energy-efficiency issues, or even within disciplines courses, there is no emphasis on the benefits of adopting BEE technologies"</i>	#72
<i>"Little dissemination on the theme in the academic area"</i>	#141
<i>"Lack of education on the theme in universities"</i>	#145
<i>"Lack of disciplines on the theme in universities"</i>	
<i>"The subject in question should be compulsory in undergraduate courses"</i>	#288
<i>"There is no incentive for academic institutions to teach (educate) students about the importance of the use of energy-efficient technologies"</i>	#317
<i>"Inadequate, outdated and/or low quality higher education"</i>	#332
<i>"I believe that the barrier starts in education. Many still see energy efficiency as a "plus" and not as a building need, and this is due to the fact that many universities still treat energy efficiency that way"</i>	#338
<i>"Low quality of technical education and undergraduate courses"</i>	#502
<i>"Lack of specialization courses focused on energy efficiency"</i>	#609
<i>"Academia treats the theme less importantly"</i>	#702
<i>"Undergraduate courses do not address energy efficiency technologies "</i>	#712
<i>"Lack of courses at universities turned to prepare students to design and work with energy-efficient technologies"</i>	#744
<i>"Lack of technical information for training purposes"</i>	#781

Some respondents believe that energy utilities should assume an important role in supporting the adoption of BEE Technologies (Table 9), which is a point of controversy that deserves to be discussed.

These few statements can be considered included into the barrier “*Lack of economic incentives*”.

**Table 9** – New barriers, added by the respondents, related to “lack of economic incentives”.

STATEMENT	#RESPONDENT
<i>"There is no participation of energy concessionaires for the dissemination and encouragement of the adoption of energy-efficient technologies"</i>	#76
<i>"Energy utilities' reluctance to encourage the adoption of energy-efficient technologies "</i>	#175
<i>"Energy utilities are afraid of losing their market share"</i>	#223
<i>" Energy utilities do not want to lose market share "</i>	#272

A short analysis of Table 5-9 demonstrated that no new barriers arise from respondents' comments.

## Conclusions

This paper evaluated the importance, according to Brazilian experts, of 27 barriers to the adoption of BEE technologies found in the literature. A structured questionnaire was used to carry out this survey.

Two quantitative methods, cluster analysis and factor analysis, confirmed, for the Brazilian scenario, the taxonomy proposed by an extensive qualitative research previously published by the authors, grouping the barriers into six categories: Financial/economic barriers, Government/political/regulatory barriers, Cultural/social/behavioral barriers, Market barriers, Professional/technical barriers, and Technological

barriers. The factor analysis showed that the Financial/Economic and Government/Political/Regulatory barriers are the most important for the Brazilian reality, showing that the Brazilian society has high expectations about the government interference in this matter.

Although the respondents raised no new barriers, they gave insights into new research directions like the inability of Brazilian industries to develop BEE technologies, the impact of BEE technologies imports on the Brazilian energy-efficiency sector, the role of the utility companies in supporting research on BEE technologies, the inadequacy of university's curricula for BEE technologies, etc.

Thus, this research showed that the barriers to the adoption of BEE technologies pointed out in the literature were recognized as valid to the Brazilian scenario. Therefore, these findings can assist government agencies, researchers, and experts to take a critical look at possible strategies that can be proposed to overcome such barriers.

#### **CRedit authorship contribution statement**

**Talita Mariane Cristino:** Conceptualization, Methodology, Software, Validation, Formal analysis, Investigation, Writing - original draft, Visualization, Project Administration. **Antonio Faria Neto:** Conceptualization, Methodology, Investigation, Resources, Data curation, Writing - review & editing, Supervision. **Frédéric Wurtz:** Writing - review & editing, Supervision, Funding acquisition. **Benoit Delinchant:** Writing - review & editing, Funding acquisition.

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#### **APPENDIX**

##### *A.1 Pearson's coefficient correlation matrix*

The Pearson's coefficient correlation matrix, or simply correlation matrix, is presented in Table A.1.

**Table A.1** - Pearson's coefficient correlation matrix.

Pearson's coefficient correlation matrix																											
	Bar_01	Bar_02	Bar_03	Bar_04	Bar_05	Bar_06	Bar_07	Bar_08	Bar_09	Bar_10	Bar_11	Bar_12	Bar_13	Bar_14	Bar_15	Bar_16	Bar_17	Bar_18	Bar_19	Bar_20	Bar_21	Bar_22	Bar_23	Bar_24	Bar_25	Bar_26	Bar_27
Bar_01	1	0.11	0.20	0.18	0.01	0.15	0.02	0.05	0.12	0.05	0.40	0.27	-0.02	0.29	0.05	0.12	0.13	0.14	0.04	0.38	0.07	0.01	0.11	0.39	0.06	0.01	0.10
Bar_02	0.11	1	0.15	0.17	0.10	0.11	0.17	0.17	0.16	0.00	0.09	0.14	0.33	0.12	0.07	0.17	0.12	0.16	0.41	0.15	0.17	0.36	0.11	0.14	0.13	0.11	0.14
Bar_03	0.20	0.15	1	0.15	0.28	0.17	0.35	0.25	0.20	0.21	0.23	0.22	0.13	0.03	0.34	0.23	0.56	0.12	0.15	0.28	0.30	0.16	0.23	0.25	0.39	0.26	0.21
Bar_04	0.18	0.17	0.15	1	0.07	0.31	0.11	0.12	0.24	0.01	0.15	0.28	0.08	0.14	0.07	0.54	0.18	0.29	0.07	0.32	0.12	0.12	0.42	0.22	0.13	0.05	0.35
Bar_05	0.01	0.10	0.28	0.07	1	0.12	0.12	0.14	0.18	0.37	0.21	0.10	0.02	0.10	0.51	0.11	0.26	0.08	0.13	0.19	0.23	0.17	0.16	0.16	0.19	0.50	0.17
Bar_06	0.15	0.11	0.17	0.31	0.12	1	0.00	0.09	0.18	0.06	0.17	0.26	0.01	0.10	0.15	0.49	0.13	0.33	0.07	0.36	0.10	0.01	0.38	0.18	0.16	0.06	0.27
Bar_07	0.02	0.17	0.35	0.11	0.12	0.00	1	0.39	0.16	0.03	0.08	0.16	0.38	0.02	0.13	0.10	0.39	0.09	0.19	0.09	0.29	0.29	0.14	0.18	0.41	0.17	0.25
Bar_08	0.05	0.17	0.25	0.12	0.14	0.09	0.39	1	0.2	0.27	0.13	0.15	0.27	0.03	0.24	0.18	0.27	0.10	0.15	0.21	0.59	0.20	0.22	0.11	0.29	0.21	0.23
Bar_09	0.12	0.16	0.20	0.24	0.18	0.18	0.16	0.20	1	0.22	0.23	0.16	0.05	0.11	0.14	0.30	0.20	0.34	0.13	0.28	0.24	0.11	0.33	0.21	0.21	0.13	0.23
Bar_10	0.05	0.00	0.21	0.01	0.37	0.06	0.03	0.27	0.22	1	0.20	0.08	-0.02	0.12	0.31	0.10	0.25	0.17	0.08	0.17	0.43	0.06	0.17	0.13	0.09	0.22	0.07
Bar_11	0.40	0.09	0.23	0.15	0.21	0.17	0.08	0.13	0.23	0.20	1	0.45	-0.01	0.31	0.16	0.17	0.21	0.15	0.03	0.45	0.16	0.08	0.16	0.42	0.15	0.11	0.12
Bar_12	0.27	0.14	0.22	0.28	0.1	0.26	0.16	0.15	0.16	0.08	0.45	1	0.13	0.30	0.13	0.36	0.25	0.26	0.08	0.53	0.19	0.11	0.21	0.40	0.17	0.09	0.17
Bar_13	-0.02	0.33	0.13	0.08	0.02	0.01	0.38	0.27	0.05	-0.02	-0.01	0.13	1	0.04	0.10	0.12	0.21	0.07	0.36	0.06	0.24	0.44	0.12	0.07	0.27	0.18	0.19
Bar_14	0.29	0.12	0.03	0.14	0.1	0.10	0.02	0.03	0.11	0.12	0.31	0.30	0.04	1	-0.05	0.03	0.06	0.26	0.13	0.14	-0.05	0.12	-0.02	0.22	-0.02	0.00	0.07
Bar_15	0.05	0.07	0.34	0.07	0.51	0.15	0.13	0.24	0.14	0.31	0.16	0.13	0.10	-0.05	1	0.20	0.35	0.09	0.12	0.27	0.40	0.13	0.28	0.15	0.30	0.49	0.17
Bar_16	0.12	0.17	0.23	0.54	0.11	0.49	0.10	0.18	0.30	0.10	0.17	0.36	0.12	0.03	0.20	1	0.27	0.35	0.10	0.47	0.23	0.11	0.46	0.19	0.20	0.09	0.30
Bar_17	0.13	0.12	0.56	0.18	0.26	0.13	0.39	0.27	0.20	0.25	0.21	0.25	0.21	0.06	0.35	0.27	1	0.19	0.17	0.32	0.35	0.25	0.24	0.25	0.29	0.32	0.26
Bar_18	0.14	0.16	0.12	0.29	0.08	0.33	0.09	0.10	0.34	0.17	0.15	0.26	0.07	0.26	0.09	0.35	0.19	1	0.15	0.29	0.13	0.10	0.29	0.24	0.10	0.04	0.25
Bar_19	0.04	0.41	0.15	0.07	0.13	0.07	0.19	0.15	0.13	0.08	0.03	0.08	0.36	0.13	0.12	0.10	0.17	0.15	1	0.15	0.12	0.34	0.10	0.07	0.19	0.24	0.18
Bar_20	0.38	0.15	0.28	0.32	0.19	0.36	0.09	0.21	0.28	0.17	0.45	0.53	0.06	0.14	0.27	0.47	0.32	0.29	0.15	1	0.28	0.11	0.38	0.41	0.24	0.12	0.27
Bar_21	0.07	0.17	0.30	0.12	0.23	0.10	0.29	0.59	0.24	0.43	0.16	0.19	0.24	-0.05	0.40	0.23	0.35	0.13	0.12	0.28	1	0.25	0.32	0.11	0.34	0.28	0.20
Bar_22	0.01	0.36	0.16	0.12	0.17	0.01	0.29	0.20	0.11	0.06	0.08	0.11	0.44	0.12	0.13	0.11	0.25	0.10	0.34	0.11	0.25	1	0.18	0.15	0.29	0.25	0.24
Bar_23	0.11	0.11	0.23	0.42	0.16	0.38	0.14	0.22	0.33	0.17	0.16	0.21	0.12	-0.02	0.28	0.46	0.24	0.29	0.10	0.38	0.32	0.18	1	0.22	0.31	0.14	0.34
Bar_24	0.39	0.14	0.25	0.22	0.16	0.18	0.18	0.11	0.21	0.13	0.42	0.40	0.07	0.22	0.15	0.19	0.25	0.24	0.07	0.41	0.11	0.15	0.22	1	0.23	0.10	0.23
Bar_25	0.06	0.13	0.39	0.13	0.19	0.16	0.41	0.29	0.21	0.09	0.15	0.17	0.27	-0.02	0.30	0.20	0.29	0.10	0.19	0.24	0.34	0.29	0.31	0.23	1	0.31	0.25
Bar_26	0.01	0.11	0.26	0.05	0.50	0.06	0.17	0.21	0.13	0.22	0.11	0.09	0.18	0.00	0.49	0.09	0.32	0.04	0.24	0.12	0.28	0.25	0.14	0.10	0.31	1	0.25
Bar_27	0.10	0.14	0.21	0.35	0.17	0.27	0.25	0.23	0.23	0.07	0.12	0.17	0.19	0.07	0.17	0.30	0.26	0.25	0.18	0.27	0.20	0.24	0.34	0.23	0.25	0.25	1

## A.2 KMO test and the Bartlett's test of sphericity

KMO and the Bartlett's test is performed, and the result of test is shown in Table A.2.

**Table A.2** - Results of the KMO test and the Bartlett's test of sphericity.

<b>KMO and Bartlett's test</b>		
Kaiser-Meyer-Olkin measure of sampling adequacy		0,851
	Approx. $\chi^2$	8361.885
Bartlett's test of sphericity	df	351
	Sig.	0.000

Bartlett's test of sphericity presented inexact  $\chi^2$  estimation of 8361.885, level of degree freedom (df) of 351, and significance level less than 0.001, showing that the correlation matrix is statistically different from the identity matrix. In other words, the correlations in the matrix are statistically significant. Therefore, the variables can be summarized in underlying factors, by two methods: variable clustering analysis and factor analysis.

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