# Energy efficiency programs in Brazil: A systematic analysis through Natural Language Processing

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**Abstract.** This study examines the energy efficiency research and regulatory frameworks, with a specific focus on Brazil. Despite the increasing focus from Brazilian authorities, who aim to reduce total electricity consumption by 11.57% by 2030, there is a notable gap in studies involving national regulatory bodies and labeling practices. This research, through a systematic review utilizing natural language processing, identifies and compares key themes from global studies within the Brazilian context. Our findings highlight the consumer's understanding and the impact of the Energy Star labeling program, emphasizing the importance of energy labels in classifying energy efficiency. Although there has been an uptick in the adoption of energy-efficient products in Brazil, consumer awareness remains low, limiting the effectiveness of these measures. The principal challenge of this study is the limited research specifically focused on Brazil, hindering robust comparative analyses.

**Keywords:** Energy efficient, Certification, Energy label, Brazil, Natural language processing.

## 1 Introduction

Energy efficiency has emerged as a critical priority across both developed and developing nations, driven by objectives to meet climate targets and reduce poverty. It has been progressively integrated into the economic development agendas of numerous countries as a vital tool to complement their broader development goals [1]. Achieving an energy-efficient economy necessitates concerted efforts and strategic interventions, such as information sharing between consumers and manufacturers. Effective measures like labeling programs and standards have been instrumental in this regard [2][3].

Globally established and implemented in over 40 countries, including the European Union, United States, Australia, China, and Brazil, energy labeling schemes are recognized as a highly effective, low-cost intervention for promoting energy efficiency. These schemes not only facilitate significant reductions in energy consumption but also yield substantial environmental benefits, cost savings, and promote sustainable energy use [4]. As a policy tool, labeling and regulatory frameworks enhance the energy efficiency of household appliances by classifying them based on their energy performance, thereby aiding consumers in making informed purchasing decisions [5].

This article aims to evaluate energy efficiency initiatives by analyzing and comparing global research findings with the Brazilian context. We conducted a comprehensive literature review using the Web of Science and Scopus databases to identify primary studies on the topic, focusing on the major themes discussed by various authors. Employing natural language processing, a branch of computational linguistics that enables computers to understand and manipulate human language, we categorized the identified topics and outlined the primary approaches of the studies. The subsequent analysis aims to explore these themes within the Brazilian setting, seeking to understand the key challenges and assessments of energy efficiency programs.

## 2 Research method and data

Our study employed a systematic review methodology to rigorously analyze academic papers related to energy efficiency programs. The process followed a structured workflow, illustrated in Fig. 1, which outlines each step of our review process from initiation to conclusion.

In the initial phase, we conducted a comprehensive bibliographic search across key academic databases to gather relevant literature. This search was aimed at collecting a broad spectrum of articles that discuss the implementation and outcomes of energy efficiency initiatives.

Following the collection phase, we extracted key points from the authors' conclusions in each article for preliminary analysis. The subsequent sorting and categorization of these articles were performed using advanced natural language processing (NLP) techniques. NLP enabled us to efficiently organize the data by identifying recurring themes and central issues addressed within the literature. This automated process ensured a high level of accuracy and objectivity in how information was grouped and analyzed, allowing for a nuanced understanding of the field.

This methodological approach provided a systematic and replicable framework for evaluating the diverse aspects of energy efficiency programs as discussed in the academic literature, thereby supporting the integrity and validity of our findings.

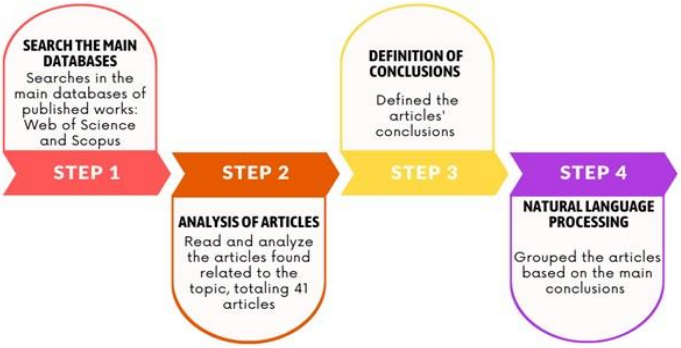


**Fig. 1.** Workflow chart.

## 2.1 Database

For each database, in addition to selecting the field and category related to the topic, the possibility existed to select studies presented in the form of articles covering English, Spanish, and Portuguese.

We choose the keywords according to the scope of this study. However, it should be noted that some "AND NOT" terms were included in the database due to the number of articles that were incompatible with the topic, as the analysis focused on household appliances. As for the definition of the field/category, we decided to limit ourselves to the field related to "energy." This decision was motivated by the considerable number of unrelated articles found in other categories, which would have made it challenging to select and read the relevant articles. The keywords chosen were:

- ALL= ((("certification" OR "certifications" OR "label" OR "labeling") AND ("energy" OR "consumer" OR "products") AND ("efficient" OR "efficiency") AND ("EU" OR "Green Seal" OR "Scientific Certification Systems" OR "Energy Guide" OR "Energy Star" OR "Green-e") NOT ("building") NOT ("computer") NOT ("conversion") NOT ("food") NOT ("agriculture") NOT ("materials") NOT ("vehicles")))

Fig. 2 shows that the number of articles in Scopus was 388 and in Web of Science 47. After reading the abstracts and titles, we selected 21 and 26 articles for each database. Furthermore, we found eight identical articles and six previously selected for their relevance to the topic. Finally, this brings the total number of articles to be analyzed and subsequently grouped to 41.

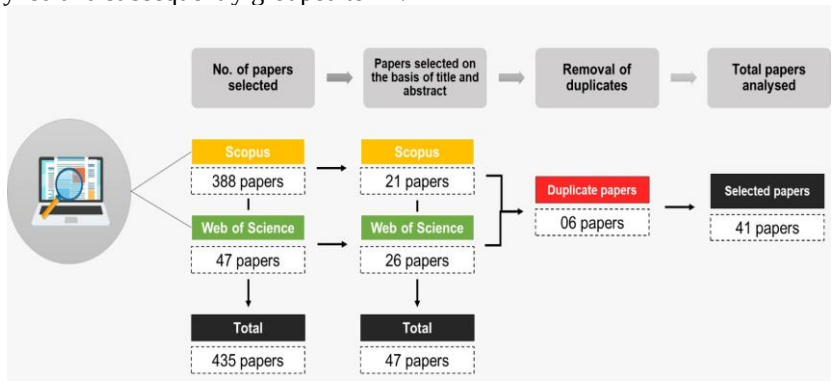


**Fig. 2.** Research Flowchart

A total of 388 articles were retrieved from Scopus and 47 from the Web of Science. Upon reviewing titles and abstracts, 21 from Scopus and 26 from Web of Science were deemed pertinent for further analysis. We identified eight duplicates and included an additional six articles recognized for their significance to the topic, resulting in a corpus of 41 unique articles to be examined in-depth and categorized. The principal attributes of these articles are delineated in Appendix 1. Based on conclusions of these articles, the papers were grouped as described in Section 2.2.

### 2.2 Thematic Grouping of Articles

Natural Language Processing (NLP) is a field of computational linguistics that focuses on enabling computer systems to understand and process natural language for specific tasks [44].

We employed the Sentence-BERT (SBERT) model, specifically "all-mpnet-base-v2," for its proven effectiveness in semantic search tasks [44]. The chosen SBERT model, which builds upon the PyTorch deep learning framework and the Transformers library from Hugging Face, Inc., facilitated the semantic grouping of our data.

Prior to SBERT application, we generated summaries of each article, which served as the basis for our analysis. To refine the input for the SBERT model and enhance the accuracy of grouping, we removed location names and citations. This step was crucial in minimizing potential biases and errors in the semantic analysis. Subsequently, we utilized Grammarly.com to correct grammatical inconsistencies within these summaries.

Post preprocessing, we obtained sentence embeddings that encapsulate the semantic information of the article summaries. These embeddings were then subjected to k-means clustering. K-means aims to minimize the Within-Cluster Sum of Square (WSS) as delineated in our Equation 1,

$$WSS = \sum_{j=1}^{k} \sum_{i \in C_j}^{n} ||x_i^j - c_j||^2, \quad (1)$$

with $k$ representing the number of clusters, $n_i$ is the count of data points in cluster $i$, $x_i$ an individual point, and $c_j$ is the centroid of the cluster $j$.

The k-means algorithm was implemented within a Python environment (see the complete algorithm in the link[1]). Initially, we employed the elbow method to determine the optimal number of clusters. This method helped us avoid arbitrary selection of cluster numbers and facilitated the identification of a clustering structure that best fit the data. To ensure robustness, we didn't settle on a single cluster solution; instead, we iterated the algorithm three times, each time evaluating a different number of clusters until an appropriate grouping was achieved.

## 3 Analysis and Discussion of Results

In our analysis, the pre-trained SBERT model was implemented using the Python programming language to generate sentence embeddings. We then produced an elbow method graph to assist in determining the appropriate number of clusters, which is depicted in Figure 4. This graph plots the number of clusters against the Within-Cluster Sum of Squares (WSS), represented by a blue solid line.

[1] https://bit.ly/energy-cluster-br

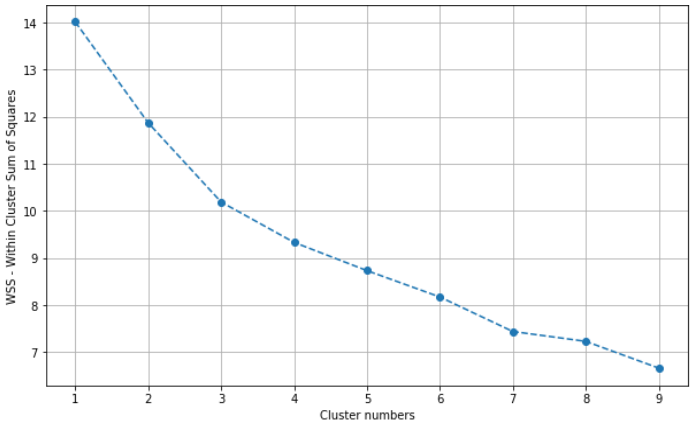


**Fig. 4.** - Elbow Method for Optimal Number of Clusters.

Conventionally, the 'elbow point' on the graph indicates the optimal cluster count, providing a balance between maximizing variance explanation and minimizing model complexity. However, as indicated in Figure 4, our analysis revealed an absence of a discernible elbow, which could suggest a high dimensionality in the data or a uniform distribution of the distances in the multidimensional space. This result necessitates a more nuanced approach to cluster determination and potentially the exploration of alternative clustering methods or dimensionality reduction techniques to better elucidate the underlying structure of the data.

Faced with the challenge of an indistinct elbow in the graph, we proceeded to form clusters with k values of 3, 4, and 5 to explore the data segmentation at various levels. We applied the k-means algorithm three separate times to these k values, each iteration visualized in Figure 5. For a detailed examination, we scrutinized the composition of each resulting cluster, as shown in the respective sub-figures: 5(a) for three clusters, 5(b) for four, and 5(c) for five clusters, with each analyzed within a spreadsheet format to facilitate comparison.

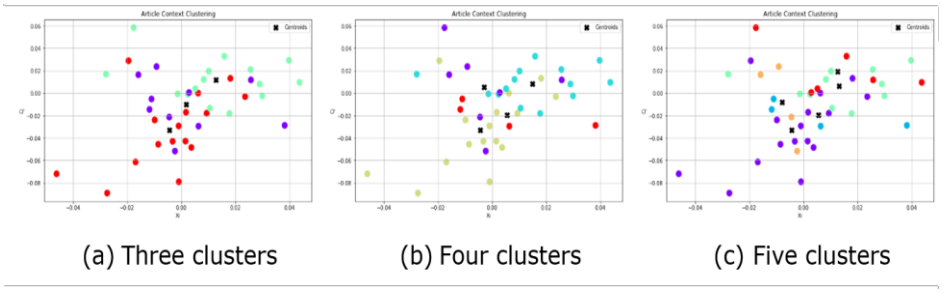


**Fig. 5.** Clustering visualizations.

Table 1 presents the groupings derived from our clustering process and offers a synopsis of each cluster's thematic focus. Notably, Clusters 1 and 0 encompass the

majority of the articles at 39.02% and 36.59%, respectively. The table's second column elucidates the prevalent topics within these clusters, with a marked emphasis on energy efficiency labels and the nuances of consumer knowledge in the realm of energy conservation.

**Table 1.** Grouping of the research carried out

| Cluster | Description | Percentile (%) |
|---|---|---|
| 0 | Consumer awareness of labelling and efficient products | 36.59 |
| 1 | Energy efficiency labelling | 39.02 |
| 2 | Energy Star energy efficiency and energy saving program | 24.39 |

These clusters reflect the distinct but interrelated facets of energy efficiency research. Cluster 0 centers on consumer awareness and understanding of labeling, while Cluster 1 is dedicated to the specifics of the labeling itself. Cluster 2 examines the broader scope of the Energy Star program and its effectiveness in energy savings. The distribution of articles within these clusters underscores the critical focus areas in the discourse on energy efficiency and conservation.

The prevalent topics in the literature, energy efficiency labels and consumer awareness of such labels and energy-efficient products, draw significant attention. These labels serve as universal indicators that allow consumers to differentiate between products based on efficiency, transcending language barriers [31]. Studies indicate that effective labels not only guide consumers to make better choices but also contribute to a broader energy-efficient landscape [49].

Additionally, energy labels are seen as pivotal in leading consumers towards products with lower lifetime costs, thus benefiting both the individual and society by reducing energy consumption [50]. Recommendations for future work underscore the importance of reinforcing energy labelling to foster sustainable advancements in household appliances within the European context [31]. In other words, by disseminating information about household appliances to consumers through energy efficiency labels, it is expected that manufacturers will feel encouraged to design and market more energy efficient products, thus reinforcing technological innovation with better prices and products [13 ].

Since 2003, Brazil has mandated energy efficiency labels on products, with each household appliance line bearing its own label, reflecting unique technical characteristics and efficiency grades [45]. The labels employ a color-coded system, ranking products from 'most efficient (A)' to 'least efficient (C to G)', with other salient features highlighted. Post-implementation of these labels, a shift in consumer behavior was noted, with increased sales of 'A' rated appliances and a decrease in lower-rated products [47].

Studies investigating consumer behavior reveal varied familiarity and purchasing trends influenced by factors such as ethnicity and housing status. For instance, Hispanics and Asians were found to be less acquainted with the Energy Star label, prompting suggestions for multilingual program advertising and extended incentives to renters [14]. In the U.S., the willingness to pay a premium for Energy Star-labelled

products was documented, with consumers influenced by both private and public benefits [15].

In Brazil, the impact of compulsory energy labelling was scrutinized using a structural model of appliance choice. Findings highlighted consumer underestimation of energy costs and a modest product switch rate post-program initiation, which paradoxically led to an increase in energy efficiency even as larger, slightly more energy-consuming refrigerators were purchased [45].

The importance of energy efficiency programs, supported by public and/or private incentives for reliable and efficient certified products, is also noted. Such initiatives are critical in reducing information asymmetry [2][3]. The U.S. Energy Star program, recognized by 90% of American households, exemplifies a successful voluntary initiative and has set an international benchmark for energy efficiency [8][14][15][28][51].

Parallel to the Energy Star, Brazil introduced the PROCEL energy saving label in 1993. This label, part of the Brazilian Labelling Program (PBE), marks appliances that perform well in category 'A' for efficiency and are indicative of other quality attributes. The nation's ambitious energy-saving goals include a 11.57 percent reduction in total electricity consumption by 2030, as delineated in the 2011 National Energy Efficiency Plan (PNEF) by the Ministry of Mines and Energy (MME), consistent with the projections of the National Energy Plan 2030 [48]. An analysis of the 2001-2010 period underlines significant energy savings, particularly in refrigerators and air conditioners, with a more pronounced proportional reduction in consumption when compared to electric motors, which, however, have a larger energy impact due to their pervasive use and operational durations [47].

## 4 Conclusions

In this study, we conducted a systematic review to map the energy efficiency landscape, employing natural language processing to thematically categorize the literature. Our subsequent analysis revealed the intricate relationship between the identified themes and their application within the Brazilian context.

The body of research underscores the importance of energy efficiency programs and the influence of clear, well-explained labels on consumer behavior. The studies collectively suggest that consumer education and the widespread dissemination of energy programs are vital in driving energy-efficient choices. Specifically, the research points to informational campaigns as a key factor in fostering energy-efficient behaviors.

In Brazil, the adoption of the Energy Efficiency Law correlates with an uptick in the purchase of high-efficiency (category A) products and a decline in less efficient ones. However, the research indicates a persistent gap in consumer understanding regarding energy costs—a gap that remains even with the presence of energy labels. This lack of awareness often leads to choices that only offer marginal gains in efficiency.

For future initiatives, it is recommended to undertake a deeper evaluation of the Brazilian Labeling Program to assist its effectiveness domestically. An ideal strategy

would address both the classification of products and the elevation of consumer consciousness regarding actual energy savings. By doing so, the aim is to enhance not just the perception of efficiency but also the realization of its benefits in terms of reduced overall energy consumption.

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**Appendix 1.** Main conclusions of selected articles

| Author | Main conclusions |
|---|---|
| [06] | Experience in North America and numerous European studies show that minimum energy efficiency standards for appliances are the most cost-effective way to achieve deep cuts in electricity consumption in Europe. |
| [07] | Energy Star has a proven track record in its established programs, saving 740 petajoules of energy and avoiding 13 million tones of carbon emissions. |
| [08] | Since 1992, Energy Star has become a brand recognized by a significant number of consumers and a collaborative effort that brings together a variety of separate market transformation programs. |
| [09] | Identified seven pillars: (1) Government support and credibility, (2) Budget, (3) Promotion and partnerships, (4) Label clarity, (5) Target product category, (6) Legislative mandates, and (7) Incentives. |
| [10] | Proposed energy label for electric fans in Malaysia, which could be used elsewhere to save energy and indirectly reduce greenhouse gas emissions. |
| [11] | The US EPA ENERGY STAR Product Specification Development Team drives the growth of the program by providing new specifications. Developing a successful ENERGY STAR specification depends on asking the right questions about a product and then carefully collecting the relevant data. |
| [12] | By 2006, US EPA ENERGY STAR products had saved 4.8 EJ of primary energy, $47 billion in energy bills (at a 4% discount), and avoided the equivalent of 82 Tg C (eq). |
| [13] | For the five main household appliances, the lack of awareness of the energy label can lead to a significant bias in both the estimates of the adoption rates of the appliances in the class. |
| [14] | That while overall awareness of the Energy Star label may have increased, certain racial and ethnic groups appear to remain relatively unaware of the Energy Star label, namely Asians and Hispanics. This suggests that the EPA may need to use different marketing techniques to target information about the Energy Star label to these populations. |
| [15] | The preferences for ENERGY STAR refrigerators are motivated by private (energy cost savings) and public (environmental) benefits. Preference for ENERGY STAR refrigerators decreases with age, but is stronger among men than women. |
| [16] | Suggestions for improving China's labelling system should include Improving relevant laws, regulations and policies; Standardizing energy efficiency class standards; Playing an important role in corporate environmental management; Improving the social monitoring system; Raising consumer awareness of environmental protection and energy saving. |
| [17] | The results show that providing information on operating costs or emissions increases the efficiency of the willingness to pay. |
| [18] | The subsidy system is not a good policy instrument for promoting energy efficiency. The application shows that a combination of a tax and a subsidy can be designed to facilitate |

| | |
|---|---|
| | the implementation of market-based instruments while improving the efficiency of energy policy. |
| [19] | Recommend that the HPwES program: evolve to better meet the needs of specific types of sponsors; implement a national marketing campaign; establish closer links with other DOE programs; and conduct research to better determine the programs impact and awareness of energy savings. |
| [5] | The Minimum Energy Performance Standard (MEPS) for frost-free refrigerators in India, equivalent to a 1-star rating, is very high, allowing very high consumption models to be sold on the market. Recommend a significant reduction in MEPS consumption. |
| [20] | That using the Elaboration Likelihood Model (ELM) and the Theory of Planned Behavior (TPB) together to design, monitor and evaluate such programs is a promising approach. |
| [21] | Show that the majority of consumers choose energy-efficient appliances because they can save money on their electricity bills. The continuing rise in electricity prices and the long lifespan of the appliances were two possible reasons for this finding. Consumers did not have in-depth knowledge of the scheme. |
| [22] | To promote green appliances, the authors recommend that the South Korean government expand the list of mandatory items included in its labelling program. For manufacturers, it's important to emphasize that consumers appropriately associate information about energy efficiency and respect for the environment with a reasonable monetary value. The that appliance manufacturers focus on improving energy efficiency levels and obtaining environmental labels. |
| [23] | That rebate policies increase the share of sales of ENERGY STAR appliances by 3.3 to 6.6 percentage points, which translates into an impact of 9 to 18 percent on the average level of sales of ENERGY STAR appliances in the US between 2001 and 2006. The ENERGY STAR rebates increase the use of energy-efficient appliances. |
| [24] | The energy label concerns consumers, it must be adapted to local consumer preferences while providing useful and understandable information. This study is based on consumer research conducted on a sample of the population and includes constructive suggestions from the respondents. |
| [25] | The importance of better consumer education and communication on the part of manufacturers, consumer organizations and legislators. |
| [26] | Sales of high-efficiency appliances increase significantly in the long term as a result of the policy. Both the announcement and the physical implementation of the new label in shops have a significant effect. |
| [27] | The revision of the current EU energy label to make the lifetime cost of energy more visible. More generally, they show that lifetime cost information is a key determinant of purchase decisions, in contrast to the indicative information provided by the EU energy label. |
| [28] | The results do not prove that households with Energy Star (ES) appliances use less energy than those without ES appliances. Some of the factors that may reduce the energy savings of ES labelled appliances include a behavioral rebound effect or lack of enforcement of the standard. |
| [29] | Exposing consumers to non-energy related appliance features may discourage them from choosing energy efficient appliances, while providing information on running costs in the EU energy label leads to more energy efficient choices when consumers face typical market trade-offs between energy efficiency and purchase price. |
| [30] | The providing information on the duration of the program on the energy label would also be effective, but requires consumers to be able to understand it correctly. |
| [31] | The energy labelling system is outdated and should be fundamentally revised to take into account consumer behavior or inappropriate choice of program. |

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| [32] | The ideal system would be one that motivates and challenges manufacturers to develop more energy-efficient products. This will encourage consumers to demand more energy-efficient products, while reducing their overall expenditure. |
| [33] | The rural households with higher per capita income, larger size and living area are more likely to purchase energy-efficient labelled appliances. Providing subsidies for energy-efficient appliances to rural households in rural China may encourage the choice of energy-efficient appliances. |
| [34] | The regulatory changes to MEPS and energy labelling that took effect in 2011 generally increased the share of sales of A+ and better labelled appliances and decreased the share of sales of A and <A labelled appliances in the eight EU countries included in the sample. |
| [35] | When the rescaled labels are presented alone, the rescaled A to G labelling scheme significantly increases the estimated purchasing power for the highest rated refrigerators compared to the previous A+++ to D labelling scheme. |
| [36] | The consumers generally do not understand the unit of measurement of energy consumption provided on energy labels. Providing additional information in monetary terms is technically challenging, but would reduce this knowledge gap, according to the participants. |
| [37] | Promotion of financial education programs and tools specific to the energy sector in order to increase the uptake of energy efficient durable goods. |
| [38] | The energy cost information on labels facilitates comparison of refrigerators based on energy efficiency and leads to a positive willingness to pay for higher levels of energy efficiency. |
| [39] | The majority of consumers still seem to be unfamiliar with the new format of the efficiency label for household appliances and have problems understanding the information on energy consumption and technical information. |
| [40] | The addition of energy cost information to energy labels does not affect the overall likelihood of purchasing a refrigerator, but does shift the distribution of purchases from higher rated A+++ products to lower rated and lower priced products. |
| [41] | The majority of people do not currently recognize the new energy classes and that there is some confusion among consumers about the new energy efficiency labelling system. |
| [42] | The consumers have responded positively to the labels, with 88,11% of respondents willing to pay for better quality appliances that promote a safer environment. |
| [1] | The consumers were more likely to choose more energy efficient air conditioners when the information was presented in terms of estimated cost per hour or using an Energy Star rating. |
| [43] | The energy labelling program and the three-subsidy program promoted households' choice of energy efficient refrigerators, but the effects of the different subsidy program differed, with the trade-in subsidy being less effective in promoting the sale of energy efficient refrigerators. |