UNIVERSIDADE ESTADUAL PAULISTA
"JÚLIO DE MESQUITA FILHO"
Câmpus de Sorocaba

PROGRAMA DE PÓS-GRADUAÇÃO em
Ciências Ambientais

Fábio de Oliveira Neves

Methodology for Assessment Energy Efficiency in the Industrial Sector

Sorocaba

2022

Fábio de Oliveira Neves

Methodology for Assessment Energy Efficiency in the Industrial Sector

Thesis presented as a requirement for obtaining the title of Doctor of Environmental Sciences at the São Paulo State University "Júlio de Mesquita Filho" in the Area of Concentration Diagnosis, Treatment and Environmental Recovery

Supervisor: Prof. Dr. Sandra Regina Monteiro Masalskiene Roveda
Co-Supervisor: Prof. Dr. Andrea Trianni
Prof. Dr. Eduardo Verri Liberado

Sorocaba

2022

Neves, Fábio de Oliveira.

N518m Methodology for assessment energy efficiency in the industrial sector / Fábio de Oliveira Neves. – Sorocaba, 2022.
179 p.
Tese (Doutorado) – Universidade Estadual Paulista (Unesp), Instituto de Ciência e Tecnologia, Sorocaba

Orientadora: Sandra Regina Monteiro Masalskiene Roveda
Coorientador: Andrea Trianni
Coorientador: Eduardo Verri Liberado

1.Energy industries. 2. Fuzzy sets. 3. Technology. 4. Industry. 5. Decision-making Mathematical models. I. Título.

Sistema de geração automática de fichas catalográficas da Unesp. Biblioteca do Instituto de Ciência e Tecnologia, Sorocaba. Dados fornecidos pelo autor(a).
Essa ficha não pode ser modificada

unesp

UNIVERSIDADE ESTADUAL PAULISTA

Câmpus de Sorocaba

CERTIFICADO DE APROVAÇÃO

TÍTULO DA TESE: Methodology for Assessment Energy Efficiency in the Industrial Sector

AUTOR: FÁBIO DE OLIVEIRA NEVES

ORIENTADORA: SANDRA REGINA MONTEIRO MASALSKIENE ROVEDA

COORIENTADOR: EDUARDO VERRI LIBERADO

COORIENTADOR: ANDREA TRIANNI

Aprovado como parte das exigências para obtenção do Título de Doutor em CIÊNCIAS AMBIENTAIS, área: Diagnóstico, Tratamento e Recuperação Ambiental pela Comissão Examinadora:

Profª. Drª. SANDRA REGINA MONTEIRO MASALSKIENE ROVEDA (Participaçao Virtual)
Engenharia Ambiental / Unesp ICT Sorocaba

Prof. Dr. ANTONIO CESAR GERMANO MARTINS (Participaçao Virtual)
Departamento de Engenharia Ambiental / Instituto de Ciencia e Tecnologia UNESP Campus de Sorocaba

Profª. Drª. GRACIELE PARAGUAIA SILVEIRA (Participaçao Virtual)
Departamento de Física, Química e Matemática (DFQM) / Universidade Federal de São Carlos - Campus Sorocaba

Prof. Dr. JOSÉ LUIZ PEREIRA BRITTES (Participaçao Virtual)
Faculdade de Ciências Aplicadas (FCA) / Universidade Estadual de Campinas (UNICAMP)

Prof. Dr. ROBERTO AKIRA YAMACHITA (Participaçao Virtual)
Centro de Excelência em Eficiência Energética / Universidade Federal de Itajubá

gov.br Documento assinado digitalmente
ROBERTO AKIRA YAMACHITA
Data: 23/03/2022 15:42:04-0300
Verifique em https://verificador.iti.br

Sorocaba, 11 de março de 2022

I dedicate this work to my family and the world friend

ACKNOWLEDGEMENT

First, I would like to thank all my friends and family who during these four years understood my physical absence. You managed to do without my jokes and puns!

To all my professors in whom I had the happiness and opportunity to be educated and prepared for this moment, from kindergarten to graduate school. You all carry the world on your back. My sincere thanks!

The Prof. Dr. Sandra Regina Monteiro Masalskiene Roveda for the guidance of an “unknown”. To professors Andrea Trianni and Eduardo Verri Liberado for their co-orientation and help in the other works. To Professor Fernando Pinhabel Marafão for his initial help in the doctoral project. And to professors José Arnaldo Frutuoso Roveda and Antônio César Germano Martins for their supervision during their teaching internship. Thank you for the clarity in the teachings and for the coexistence during this doctoral period.

To Drs. Antônio César Germano Martins, José Luiz Pereira Brittes, Roberto Akira Yamachito, Graciele P. Silveira, Henrique Ewbank, Fernando Pinhabel Marafão and Magda da Silva Peixoto for accepting the challenge of being part of the examining board and helping to build the research through their contributions.

I would also like to thank the undergraduate and graduate students along with technical workers who sustaining the university along with the faculty.

To the LABGEMM laboratory, I thank you on behalf of Giovana. Which I was part of for 2 years, mainly to my partners and ex-lab partners with whom I had a great relationship.

To all the companies that responded to the questionnaires so that I could compose the case studies. Thank you very much!

To Capes for providing me with financial support through a scholarship.

And finally, all those who work and worked, or even fell, during the Covid-19 pandemic. In addition to those who fight for a public, free, secular, inclusive and quality university, all my affection and respect. The future belongs to us!

EPIGRAPH

And then what do you want?

"I creaked the sheets of newspaper
Opening their blinking eyelids.
And soon
from every distant border
A smell of gunpowder rose
Chasing me home.
in these last twenty years
there’s nothing new
in the roar of storms
we are not happy,
That’s right
But also why
Would we be sad?
the sea of history
Is busy.
the threats
and the wars
We will have to cross them.
Break them in half,
cutting them
How a keel cuts the waves"
Vladimir Maiokóvski
Own translation

EPIGRAPH

Vício da fala

Para dizerem milho dizem mio
Para melhor dizem mió
Para pior pió
Para telha dizem teia
Para telhado dizem teiado
E vão fazendo os telhados
Oswald de Andrade

ABSTRACT

Energy efficiency (E.E.) is vital for the technological development of a country, as it is intrinsically linked to the daily lives of people, public and private institutions, being a demand for national sovereignty, in addition to having enormous potential to avoid greenhouse gas emissions. However, the reduction of energy consumption has been decreasing, a trend that has important implications for consumers, companies and the environment. The increase in EE is linked to the type of sector and contribution, which is characterized by its intensity, as in the case of the industrial sector. Specifically, Brazil is currently the sixteenth country in industrial production, with a large part of its production coming from small and medium-sized companies. The absence of methodologies for EE assessment has driven a considerable part of the industrial sector to not have a safe direction in conducting the reduction of energy consumption. Thus, this thesis has as its central objective to build a metric to assist in the assessment of energy efficiency of small and medium-sized companies in Brazil. For that, using fuzzy logic, two analyzes were built to develop an assessment of the main priorities that the company should adopt. One measure is composed of a criticality index, which describe the company's main critical points considering aspects of environmental quality, cost management and industrial management in relation to EE measures, and the second by the technological improvement index that checks the main gaps of the predominant technologies of the production system: engine, lighting system, air conditioning, air compressor, refrigeration system, heating system, ventilation system, boilers and condensers. Seven case studies of companies from different industrial sectors were analyzed, in which an energy efficiency rating range was assigned through the criticality and improvement index. The analysis point out that most of the companies are within the critical range for aspects of industrial management and very inappropriate for improvement rates. In addition to these conclusions, the model indicated which actions should be taken for companies to complement or reach the energy consumption considered satisfactory. The developed model is an important tool for decision-making in small and medium-sized companies due to the different approaches contained in its structure.

Keywords: Energy efficiency. Small and Medium Enterprises. Fuzzy Logic. Criticality Index. Technological Gap.

RESUMO

A eficiência energética (E. E.) é vital para o desenvolvimento tecnológico de um país, pois está intrinsecamente ligada ao cotidiano das pessoas, instituições públicas e privadas, sendo uma demanda por soberania nacional, além de possuir enorme potencial para evitar as emissões de gases de efeito estufa. Todavia, a redução do consumo de energia vem diminuindo, tendência que tem implicações importantes para consumidores, empresas e meio ambiente. O aumento da EE está atrelado ao tipo de setor e contribuição, que se caracteriza pela sua intensidade, como é o caso do setor industrial. Especificamente, o Brasil, atualmente, é o décimo sexto país em produção industrial tendo em sua grande parte da sua produção proveniente de pequenas e médias empresas. A ausência de metodologias para avaliação da EE tem impulsionado parte considerável do setor industrial a não ter direcionamento seguro na condução da redução do consumo energético. Desta forma, esta tese tem como objetivo central construir uma métrica para auxiliar na avaliação da eficiência energética das pequenas e médias empresas no Brasil. Para tanto, por meio da utilização da lógica fuzzy foram construídas duas análises para desenvolver uma avaliação das principais prioridades que a empresa deverá adotar. Uma medida é composta por um índice de criticalidade, que descreve os principais pontos críticos da empresa considerando aspectos de qualidade ambiental, gestão de custos e gestão industrial em relação às medidas de EE, e a segunda pelo índice de melhoria tecnológica que verifica as principais lacunas das tecnologias predominantes do sistema produtivo: motor, sistema de iluminação, ar condicionado, compressor de ar, sistema de refrigeração, sistema de aquecimento, sistema de ventilação, caldeiras e condensadores. Foram analisados sete estudos de casos de empresas de diferentes setores industriais. Em que foi atribuído, através, do índice de criticalidade e de melhoramento uma faixa de avaliação de eficiência energética. Foram avaliados sete estudos de casos com empresas de diversos setores industriais, verificando que a maioria está dentro da faixa crítica, para aspectos de gestão industrial e muito inapropriado para os índices de melhoramento. Além dessas conclusões, o modelo indicou quais ações devem ser tomadas para que as empresas complementem ou alcancem os consumos de energia considerados satisfatórios. O modelo desenvolvido mostra-se uma importante ferramenta para a tomada de decisão de pequenas e médias empresas devido às diferentes abordagens contidas na sua estrutura.

Palavras-chave: Eficiência energética. Pequenas e Médias Empresas. Lógica Fuzzy. Índice de Criticalidade. Gap Tecnológico.

LIST OF ABBREVIATIONS

EE	Energy Efficiency
PDE	Ten-Year Energy Plan
IEA	International Energy Agency
PROCEL	National Energy Conservation Program
PROESCO	Support for Energy Efficiency Projects
PEE	Energy Efficiency Programs
SMEs	Small and medium-sized enterprises
MEI	Individual Micro-Entrepreneur
ME	Micro Enterprise
EPP	Small Business
MSMEs	Micro Small and Medium Enterprises
GHG	Greenhouse Gases
IBGE	Brazilian Institute of Geography and Statistics
ISO	International Organization for Standardization
HVAC	Heating, Ventilation, and Air Conditioning
IPCC	Intergovernmental Panel on Climate Change
NDCs	Determined National Contribution
CCUS	Carbon Capture, Utilization and Storage
OECD	Organization for Economic Cooperation and Development
BTU	British Thermal Units
MME	Ministry of Mines and Energy
CONSERVE	Electricity Conservation Program
PBE	Brazilian Labeling Program
RGR	Global Reversion Reserve
ENCE	National Energy Conservation Label
CONPET	National Program for the Rationalization of Use of Oil and Natural Gas Derivatives
PDCA	Plan-DO-Check-Act
IAC	Industrial Assessment Center
ARC	Assessment Recommendation Code
US	United States

CTMotores	Technical Committee of Motors
CEPEL	Electric Energy Research Center
EEM	Energy Efficiency Management
VSDs	Variable-Speed Drives
VFD	Variable Frequency Drives
KPIs	Key Performance Indicators
PF	Membership Function
ECCi	Electrical Capacity of the Indicator
DMi	Electrical Demand
UEEi	Each Indicator and Electricity Usage
ECCk	Standardized Electrical Capacity
GAT	Gap Technological
SEBRAE	Brazilian Support Service for Micro and Small Enterprises
DIEESE	Inter-union Department of Statistics and Socioeconomic Studies
ESCOS	Energy services companies

LIST OF FIGURES

LIST OF TABLES

SUMMARY

I INTRODUCTION

Discussions related to energy demand have been increasingly linked to the concept of its efficiency and its preponderant role in environmental behavior and global energy policies, especially those related to climate change (COILIN et al., 2020; HUANG et al., 2017; WORRELL et al., 2009). According to a report by the Global energy & CO_2 Status Reset (International Energy Agency) (IEA/INTERNATIONAL ENERGY AGENCY, 2019a), two thirds of the total emission of greenhouse gases and 80% of the emission of carbon dioxide (CO_2) are related to energy issues. Consequently, sustainable development and the reduction of emissions from the energy sector to mitigate climate change involve the promotion of clean and efficient energy, becoming part of the integral aspects of the planning, analysis, and formulation of energy policies (IEA/INTERNATIONAL ENERGY AGENCY, 2017).

According to data released by (INTERNATIONAL PAINEL ON CLIMATE CHANGE, 2021a), climate events arising from CO_2 emissions will multiply. Even if atmospheric carbon is neutralized, the temperature will increase 1.5ºC above pre-industrial levels, consolidating the occurrence of extreme climatic effects (INTERNATIONAL PAINEL ON CLIMATE CHANGE, 2021a). Furthermore, without a drastic reduction in emission of carbon dioxide, the forecast for the 21st century will exceed 2ºC in relation to pre-industrialization. The effort to reduce CO_2 involves the cultural displacement of the main emission engines, such as the industrial one.

Added to that, data released by the International Energy Agency (IEA/INTERNATIONAL ENERGY AGENCY, 2017) point to the growth of the global economy and show that by 2040 energy consumption is expected to increase by about 30%, and that the world population is expected to reach 9 billion people, mainly concentrated in the urban areas. These environmental and economic influences triggered by the increase in energy demand tend to cause social impacts resulting from the large population growth. In this sense, worldwide efforts have been made to ensure management policies that encourage access to modern forms of energy and its improvement in efficiency as a strategy to enable environmental gains.

In Brazil, discussions on energy efficiency have their initial framework established by Law nº. 10.295, which defines the National Policy for Rational Use and Energy Conservation and by Decree nº. 4.059, of December 2001, which regulated this law, defining procedures to establish energy efficiency indicators and levels. Since then, national planning related to promoting its efficiency and the use of renewable energy sources has been presented in the Ten-

Year Energy Plan (PDE) (BRASIL, 2001). This plan is designed to express the government's prospects for expanding the energy sector based on the following dimensions: economic, strategic, and social. Currently, it also considers the conditions assumed under the Paris Agreement, linked to the national policy on mitigation and adaptation to climate change.

The PDE points out aspects of energy efficiency that must be resolved in different sectors. For the industrial sector, which is the largest energy consumer in the country, the following highlights:

“investments in energy efficiency are not prioritized because of the lower weight of the energy cost in most segments, due to the lack of an industrial culture that gives importance to EE and difficulty in measuring results”(BRASIL, 2016a).

These restrictions lead to difficulties in motivating management changes. There is a hindrance to encourage them to transform their organizational culture by innovating and taking on new risks, having greater investments in new technologies and processes that prioritize tangible results.

With the recent association of Brazil with the International Energy Agency (International Energy Agency - IEA), the country gains prominence in the global energy debate (BRASIL, 2017c). However, the promotion of national energy efficiency still needs attention (integration of energy elements planned and designed to establish an energy policy and objectives). Although there are well-established initiatives such as, for example, the National Energy Conservation Program - PROCEL, Support for Energy Efficiency Projects - PROESCO and the Energy Efficiency Programs – PEE “a more effective action is necessary to, in fact, insert energy efficiency as an instrument of competitiveness” (BRASIL, 2016a).

The PROCEL presents some energy efficiency improvement programs that, without them, the energy issue in Brazil would possibly go into decline. The most productive Brazil program (B+P) which aims to increase the productivity and competitiveness of Brazilian SMEs, the ALIANÇA program which seeks the EE of energy-intensive industries and the structure of the industrial sector through studies and standardization. The methodology proposed in this thesis would contribute to the development of the three programs proposed by PROCEL and to the reduction of industrial energy consumption (BRASIL, 2022).

It is worth noting that the industrial sector accounts for some important characteristics of national energy consumption: 32.6% of energy expenditure with perspectives of 47% for the year 2026. Energy conservation will represent 5% of the final demand expected for 2026 and

7% of the total electricity consumption for the year 2050. By 2050, gains in energy efficiency can reach 19% of industrial consumption (BRASIL, 2016b).

According to the Brazilian Institute of Geography and Statistics (BRASIL, 2017a), small and medium-sized enterprises (SMEs) correspond to 85% of the Brazilian industrial sector. With a total of 1,738,021 companies, of which 1,054,998 are Individual Micro-Entrepreneur (MEI), 571,219 Micro Enterprise (ME) and 111,804 Small business (EPP) (BRASIL, 2021). In this scenario, (YOSHINO, 2003) and (ARAÚJO, 2017) pointed out structural barriers for the implementation of measures and assessments of energy efficiency in Brazil. Among them, the following stand out:

- information barriers: ignorance about the company's physical, structural and organizational energy consumption.
- technical barriers associated with the size and low technological capacity of industries.
- institutional barriers: the lack of knowledge and the reality of companies indirectly affect MSMEs and the design of programs to rationalize the use of energy, which are generally unsuitable for all micro, small and medium-sized companies.
- economic and financial barriers: uncertainties about future energy prices, especially in the short term.
- organizational barriers: organizational capacity is mandatory for the implementation of energy efficiency programs.

Asymmetric events such as the COVID 19 pandemic and wars such as the one in Eastern Europe alter the flow of energy consumption. According to the International Energy Agency, the energy sector was severely affected by repeated lockdowns in 2020 stemming from Covid 19, as the deceleration of several economic sectors, such as the industrial around the world, reducing energy usage by 4% of the total value. However, even as the waves of the pandemic continued to roll out across the world, in 2020, stimulus packages and vaccine rollouts allowed much economic activity to return, and global energy demand was seen recovering by 4.6% in 2020. 2021, surpassing pre-pandemic levels. In the war in which it takes place in Eastern Europe, Russia is the main exporter of Ural, a semi-acid oil, which is easily distributed, mainly consumed in some European countries. In addition to this, with the sanctions imposed on Russia, Europe has been suffering from the lack of energy from oil and gas in Eastern Europe, consequently, part of Europe will experience economic and social difficulties due to the need for energy to supply its various sectors. Showing that any dissonant event that alters the relationship of energy use, socio-economic factors are altered, harming the quality of various sectors and actors, like the industrial.

Furthermore, in energy management, it is easy to make decisions when there are mechanisms for measuring results, such as the performance of an energy initiative put into practice, as shown by Cagno et al. (2010) that verifies the main environmental and economic critical points and improvement in companies in northern Italy and, Neves et al. (2022) which shows which are the main economic and production-related factors that affect energy performance. Both works outline that qualitative campaign actions within companies can determine their respective desired performance.

The literature has shown the existence of two distinct approaches for the characterization of EE measures, in which both have been built since the 1960s. The first one proposes particular measures based on lists of attributes (BERNDT, 1978; MICKOVIC; WOUTERS, 2020; PYE; MCKANE, 2000; SKUMATZ; DICKERSON, 1998; SKUMATZ; GARDNER, 2005; WAGNER; MATHUR, 2013; WORRELL et al., 2009; ZHANG et al., 2018). In general, the characterization is made showing the economic aspects. In the second approaches, some authors seek to establish a structure capable of incorporating a more general set of attributes (FLEITER; HIRZEL; WORRELL, 2012; HAN et al., 2020; LUNG et al., 2005; MILLS; ROSENFELDS, 1996; MOKHTAR; NASOOTI, 2020; TAYLAN; KAYA; DEMIRBAS, 2016; TRIANNI et al., 2019; TRIANNI; CAGNO; DE DONATIS, 2014; WORRELL et al., 2003). In this perspective, (WORRELL et al., 2003) propose a methodology to indicate the potential for improving EE in an industry or sector, in which they include productivity benefits in EE assessments, thereby doubling their cost-benefit ratio and economic evaluation. (FLEITER; HIRZEL; WORRELL, 2012) group the attributes by areas, presenting political points of view to decision-making managers, without, however, presenting relevant understandings, such as those related to energy, the environment and economic, social and other aspects. (TRIANNI; CAGNO; DE DONATIS, 2014) bring to light the characteristics of the attributes that help to understand the implementation of energy efficiency measures. These are organized into categories that include economic, environmental and energy aspects related to implementation, production and interaction with other systems. However, that authors emphasize that any reliable assessment of attributes, in general, is an extremely critical aspect, as they are not easily quantifiable. (SHI et al., 2020), builds a platform on the diffusion of energy efficiency technologies stating that energy efficiency measures should not be implemented abruptly and mistakenly. It is important to note that the works shown are of academic origin. In which the Italian and Swedish schools stand out

Still, (CAGNO et al., 2010) develop a rapid energy efficiency assessment methodology for critical points of excessive energy consumption in Italian SMEs, called priority index. That index is the result of the aggregation of environmental criticality measure and cost of SMEs with another measure of improving technological gaps, in which geometric mean and descriptive statistics were used to analyze the company's priority points. For the authors, the structure of a small and medium-sized company is so complex and diffuse that fundamental issues arise in industrial management, causing decision makers to leave issues related to energy improvement in the background.

In short, important studies have been developed in several European academic schools, but there are still ways to be taken in the search for a form of methodology that above all improves industrial EE in Brazil.

The difficulty in decision-making by industrial managers is mostly due to the qualitative nature of the energy indicators that end up influencing environmental costs and impacts. The various uncertainties in the generation and conservation of energy for the rational and efficient use of industrial EE bring with it incompatibilities for economic feasibility and management of environmental impacts.

One of the tools that assist and have the characteristic of working with qualitative indicators is fuzzy modeling. It allows the control of information in a rigorous way, considering the form:

- ✓ How imprecision and uncertainty are described, making them powerful enough to handle them more efficiently (BARROS; BASSANEZI, 2006; LEE, 1990),
- ✓ Allowing the reduction of complexity and implementation, becoming a solution to problems hitherto intractable by classical techniques (GUDWIN; GOMIDE, 1994; SANYA; BART, 2004).
- ✓ The fuzzy analysis process can be used as a diagnostic method for qualitative decision making, or be converted into a scalar proportional value for external performance by means of conventional actuators (SANYA; BART, 2004; ZADEH, 1978; ZIMMERMANN, 2001).

In this context, this doctoral research uses fuzzy logic as an adequate method to model problems that present obstacles in its analysis, such as those arising from energy efficiency.

With this, SMEs would have a diagnostic method to analyze how EE measures should be implemented.

II Objective

According to what was pointed out above, the central point of this thesis is to develop a methodology that can help decision makers to boost industrial energy efficiency, and that is capable of:

- characterize the main energy consuming areas of SMEs.
- analyze whether there are gaps in the managerial and technological relationship.
- check the industrial EE potential at critical and technological points
- suggest adaptations (in process or equipment) that lead to better energy efficiency of industrial facilities.
- build a mathematical model of using fuzzy logic

To achieve these capabilities, EE indicators applicable to the national industry were studied or developed.

III Motivation

In a context where the population increases and requires a growth in the consumption of products, the demand for production is part of a comprehensive discussion on aspects of sustainability linked to the productive sector. As this debate has become necessary as a turning point for the reduction of gases that causes the greenhouse effect, it is crucial to link organizations to a new order called green production that is consolidating itself in the productive economic scenario.

In Brazil, the industry sector is the main source of gas emission that cause greenhouse effect, from energy consumption. The annual energy balance of Brazil, exposed by the Energy Research Company (BRASIL, 2020a), shows that in 2020, the industry represented 32.1% of total energy consumption, being the first largest consumer sector followed by the energy sector transport (31.2%). Although the energy consumption of Brazilian industrial sector is be focused on the energy of concessionary, most of it come from renewable energy (electricity) and, some of its processes use non-renewable sources of energy. The International Energy Agency (IEA/INTERNATIONAL ENERGY AGENCY, 2020a) warns that if national governments do not make drastic changes in their national sovereignty political platform, the demand for energy will increase 1.3% per year until 2040, resulting in energy market tensions along with a continuous march of GHG emissions related to energy consumption, resulting in higher premature pollution-related deaths and in severe impacts on climate change by CO_2 emissions.

Concerning to environmental appeals, the definition of energy demand scenarios in the industry faces some uncertainties given the diversity and complexity of industrial processes. Coupled with the constant and direct influences of the domestic and foreign markets, according to the IBGE annual industrial survey (IBGE, 2021) the production losses represent around 20% of transformation costs, and companies consume twice what they need during the conversion process of raw materials and-or finished products. In this way, the efficient use of energy in industrial sectors becomes a necessary tool in reducing energy consumption and, consequently, in reducing costs, increasing productivity and industry competitiveness.

In normative terms, the International Organization for Standardization shows that ISO 50001 certification is still a few steps away from its implementation. Although it follows the dynamics of the same tool used in the implementation of ISO 9001 and ISO 14001 standards, other standards such as 5001 are effective when both are already consolidated (NEVES et al., 2022; REIS et al., 2018).

In light of it, energy used in industrial sector triggered a consumption growth in the period from 2010 to 2018 of 0.9% per year, corresponding in 2020 to 37% (156 exajoule (Ej)) of the final energy use and reaching 300 Ej in 2050, and this growth has been spurred to a large extent by a continuing long-term trend in energy-intensive sectors (IEA/INTERNATIONAL ENERGY AGENCY, 2021a).

The Brazilian Energy Research Company also believes that technological evolution and forms of production should become more efficient in terms of energy and choice of materials, reducing or replacing inputs. The Global energy efficiency shows that the load of industrial energy reduction can reach 18% of energy demand in 2050, considering that energy vectors have an important share in costs, since they represent approximately 20% of the total transformation costs, being cross-cutting technologies (non-specific technologies or related to their own production, which are used for several different production systems within industrial system) that comprise most of the energy consumption. Among the examples, systems powered by electric motors represent about 70% of the world's electricity consumption (CAGNO; TRIANNI, 2014; IEA/INTERNATIONAL ENERGY AGENCY, 2011; TRIANNI; CAGNO; DE DONATIS, 2014). The industrial lighting is the most widespread and accounts for about 5% of the world's electricity consumption (IEA, 2006). Compressed air can reach around 10% of industrial electricity consumption, while HVAC (heating, ventilation, and air conditioning) systems have a range of 10-20% of final energy consumption in some industrial contexts (CAGNO; TRIANNI, 2014; TRIANNI; CAGNO; DE DONATIS, 2014). Despite the relevance in terms of energy consumption, the rate of implementation of energy efficiency measures in cross-cutting technologies is still very low, often not exceeding 50% of the recommended actions (ANDERSON; NEWELL, 2004; BUNSE et al., 2011; CAGNO; TRIANNI, 2012).

It is important to note that these technologies are already used in many companies, but when used properly, it has good economic profitability and energy consumption. Other, more complex, and costly measures can be used in the medium and long term regarding increased productivity, improved product quality and reduced losses. Taking these measures is urgent considering the demands proposed in the Intergovernmental Panel on Climate Change (IPCC) that the global temperature increase should not exceed 2ºC compared to pre-industrial levels in order to not disturb the environment balance. Since there is a concrete possibility of this temperature increase of around 40 to 60%, and, that the targets for Determined National Contribution (NDCs) would still be below 24% of what is needed for 2050 (BRASIL, 2020b; INTERNATIONAL PAINEL ON CLIMATE CHANGE, 2018), the industrial sector has a clear indication that more needs to be done than what has already been proposed. In Brazil, according to the National Energy Balance Report in the year 2021, emissions from the industrial sector corresponded to 70.7 Mt CO_2^{-eq} (Millions of tons-equivalent of CO_2).

In short, the proposed methodology aims at contributing to reduce industrial energy consumption and addresses environmental, financial, and managerial aspects related to predominant technologies in the production process. Therefore, it also contributes to the compliance with Law 10,295, of October 17, 2001, of the National Conservation Policy and Rational Use of Energy and Decree 4059 of December 19, 2001, (ANNEL, 11).

In addition to those points, this work also introduces the following topics as a constituent of originality:

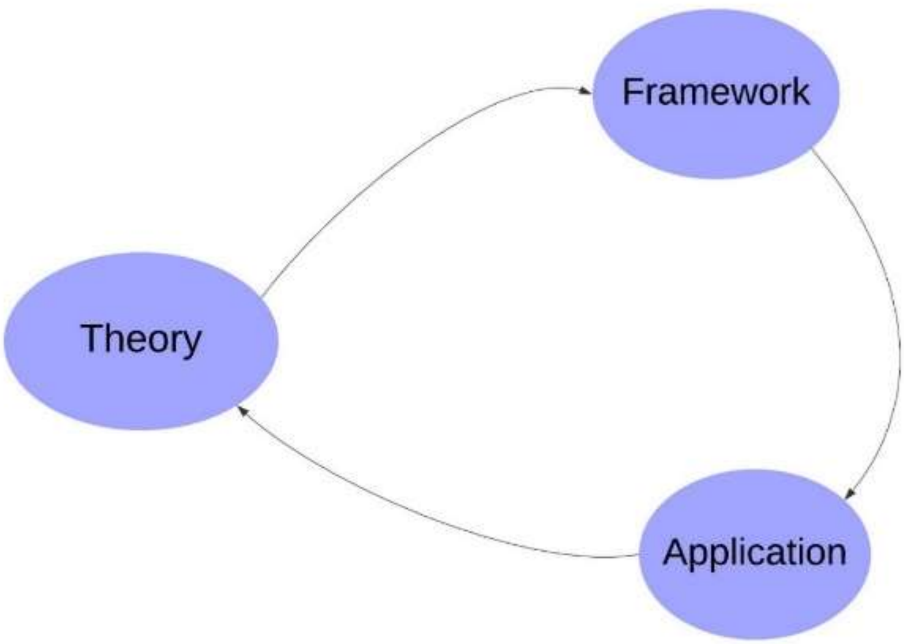
- Proposal of two method to assess energy efficiency in small and medium-sized companies as a support for decision-making for industrial managers.
- Use of a method for SMEs to ascertain the main points of energy consumption characterized by a low budget of energy management programs.
- A structured method that can contribute to the absorption of subjectivity in the decision making of the high energy consumption taken by industrial managers.

In conjunction with the aspects shown previously, this work also scientifically contributes to achieve the objectives of the national share determined for the reduction of the temperature and to cooperate with the reduction of the industrial sector energy costs, through clean industrial processes, expanding the measures for energy efficiency and low carbon infrastructure. Considering that Brazil needs to adopt public policies in line with a consolidated scientific base, there is a great scientific potential and applicability of this methodology in the Brazilian industrial sector.

IV Research methodology

This work follows the methodology proposed by (JENSEN, 2005) which involves three aspects: theory, framework and application. Thus, this work develops applications from academic theories on the subject, which are used to modify and improve the solutions in practical cases. Tools that most often use effective mathematical models' approach; and that consider that formal questions can be structured by various analyzes and applicable models through existing tools, such as fuzzy logic. They are synergistic vectors (Figure 1) for the transformation into a new tool, measure or methodology in the various sectors that make up the social environment, such as the industrial sector, in a new paradigm (MISHRA; ALOK, 2011).

Figure 1. Synergistic vectors for research methodology



Source: Adapted from (Jensen, 2005)

Still, the approach adopted to the research is the combined one, which uses the analysis of qualitative and quantitative data in a single study. The use of this approach allows using the combinations of both analyzes to offer a better understanding of the research, while alone, it allows the disadvantage of one method to be overcome by the advantage of the other (CRESWELL; PLANO CLARK, 2010). Both qualitative and quantitative methodology provides a better understanding of the construction of the methodology, as it can combine qualitative data generating quantitative metrics.

For the development of the model, the R software was used, through the Fuzzy R package. Since it is a free programming language.

V Thesis Organization

Introduction - presents the characteristics of the research scenario, the general and specific objectives, the motivation and the research methodology.

Chapter 1: Presents the general concepts related to energy efficiency in the industrial sector, so that it is possible to understand its application in research within the proposed model. In addition, the chapter presents the industrial profile and a taxonomy considering this field of literature.

Chapter 2: Presents the Reference Model proposed for the diagnosis of energy efficiency in the industrial sector. Chapter describes the indicators, the criticality index, and the improvement index for the 9 transversal technologies for EE diagnosis in the industrial sector.

Chapter 3: Presents the analysis and adequacy of the model through case studies from Brazil

Chapter 4: exposes the final considerations of the work and presents some proposals for future work.

1. LITERATURE REVIEW

This chapter proposes to develop a general review of the literature, which will address the Brazilian and world scenarios of energy efficiency with a focus on the industrial sector, in addition to building a taxonomy of industrial EE, using bibliometric analysis techniques, through a comprehensive and systematic review of the literature.

1.1 Scope of the chapter

The main objective of this chapter is to develop, through a literature review, the description of industrial EE scenarios in addition to developing a related framework for energy consumption of companies. For this, a wide and systematic literature review was developed through academic works: papers, conference works and books. To assist in the development of this systematic literature review, the following bibliometric analyzes were used. Content analysis that according to (BERELSON, 1952) "*is a research technique that aims to describe the manifest content of communication in an objective, systematic and quantitative way*". In addition to analysis of social networks, which according to (SILVA et al., 2006) are "*structures composed of nodes, or vertices, which are the actors of social networks, connected by a set of lines, or edges, which correspond to the ties between the actors*". Also, the main industrial performances responsible for the structure of industrial energy efficiency were surveyed.

In summary, Figure 1.1 provides an overview of Chapter 1.

Figure 1.1 shows the structure of chapter 1. the first block establishes the context in which the classification elements relevant to a classification metric, to be developed, are removed. the second block shows the mathematical treatment using fuzzy logic. And finally, the third and fourth blocks have the metric and its functions.

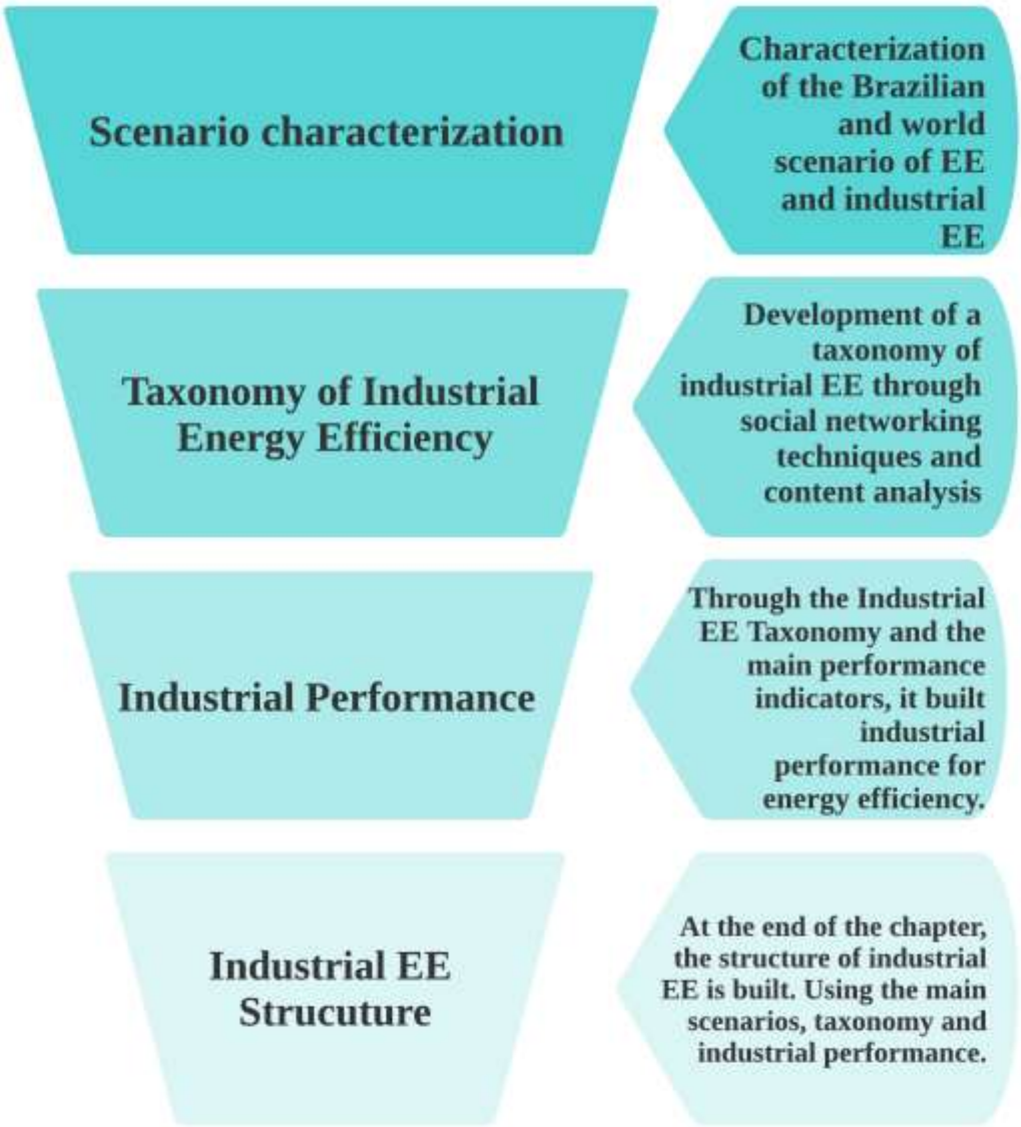
1.2 Energy efficiency

Energy efficiency has several facets, but within the industrial context, the most common is that it states that a system or a process to be efficient is when it reduces losses and optimizes the use of energy at its input. (MARTIN et al., 1999), (LOVINS, 2004). In any case, energy efficiency can be considered according to Equation (1.1).

$$E.E = \frac{output\ of\ goods\ or\ services, energy}{energy\ input\ into\ the\ system} \tag{1.1}$$

where it represents the amount of work produced (W) and the amount granted by a source to each unit of time,

Figure 1.1. Overview of the Structure of Chapter 1



Source: Own Authorship

In the sectors highlighted by the International Energy Agency (IEA/INTERNATIONAL ENERGY AGENCY, 2020b) (residential, industrial, transport, commercial, public services, fishing, agriculture and forestry), energy efficiency is represented in physical or economic terms, addressing technological progress towards the improvement of the productive system. Thus, the E.E, reflecting on the industrial sector in which the indicator energy production is defined as:

The Equation (1.2) represents energy efficiency in a manufacturing system.

$$E.E = \frac{production\ output}{power\ input} \tag{1.2}$$

where denotes the output rate of production.

For the industrial sector, the high energy efficiency, obtained by Equation 1.2, can give companies the necessary competitiveness to reduce costs, besides reducing energy consumption. Improving industrial energy efficiency is one of the most effective ways for companies to reduce greenhouse gas emissions.

One of the main strategies for reducing energy consumption is to seek energy efficiency in the machines, either through less power demand or process time, or increase production while maintaining constant energy consumption (THIEDE; BOGDANSKI; HERRMANN, 2012).

1.3 Energy scenario

The consumption structure using non-renewable and high-carbon energy sources is one of the main barriers to be faced for a more sustainable future from an environmental, social and economic point of view. According to the International Energy Agency's Carbon Capture, Utilization and Storage (CCUS) report (IEA/INTERNATIONAL ENERGY AGENCY, 2021b), strengthened climate goals and new investment incentives are providing unprecedented momentum for CCUS, with plans for more than 100 new facilities announced in 2021 of the industry to remove carbon from the atmosphere. While recent progress is encouraging, the planned pipeline of projects would fall far short of the 1.7 billion tonnes of CO_2 capture capacity deployed by 2030 in the Net Zero by 2050 scenario.

The energy matrix in which oil is the main source of fuel consumption reflects how the global primary energy demand policy will face several challenges if energy sources are to become mostly renewable and low carbon. In the last decades, global energy use has increased a lot, from 8,801,336 ktoe (1ktoe =1.163 GWh) in 1990 to 14,421,151 in 2018 (IEA/INTERNATIONAL ENERGY AGENCY, 2020a).

Still, energy performance is one of the main supports to guarantee economic growth as a sustainable tool. Therefore, the adoption of economic measures as an attitude to improve energy supply tends to generate social and economic development in each region.

The International Energy Agency (IEA/INTERNATIONAL ENERGY AGENCY, 2019b) projects an expansion of world energy consumption of approximately 50% in the period from 2018 to 2050, especially in countries that are not part of the Organization for Economic Cooperation and Development (OECD) and in regions where economic growth will be huge in the next annual period, such as Asia. It is estimated that the share of energy demand is dominated by Asian countries, corresponding to almost 50% of demand in any scenario. By 2040, the Asia-Pacific energy market will be almost twice the size of Europe and Anglo-Saxon

America combined, linked to the expansion of final energy consumption among the industrial sector outstands, including the sub-sectors: refining, mining, manufacturing, agriculture, and construction. In this specific case, non-OECD countries account for more than half of the end use of energy during the projection period. The trend for the global industrial sector is to increase by more than 30% in the period stipulated from 2018 to 2050, although in the year 2020 it had a decrease due to the pandemic of COVID-19. In 2050, global industrial energy consumption is expected to reach 315 quadrillion British thermal units (Btu) (1Btu = $2.93_{x}10^{-10}$ GWh) (IEA/INTERNATIONAL ENERGY AGENCY, 2020b).

In other sectors such as transport and construction, there is a tendency to increase, respectively, by 80% and 65% (48 quadrillion Btu). Being that increase in income, urbanization and broader access to electricity will also lead to an increase in energy demand. The growth in final energy consumption will result in a 79% increase in electricity, mainly as the quality of life of the population more broadly improves in non-OECD countries (IEA/INTERNATIONAL ENERGY AGENCY, 2020a). For (VAN RUIJVEN; DE CIAN; SUE WING, 2019) the implications of social energy vulnerability vary widely according to socio-economic development, differentiating them by their ability to adapt to the changing circumstances of the total energy demand.

Nevertheless, there is an increase in the trend of end-use energy through large campaigns and mobilizations for the generation of electricity from renewable sources, through public agencies such as the International Energy Agency. Sources such as solar, wind and hydroelectric have been had the fastest growing in this period, 3.1% of annual global consumption. The World Energy Outlook (IEA/INTERNATIONAL ENERGY AGENCY, 2019b) emphasizes that anticipated actions on GHG emissions using renewable sources remove probable uncertainties from technologies through conversion to electricity. Although a quarter of all electricity in the world was produced by renewable sources since 2017, the transition from using non-renewable to renewable sources has not been occurring at the speed expected to decrease the temperature estimated by the IPCC (1.5ºC at pre-established levels) (industrials), as from 2018 to 2019 there was an increase in CO_2 emissions of around 1.3% (BRIEF, 2020; INTERNATIONAL PAINEL ON CLIMATE CHANGE, 2018).

The Brazilian energy scenario started in the 1970s with the great crisis of the oil price shock, in which several actions were taken aimed at the conservation and use of its derivatives. In the same period, a great race for greater diversification of the energy matrix began, in a effort to ensure the demand for energy consumption, highlighting Proálcool (MME) as a successful project. From this period on, the Brazilian government perceives the need for projects and programs that make energy consumption feasible in a more efficient way, mainly for the industrial sector that mostly consumes energy derived from petroleum products, thus, in 1981, the program of energy efficiency Electricity Conservation Program - CONSERVE is launched in Brazil (PIMENTEL, 2011).

From then on, several planning means for the energy sector began to be developed to meet the demand directed to economic and infrastructure growth. Highlighting:

- Brazilian Labeling Program (PBE) – 1984
- National Electricity Conservation Program (PROCEL) -1985
- National Derivative Petroleum Conservation Program -1991
- Energy efficiency program (PEE) -1998
- Law nº 10295 National Policy for Conservation and Use of Energy -2001
- Building Labeling Program -2014

For the Brazilian Labeling Program, the key point is to obtain consumer decision making on the purchase of a product, being able to take into consideration not only the price, or design, but also the energy consumption of the product, in addition to stimulating the competitiveness of the industry through the induction of a technological innovation process.

The assessment of tangible products regulation by the Brazilian Labeling Program is periodically evaluated by Inmetro in which it verifies the conformity of samples that are correctly labeled with the mandatory information. Additional, the PBE functions as a stimulus instrument for the manufacture of more energy efficient instruments. In addition to performance, PBE establishes safety requirements for products, so that the possibility of a consumer accident is minimized.

The National Electricity Conservation Program (PROCEL) aims to promote the use of electric energy. Within this initiative, a seal called the PROCEL Seal was developed, with the purpose of guiding the consumer in purchasing products with better levels of energy efficiency among their counterparts. The resources used were from Eletrobrás and the Global Reversion Reserve - RGR.

This form of Labeling is a way to highlight the fulfillment of performance requirements determined in technical standards and regulations. The National Energy Conservation Label (ENCE), applied to energy efficiency programs, has a rating from “A” (most efficient) to “E” (least efficient), providing not only information about energy consumption but also consumption of water.

The PROCEL's labeling performance, can occur through 9 subprograms, from the industrial sector, Industrial Energy Efficiency - Procel Indústria stands out.

The National Program for the Rationalization of Use of Oil and Natural Gas Derivatives (CONPET) has the purpose of personal training and dissemination of activities in cargo and passenger vehicles, involving various sectors including transport, industrial, residential, commercial, agricultural, and power generation. The demands of the program to rationalize the use of oil products and natural gas contribute to the articulation of three of the four points of sustainability monitored by the Brazilian Institute of Geography and Statistics (IBGE), economic, environmental, and institutional strategies, without mentioning the social aspects, although it can be included and worked during the other three strategies (FREITAS et al., 2020).

Specifically, in the industrial sector, CONPET's initiatives are mainly aimed at Petrobrás. Among the various sources of funds for projects foreseen in the Annual Conservation Plans for refineries, there are resources managed by CONPET. However, CONPET's main means of action is around exploration and production. With the change in organizational culture, CONPET's performance has noticed constant changes in the reduction of consumption of electricity and fuels at Petrobras.

The Energy Efficiency Program aims to promote the efficient use of electricity in all sectors of the economy. The projects must demonstrate the economic feasibility of improving the energy efficiency of equipment, processes and end uses of energy and stimulating the development of new habits in organizations as well as replacing less-energy efficient technologies.

Law No. 10,295 became a regulatory framework in Brazil. It defines the maximum levels of specific energy consumption, or minimum EE for energy-consuming machines and devices manufactured or marketed in Brazil, based on relevant technical indicators (HADDAD, 2002). Sectors of society that can benefit from the results of the application of the law presents as an example, when a technological improvement is stimulated aiming at a lower consumption of energy in a washing machine, one can obtain, as a consequence, a lower consumption of water. In the technological development of compact fluorescent lamps, it is possible to achieve excellent results both in terms of luminous efficiency and to obtain a product that does not generate distortions to the energy distribution network, such as electrical current harmonics (HADDAD, 2002).

1.4 Industrial energy scenario

It is important to highlight that the laws organized in section 1.2 have, as their primary scenario regarding energy consumption (electricity and fuels), the main industrial sector, as shown in the Table 1.1.

Table 1.1. Industrial Consumption by Sector

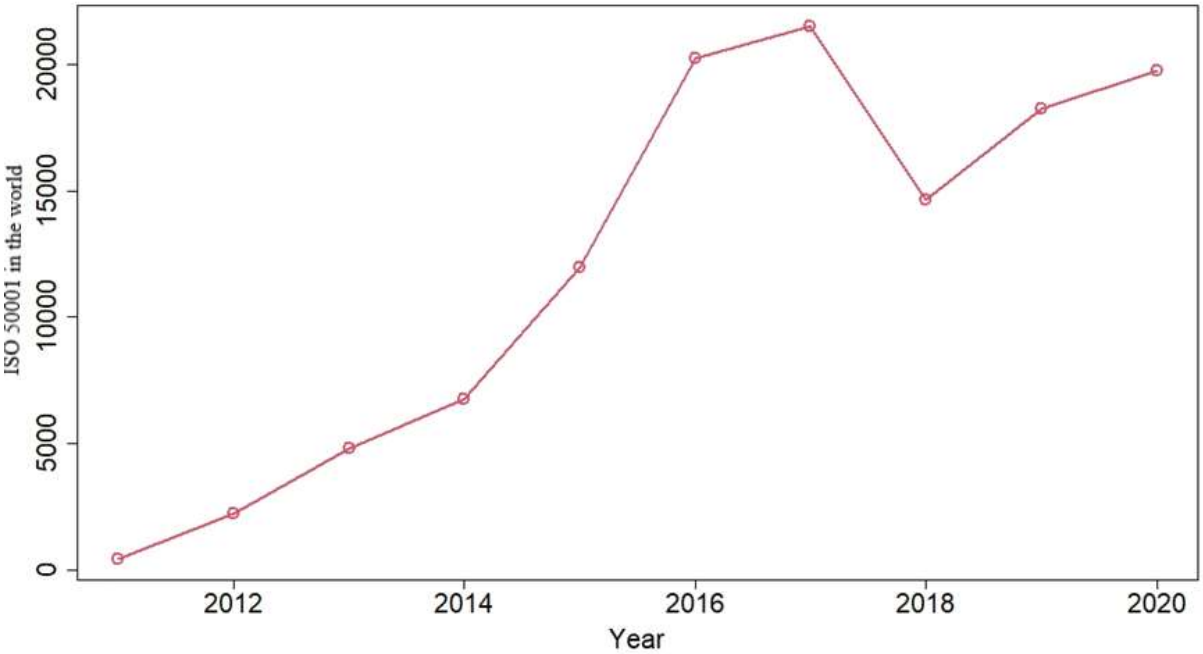
Sector	Participation	GWh
Metallurgical	23.00%	37.757
Food products	13.30%	21.874
Chemical	10.60%	17.371
Non-metallic mineral products	7.70%	12.642
Extraction of Metallic Minerals	7.10%	11.641
Rubber and Plastic Material	5.70%	9.380
Paper And Cellulose	5.20%	8.594
Automotive	4.10%	6.778
Textile	3.70%	6.037
Metal Products (Except Machinery and Equipment)	2.60%	4.205
Total	83.00%	136.278

Source: ISO Survey (2022)

Sectors that have less than two percent add up to the remainder of the 17%. Metallurgical sector is the main consumer. (ISO, 2020)

For the industrial sector, in addition to the programs mentioned above, what is growing a lot nowadays, as shown in the Figures 1.2 and 1.3, and which has great adherence, is the ISO 50001 certification system (which is an international standard that establishes practices for the implementation of Electric Energy Management Systems in companies and organizations) (ISO, 2020).

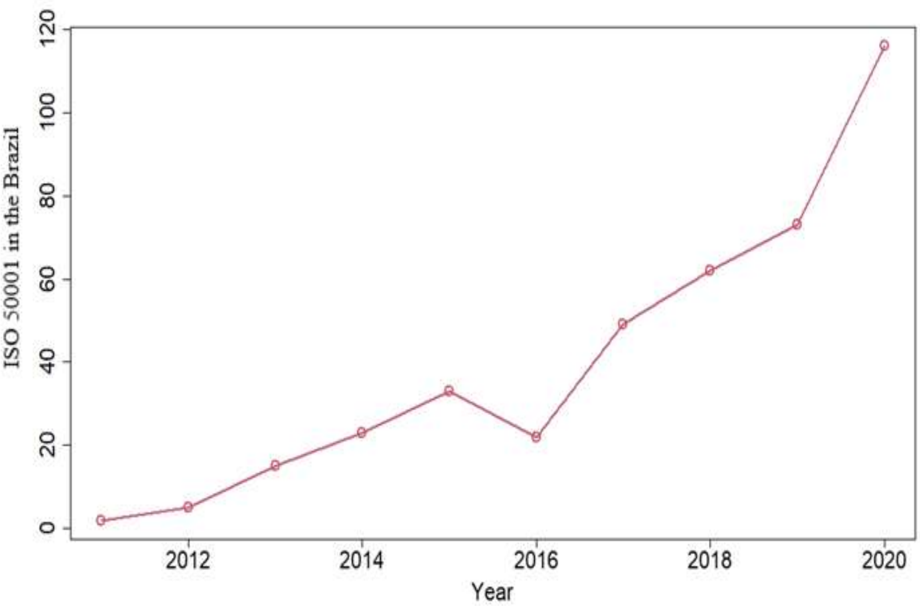
Figure 1.2. Number of ISO 50001 certificates worldwide



Source: ISO Survey (2022)

The drop in certifications in the period 2016 to 2018 occurs in the update of the standard, thus, companies that already had the ISO 50001 certification must develop the update, otherwise they may lose their certification.

Figure 1.3. Number of ISO 50001 certificates in Brazil



Source: ISO Survey (2022)

Table 1.2. Countries with the highest number of certifications

	Country	certificates
1	Germany	5786
2	China	2934
3	United Kingdom of Great Britain and Northern Ireland	1184
4	Italy	1168
5	France	812
6	India	773
7	Spain	625
8	Hungary	472
9	Turkey	306
10	Bulgaria	252
11	Czech Republic	241
12	Austria	236
13	Taiwan, Province of China	234
14	Latvia	213
15	Thailand	199
16	Croatia	194
17	Ireland	173
18	Belgium	146
19	Poland	141
20	Denmark	135
21	Russian Federation	135
22	Sweden	118
23	Greece	109
24	Serbia	87
25	Vietnam	84
26	Iran (Islamic Republic of)	82
27	Netherlands	75
28	Brazil	73
29	Hong Kong	70
30	Korea (Republic of)	63

Source: ISO Survey (2022)

Brazil, albeit with an upward trend, shows a large gap in a scenario of implementation of energy efficiency measures for the industrial sector (ISO, 2020). Although it is the main world economy, the United States is currently not among the main countries that issued the certification. In the year 2020 there were only 44 certificates registered in the ISO Survey.

Although, the implementation system adopted by the management model in ISO 50001 is the same of ISO 9001 (international standard that guarantees the quality of products and services) and ISO 14001 (international standard that specifies requirements for an

Environmental Management System for an organization to be able to manage immediate and long-term environmental impacts), it has already consolidated the structure of continuous improvement Plan-DO-Check-Act (PDCA) that incorporates daily practices in the organization of industrial management in the organization. The PDCA is shown in Table 1.3 (NEVES; SALGADO; BEIJO, 2017).

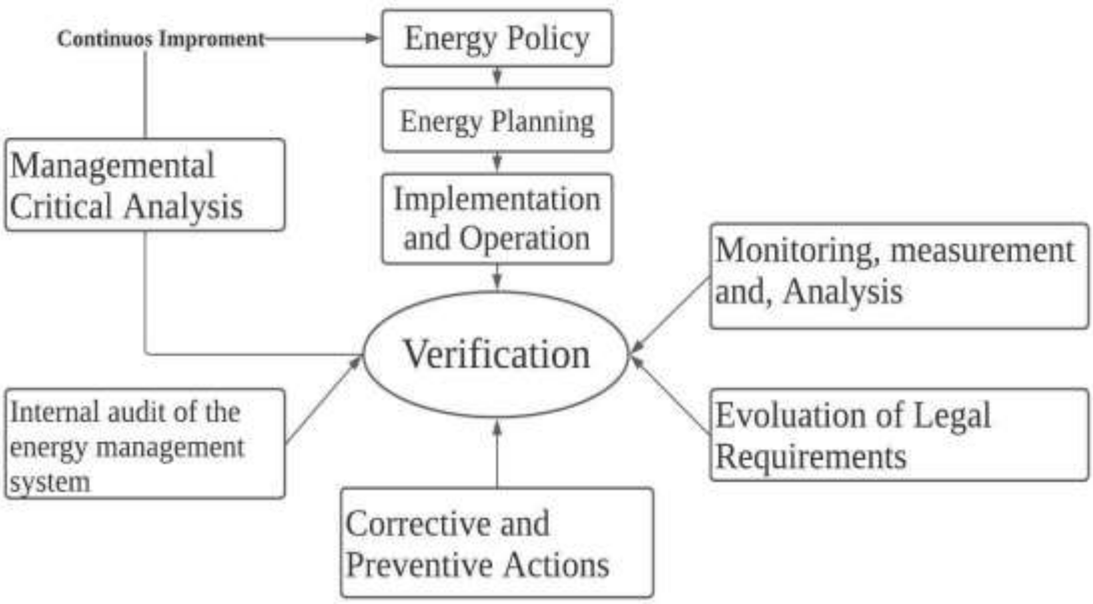
Table 1.3. Circle PDCA

Name	Initial	Meaning
Plan	P	It consists of establishing the goals on control items, as well as the way to achieve the proposed goals.
Do	D	It consists of doing the tasks exactly as foreseen in the plan and collecting the data to verify the process.
Check	C	Based on the data collected in the execution, compare the results achieved to the planned objectives.
Act	A	If deviations are detected, it will be necessary to create actions to make definitive corrections, so that the problem does not recur.

Source: Own Authorship

The ISO 50001 certification system, as well as the other ISO standards, is structured through the following energy steps: policy, planning, implementation and operation, verification, and critical analysis by senior management, as shown in the Figure 1.4 (ISO, 2020).

Figure 1.4. General Structure of ISO 50001



Source: Own Authorship

In this way, ISO 50001 shows that the review of the energy performance of the organization is linked to the organization through the database and other information (database and transparent information related to the energy consumption of the industry), leading to opportunities for improvement.

Another means that guides the reduction of energy consumption in industries that has been gaining great prominence mainly in the USA is the Industrial Evaluation Center. It is a United States Department of Energy program created in 1976 in response to the oil embargo and rising energy costs. The program is focused on reducing energy consumption in small and medium-sized companies, through the help of small and medium-sized manufacturing facilities and is currently managed through the Advanced Manufacturing Office (INDUSTRIAL ASSESSMENTER CENTER, 2021).

The program consists of recommendations for improvements in cross-cutting technologies (engines, lighting system, compressed air, HVAC, and others), where the evaluation time is estimated in 1 day and the result evaluation report is designed for medium and small manufacturers to identify ways to save energy by reducing waste and improving productivity, while providing hands-on training in industries to engineering students (INDUSTRIAL ASSESSMENTER CENTER, 2020).

Over the years, the Industrial Assessment Center (IAC) program has conducted more than 19,300 assessments withmore than 145,000 associated recommendations. Nowadays, in addition to cross-cutting recommendations, the scope of the reports includes improving cyber security awareness, exploring smart manufacturing technologies, and implementing comprehensive energy management systems (INDUSTRIAL ASSESSMENTER CENTER, 2020).

The top ten recommendations are shown in Table 1.4. In order to organize the data in a useful way, a coding system called the Assessment Recommendation Code (ARC) was developed to list each recommendation, this database is a product of the Industrial Assessment Centers that aggregates results of assessments carried out by Universities. US accredited to the Department of Energy's Office of Advanced Manufacturing. This manual, developed for the program, contains a list of recommendations involving improvements in energy efficiency, waste minimization and manufacturing productivity (INDUSTRIAL ASSESSMENTER CENTER, 2002).

Table 1.4. Main IAC improvement recommendations

	ARC	Description	Average Saving	Average Cost	Average Payback (years)	Imp Rate
1	3.7392	Apply a protective coating to racks and tanks	$2.66	$24.00	0	100.00%
2	2.4157	Establish a predictive maintenance a program	$8.43	$2.07	0.50	87.60%
3	2.4152	Use only certified Motor repair shops	$3.11	$4.05	1.30	85.70%
4	2.2135	Repair and eliminate steam leaks	$44.09	$4.70	0.40	83.80%
5	2.4227	Use compressor air filters	$3.54	$2.32	0.50	82.80%
6	2.4236	Eliminate leaks in inert gas and compressed air lines/valves	$6.28	$1.71	0.40	82.70%
7	2.2164	Turn OFF steam tracing during mild weather	$8.03	$29.60	0.50	80.00%
8	2.2113	Repair or replace steam traps	$36.26	$7.90	0.50	79.60%
9	2.6125	Keep equipment clean	$25.49	$20.07	0.50	79.40%
10	4.821	Pay bills on time to avoid late fees	$2.86	$129.00	0.10	77.40%

Source: IAC (2022)

The specific legislation, in Brazil, that takes care of cross-cutting technology (electrical motors only), is the Technical Committee of Motors, CTMotores, showing the evolution of the minimum efficiency of the three-phase induction motors. The CTMotores is made up of representatives from the Electric Energy Research Center (CEPEL), Eletrobrás, Inmetro and the Ministry of Mines and Energy.

The specific motor regulation, established by Decree no. 4,508 / 2002, covers three-phase induction motors, squirrel-cage rotor, voltage 600V, power from 1CV to 250 CV, number of poles 2, 4, 6 and 8. In this regulation, two yield tables were defined: the standard line and the high yield line.

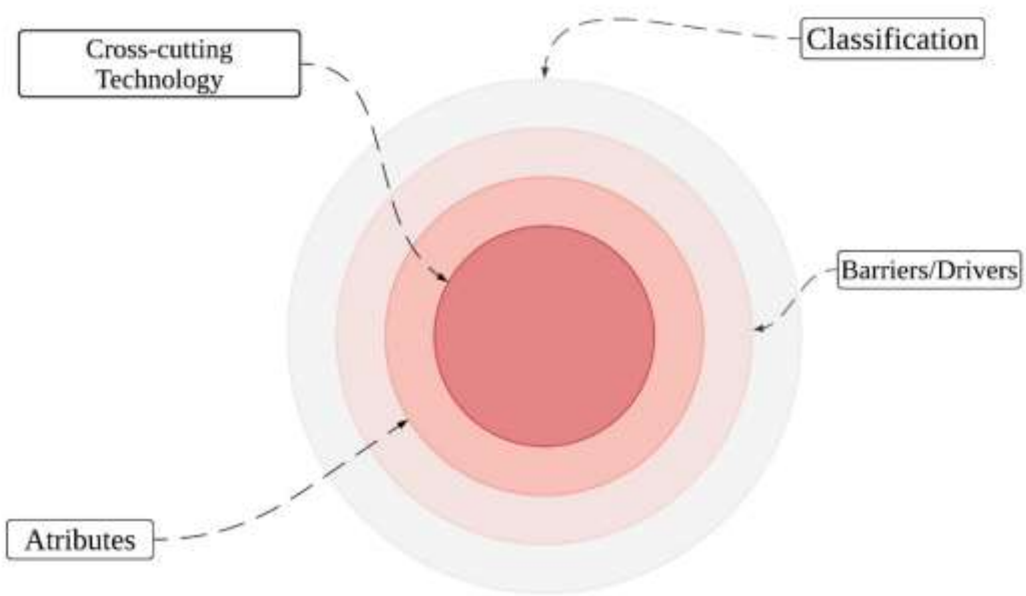
1.5 Industrial energy efficiency

Small and medium-sized enterprises (SMEs) often face difficulties in obtaining strategies for implementing energy efficiency measures due to the lack of financial support and management strategy. The lack of technological capital and technical staff hinder the implementation of the energy parameters because of the shortage of either time or resources to focus on that activity (THOLLANDER; DANESTIG; ROHDIN, 2007).

In general, a taxonomic framework that can describe industrial energy efficiency is shown in Figure 1.5. The structure shows, through Figure 1.5, how each step behaves within the E.E. taxonomy. industrial. The classification juxtaposes barriers/drivers, attributes and cross-cutting technologies. Barriers/Drives assume cross-cutting attributes and technologies. And the attributes overlap over cross-cutting technologies.

This structure shows the relationship between classifications and barriers/drivers, between barriers/drivers and attributes, and between attributes and cross-cutting technologies.

Figure 1.5.Taxonomic Structure of Industrial Energy Efficiency



Source: Own Authorship

The literature related to industrial energy efficiency has been developed, above all, through the survey of the main barriers and drivers, shown in the second stage.

1.5.1 Barriers

Furthermore, increasing energy efficiency represents a considerable value for economies in general. Along with cost savings, energy efficiency can offer other benefits that can help companies to grow and develop, for example, by improving productivity, profitability, competitiveness, and product quality. By reducing dependence on energy imports and reducing environmental impacts, the value increases, not only for companies, but also for society. Despite the benefits arising from EE measures, its implementation in companies is not an easy task, due to the existing barriers that must be identified to define motivation strategies that can combat these barriers, especially those related to ways of dealing with new technological ways , since they require internal and external influences for changes in behavior and not only economic incentives for the implementation of energy efficiency measures or information campaigns (HENRIQUES; CATARINO, 2016).

A system of improvements in equity linked to a robust technological system needs to be in place to support technical changes and economic development in institutions. Changes in the infrastructure of companies guide structural modifications in concepts of improvement, such as that linked to energy consumption (CARLSSON, 1992). These barriers to energy efficiency, such as lack of financial and managerial, technological, investment and innovation support, explain the difficulty in implementing energy efficiency (THOLLANDER; OTTOSSON, 2008).

Energy management is a means of overcoming barriers to energy efficiency. Both support from top management and an approach through various energy management programs are important elements such as an internal policy that changes the organizational culture scenario (WORRELL et al., 2009). For (THOLLANDER; OTTOSSON, 2008) the goals of an industrial energy management system are at a lower organizational level than the business strategies. The linkage within the focus of small and medium industries can be a vector for a successful adoption of energy management practices and consequently a reduction in the energy consumption of manufactures (THOLLANDER and OTTOSSON, 2007).

(SORRELL et al., 2000) defines the barriers to energy efficiency as follows:

> *"A postulated mechanism that inhibits investments in technology that are energy efficient and (at least apparently) are economically efficient"* (SORRELL et al., 2000).

Table 1.5 is adapted showing the approach raised by (SORRELL et al., 2000) together with (CHAI; YEO, 2012) who classify the barriers as: economic, organizational, behavioral, and institutional

Table 1.5. Barriers to the implementation of energy efficiency measures

Classification	Barriers	Comment	Author
Organizational	Power	Low power management status can lead to lower priority for energy issues in organizations	(SORRELL et al., 2000)
	Culture	Changing organizational culture to accept the implementation of EE measures to reduce environmental impacts	(SORRELL et al., 2000)
Institutional	Lack of tax incentives	Government aid for companies that do not implement EE measures	(CHAI; YEO, 2012)
	Legislation	Legislation for implementing measures that reduce environmental impacts, such as industrial EE	(CHAI; YEO, 2012)
Economy	Heterogeneity	A technology that can have economic variation	(SORRELL et al., 2000)
	Hidden expenses	Hidden indirect costs: Costs of collecting and analyzing information, interruptions in production, inconvenience and, etc.	(SORRELL et al., 2000)
	Access to capital	Limitation of capital may prevent the limitation of energy efficiency measures	(SORRELL et al., 2000)
	Risk	The risk of short-term return is the main reason for energy efficiency measures	(SORRELL et al., 2000)
	Imperfect information	Lack of information makes it difficult to implement energy efficiency measures	(SORRELL et al., 2000)
	Incentives Division	If there is no gain from energy efficiency investments, there is likely to be less interest in implementing energy efficiency measures	(SORRELL et al., 2000)
	Lack of funding	Important inhibitory factor for the implementation of energy efficiency measures	(CHAI; YEO, 2012)

continuation

Table 1.5. Barriers to the implementation of energy efficiency measures

Concluded

Classification	Barriers	Comment	Author
Behavioral	Limited rationality	Decisions made by rules	(SORRELL et al., 2000)
	Form of information	The information must be specific	(SORRELL et al., 2000)
	Credibility and trust	The information must be credible and reliable to provide information on energy efficiency measures	(SORRELL et al., 2000)
	Inertia	Individuals who are opposed to changes within the organization may result in energy efficiency measures	(SORRELL et al., 2000)
	Values	The implementation of energy efficiency measures is more likely to be successful if there are people committed to the project	(SORRELL et al., 2000)
	Inability to process information	Individuals with limited rationality	(SORRELL et al., 2000)
	Resistance to change	Difficulty accepting structural changes in the company	(CHAI; YEO, 2012)

Source: Own Authorship

Many authors dedicate their work in the deep investigation on the failure in the implementation of measures of technology coming from the predominant technology of the productive system, as the purpose of identify barriers. (NAGESHA; BALACHANDRA, 2006; ROHDIN; THOLLANDER; SOLDING, 2007) found that financial barriers are the most significant, others identified information as the most important one (ROHDIN; THOLLANDER, 2006), in which the overcoming of barriers leads to the adoption of energy efficiency in a more assertive way.

For (BROWN, 2001)

> *“The existence of market failures and barriers that inhibit socially optimal levels of investment in energy efficiency is the main reason for considering public policy interventions. In many cases, viable, low-cost policies can be implemented to eliminate or compensate for market imperfections and barriers, allowing markets to operate more efficiently for the benefit of society. In other cases, policies may not be*

> *viable; they may not fully eliminate the target barrier or imperfection; or they can do it at costs that exceed the benefits"*(BROWN, 2001).

(BROWN, 2001) pinpoints through a systematic review of the literature, market failures, such as incentives placed with the problem of the principal agent, distortion in fiscal and regulatory policies and uncharged costs. The author highlights as main barriers, the low priority to energy issues, capital market barriers and incomplete energy efficiency markets. (SUDHAKARA REDDY; KUMAR RAY, 2011) identifies consumers as actors involved in the process of improving energy efficiency, presenting ignorance or awareness regarding high initial costs and the existence of issues beyond energy costs. And (WEBER, 1997) reports that the barriers describe the non-implementation of investments in energy efficiency as good cost-benefit, having three pertinent characteristics of the non-implementation: the objective obstacle, the impaired subject and the impaired action. (DECANIO, 1998), in an investigation on lighting upgrades, emphasizes that besides the economic importance, there are several organizational and institutional factors that move the payback as the equipment supplier and who supplies the equipment installation.

Hidden costs prevent companies from developing projects to improve energy efficiency. It can result in poor quality of technologies and equipment with energy efficiency or the hiring of personnel. Another event determined by the barriers is the co-benefits, in addition to the improvement linked to efficiency, industrial techniques that help improve energy efficiency are also observed (LUNG et al., 2005; TRIANNI; CAGNO, 2012; TRIANNI; CAGNO; FARNÉ, 2016; WORRELL et al., 2003). (TRIANNI; CAGNO; DE DONATIS, 2014) in studies carried out in European foundry companies show that the perceptions of the barriers stem from the lack of resources dedicated to improving energy efficiency. Among the difficulties in carrying out these measures is the existence of other priorities such as the importance of ensuring business continuity, in which smaller companies (SMEs) with simpler production processes tend to perceive greater barriers to energy efficiency.

For (SCHLEICH et al., 2016) the external barriers of the market depend on its flaws in addition to institutional configurations. Market failures, such as liquidity restrictions, are examples of external barriers, as some individuals do not have access to money to invest in energy efficient technologies (GILLINGHAM; NEWELL; PALMER, 2009). When industrialists need to rely on capital to finance investments and the markets do not support it as credit restrictions, investment to improve energy consumption may be impaired. (JAFFE; STAVINS, 1994) also verify that the barriers linked to external capital are not market failures, but can compromise the company's rational behavior, as they deal with the constant uncertainties and risk arising from high rates of return.

(HIRST; BROWN, 1990) point out among the existing structural barriers to energy efficiency, the behavioral ones as the structural change of the internal manufacturing activities concerning the energy efficiency. For (SCHLEICH et al., 2016) rational and predictable behavioral barriers are related to internal barriers. The benefits and costs of an investment vary between individuals and if an investment is profitable for one, it probably may not be for another. The heterogeneity of those responsible plays a great role in explaining the variation in energy efficiency, since individuals differ in their time, risk, and preferences, thus (SHOVE, 1998) portrays the socio-technical barriers.

> *"Technical change is a unilateral technology transfer process and ... social obstacles or non-technical barriers hinder technological progress. What is missing is an appreciation of the social contexts of the energy saving action and the socially situated character of technical knowledge. As we will see, the restoration of these missing elements has indirect consequences for the rest of the conventional package, so much so that the entire tidy building begins to collapse".* (SHOVE, 1998)

The barriers of operational aspects do not necessarily belong to a single conceptual field (CAGNO; TRIANNI, 2013), and may overlap between the various theoretical fields of this line of research, as highlighted by (SORRELL et al., 2000). Through his development of taxonomy, as the main reference in working with barriers, such as energy implementation, economic, organizational and behavioral theories can be capitulated, admitting that possible interactions between barriers occur. Nevertheless, the study by (PALM; THOLLANDER, 2010; ROHDIN; THOLLANDER; SOLDING, 2007) highlights that it can neglect side effects that in combination can significantly affect the importance of barriers.

(CAGNO; TRIANNI, 2012) show that the value of a certain barrier depends on the intervention to differ as the company's level of assessment, whether by technology area for a specific measure. According to the authors, although general barriers seem more relevant at the company level, big differences appear when considering barriers dependent on intervention by technology area, as well as in the level of energy efficiency measurement, still, the differences can also be appreciated when evaluating the barriers independently according to some characteristics of the company (by the size, complexity of production and capacity for innovation).

(SAFARZADEH; RASTI-BARZOKI; HEJAZI, 2020) classifies approaches to energy policy instruments, in which barriers and benefits verifying that energy pricing policies can be considered an effective method and analytical methods can be seen as instruments for policy makers to determine ideal levels of decision variables.

1.5.2 Drivers

For the drivers, (THOLLANDER; OTTOSSON, 2008) portray that they are antagonistic to barriers, in which "*different types of factors that pressure investments in technologies that are efficient in terms and economic terms*". Nevertheless, as highlighted by (THOLLANDER; OTTOSSON, 2008) and reinforced by (CAGNO; TRIANNI, 2013), the definition of drivers is still confusing. Being defined by (CAGNO; TRIANNI, 2013) as:

> "*factors that facilitate the adoption of energy efficiency technologies and practices, going beyond the investment vision and including the promotion of a culture of energy efficiency and conscience*" (CAGNO; TRIANNI, 2013).

Despite that, the denominations advance in the understanding of what drivers are. It meets the need to overcome barriers arising from different natures. Table 1.6 shows some drivers shown in the literature.

Table 1.6. Drivers for Industrial Energy Efficiency

Classification	Drivers	Comment	Author
Regulatory	Green image	Improving the company's image by adopting energy efficiency measures	(CAGNO; TRIANNI, 2013)
	Long-term energy strategy	Development of a plan so that energy consumption is adequate in the long term	(TRIANNI; CAGNO; FARNÉ, 2016)
	Willingness to compete	Improvement of the company's productive and financial capacity with improved energy consumption	(TRIANNI; CAGNO; FARNÉ, 2016)
	Voluntary agreements	Employee commitment to implement long-term energy efficiency measures	(CAGNO; TRIANNI, 2013)
	Informational	Clarity and reliability of information in the energy efficiency implementation process	(TRIANNI et al., 2016)
	External energy audit/submetering	Model for implementing EE measures for other companies	(TRIANNI et al., 2016)
	Increasing energy tariffs	By increasing energy tariffs it will help implement EE measures	(CAGNO; TRIANNI, 2013)
	Efficiency due to legal restrictions	Implementation of laws and codes that help develop energy consumption reduction	(TRIANNI; CAGNO; FARNÉ, 2016)
	Technological appeal	Implementation of technological improvement to help reduce energy consumption	(CAGNO; TRIANNI, 2013)

continuation

Table 1.6. Drivers for Industrial Energy Efficiency

concluded

Classification	Drivers	Comment	Author
Economic	Cost reduction from lower energy use	Financial savings with reduced energy consumption	(TRIANNI; CAGNO; FARNÉ, 2016)
	Information about real costs	Determination of industrial energy access control parameters	(CAGNO; TRIANNI, 2013)
	Management support	Attractive management of industrial energy efficiency	(TRIANNI; CAGNO; FARNÉ, 2016)
	Public investment subsidies	Assistance to help implement energy efficiency measures	(TRIANNI et al., 2016)
	Private financing	Internal assistance to the industry to help implement energy efficiency measures	(TRIANNI; CAGNO; FARNÉ, 2016)
Informative	Management with ambitions	Top management will direct projects to improve energy consumption	(CAGNO; TRIANNI, 2013)
	Staff with real ambitions	High manages in order to change the cultural structure of energy consumption reduction	(TRIANNI; CAGNO; FARNÉ, 2016)
	Knowledge of non-energy benefits	Employees will develop skills in the subject of energy efficiency	(TRIANNI et al., 2016)
	Availability of information	The company will determine an implementation calendar with information for all employees	(TRIANNI; CAGNO; FARNÉ, 2016)
Vocational training	Programs of education and training	Development of internal employee training programs	(TRIANNI; CAGNO; FARNÉ, 2016)
	Technical support	Technical support development	(TRIANNI et al., 2016)

Source: Own Authorship

Drivers somehow have a central role in the implementation of energy efficiency measures, by various interested categories (Table 1.6) (TRIANNI et al., 2017), such as regulation, economic, information and vocational training (CAGNO et al., 2017; CAGNO; TRIANNI, 2013; TRIANNI; CAGNO; FARNÉ, 2016).

Furthermore, economic drivers are widely used not only as tools to deal with economic or financial barriers, shown in Table 1.6, but also to increase interest, generate awareness, etc. (CAGNO et al., 2017). Yet again, in empirical work on resource use and material productivity, (STEGER; BLEISCHWITZ, 2011) confirmed that: activities are influenced by a number of inconsistent forces, people respond to a variety of incentives and motivators are related to many other aspects that have an impact on them.

Drivers information is considered very important, since it can be promoted through awareness campaigns (CAGNO et al., 2017), due to the characteristic of receiving adequate, reliable and clear information. In this sense, the researchers' attempt to offer new sharing platforms for information on energy efficiency measures is remarkable (BLOMQVIST; THOLLANDER, 2015). Regulation or legislation is fundamental (SY, 2014), especially in aspects that regulation supports energy sustainability (SY, 2014). Notably, the drivers of regulatory actions are considered of moderate importance, when compared to economic and information, which reflects the generally skeptical attitude of companies towards the political interventions that (CAGNO et al., 2017) experiment in his work.

Drivers categorized internally as vocational training are considered energy management practices. In particular for drivers related to internal culture, this helps in hosting the implementation of energy efficiency measures.

1.5.3 Attributes

Adding to these episodes shown in the description of barriers and drivers, the taxonomic structure shown, through Figure 1.5, goes beyond these aspects, portraying the behavior of industrial energy efficiency. Social network analysis shows the relationship between each perspective shown in the Venn diagram (Figure 1.5).

Still, beyond barriers and drivers (Figure 1.5), considering the predominant technology of the productive system, several works stand out as pioneering two lines of thought, the first being describing attributes and how the attributes are recognized among them.

(PYE; MCKANE, 2000) as well as (MILLS; ROSENFELDS, 1996) also highlight the improvement of environmental and economic aspects, such as: increased productivity, reduced environmental compliance costs, reduced production costs, waste disposal costs, improvement product quality, improved capacity utilization, better reliability, and greater worker safety. Consequently, (PYE; MCKANE, 2000) recognize that quantifying the total benefits of energy efficiency projects helps companies to fully understand the financial opportunities for investing in energy efficiency measures. Rather than focusing on results, they point out that saving energy is not only the main measure of industrial decision-making, but a part of the total benefits of an energy efficiency project, (PYE; MCKANE, 2000).

(SKUMATZ; DICKERSON, 1998; SKUMATZ; GARDNER, 2005) studies methodologies for a form evaluation of energy efficiency that are difficult to measure, based on the results of several projects developed in the last decades, the author developed and was responsible for measuring the non-energy impacts, both positive and negative of industrial energy efficiency programs. Still, it is important to highlight that the benefits accumulate in three different perspectives, including (1) perspective of utility, taxpayer, and shareholder; (2) social perspective; (3) customer or participant perspective. Focusing on the category "industrial and commercial participants".

(NEHLER, 2018) demonstrates that different types of non-energy benefits are observed in several industrial areas due to energy efficiency measures and are rarely recognized in decisions about energy consumption improvements. However, the character of non-energy benefits, the diversity and relationships between them provide opportunities for non-energy benefits to be included in energy efficiency decisions in a variety of ways. As well as non-energy monetary benefits can be included in investment calculations that contribute to cost effectiveness, while effects that are difficult to measure and quantify can be used qualitatively in investment valuations as extra arguments. (NEVES et al., 2020) argues that both the environment work along with the style of the operation and maintenance strongly influence the way of implementing benefits that lead to industrial energy efficiency.

(PALM; BACKMAN, 2020) raises an analysis that communication becomes an information barrier to improve energy efficiency in small and medium-sized companies and considers functional communication as a facilitator of energy efficiency programs. And that in the process of implementing energy efficiency measures, municipalities should avoid offering audits, but making alternatives available as methods that facilitate knowledge among participants, through exchanges between SMEs.

The second stream of literature seeks to go a further step than just presenting a list of attributes, providing a framework for improving energy consumption that can incorporate a more general set of aspects of improvement.

(MILLS; ROSENFELDS, 1996) demonstrates a class of benefits at the national level, improving competitiveness, energy security, job creation, environmental protection, while this framework relates to decision-making processes. Among the classes of benefits, there are the environmental ones: reduction of internal pollution of the environment, increase of thermal comfort and improvement of factors associated with health and safety, such as the capacity of exhaust heat recovery systems to decrease the probability of insufficient ventilation rates. Determining that the managerial part keeps costs lower, improves the productive one, since it has workers in a better environment, they reduce the amount needed for a given task. And with economic aspects reducing direct and indirect costs by reducing the energy capacity of the equipment, while recognizing the benefits at a broader level, these authors provide a detailed description of the benefits to users made possible by energy efficiency measures. Pointing to a crucial factor, efficient technologies provide equivalent services at lower costs, but the non-energy benefits add value or improve the services of efficient technologies.

(WORRELL et al., 2003) advocate the inclusion of productivity benefits in a clear way in the evaluations of energy efficiency measures, as this would double its cost-effectiveness and economic evaluation. Even so, the author points out the generalized omission of these benefits in most studies of energy efficiency measures. On the contrary (MILLS; ROSENFELDS, 1996; WORRELL et al., 2003) adds another category to identify culturally determined, however noteworthy benefits, such as reduced responsibility, improved public image, delays / reduced capital expenditure, additional space and better worker morale.

(LUNG et al., 2005) examine the importance of the economy as an accessory resulting from the adoption of energy efficiency measures. The term of auxiliary economy refers to the total possibility and quantification of the savings resulting from adoption of energy efficiency measures. In the same way (WORRELL et al., 2003) applies the proposal to a large set of energy efficiency projects. It is divided into five categories: operations and maintenance, production, work environment, environment, and others (such as discount / incentive achieved, reduced / eliminated demand charges, rental equipment costs, avoided / delayed costs).

(FLEITER; HIRZEL; WORRELL, 2012) develops a systematic literature review providing a first justification for categorizing the attributes of energy efficiency measures, considering as selection criteria: relevance, applicability, specificity, independence, and distinction. The authors then list twelve attributes grouping them into three areas: relative advantage (internal rate of return, return period, initial expenditure, and non-energy benefits), technical context (distance from the central process, type of change, scope of impact and time EEM life cycle) and information context (existence of transaction costs, necessary knowledge for planning and implementation, diffusion progress and sectorial applicability).

(GAHM et al., 2016) develops a program on energy efficiency, with three dimensions: energy coverage, energy supply and energy demand. Influencing the total amount of demand for applied energy sources / or the course of that demand, improving energy conversion in the internal conversion system or in the external conversion system. Leading to increased complexity for two reasons, on the one hand, energy-oriented objectives are considered, on the other hand, the (technical) characteristics of energy demand supply often led to non-linear constraints. At the same time, benchmark instances must be developed to allow comparison of solution methods.

(LUNG; NIMBALKAR; WENNING, 2019) developed a platform to analyze energy saving projects in which it integrates economic aspects streamlined by the IEA “capturing the multiple benefits of energy efficiency” (KESICKI; YANAGISAWA, 2014). It integrates multiple energy benefit analyzes and assessment reports with the expectation of leading to greater implementation of energy efficiency projects.

(TRIANNI et al., 2019) develops an industrial management assessment model to carry out energy improvement actions that have relevant consequences for industrial decision makers in terms of the energy efficiency supply chain. (LUNG; NIMBALKAR; WENNING, 2019) develops a platform to analyze energy saving projects in which it integrates economic aspects streamlined by the IEA “capturing the multiple benefits of energy efficiency” (TRIANNI; CAGNO; FARNÈ, 2014).

The review of both research theses on EEMs of energy efficiency attributes advances from the perspective of grouping of attributes, within a classificatory and practical process. Possessing a great step of academic relevance developed for both currents of research, shown by the work of (TRIANNI; CAGNO; DE DONATIS, 2014). Having the verification of the actions of these attributes through their intensity in industrial energy efficiency is an important step towards a new approach along these lines and in a more practical way in industries.

The existence of these theoretical perspectives also influences the characterization of the predominant technologies of the production process, mainly in the formatting of individual methodologies that can assist in the implementation of measures to control energy consumption. Thus, tracing the industrial taxonomy (Figure 1.5) is necessary, as shown in the following analyses

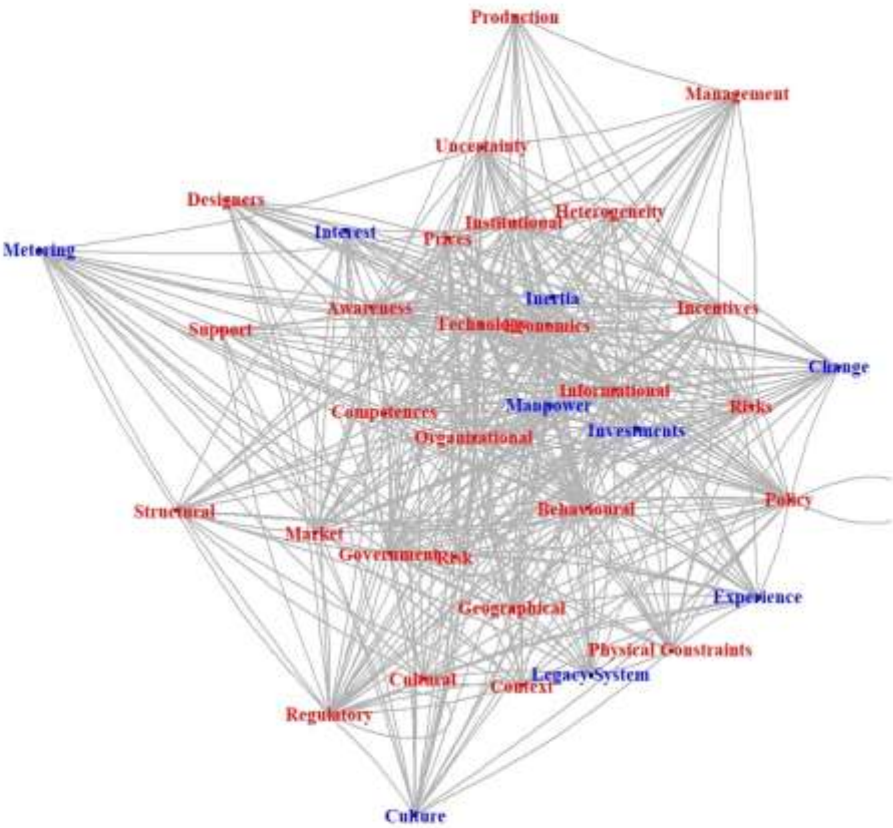
In Figure 1.6 shows the relationship between the classification of barriers and their respective classifications, in addition to Table 1.5. The words in red refer to the classifications of barriers while the words in blue refer to barriers.

Figure 1.6 shows the behavior among the connections between classifications and barriers. It is observed that most barriers are related to internal, industrial and economic issues.

The literature shows that the main barriers in this aspect are those that industries have greater difficulty in overcoming their adversities, which are intrinsic. The classifications with the greatest connections are heterogeneity, organizational, informational, behavior, economics, technology, risks and institutional, the intermediate range awareness, government, institutional and support. Finally, the classifications with the lowest connections are structural, regulatory, policy, risks and management, designers, uncertainties, physical constrains.

The Social networks (Figure 1.6) are analyzed according to where the most connections occur. In this way, you can observe in which part a given word becomes more "important", as it interpolates with other words in greater quantity.

Figure 1.6. Analysis of Social Networks between Classifications and Barriers



Source: Own Authorship

Subtitle:

Red: Classifications

Blue: Barriers

(NICHOLS, 1994) portrays those barriers do not consider the reduction in benefits associated with EE technologies or additional costs associated with them. Thus, studies overestimate the potential for efficiency. (NICHOLS, 1994) also identified three broad categories of hidden costs that explain this relationship with heterogeneity, organizational, informational, behavior, technology and institutional classifications. These are: (*i*) overhead energy management costs, (*ii*) specific costs for an investment in technology, and (*iii*) loss of benefits associated with an efficient technology, in which it has been evolving with the development based on this research topic.

Also, related to internal issues, there are differences of interest within the company, which may arise from possible conflicts due to the use of limited resources. As highlighted by (MORGAN, 1997) energy issues departments are assigned to organizational departments such as engineering and maintenance departments. Since senior management can consider peripheral energy issues, limiting its power, resources and support. In this way, EE opportunities can be missed, even though it may be technically and economically viable.

Adding Figure 1.6, in Annex 2.1, 20 main associated words of the classification articles were verified, with seven barriers, through the content analysis technique. Which characterizes verifying which words are most frequently associated with a given word (Annex 2.1). The central feature of the associations of the seven barriers (organizational, institutional, financial, behavioral, competences, policy and awareness) is that the associations refer to three basic groups.

Checking the social networks (Figure 1.6) and the content analysis (Annex 2.1) we have the following conclusions:

(a) related to technological aspects (Technology, Machinery, Instruments, among others).

As described by (TRIANNI et al., 2013), the association of barriers with this type of characteristic shows the difficulty of companies in overcoming barriers of technological origin, since many companies see the shift from the technological structure to efficient energy consumption as an obstacle.

(b) related to environmental issues (Greenhouse, Eco Efficiency, Environmental, among others)

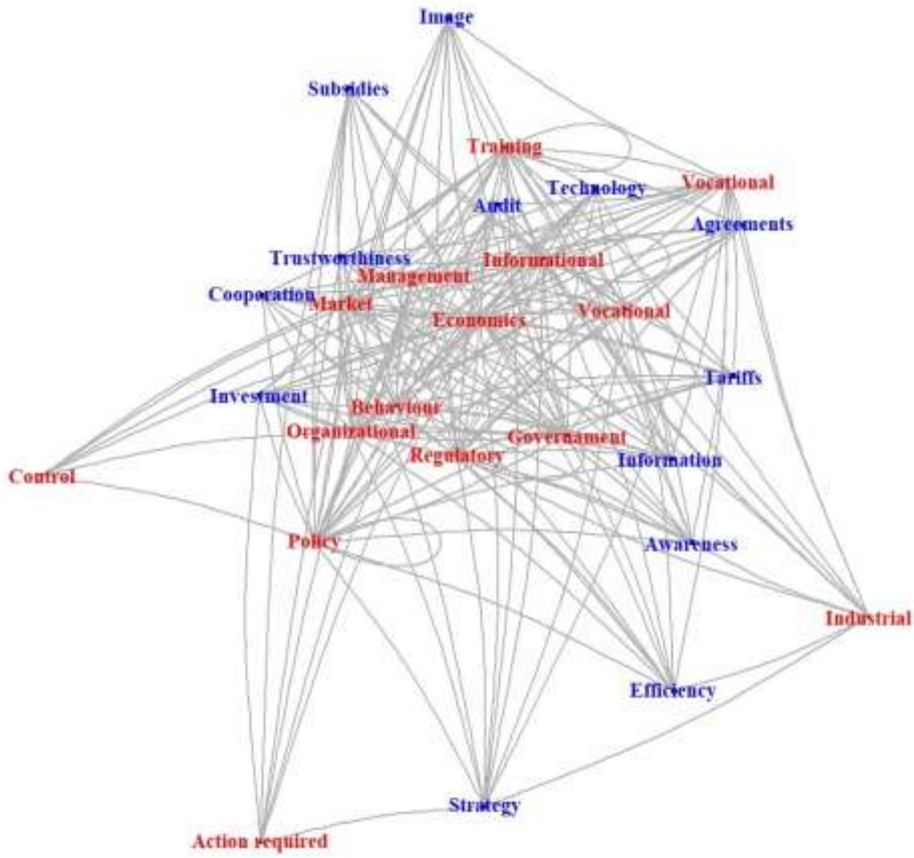
Complemented by the lack of environmental regulation and, consequently, the lack of economic incentive to implement measures that help to implement measures that overcome the barrier of industrial energy consumption. For (SORRELL et al., 2000)) the value barrier is intrinsically associated with environmental aspects, as it has become an external principle that society is imposing on various sectors, such as the industrial (THOLLANDER; OTTOSSON, 2008).

(c) and finally, to organizational aspects (Production, Administration, Process, Relationship, among others).

(MARTIN et al., 2012) shows that aspect "*c*" is directly related to favorable management practices associated with greater productivity. In which the authors highlight that specific management practices and EE are similar to the "energy efficiency paradox" and that they have a strong empirical connection with the organizational structure. Complemented by (APEANING; THOLLANDER, 2013) shows that the lack of economic structure hampers in an efficient organizational structure to reduce energy consumption.

The words in red refer to driver classifications while blue words refer to drivers. As for Figure 2.7 that relates the classification with the drivers, it is observed that the main drivers that have connections with the classifications are related to economic and organizational aspects. The main classifications are Government, Economics, instruments, behavior, organizational, Market, Management and Informational. The classifications considered intermediate Action required, industrial, control, policy, Training and Vocational And, finally, the classifications that are outside the middle block Quality, External and Behaviors.

Figure 1.7. Social network analysis between classifications and drivers



Source: Own Authorship

Subtitle:

Red: Classifications

Blue: Drivers

In Appendix 2.2, as well as in Appendix 2.1, the main associations arising from the classifications were analyzed and the main key elements of the six drivers were addressed, through the most cited words. Three aspects of the barriers were also raised: environmental, technological and organizational. As already highlighted, although these aspects are an obstacle, it becomes a motivator to implement EE measures.

Several studies portray drivers with different natures that can encourage companies to adopt EEMs. In general, the works highlight that the existence of motivators within the company can help in the implementation of measures that reduce energy consumption. Conversely, as highlighted in Figure 2.6, barriers can be motivating to implement energy efficiency measures, even to overcome them, being emphasized by two of the four drivers mentioned, which are the same as barriers: political and economic (BRUNKE; JOHANSSON; THOLLANDER, 2014; CAGNO et al., 2013)

For (SA; THOLLANDER; RAFIEE, 2018) energy efficiency in an industrial plant must be incorporated with the optimization of the process and the adequate replacement of machinery, as long as it can do the same task and with less energy use (HASANBEIGI; PRICE, 2012). Considering the high cost of machines tends to be a barrier, however, the replacement of new machines can be justified as long as the financial gain is in a shorter period and the production process continues to function with quality (HASAN; TRIANNI, 2020; HASANBEIGI; PRICE, 2012; MALINAUSKAITE et al., 2019).

Now, as shown in Figure 1.5 the Veen diagram both barriers and drivers overlap attributes. The next analyzes show this connection between barriers/drivers on attributes. In Figure 1.8 shows the behavior of barriers on attributes.

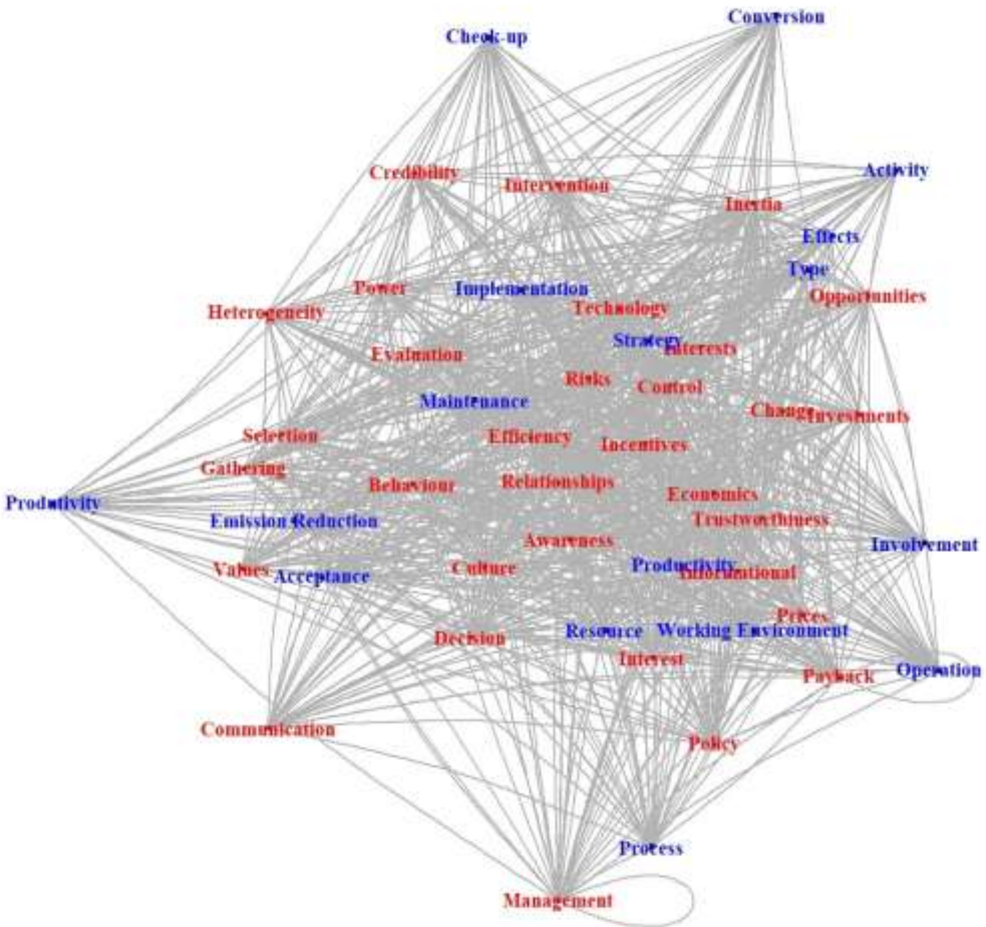
In Figure 1.8, the connections between barriers and attributes have a wider range. It is observed that the core group with the greatest number of barriers is distinguished by the aspects of being technological, investments and organizational open a wide range of connections for the attributes, especially those raised by (TRIANNI; CAGNO; DE DONATIS, 2014). And that of the ends to organizational aspects and technological functioning attributed to energy consumption management.

The words in red refer to barriers while the words in blue refer to attributes.

The large number of connections between the attributes and the barriers shows that there is no strong link behavior between the topics, although these are the aspects with the largest studies found in the literature. For (TRIANNI; CAGNO; DE DONATIS, 2014) greater attention to the attributes is given to industrial decision makers, as they must have a more comprehensive view of the useful measures that must be implemented to overcome the barriers of energy efficiency measures, thus presenting the main perspectives that the characterize. By not having a broad view of the aspects that guide them, the attributes are disconnected from the relationships that the barriers must overcome (TRIANNI; CAGNO; DE DONATIS, 2014).

In Figure 1.9 shows the connection between drivers and attributes.

Figure 1.8. Social network analysis between barriers and attributes

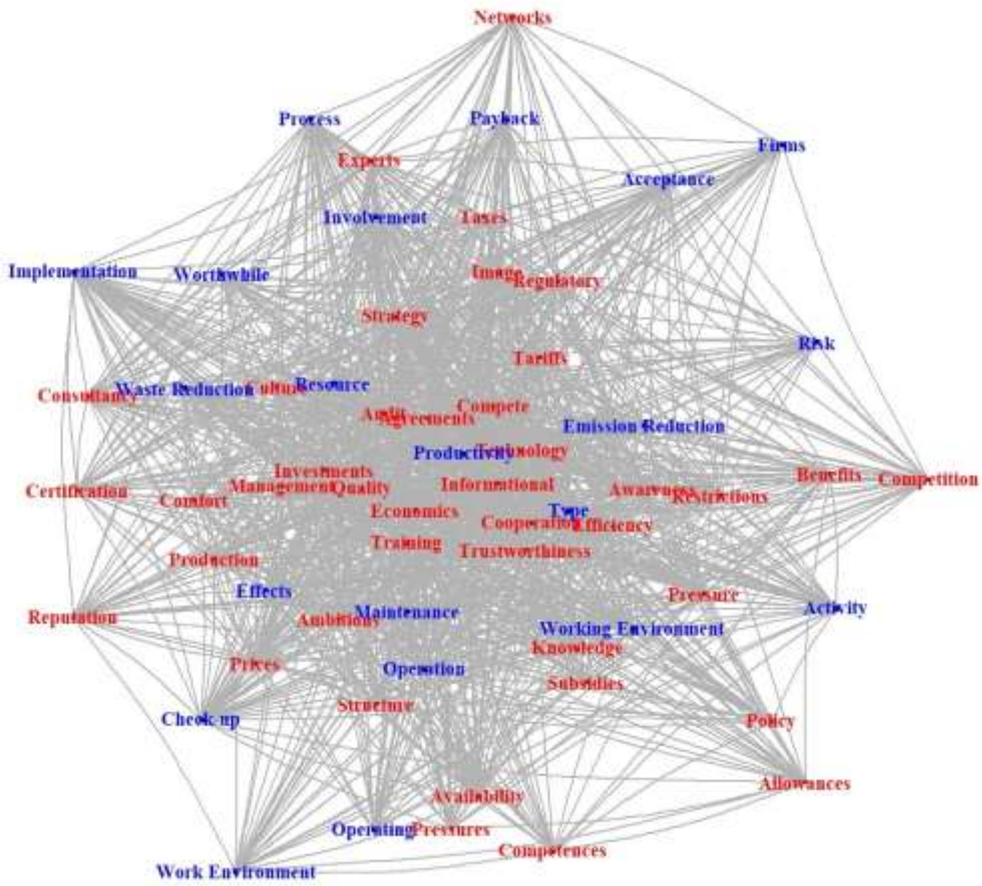


Source: Own Authorship.

For Figure 1.9 the drivers with the highest connections are management and technology. And the end driver is the policy. It is observed that, as in Figure 1.7, the political, economic, environmental and organizational aspects, in addition to technical equipment issues. Unlike Figure 1.8, Figure 1.9 does not have many connections. This is since there is a greater number of studies on barriers compared to drivers.

For (PYE; MCKANE, 2000) the recognition of the attributes of total benefits of energy efficiency projects helps to understand the investment opportunities in energy efficiency measures. The authors further argue that reducing energy consumption is the main policy in industrial decision-making, and therefore, reducing energy consumption should be correctly oriented as part of the total benefits of developing an EE project. Furthermore, (SUDHAKARA REDDY, 2013) complements that, by decreasing the technology price policy, it becomes a major factor for a faster penetration in industries. Thus, it is assumed that the security of price reduction can lead to an increase in technology adoption.

Figure 1.9. Social Network Analysis between drivers and attributes



Source: Own Authorship

The words in red refer to drivers while words in blue refer to attributes..

In Appendix 2.3, which includes articles referring to the classifications of drivers and barriers, in addition to specific articles on barriers and drivers, there are associations of attributes, shown in Figure 1.1 and 1.5.

The associated attributes are highlighted in the Framework for industrial energy efficiency (TRIANNI; CAGNO; DE DONATIS, 2014), with 14 attributes being analyzed. With four different approaches of attributes, costs, energy, environmental and organizational (productivity, operation, strategy, culture, process, involvement, acceptance, check-up, effects, risks and impact).

For costs, there are three associated scenarios related to the economy (economy, development, investments), the environmental (emission, reduction) and organizational (efficiency, industry, product, among others) issue. Two aspects related to energy, referring to political issues (scenario, region, among others) and organizational. And referring to three aspects of environmental coverage, political (region and scenario), organizational (product, technology and process) and economic (improvement, economy and consumption).

Costs to reduce energy consumption for SMEs such as implementation, adaptation of EE measures, engineering/contractor fees and equipment purchase can be considered costly due to low budget. On the environmental issue, the economics of reducing and emitting greenhouse gases are articulated with the implementation of EE measures. Linked to this aspect, financial savings in the medium- and long-term help to implement measures that reduce energy consumption.

Associations for organizational attributes contribute to three aspects: technological (system, technological, model and others), economic (cost, economy, saved others) and productive system (product, process, barrier).

Technological aspects point to a crucial factor, technologies that are efficient provide equivalent services at low costs, and non-energy benefits add value or improve the services of efficient technologies. In this way, they result in economically non-sensitive segments in which non-energy benefits can assume a special importance. However, efforts to incorporate it into marketing projects will help to accelerate the adoption of energy efficiency measures(BROWN, 2001).

Relating the economic attributes with the main organizational associations, several techniques such as payback is widely used in the industry because it is an intuitive method, associated mainly by measures that can be implemented and that can be adapted in a short period of time and with a period short return. Also, according to (TRIANNI; CAGNO; DE DONATIS, 2014) in most of the attributes not energy efficiency measures do not profoundly affect the organization as it requires limited corporate involvement.

And related to the industrial system, the dynamics of the energy system as described in the PDCA cycle (Figure 1.3) portrays to some extent that the organizational and managerial structure is one of the most important factors in reducing energy consumption. Thus, having an adequate organizational structure with techniques and models that help to implement standards such as the methodology that makes a diagnosis of energy consumption, developed in this thesis, will direct decision makers to an adequate choice for SMEs. (CAMERON; WHETTEN; BOZEMAN, 1983) portray that when relevant information is not standardized due to a lack of adequate procedures, it can be said that there is already a lack of lucidity from the top management of the industry. In this way, the entire chain of the industrial system will be harmed by a failure to reduce energy consumption.

Finally, Figure 1.10 shows the connection between attributes and cross-cutting technologies, closing the taxonomy of the structure of industrial energy efficiency.

The words in red refer to attributes while the words in blue refer to cross-cutting technologies.

In the social network, shown in Figure 1.10, it shows two large clusters connected through the cross-cutting motor, ventilation e heating technology. This connection between the engine and the two clusters is because this technology is the most used, representing 70% of total energy consumption. The rightmost cluster shows three cross-cutting technologies: lighting system, air compressor and HVAC, mainly with attributes that determine energy costs, environmental impacts and industrial management. In the leftmost cluster, the cross-cutting technology that makes connections with the attributes is ventilation, and the most connected attributes are related to internal management, maintenance and stability and cost of the device.

The four technologies are those that have been heavily studied. As mentioned above, the engine represents around 70% of energy consumption, with compressed air using around 10%. This large energy consumption is an opportunity for further studies, because with the excessive energy consumption it is necessary to investigate the causes and complications that each technology determines.

From this perspective, in addition to compressed air, the lighting system together with the HVAC, any effort to achieve energy efficiency produces continuous improvements, as verified by the attributes in connection with cross-cutting technologies in energy costs and industrial management. And the environmental impacts are related according to (FLEITER; HIRZEL; WORRELL, 2012; WORRELL et al., 2003) the reduction of pollutant emissions.

And finally, the ventilation system (separate from the HVAC system) reflects a lot to the place where the appliance is. Oriented that the maintenance attribute helps to reduce energy consumption as an internal company policy (ROHDIN, 2008).

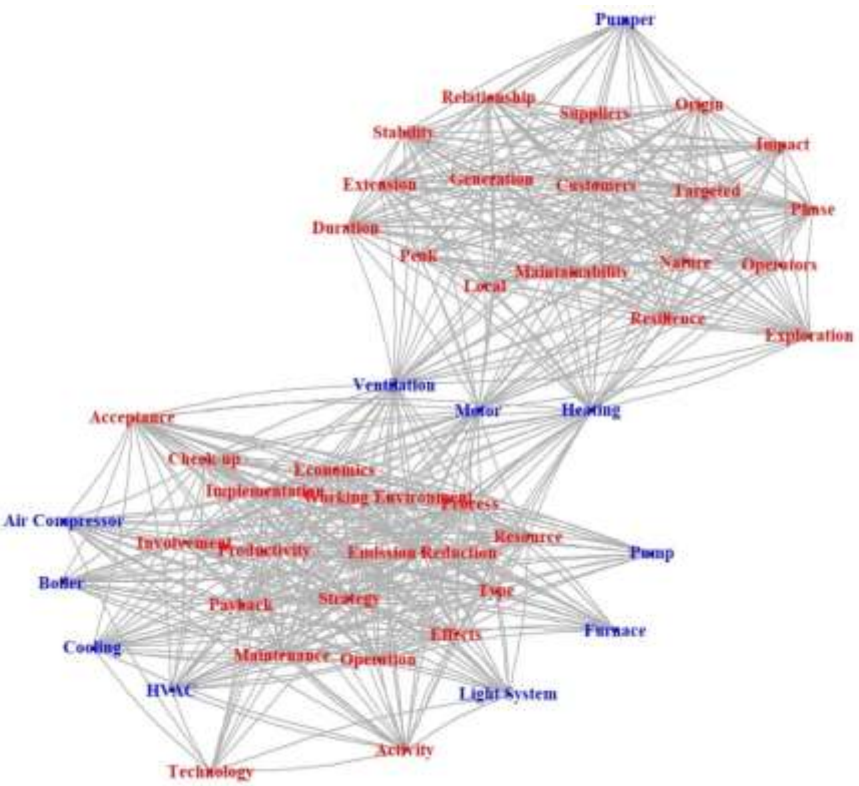
In Appendix 2.4, which shows the associations of works on the topic of classifications (drivers and barriers), barriers and drivers and attributes, it shows the words with the highest frequency of associations on each technology. Unlike Figure 1.10, the HVAC system was considered each technology separately (heater, ventilation and air conditioning).

By the characteristic of the words raised four important aspects.

i. Cross-cutting technology functionality

(VIDMAR, 2008) considers that the energy conservation of each technology is more important than pure EE, as energy conservation achieves a reduction in energy use by reducing system output and input, while pure EE reduces consumption. Also, (MARTIN et al., 1999) points out that it is difficult to predict the viability of a technology to be successful when implemented without a prior study of its functionality, since certain technologies reach different levels of efficiency depending on local conditions, including quality of inputs and style of operation.

Figure 1.10. Analysis of Social Networks between attributes and cross-cutting technologies



Source: Own Authorship

ii. Energy saving

(BUNSE et al., 2011) highlights that companies' energy accounting takes place through constant monitoring of EE and analysis of energy consumption in supporting manufacturing processes, being an important basis for energy management, as it allows decision makers to identify opportunities for improvement and track the effects of their decisions on their use. In addition, monitoring the company's industrial energy consumption should aim to predict whether EE can be achieved or not (KANNAN; BOIE, 2003; SCHULZE et al., 2016). In this sense, (THOLLANDER; OTTOSSON, 2010) emphasize that in many organizations, particularly those with many divisions and departments, inadequate allocation of energy costs can slow down energy management efforts (ROHDIN; THOLLANDER, 2006), further, (THOLLANDER; OTTOSSON, 2010) suggest that a monitoring system using sub-mediation in facilities for an adequate energy cost allocation facilitated the efficient use of energy costs per square meter.

iii. Organizational System

The successful adoption of energy efficiency measures means in some cases that the installation of cross-cutting equipment may require awareness at all hierarchical levels about efficiency, thus having a broader corporate involvement of the entire production unit. Although, in some cases, only a few people may be involved, such as maintenance staff. Thus, it is important to identify where the implementation of EE measures will be affected, which will help the company to implement an adequate strategy for successful implementation. In addition, (MORAIS et al., 2020) the implementation of cross-cutting technologies that would effect the reduction of energy consumption would be easy to implement and involvement of the people involved perform EEM properly. Implementation can even be easy when implementation requires minimal effort, routine, when not much skill is required, however operators may need to learn a new procedure to correctly install the gauge, difficult if a lot of staff effort is required. Since the procedure can be complicated, or even finding reliable contractors, and very challenging, when implementation can be unpleasant and even liable to resistance.

iv. Technological changes

The distinction of implementing EE measures from cross-cutting technologies is constituted as *a*) a simple renewal or recovery of existing functions; *b)* an optimization in the use of an existing technology; *c)* adaptation of the equipment; *d)* a new installation of energy-efficient equipment. For (WORRELL; BIERMANS, 2005) and (TRIANNI; CAGNO; DE DONATIS, 2014) knowledge of characteristics is important to differentiate technology decision-making behavior. For (SANDBERG; SÖDERSTRÖM, 2003), simple refurbishment and retrofit investments can be easier to make when buying new equipment because conditions remain the same. And taking more recent research portrays that it is important to distinguish

EE measures from recovery, optimization and innovation due to their different impacts within the production system. Still, (MORAIS et al., 2020) portrays that the adoption of some EE measures is somehow not unified, as one can be considered as a unique effort in which only its own implementation does not limit it to other measures, while others require verification. periodic.

Still, adding to the previous aspects, the Table 1.7 develops a small survey of some measures developed individually in some regions where access to technology to reduce energy consumption or programs is still inaccessible. They focus on the infrastructure part of the industry that includes different innovative methods for cross-cutting technologies. The considerations in Table 1.7 show that the set of works exposes the positive performance of improving energy consumption, most of these analyzes occur with unique experiences in the energy management process.

One work is done through an energy management program that includes auditing, another is through actions of efficient technologies, in addition to government policies that have been adopted for the efficient use of energy in the sector. The results of the different types of energy management system are in high demand, as transversal technologies are specifically responsible for energy consumption. The motor accounts for approximately 70% of the world's energy consumption, 60% of which by the induction motor (ALSOFYANI; IDRIS, 2013; SAIDUR; HASANUZZAMAN; RAHIM, 2012; SAIDUR; RAHIM; HASANUZZAMAN, 2010). Compressed air accounts for 15% of industrial energy consumption, with 10 to 20% of the energy used in the compressed air system being used for useful work (NEHLER; PARRA; THOLLANDER, 2018; SAIDUR; RAHIM; HASANUZZAMAN, 2010).

For HVAC, operating temperatures range from -40 ° C to 85 ° C, so when the system is running on energy opportunities it should maintain a 5% loss in production count (AMERICAN SOCIETY OF HEATING REFRIGERATION AND AIR CONDITIONING ENGINEERS, 2020; BRUNDAGE et al., 2014; KHAN; RYAN; ABEBE, 2017; TEKE; TIMUR, 2014). And industrial lighting is of great importance because it is valued not only in terms of safety, but also in terms of energy consumption (BALOCH et al., 2018; TRIANNI; CAGNO; DE DONATIS, 2014). Visual comfort demonstrates quality in the work environment, in which, according to European standards, it is defined as a subjective state of well-being in the visibility induced by the visual environment of buildings. Thus, the actions for the efficient use of energy in the industries depend on how they overcome some barriers, mainly those highlighted in Table 1.7, in the decision making of the efficient use of energy (CAGNO et al., 2019).

Table 1.7. Proposals for energy saving economy systems

	EEM	Description	Impact Manager	Source
Motor	Minimum Efficiency Performance Standards	Brazilian motor regulation program and other equipment that defines its mandatory efficiency level.	EE for Variable-Speed Drives (VSDs)	(ANDRADE; PONTES, 2017; BORTONI et al., 2013, 2020; GARCIA et al., 2007)
	Motor Rebate Program	Efficiency programs that benefit taxpayers with indirect and cascade-induced economic impacts.	EE for new premium efficiency engines, variable frequency drives (VFD)	(CHOI; EOM; MCCLORY, 2018)
	Methodology for Evaluation of EE in Induction Motors	Unified training methodology and laboratory equipment in energy efficiency research in induction motors	EE in electrical charge loss and reports CO_2 emissions	(DINOLOV, 2020)
	National Project on Energy Saving through Upgrading Electric Motors	Chinese national economy project with the purpose of facilitating the application and dissemination of high efficiency EMs.	EE measures, Energy-saving Companies and measures environmental	(LIU et al., 2017; ZHOU et al., 2015)
	Motor drive controller	Control methodology of three-phase induction motor unit due to its rejection and disturbances	EE for three-phase induction motor	(HAJIAN et al., 2009)

continuation

Table 1.7. Proposals for energy saving economy systems

	EEM	Description	Impact Manager	Source
Lighting systems	Optimization of indoor lighting tension	Variation of active and reactive power as a function of voltage for lighting devices	EE for interior lighting	(BOHARB et al., 2016)
	Energy management system	Lighting system to improve the quality of ambient lighting	EE for luminance with luxmeter.	(GORDIĆ et al., 2010)
	Short- and long-term monitoring	Identify lighting efficiency measures at industrial manufacturing	EE for lighting retrofit	(LEE, 2000)

continuation

Table 1.7. Proposals for energy saving economy systems.

	EEM	Description	Impact Manager	Source
Compressed Air	Optimization model of the industrial compressed air system	Compressed air system in the hot region on the effect of the inlet temperature on the isentropic efficiencies of the compressor and on the efficiency of the intercooler.	EE for ambient temperature, variation in isentropic efficiencies, and intercooler effectiveness	(AZIZIFAR; BANOONI, 2016)
	Performance control methodology for compressed air systems	General computational approach applied to energy performance control for compressed air systems	EE for operations, maintenance and energy accounting in compressed air systems	(BENEDETTI et al., 2019)
	Energy management in compressed air systems	Energy management procedure to monitor and control electricity consumption and maintain the energy performance of compressed air systems	Identification of Energy Inefficiency of Compressed Air	(CABELLO ERAS et al., 2020)
	Metric to characterize the performance of the compressed air system	Simplified method that uses unique metrics to determine the performance of the compressed air system in relation to energy consumption.	EE for charge compressor	(SHAW; MATHEWS; MARAIS, 2019)

continutiation

Table 1.7. Proposals for energy saving economy systems.

concluded

	EEM	Description	Impact Manager	Source
HVAC	Energy efficiency management in HVAC systems	Energy efficiency in series production systems	EE for machine recovery time	(BRUNDAGE et al., 2014)
	Optimal scheduling strategy based on activity type and weather	Daily schedule of activities allowing energy savings	EE for internal environmental	(KHAN; RYAN; ABEBE, 2017)
	On-demand ventilation and energy conservation of HVAC systems	Ventilation demand model and projected and optimized exhaust rate determination of the system	EE for industrial exhaust systems	(LIU et al., 2020)
	Framework for dimensioning the HVAC	Sizing method that guarantees a certain minimum level of performance of the HVAC system	EE for safety factor	(SUN et al., 2014)

Source: Own Authorship

Table 1.7 shows that the studies propose a positive performance of improving energy consumption. Most of these analyses consider unique experiences in the energy management process.

The studies covered in Table 1.7 address a wide range of energy management programs that have been adopted for efficient energy consumption in the industrial sector. Results of different types of energy management systems (ANDRADE; PONTES, 2017) are highly demanded, as cross-cutting technologies are specifically related to energy consumption.

The motor sector accounts for approximately 70% of the world's energy consumption, 60% of which are by induction motors (ALSOFYANI; IDRIS, 2013; SAIDUR; HASANUZZAMAN; RAHIM, 2012). Compressed air accounts for 15% of the industrial energy consumption, with 10 to 20% of the energy used in the compressed air system actually being used for useful work (NEHLER; PARRA; THOLLANDER, 2018; SAIDUR; RAHIM; HASANUZZAMAN, 2010). For HVAC, operating temperatures range from -40 °C to 85 °C; therefore, when the system is running on energy opportunities, it should maintain a 5% loss in production (BRUNDAGE et al., 2014; TEKE; TIMUR, 2014).

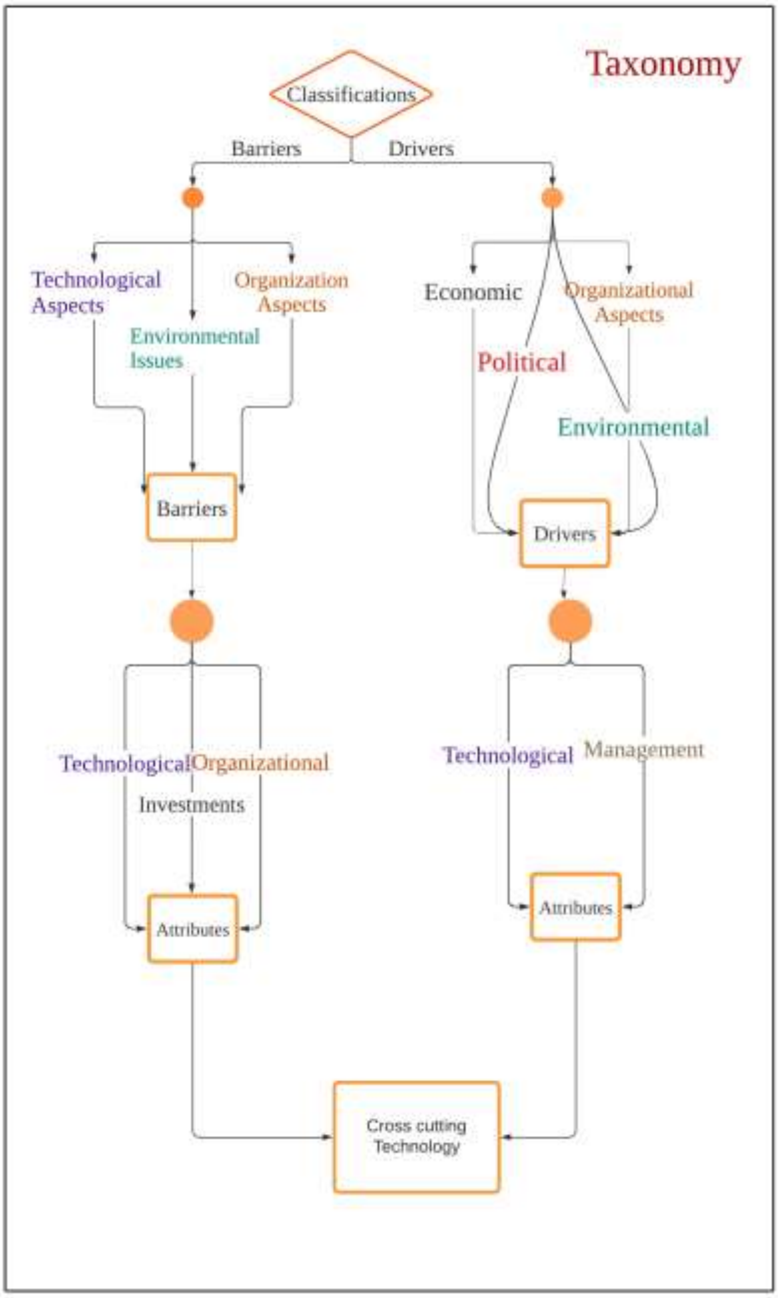
Finally, industrial lighting is of great importance because it is valued not only in terms of safety, but also in terms of energy consumption (BALOCH et al., 2018; TRIANNI; CAGNO; DE DONATIS, 2014). Visual comfort means quality in the work environment; according to European standards, it is defined as a subjective state of well-being in visibility induced by the visual environment of buildings. Thus, the actions for an efficient use of energy in industries depend on how they overcome barriers in the decision-making process of an efficient use of energy (CAGNO; MOSCHETTA; TRIANNI, 2019).

Figure 1.11 shows the result of the taxonomy built, it is observed that in the barriers and their attributes, the technological and organizational aspects were the most found in the systematic review of the literature, while the drivers do not have a concentration of specific themes, as a result of this line still not be as comprehensive as the barriers, thus, there is a generalization of studies when the topic is the drivers and their respective attributes. And finally, both are added to the cross-cutting technologies that, as shown in Figure 2.5, are influenced by classification, drivers/barriers, and attributes.

In addition to Table 1.7 which brings a picture of proposals for energy saving systems closes the cycle of Figure 1.1, Table 1.8 shows the main performance indicators that improve industrial performance, considering energy efficiency programs. In this way, closing the industrial energy efficiency framework.

Indicators for evaluating energy efficiency were initially reviewed and discussed by Patterson. Focusing mainly on thermodynamic and economic (physical) indicators with regard to their applicability at the policy level (PATTERSON, 1996). (TANAKA, 2008) also addresses energy efficiency performance measures for policies but targets the industrial sector directly. EE indicators such as absolute energy consumption, energy intensity, diffusion of specific energy saving technology and thermal efficiency are evaluated in relation to their reliability, feasibility and verifiability (TANAKA, 2008).

Figure 1.11. Summary of the Energy Efficiency Taxonomy



Source: Own Authorship

Table 1.8. Key performance indicators that improve industrial performance

Indicators	Authors
Monitoring energy end-use	(CAGNO; TRIANNI, 2013; CAI; LAI, 2021)
Energy Targets	(LINDBERG et al., 2015; LUNDGREN; MARKLUND; ZHANG, 2016)
Evolution of energy efficiency measures	(LINDBERG et al., 2015; LUNDGREN; MARKLUND; ZHANG, 2016)
Identification of energy efficiency potential	(APEANING; THOLLANDER, 2013; DONG; CHEN; WANG, 2020)
Energy Management System	(PALM; THOLLANDER, 2010)
Increase employee's awareness	(CANTORE; CALÌ; VELDE, 2016)
Identification of deviations	(COOREMANS; SCHÖNENBERGER, 2019; GIACONE; MANCÒ, 2012)
Allocation of Energy Costs	(PALM; THOLLANDER, 2010)
Interpretation of deviations	(CANTORE; CALÌ; VELDE, 2016)
Energy policy	(COOREMANS; SCHÖNENBERGER, 2019; GIACONE; MANCÒ, 2012)
Reference documents for best available technology	(OUYANG; CHEN; DU, 2021)
Skilled management facility of capacity utilization	(BENDAVID et al., 2009)
Management facility of production monitoring system	(SNATKIN et al., 2015)

Source: Own Authorship

Indicators for evaluating energy efficiency were initially reviewed and discussed by Patterson. Focusing mainly on thermodynamic and economic (physical) indicators with regard to their applicability at the policy level (PATTERSON, 1996). (TANAKA, 2008) also addresses energy efficiency performance measures for policies but targets the industrial sector directly. EE indicators such as absolute energy consumption, energy intensity, diffusion of specific energy saving technology and thermal efficiency are evaluated in relation to their reliability, feasibility and verifiability (TANAKA, 2008).

(BUNSE et al., 2011) portrays the focus on energy efficiency in manufacturing and, specifically, on the integration of efficiency metrics in production management. It is claimed that a low energy management status and hence the lack of data for efficiency measurement payback calculations are a barrier to energy efficiency. Energy efficiency KPIs and benchmarking systems are identified as industry needs for future research (BUNSE et al., 2011).

For (ANDERSSON; THOLLANDER, 2019) applying relevant energy efficiency indicators at various process levels is a complex issue, due to the complex and integrated production processes of manufacturing industries. Enabling improved energy performance measurement is an important and priority issue among energy intensive industries (ANDERSSON; THOLLANDER, 2019; BUNSE et al., 2011). Energy indicators can, for example, have a purpose to monitor the change in energy performance after implementing a measure, investigate trends in energy intensity for the industrial sector, or be used as a benchmark against equal companies (PRASHAR, 2017).

(JOHANSSON; THOLLANDER, 2018) portrays that many industrial EE indicators are physical indicators measured at an aggregated level. Since the establishment of indicators is a major factor for successful internal energy management in the industry. (AHMAD; DHAFR, 2002) and (LI, 2005) that performance indicators for manufacturing EE emphasize criteria related to cost, time and quality. With the growing awareness of energy-related costs as well as environmental impacts, companies are increasingly focusing on indicators that measure EE, in particular. Targets for reducing the carbon footprint of the product or factory generally identify company-wide improvement potentials for energy losses and costs (CHEN, 2008).

1.6 Final considerations

This chapter brought the proposal to develop the theoretical framework for the thesis. The chapter initially makes a characterization of energy efficiency and its main scenarios, focusing on the industrial. And right after, it brings a construction of the structure of industrial energy efficiency considering bibliometric methodologies.

The tools used in this chapter show the main existing gaps and extract from this context the behavior of energy efficiency in the industrial sector.

In taxonomy, it showed that the Venn Diagram that composes the production system, classifications, barriers/drivers, attributes and cross-cutting technologies, manages to develop a parameter that can guide the implementation of EE aspects. With three central aspects to the taxonomy. The first of economic management, the implementation of EE measures can direct the company to have energy savings and, consequently, a reduction in costs. Regarding environmental aspects, the reduction in energy consumption will reduce the emission of pollutants that degrade the environment. Managerial aspects that the implementation of measures that reduce energy consumption imposes on top management to develop internal mechanisms to achieve the measures.

In short, this chapter brought theoretical concepts and deepen them to assist in the literature and to serve as support for the subsequent chapters of the thesis.

2 INDUSTRIAL ENERGY EFFICIENCY ASSESSMENT MODEL

In this chapter, the paths that led to the methodological proposal will be demonstrated, such as the structure of the model, the description of the questionnaires developed in the thesis and the characterization of the model.

2.1 Scope of the Chapter

The information obtained for the construction of industrial EE assessment models comes from real companies and hypothetical data. The methodology will be developed by focusing in two indexes:

i. Criticality Index

The most delicate aspects of environmental quality, cost management and industrial management in relation to energy consumption will be analyzed.

ii. Improvement Index

This index will be analyzed individually for nine transversal technologies: boiler, air conditioning, condenser, lighting system, compressed air system, motors, refrigeration system, ventilation system and heating system.

Also, a priority general classification will be presented for the improvement index, emphasizing which transversal technology should be carefully analyzed to reduce energy consumption. And finally, the relationship between the criticality index and the improvement index will direct the company to prioritize the implementation of EE measures.

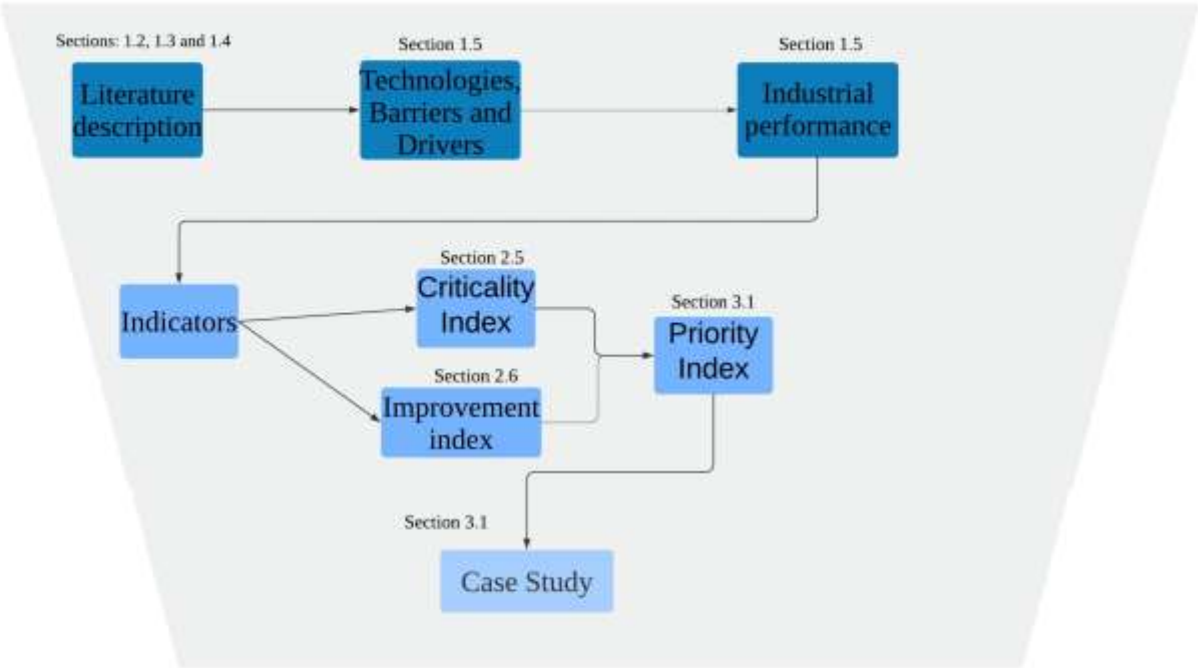
The fuzzy logic methodology was adopted as it is an efficient tool for aggregating data from different aspects, such as qualitative and quantitative. Thus, facilitating decision makers a better analysis in prioritizing EE measures.

Figure 2.1 shows the framework for development and validation of the proposed model.

2.2 MATHEMATICAL MODEL

> *"...A model is, therefore, an abstraction of reality, which is close to the true behavior of the system, but always simpler than the real system. On the other hand, if the model constructed is more complex than the system itself, we do not have a model, but a problem. This is because the main intention of modeling is to capture what is really important in the system for the purpose in question. If the model is as or more complicated than reality, why a model? For example, in a system formed by an automobile assembly line, with machines and operators, it is irrelevant to know the color of the worker's shoes if we are concerned with the number of automobiles produced in the month."* (CHWIF; MEDINA, 2014)

Figure 2.1. Framework for development and validation of the proposed model



Source: Own Authorship

According to (ZILL; CULLEN, 2006), the construction of a mathematical model starts with the diagnosis of the variables responsible for the changes in the system. As per the definition of modeling as a simplification of a real problem, it is preferable not to include all possible decisions in the model. It is important to discern which relationships and hypotheses should be considered and represented.

The process of modeling a real system must be concise to remove unnecessary complexity, thus, the delimitation of the study is an essential factor for achieving the proposed objectives.

2.3 FUZZY LANGUAGE MODELS

Fuzzy logic is one of the most used mathematical modeling methodologies for different areas and purposes, based on the theory of "Fuzzy" sets, in 1965 in a publication by Zadeh, in the journal Information and Control, in the United States. Its central principle is the nature of quantifying variables as something vague, indistinct, uncertain, offering them as a numerical treatment (SIMÕES; SHAW, 2007).

Unlike Boolean logic that restricts two valid alternatives, with: "right" and "wrong", values of "one" or "zero", "white" and "black", fuzzy logic represents values with a wide universe, without restrictions on number of conditions, such as infinite values between “one” or “zero”, the different color tones between white and black. Obviously, there are several applications dedicated to different types of modeling such as Boolean and Fuzzy with specific applications and recognition (SIMÕES; SHAW, 2007; ZIMMERMANN, 2001).

It is possible to gradually describe, through fuzzy logic, a certain fact in more detail, describing its various “diffuse” realities. Making it an excellent and efficient tool for modeling complex problems. Going beyond “right” and “wrong”, admitting variation in the process, with the possibility of classifying it for a certain element belonging to a domain and quantifying its degree of relevance for all these elements (SIMÕES; SHAW, 2007; ZIMMERMANN, 2001).

2.3.1 Linguistic variables

Variables represent a set within the universe of discourse. Linguistic variables are variables that allow the description of information that is usually available in a qualitative way, that is, they are variables whose possible values are words or phrases, rather than numbers, and can be represented by a fuzzy set.

Each input linguistic variable must be assigned linguistic terms that represent the states of this variable. In addition, a fuzzy set must be associated with each input linguistic term by means of a membership function. For example, the linguistic variable “height” can have the set of linguistic terms {low, medium, high}, with each linguistic term representing a specific fuzzy set.

Linguistic variables have the function of providing a systematic way for approximate descriptions of complex or ill-defined phenomena, using a type of linguistic description similar to that used by human beings. This allows the treatment of systems that are too complex to be analyzed using mathematical calculations.

2.3.2 Membership function

The membership function (PF) depends on the linguistic meaning defined for this set and its interpretation in the context of the universe of discourse, from which values are assigned to a numerical function.

They are defined from the experience and perspective of the user, and specialists, depending on the concept you want to represent and the context in which they will be used (BARROS; BASSANEZI, 2006; BARROS; BASSANEZI; LODWICK, 2017).

The membership functions can have different shapes and the most used are sigmoidal, bell, trapezoidal, triangular and gaussian. They are defined based on the specialist's experience and perspective and can be changed to improve the results (GOLDSCHMIDT, 2010).

2.3.3 Operators with fuzzy sets

As with Boolean sets, data in Fuzzy sets can be manipulated using logical methods to select and combine data from multiple sets. The basic operations on these Fuzzy subsets are similar in addition to being a generalization of the basic operations of binary logic. These operations can be used to obtain data resulting from the superposition of several Fuzzy data.

The following Fuzzy operators: OR, AND, Complement, Algebraic Sum, and Algebraic Product are described below. Let A and B be subsets of U, and μA, μB are membership values of sets A and B, for a given universe U. Then, respectively, we have:

I. OR Function

The Output Membership Value is controlled by the maximum input values. The only property the union operation requires is just that the operator returns 1 if at least one of the arguments is 1, and 0 if both are 0.

$$\mu_{A \cup B}(x) = \max(\mu_A(x), \mu_B(x)) \tag{2.1}$$

II. AND Function

The intersection means a sequence of 'AND' and is obtained through the MIN (minimum) operator. The only property that the intersection operation must satisfy is to return 1 when both arguments are 1, and 0 when either argument is 0. That is, in a set of membership values for a given element, the AND operator returns the minimum value.

$$\mu_{A \cap B}(x) = \min(\mu_A(x), \mu_B(x)) \tag{2.2}$$

III. Complement

All elements of set U that do not belong to set A

$$\mu\bar{A}(x) = 1 - (\mu_A) \tag{2.3}$$

The result of this operation is always a value greater than or equal to the highest input Fuzzy membership value. The effect of this operation is, therefore, to increase the membership value. It is observed that the Fuzzy algebraic product is an algebraic product, however, the

Fuzzy algebraic sum is not a simple algebraic sum (BARROS; BASSANEZI, 2006; ZIMMERMANN, 2001).

2.3.4 Fuzzy inference system

Fuzzy Set Theory analyzes sets with imprecise amplitudes considering membership in a matter of degree and not true and false (ROSS, 2004). Showing the fuzzy set through a curve that defines the degree of relevance between zero and one, and each point in the output space is mapped on the fuzzy set A, presented by Equation 2.4.

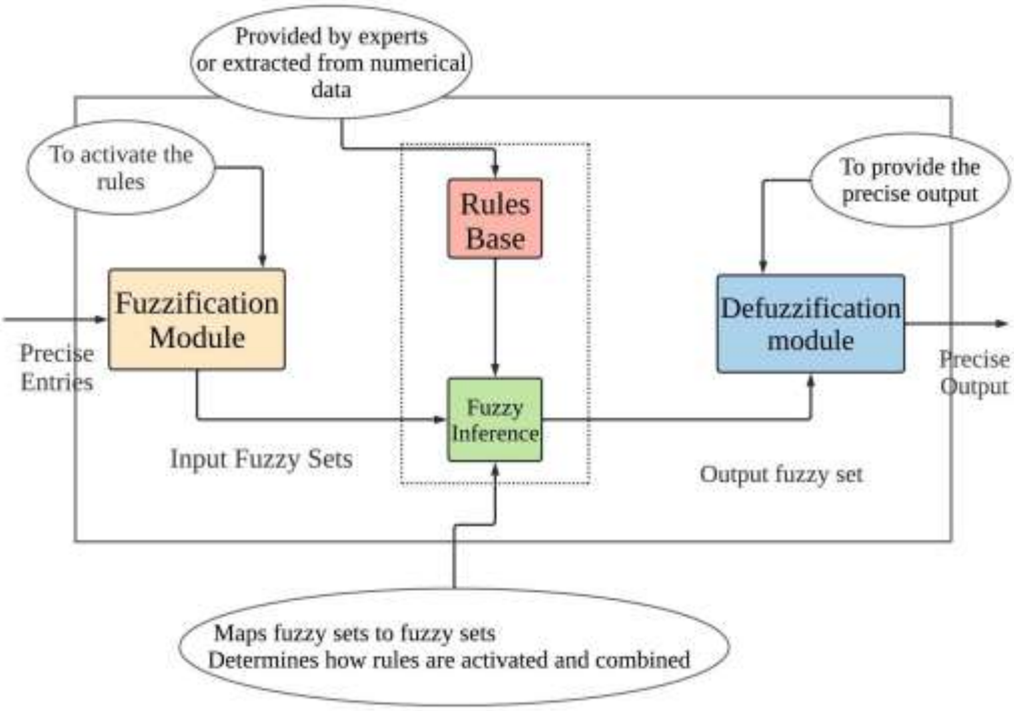
$$\mu_A = \chi \rightarrow [0,1] \qquad (2.4)$$

where χ originates from a universe set that is always a classical set and for each x ϵ χ μ_A checks the degree of relevance of the element x of χ to the fuzzy set A, with $\mu_A\ (x) = 0$ representing no membership and $\mu_A\ (x) = 1$ represents the total membership of x to the fuzzy set x.

The standard set operations are intersection (and operator), union (or operator), and complementary fuzzy subsets (non-operator). Given two or more fuzzy sets, these operations connect those sets so that they produce a single fuzzy subset.

Based on this reasoning, systems based on fuzzy rules can be defined, consisting of four steps, as shown in Figure 2.2, fuzzification, rule based, inference and defuzzification.

Figure 2.2. General scheme of a system based on fuzzy rules



Source: Own Authorship

In “fuzzification”, linguistic variables are defined subjectively (definition of input and output variables), in addition to the elaboration of their membership functions (BARROS; BASSANEZI, 2006). It is noteworthy that, in addition to being the initial phase of problem definition, the membership functions are chosen among the different types of triangular, trapezoidal, bell, Gaussian and other functions, in the way that best describes the sets that are being fuzzified (section 2.3) (SIMÕES; SHAW, 2007).

In the elaboration of the rule bases, sets of rules in linguistic form, in which “If <previous> Then <consequent>” describe the relationship between the input and output variables. The antecedent consists of a set of conditions that, when satisfied, even if partial, determine the processing of consequent rules by a fuzzy inference mechanism. Thus, when this occurs, he reports that a rule was triggered (BARROS; BASSANEZI, 2006)

Inference is the important step in “fuzzy” reasoning, in which the subjective information defined by the rule base is mathematically evaluated. It is processed in three (3) stages: aggregation, completion and composition (ABE, 2000; BARROS; BASSANEZI, 2006; BARROS; BASSANEZI; LODWICK, 2017).

I. Aggregation - consists of determining the level at which the part (SE) of the rules is fulfilled, using the conjunction (AND) which is represented by the intersection of the operator (MIN).

II. Completion - the composition of the degree of participation with the level of service (DOS) which is the significance of the rule or weight, which has a range from 0 to 1, where 1 is the greatest allowed significance or greatest weight.

III. Composition- represented by the union of the operator (MAX) uses condition validation to determine the validity of the conclusion.

And finally, defuzzification, which converts a fuzzy set into a numerical value, the most used are the Area Center or Centroid, the Center of the Highs and the Average of the Highs, thus, the delimitation of the study is an essential factor to reach the proposed objectives, completing the structure of the MAMDANI inference method.

In the thesis, the Centroid that will be used, developed by (SUGENO, 1985), (YONEYAMA et al., 2000) consists of a solution of the center of gravity abscissa. Being expressed, through Equation (2.5).

$$\mu_{FC\,(x_k\,,y_k)} = \frac{\sum_{i=1} \upsilon_i\ \mu_\upsilon\ (\ x_k\ ,y_k\ ,\upsilon_i)}{\sum_{i=1} \mu_\upsilon\ (\ x_k\ ,y_k\ ,\upsilon_i)} \tag{2.5}$$

where $\mu_{FC\ (x_k\ ,y_k)}$ is the fuzzification output, $\mu_\upsilon\ (x_k\ , y_k\ , \upsilon_i)$ is the aggregated adhesion function and $\upsilon_i \in$ U is a discrete element of the fuzzy output set.

2.4 Data collection

The method used in this research is considered a hybrid method, in which data with both qualitative and quantitative characteristics are used to develop a methodology.

Thus, initially there was the collection of real data, through two structured online questionnaires.

Shown in the link.

In the first questionnaire: questions were made about the characterization of the companies' production process: Company size, sector, costs, investments. The management of the predominant systems of the companies' production system: Predominant technologies of the production system, internal management of the company, maintenance system of the predominant technologies of the production system (corrective, preventive and predictive). In relation to the company's environmental quality: Main residues generated by the predominant technologies of the production system and energy use from the predominant technologies of the production system.

The second questionnaire was based on the search for the main energy gaps in the predominant technologies of the production system to direct aspects of technological improvement, thus, a total of 9 sets of questions were developed. The sets of questions that composes the second questionaire depend on the predominant technologies selected on the first questionnaire (question number 17). The nine sets of questions were structured according to the gaps in the following technologies: Motor, Air Conditioning, Lighting Systems, Boilers, Compressed Air, Heating, Cooling System, Ventilation System and Condenser Systems.

The questions were developed using a Likert scale (from 1 to 4), whose objective is to guide the clear perception of the company's technological gaps. The specific questions for each technology gap were adapted in line with the recommendations for improvement in the industrial assessment center report. An odd scale was not used since most studies indicate that it always point to the response of the medium that indicates "neutrality".

The criticality and improvement questionnaires can be viewed, respectively, through the links:

https://drive.google.com/drive/u/1/folders/1dv_S-AF5VDkiKGgOk66MBLPmP_ZjVccf

2.5 Criticality index

The construction of a critical composite index, in a way, follows the principle of verifying the main impacts for the company due to excessive energy consumption.

2.5.1 Environmental Quality Criticality Index

Environmental factors are at the center of the current discussion, due to constant increase in temperature as a result of the excessive emission of greenhouse effect gases (INTERNATIONAL PAINEL ON CLIMATE CHANGE, 2021b). In Brazil, the industrial sector is second in energy consumption, the first is the transport sector. Adding to these aspects, in Brazil there are few companies with adequate environmental management system that avoids the emission of waste in the terrestrial environment (PIRES; SOUTO; SILVA, 2020). With this, in addition to helping with the environmental impact, most of the time the industry can suffer from some punishments and even its image is affected.

The result of a rule-based inference system, in which Fuzzy Set Theory and Fuzzy Logic provide the mathematical tools to deal with such linguistic rules. A human operator capable of articulating his action strategy as a set of rules in the form if...then, an algorithm that can be implemented can be built in the most diverse areas.

For the energy use index, the following rules were used:

Renewable energy is very low and non-renewable energy is very high sustainable energy use is very low

Renewable energy is low and non-renewable energy is high sustainable energy use is low

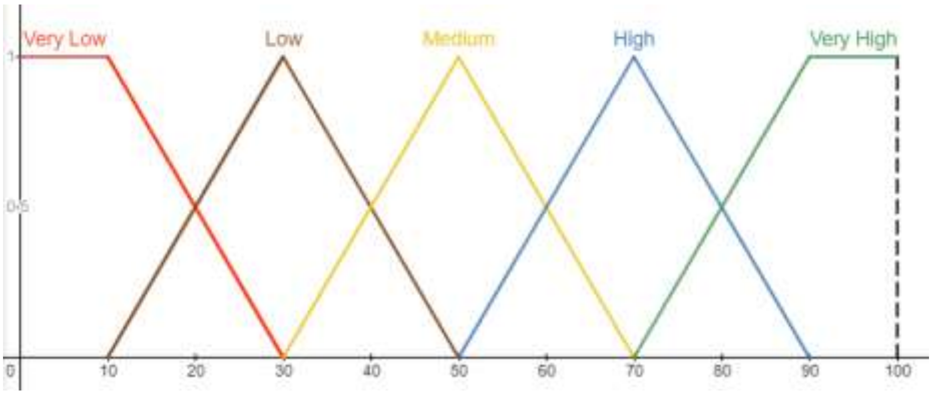
Renewable energy is average and non-renewable energy is average sustainable energy use is average

Renewable energy is high and non-renewable energy is low renewable energy use is high

Renewable energy is very high and non-renewable energy is very low and sustainable energy use is very high.

In this way, depending on the input data, it will activate a rule, over the inference system and provide the precise output through defuzzification. Figure 2.3 shows the configuration of association functions that would activate the rules determined by the input indicators. Thus, it is observed that many of them can absorb uncertainties inherent to the fuzzy methodology.

Figure 2.3. Membership Functions for the use of energy



Source: Own Authorship

Table 2.1 presents the indicators used in the fuzzification process to generate the environmental quality index, including fuzzy sets (described in section 2.1) and the question from questionaire 1 that is related to each indicator.

Table 2.1. Environmental Quality Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Use of Energy	Renewable energy source	Natural resources considered inexhaustible used as a source of energy in industries	44;45	[0; 0; 10; 30]; [10; 30;50]; [30; 50; 70]; [50,70,90]; [70,90,100,100]	Very Low; Low; Medium; High; Very High	Less-Worse
	Non-renewable energy sources	Natural resources considered exhaustible used as a source of energy in industries	44;45	[0; 0; 10; 30]; [10; 30;50]; [30; 50; 70]; [50,70,90]; [70,90,100,100]	Very Low; Low; Medium; High; Very High	Smaller-Better

continuation

Table 2.1. Environmental Quality Indicators

concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Environmental Risk	Solubility	Ability of a predominant technology of the productive system - resulting substance to dissolve upon contact with a particular solute	41;42	[0,0,3.3,9.9]; [3.3,9.9,16.5]; [9.9,16.5,23.1]; [16.5,23.1,29.7]; [23.1,29.7,33,33]	Very Insoluble; Insoluble; Average Soluble; Soluble; Very Soluble	Less-Worse
	Toxicity	Potential property that the toxic agent has to cause, to a greater or lesser degree, an adverse effect as a result of its interaction with the organism	41;42	[0,0,4.5,13.5]; [4.5,13.5,22.5]; [13.5,22.5,31.5]; [22.5,31.5,40.5]; [31.5,40.5,45,45]	Very Low; Low; Medium; High; Very High	Less-Worse

Source: Own Authorship

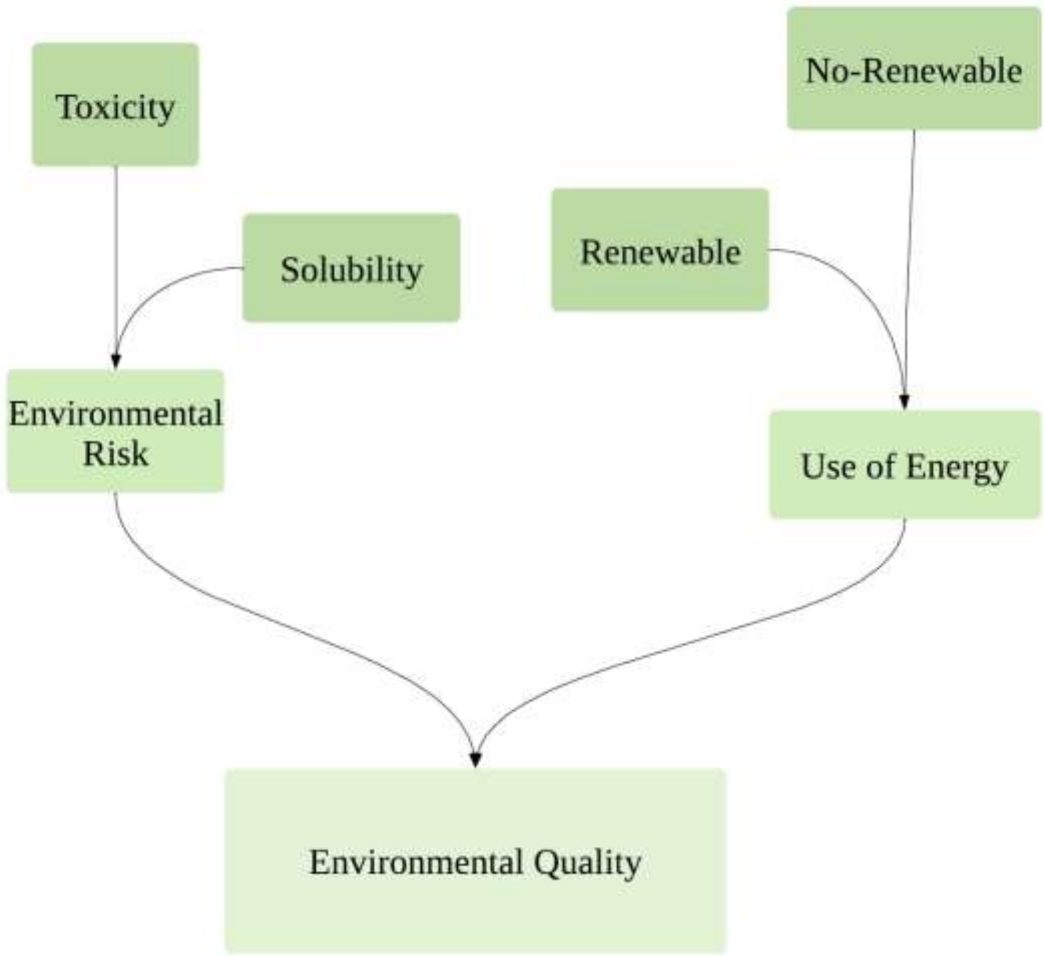
The aspects covered in Table 2.1 consider the types of resources used for the general functioning of the industry. The use of non-renewable energy was used as a complement to the energy coming from the distribution network. Furthermore, it is also important to mention that the development of the rule base (topic 2.1.3 and 2.15) considers the complementarity of the use of two different types of energy sources in SMEs. In which, the more renewable energy is better, and the more non-renewable energy is worse. Thus, through the final aggregation, a sub-index called energy use was created. It will determine the industry's characteristic in relation to energy sustainability.

Still, in Table 2.1, the indicators addressed are the solubility and toxicity of waste generated by the industry, which come from energy use. To verify both points, the amount of solutes generated from each residue was taken into account. The solubility and toxicity, respectively, are shown in Annex E and G of NBR10004 (BRASIL, 2004). Both aggregated indicators give rise to the environmental risk sub-index. By aggregating both sub-indices, the environmental quality index was created, verified in Figure 2.4.

2.5.2 Cost Management Criticality Index

The economic problems for Small and Medium Enterprises are one of the main obstacles to the implementation of measures to reduce energy consumption. The low budget for investments makes companies leave the implementation of measures that lead to energy efficiency in the background. However, notoriously, a production system with waste and inefficient use of energy compromises the achievement of a rationalized cost reduction in the company's balance sheet (WU, 2009).

Figure 2.4. Architecture for the Environmental Quality Index

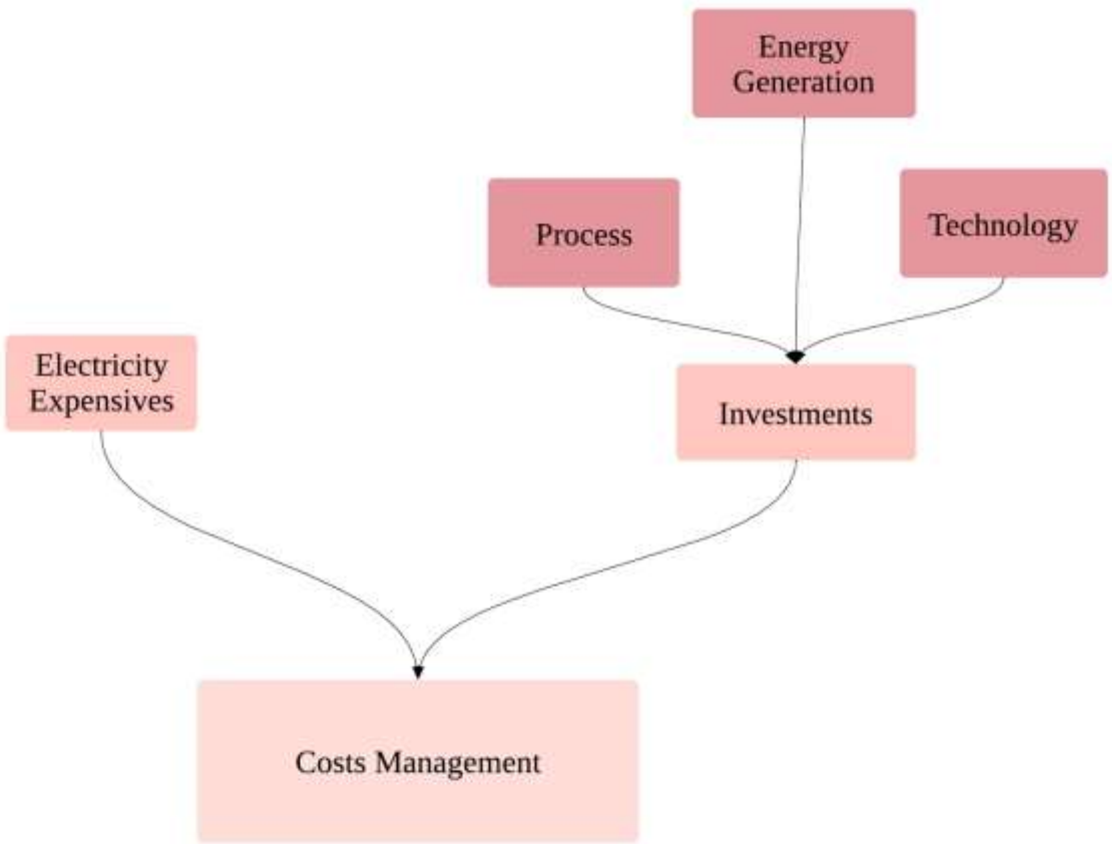


Source: Own Authorship

Tables 2.2 show the indicators used in the fuzzification process to generate the costs management index, including fuzzy sets (described in section 2.1).

The indicators covered in Table 2.2 are related to investments needed for the company to be able to deal with reducing energy consumption. The percentage of costs that each company determines annually for investment indicators was used as a unit, in addition to the percentage of monthly energy costs, due to the ease of capturing data in the annual energy balance. Also, unlike Table 2.1, the development of the rule base used 3 fuzzy sets in the input (section 2.1.3 and 2.1.5). Thus, through the final aggregation, a sub-index called investments is defined. It will determine the characteristic of the industry in relation to the necessary investment that the company must have to implement measures to reduce energy consumption. Thus, Figure 2.5 it shows the architecture of cost management indicators

Figure 2.5. Architecture for the Cost Management index



Source: Own Authorship

Table 2.2. Costs Management Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Electricity expenses	Electricity expenses	Costs from electricity	11	[0; 0; 10; 30]; [10; 30;50]; [30; 50; 70]; [70,90,100,100]	Very Low; Low; Middle; High; Very High	Smaller-Better
Investments	Technological investment	Investments in production system technologies that enable the best energy consumption in the industry	13	[0; 0; 25; 50]; [25; 50;75]; [50; 75; 100; 100]	Low; Medium; High	Less-Worse
	Investment in process	Investment in the industrial process that makes it possible to improve industrial energy consumption	15	[0; 0; 25; 50]; [25; 50;75]; [50; 75; 100; 100]	Low; Medium; High	Less-Worse
	Investment in types of power generation	Investment in various types of energy sources aimed at improving energy consumption	14	[0; 0; 25; 50]; [25; 50;75]; [50; 75; 100; 100]	Low; Medium; High	Less-Worse

Source: Own Authorship

2.5.3 Criticality Index of Industrial Management

The difficulties of industrial managers in Brazil to keep constant maintenance of their equipment is considered as one of the main problems for the implementation of measures to reduce energy consumption in Small and Medium Enterprises (PIRES; SOUTO; SILVA, 2020). This is due to the industry's rigidity in modifying the culture within it, and consequently, in changing the entire organizational dynamics.

Top management governance is a propagator of the main characteristics of government. The difficulty in taking decisions to implement EE measures, due to the lack of knowledge of this need, becomes a barrier to implementing effective measures to reduce energy consumption.

Adding to these facts, failure to maintain equipment that use high amounts of energy makes it difficult to reduce energy consumption, as SMEs portray that stopping equipment for maintenance would harm production at a given time. Thus, corrective maintenance ends up being the most used in these industries. (SIHN et al., 2018) describes that a production system with adequate energy efficiency is essential for the functionality of the technologies used and for a constant and effective production system. Tables 2.3 show the indicators that make up the industrial criticality sub-index and the fuzzy sets.

Table 2.3. Industrial Management Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Governance	Degree of skill of employees	Measures the employee's ability to cope with energy consumption measures	27	[0;0;0.5;1.5]; [0.5,1.5;2.5]; [1.5;2.5;3.5]; [2.5,3.5,4.5]; [3.5,4.5,5,5]	Very Small; Small; Medium; Big; Very Big	Less-Worse
	Management strategy	Measures the energy consumption management strategy for each predominant technology of the productive system	26	[0;0;0.5;1.5]; [0.5,1.5;2.5]; [1.5;2.5;3.5]; [2.5,3.5,4.5]; [3.5,4.5,5,5]	Very Small; Small; Medium; Big; Very Big	Less-Worse
Corrective	Corrective	Equipment Correction Frequency	30	[0; 0; 7.5; 15]; [7.5; 15;22.5]; [15; 22.5; 30; 30]	Low; Medium; High	Smaller-Better

continuation

Table 2.3. Industrial Management Indicators

Issue		Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Preventive	Operation	Operation sensitivity	Degree of criticality of a predominant technology of the productive system that can lead to a limitation of the final capacity of the operation in the industry	31	[0; 0; 6; 12]; [6; 12;18]; [12; 18; 24; 24]	Low; Medium; High	Smaller-Better
		Mean time between failures	Average equipment failure time	28	[0; 0; 3; 6]; [3; 6; 9]; [6; 9; 12; 12]	Low; Medium; High	Less-Worse
		Availability of repair personnel	Availability of employees to repair certain equipment	33	[0; 0; 25; 50]; [25; 50;75]; [50; 75; 100; 100]	Low; Medium; High	Smaller-Better
		Working Load	Equipment operating efficiency	35	[0; 0; 25; 50]; [25; 50;75]; [50; 75; 100; 100]	Low; Medium; High	Less-Worse

continuation

Table 2.3. Industrial Management Indicators

Issue		Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Preventive	Activities	Average repair time	Equipment repair time	29	[0,0,2.4,7.2]; [2.4,7.2,12]; [7.2,12,16.8]; [12,16.8,21.6]; [16.8,21.6,24,24]	Very Low; Low; Middle; High; Very High	Less-Worse
		Availability of required parts	Average time between ordering and receiving parts for normal equipment operation	32	[0,0,2.4,7.2]; [2.4,7.2,12]; [7.2,12,16.8]; [12,16.8,21.6]; [16.8,21.6,24,24]	Very Low; Low; Middle; High; Very High	Less-Worse

continuation

Table 2.3. Industrial Management Indicators

concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules
Predictive	Predictive operation	Maintenance periodicity of equipment or machines	34	[0; 0; 3; 6]; [3; 6; 9]; [6; 9; 12; 12]	Low; Medium; High	Less-Worse
	Technology data collection	Periodicity of data collection to assess the standard performance of the machines	36	[0; 0; 3; 6]; [3; 6; 9]; [6; 9; 12; 12]	Low; Medium; High	Less-Worse
	Instrumentation	Intrinsic safety measures for instruments to verify the performance of machines	38	[0; 0; 25; 50]; [25; 50;75]; [50; 75; 100; 100]	Low; Medium; High	Less-Worse

Source: Own Authorship

Indicators presented in governance were inspired and adapted from the work developed by (MARAZZA; BANDINI; CONTIN, 2010). The purpose is to verify the behavior of decision makers for the implementation of critical measures. Five fuzzy input sets were used for their rule bases, the domain was the same used by (MARAZZA; BANDINI; CONTIN, 2010). It will determine the managerial behavior that industry governance should take to implement EE measures.

Constant maintenance aspects of industrial equipment brings great benefits to industrial management. The introduction of an internal quality management parameter as determined by the PDCA System (chapter 2) would make it easier for the equipment to operate in good condition. Predictive maintenance directly contributes to operational efficiency and reduced energy consumption, as it reduces costs, errors and delays in the production flow.

As well as predictive maintenance, preventive maintenance has focus on prevention of failures for the wear and tear of industrial equipment. Faulty running equipment would result in excessive energy consumption. Thus, both preventive maintenance and predictive maintenance are important tools for reducing energy consumption.

In contrast to the maintenance mentioned before, the corrective is used in the set of maintenance only when the equipment malfunction no longer allows its operation. Thus, as seen in Figure 2.6, it does not have indicators, being aggregated in the maintenance index with the result obtained from the preventive and predictive maintenance sub-index.

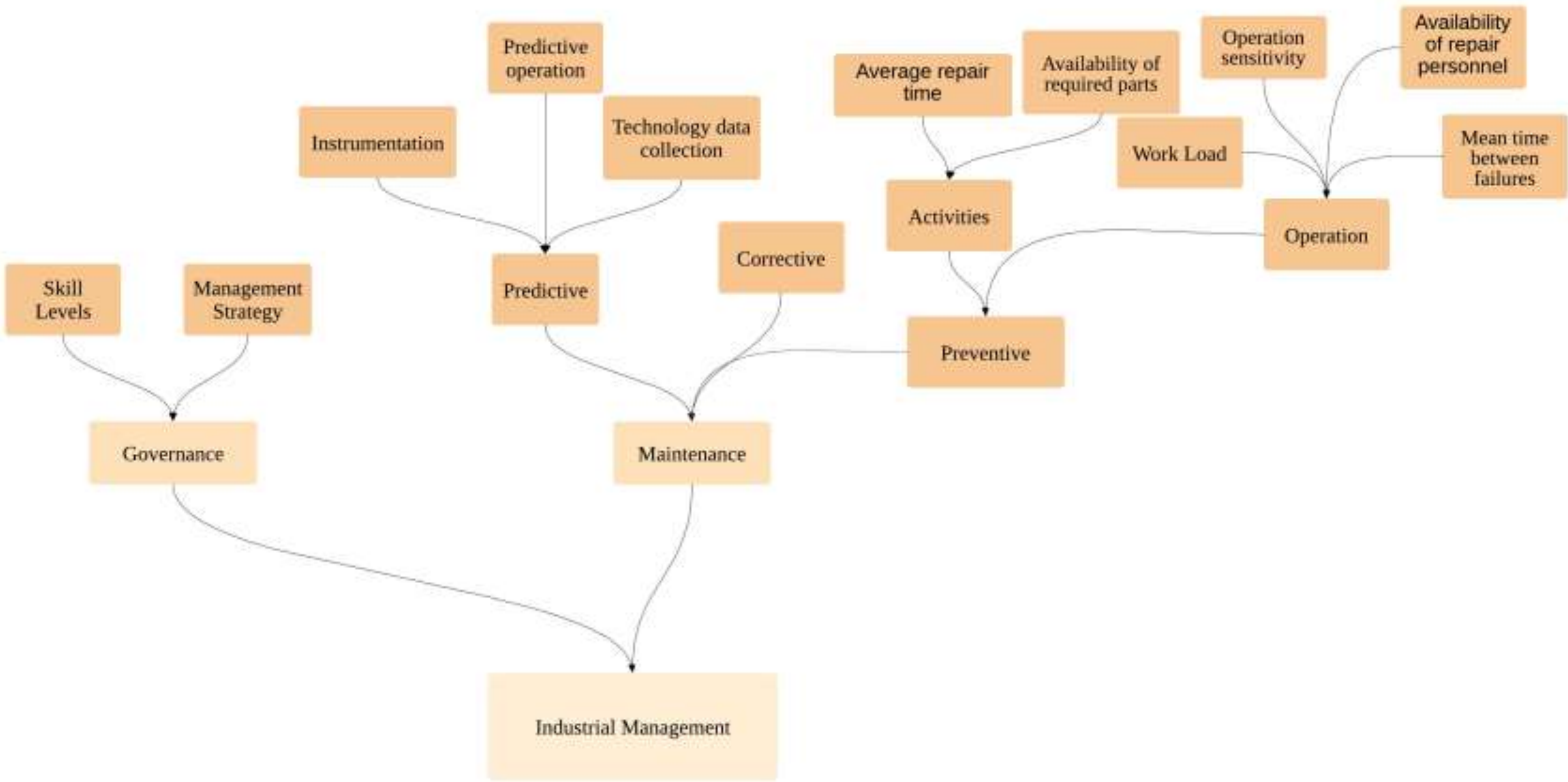
The domain for the corrective maintenance indicator corresponds to the frequency of breakdowns that the equipment goes through in the month. For predictive maintenance, the frequency of data collection and operational maintenance in the year, in addition to the percentage of the instrumentation process. In operational preventive maintenance, the domain occurs due to the percentage of availability of employees for equipment repairs and if the equipment workload is consistent with what is indicated in the manual. In addition to the average time between failures being monthly and the sensitivity of the operation is accurate on the day. And finally, the number of hours in the day it takes to get the equipment repaired and to make the necessary parts available for the equipment.

2.5.4 Criticality Index Model

As described in section 2.1, the fuzzification process aims to generate a metric that aggregates different spectra of data that contain uncertainty and abstraction.

The criticality index has environmental quality, cost management and industrial management as input variables. The variables that made up these indexes are described in Tables 2.1- 2.3. The general architecture of the criticality index is shown in Figure 2.7. The index has 4 levels. The first, through the input variables (Tables 2.1-2.3) is responsible for the development of level 2. The second level, arising from the indicators, will generate the environmental quality, cost management and industrial management indices (3rd level). The fourth level, the environmental quality indices, cost management and industrial management will be the composition agents of level 4 (the criticality index).

Figure 2.6. Industrial Management Indicators



Source: Own Authorshi

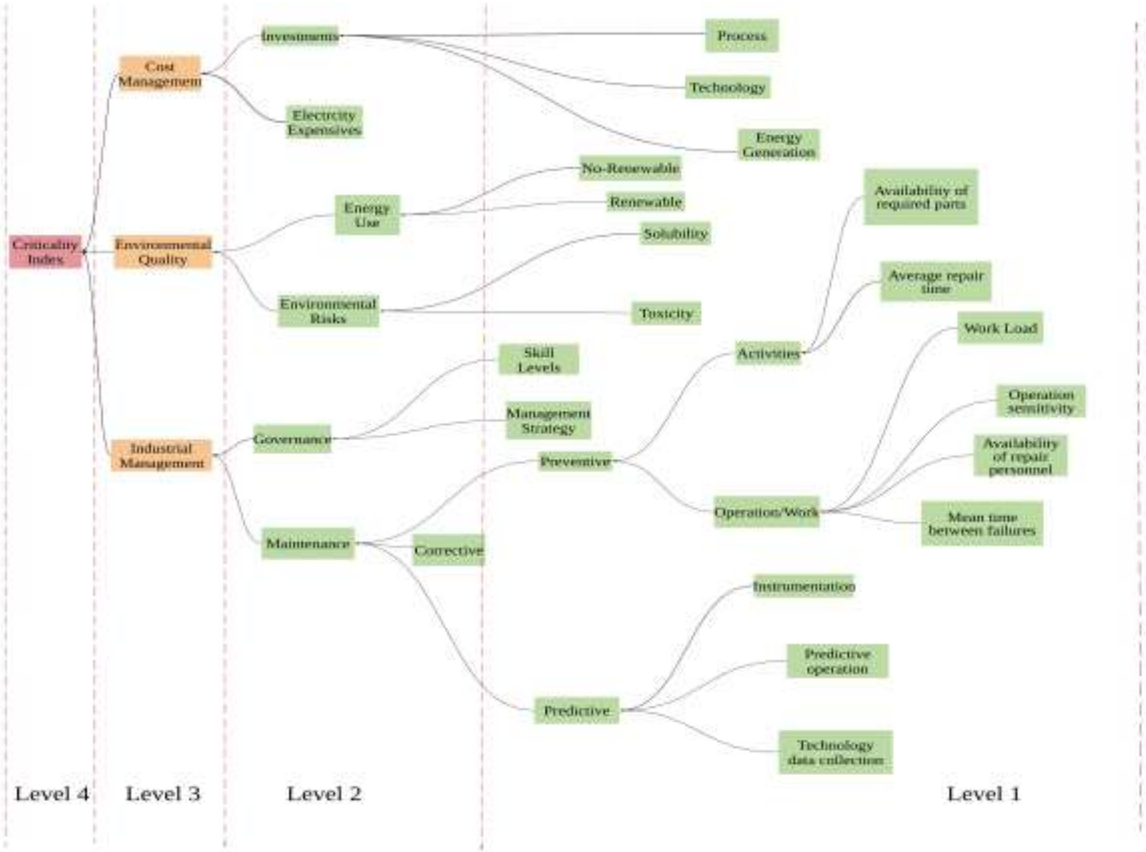
Still, it is important to point out that after the attribution of the linguistic terms, the trapezoidal functions in the ends and the triangular in the middles were used (Figure 2.8). Through the analysis involving three variables, a knowledge base with 125 linguistic rules can be established (APPENDIX 3.1), since 5 fuzzy sets were used in the input and 5 fuzzy sets in the output (Table 3.1,3.2 and 3.3) (being the fuzzy sets for the criticality index: critical (0,01,3), Potentially Critical (1,3,5), Acceptable (3,5,7), Potentially Uncritical (5,7,9) and Uncritical (7,9,10,10)), using the Mamdani inference method. The characteristic of the response is always the worst case of the entries, in order to emphasize the critical point of EE in the company being studied. And finally, the mass center of gravity was used as a defuzzification process.

Similarly, the same input sets for the environmental quality index, cost management, and industrial management were used to yield the criticality index shown in Figure 2.8.

The surface generated in the criticality index (Figure 2.9) shows that non-criticality becomes the exception within the system, since all other indexes that make up this output must have the only rule: appropriate, appropriate and effective, respectively for quality environmental, cost management and industrial management (APPENDIX 3.1). Then, the very inadequate will be the most common point of surface support.

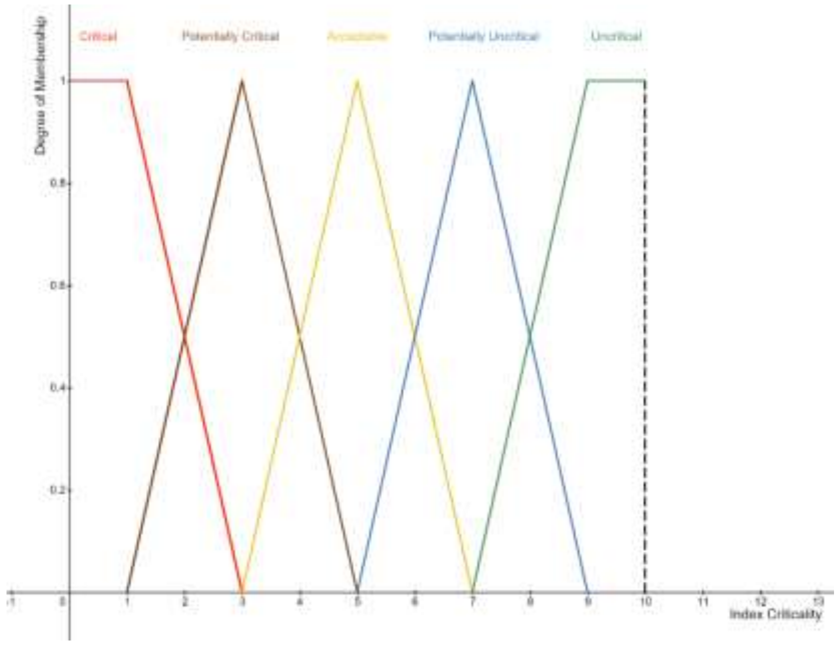
To verify that the suitability of all criticality index rule entries are robust, fictitious data was used, with the purpose of giving greater amplitude to the triggered rules and, in this way, verifying the functionality of the model. Thus, the study presents an adequate quality for the functioning of a judicious methodology. Soon after, a classification range with a universal color palette was built (Figure 2.10). The red to green hue has a sense of best to worst criticality point.

Figure 2.7. Architecture for the Criticality Index



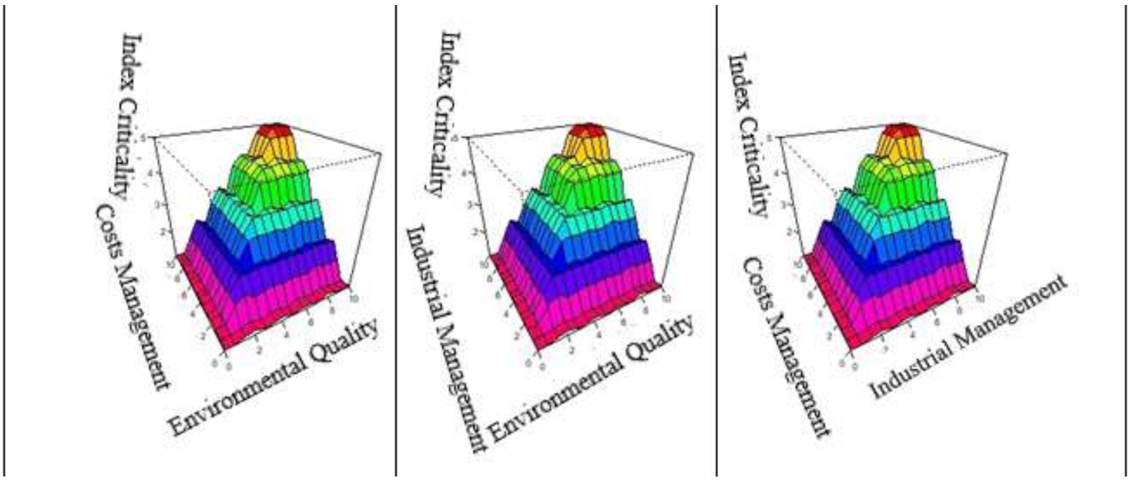
Source: Own Authorship

Figure 2.8. Membership Functions for the Criticality Index



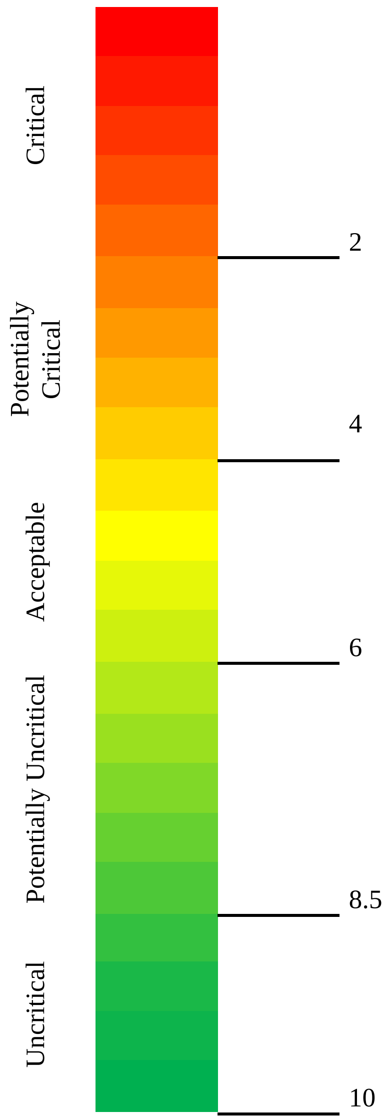
Source: Own Authorship

Figure 2.9. Criticality Index Surface



Source: Own Authorship

Figure 2.10. Criticality Index Rating Range



Source: Own Authorship

2.6 Improvement index

As described in topic 2.3, the reduction of energy consumption is at the center of the current discussion due to the increase in the Earth's temperature. The criticality index is an important step to discover points in a broader way to face possible measures to achieve the reduction of energy consumption. However, the criticality index alone is not enough to show specific points of energy consumption reduction in the industrial sector. The resolution of some energy gaps in some technologies is essential for EE to be forceful, as shown in the introduction of the thesis.

The technologies studied in the thesis were related to those that carry heat transfer, such as: boilers, heaters, refrigeration and air conditioning systems, in addition to operating systems, such as: motors, condensers, compressed air, ventilation system and lighting system.

2.6.1 Improvement index for the motor

The electric motor is an equipment that, when used constantly, in the long term, will be responsible for the highest consumption of electric energy in the industry. Also, the financial cost with a badly damaged engine is often greater than the price of the equipment itself. Still, according to (BRASIL, 2017b), in general, the motor is responsible for almost 70% of the consumption of electrical energy within the processes. Thus, improving the energy consumption of engine systems will have a direct reduction in electrical energy consumption.

Table 2.4 show the indicators used in the aggregation of the fuzzy model for the motor, along with the questions that were removed from each indicator and the assessment recommendation codes (ARC), section 1.4.

Table 2.4. Motor Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Performance	Ventilation	Operation of the ventilation system to maintain the proper functioning and performance of the motor	11;12	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Bad; Moderation; Good	Less-Worse	2.4156; 2.4157, 2.4155; 2.4152
	Operation Regime	Continuous and adequate engine speed	4;5	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Bad; Moderation; Good	Less-Worse	2.4132; 2.413
	Noise / vibrations	Vibration analysis to avoid wasting energy and parts wearing	7	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.4146

continuation

Table 2.4. Motor Index Indicators

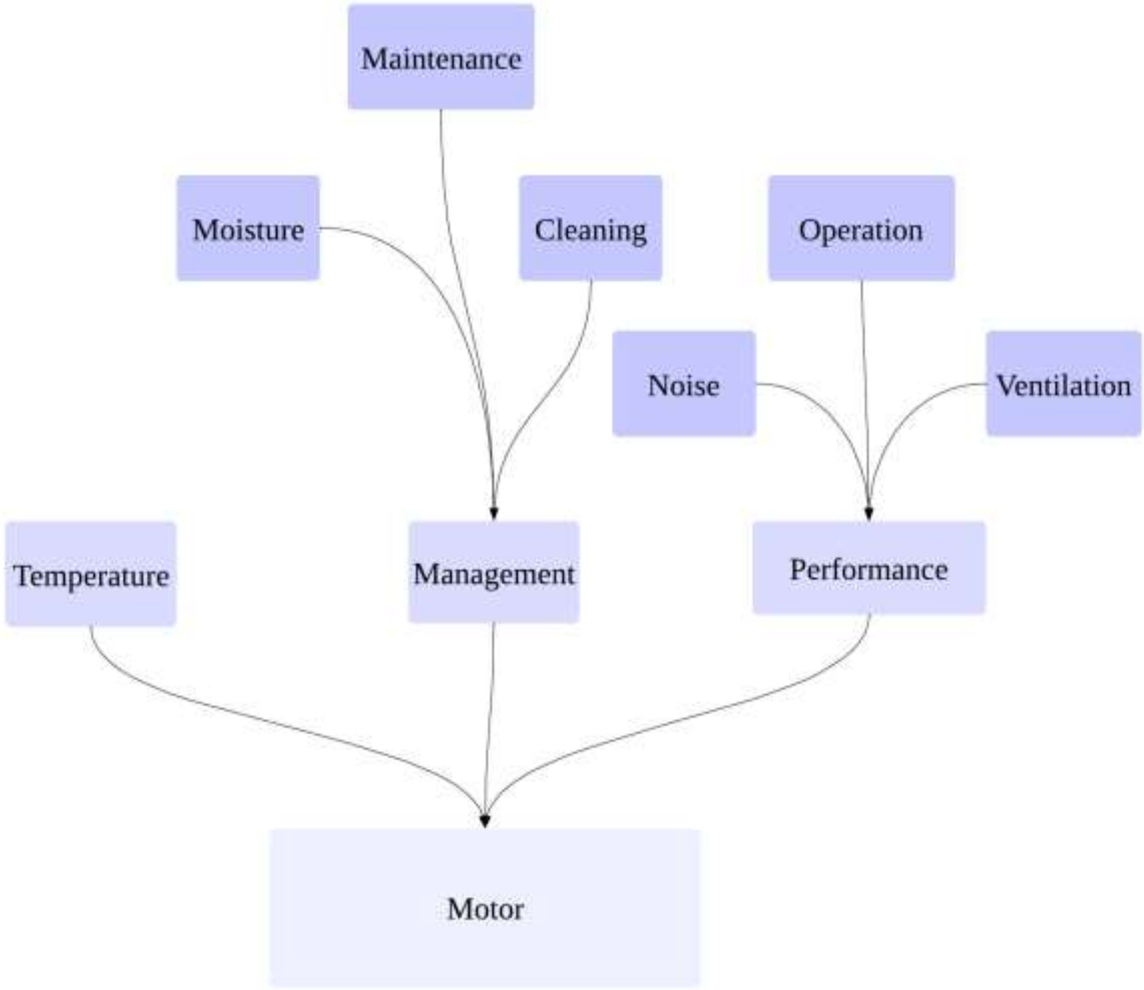
concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Management	Cleaning	Cleaning the engine in order to maintain good performance	13;14	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Dirty; Medium Cleaning; Clean	Less-Worse	2.4151
	Maintenance	Periodic maintenance of the engine in order to reduce the number of repairs	1;2; 8; 9	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.4156; 2.4157; 2.4155; 2.4152
	Moisture	Decreased humidity in order to maintain proper functioning	10	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.4151
Temperature	Temperature	Estimation of the potential of the temperature that favors the efficiency of the motor	3;6	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Minimum; Bad; Medium; Acceptable; Maximum	Smaller-Better	2.4133

Source: Own Authorship

According (KESICKI; YANAGISAWA, 2014; SAIDUR; HASANUZZAMAN; RAHIM, 2012), older and poorly maintained engines can even achieve savings on an average of 10% when energy efficiency improvements are developed. The financial impact can reach R$ 70000,00 per year. Still, the high performance of the motor without malfunctions allow for an adequate use that would facilitate energy savings within the industrial sector. Finally, as can be seen in Figure 2.11, the temperature is an input without previous indicators. The control of heat transfer to the environment, allows the motor not to lose efficiency to meet this demand, and consequently, energy efficiency becomes adequate within this framework.

Figure 2.11. Motor Improvement Index Architecture



Source: Own Authorship

2.6.2 Improvement index for compressed air system

According to the (USDOE-US, 2003), it is essential to know several characteristics such as the management of the air compressor's functionality, its performance and how the heat exchange with the environment works. This reduces the expense and need for maintenance and can improve working hours (SAIDUR; RAHIM; HASANUZZAMAN, 2010). Only through reliable measurements is it possible to improve operational parameters defined in (USDOE-US, 2003).

Table 2.5 in addition to Figure 2.12 show the behavior of the improvement index for the compressed air system.

Table 2.5. Compressed Air System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Performance	Local	Ideal size for the operation of compressed air and the production system	45;64	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.422
	Use	Periodic use of compressed air	45;64	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Smaller-Better	2.4226; 2.4227
	Cleaning	Cleaning of compressed air in for the purpose to improve its performance	46; 47; 54	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Dirty; Medium Cleaning; Clean	Less-Worse	24.236
Management	Maintenance	Periodic maintenance of compressed air in order to reduce the number of repairs	52;53;55;54; 56;57; 58;62	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.4225; 2.4235
	Moisture	Moisture removal to facilitate the operation process and improve the life of compressed air	48;49	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	24.222

continuation

Table 2.5. Compressed Air System Index Indicators

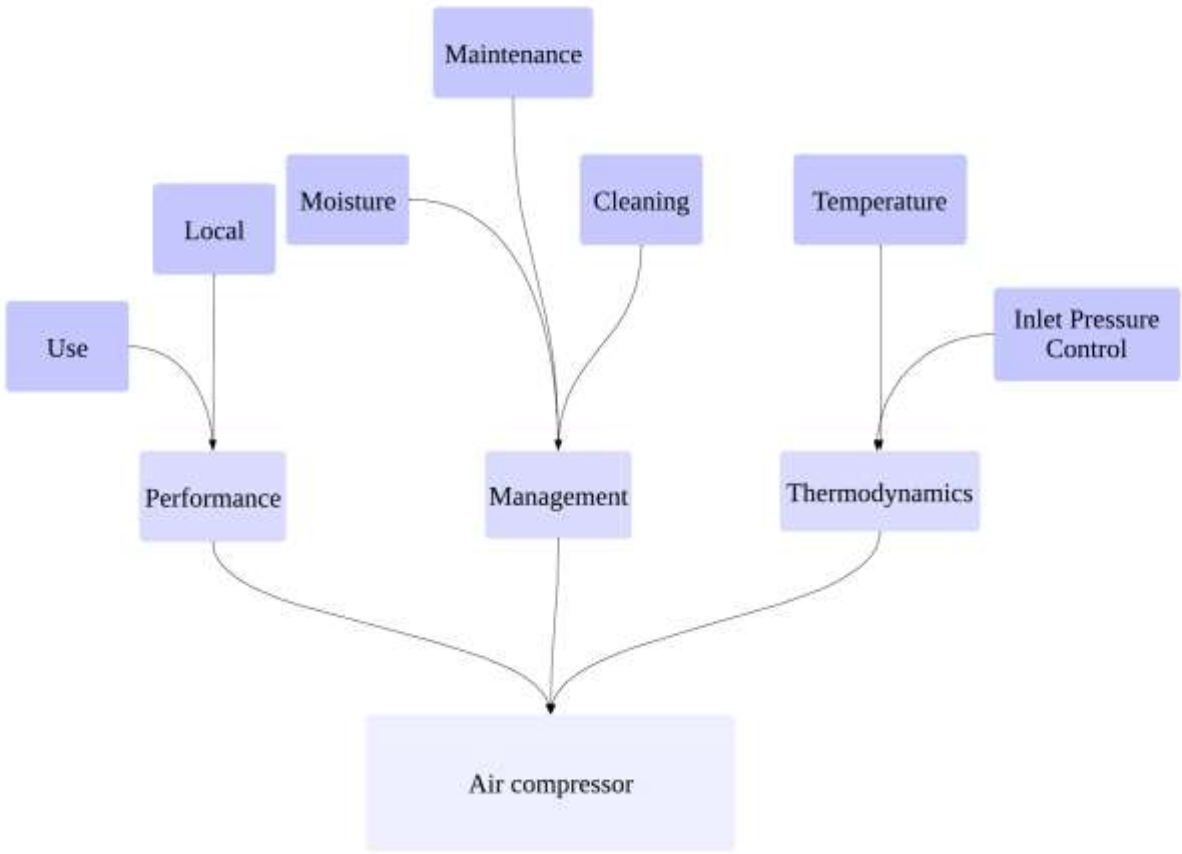
concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Thermodynamics	Temperature	Adjusting the gas pressure so that the compressed air intake is adequate.	60; 63	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Smaller-Better	2.4223
	Inlet Pressure Control	Estimation of the potential of the temperature that favors the efficiency of the air compressor	59; 61	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.4238

Source: Own Authorship

Industrial compressed air systems are sources of great waste and, as they are not part of the core activity of the business, they are often forgotten (BAKER et al., 2017). Specifically, in managing during compressed air generation, cleaning, humidity control. The performance of the installation site, as well as how its use, together with temperature and inlet pressure control, help to portray the energy consumption trend curve (BAKER et al., 2017).

Figure 2.12. Compressed Air Improvement Index Architecture



Source: Own Authorship

2.6.3 Improvement index for the lighting system

The lighting system, as well as the compressed air system, is essential to analyze general characteristics such as management and performance, and also peculiar characteristics regarding the safety of the workforce, comfort and performance of human potential. Hence, it transcends the unique need for energy savings, being linked to the scope of the greatest corporate asset that are its employees (MEKHILEF; SAIDUR; SAFARI, 2011) and contributing to avoid unnecessary efforts and accidents. Furthermore, the transversal technology system is an important instrument of industrial activities (LEE, 2000).

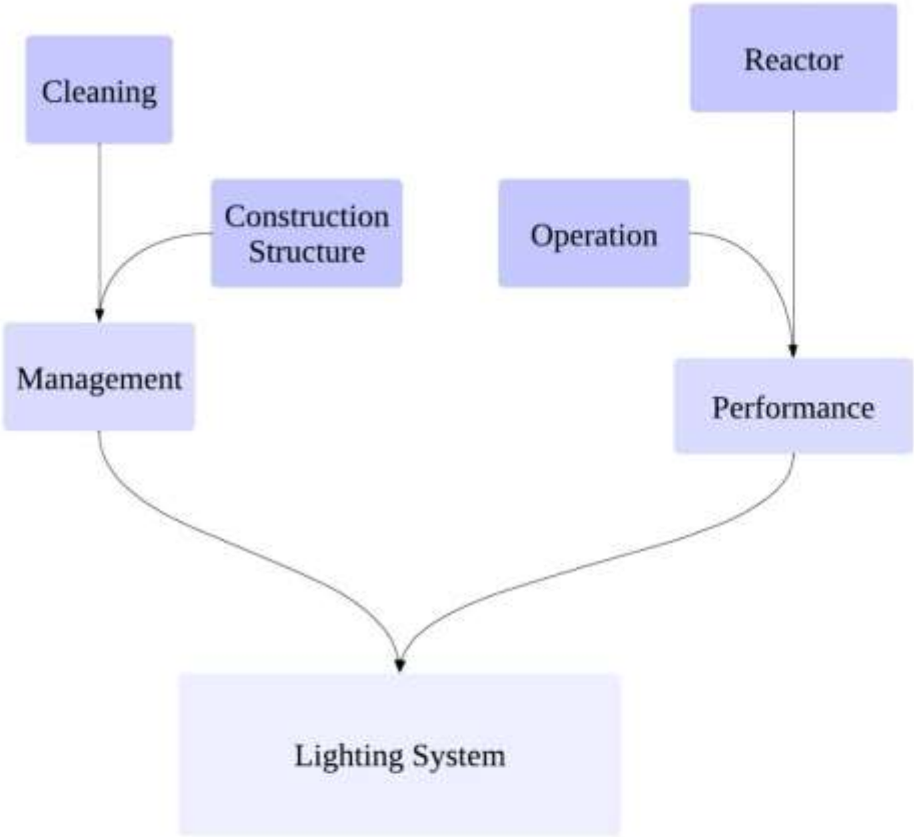
Table 2.6 in addition to Figure 2.13 show the behavior of the improvement index for the lighting system.

Table 2.6. Lighting System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Performance	Reactor	Control and stabilization of the lighting system starting current	21	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Smaller-Better	2.713
	Operating system	Appropriate working regime for the lighting system	14; 15; 16; 17	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Inappropriate; Inappropriate; Acceptable; Appropriate; Very Appropriate	Less-Worse	2.7124
Management	Cleaning	Cleaning of the lighting system in order to improve the lifetime of the lamps and improve the ambient lighting	19	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Dirty; Dirty; Middle Cleaning; Clean; Very Clean	Less-Worse	2.716
	Constructure Structure	Adequate construction so that all spaces can receive quality lighting	20; 18	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.7121; 2.714

Source: Own Authorship

Figure 2.13. Lighting System Improvement Index Architecture



Source: Own Authorship

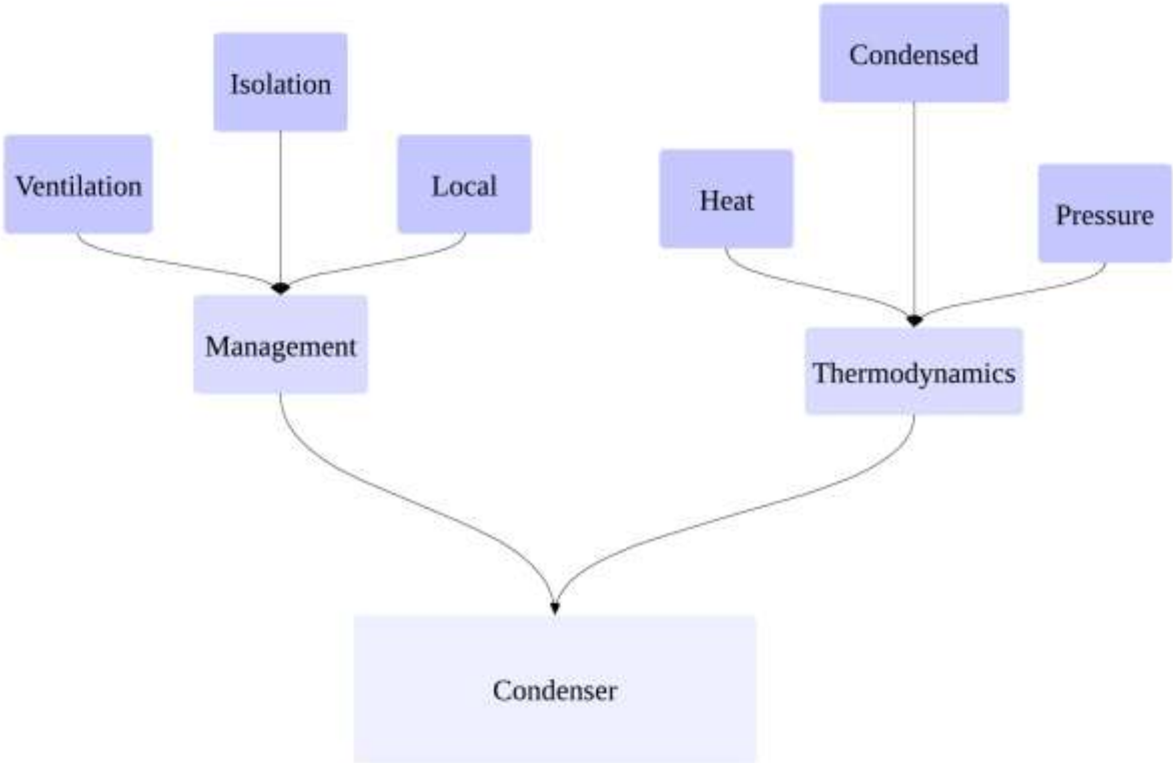
2.6.4 Improvement index for condenser

The condensation system is widely used in some industrial sectors such as food and beverage, pharmaceutical and petrochemicals. It has a characteristic of exchanging heat with the environment like an evaporator. With a serpentine attached to a set of plates, it rejects the heat received by a refrigerant fluid as it passes through the evaporator, removing heat from the environment and the heat received by the refrigerant during the compression work, to a cold source (CHUANG; SUE, 2005; OH; REVANKAR, 2005).

Industrial facilities using evaporative condenser systems can operate at temperatures ranging between 50 and 80°C. This temperature difference can lead to large energy consumption, thus raising unnecessary final expenses with industrial energy (STOECKER; JABARDO, 2002).

Figure 2.14 and Table 2.7 show the behavior of the improvement index for the condenser

Figure 2.14. Improvement index Architecture for condenser



Source: Own Authorship

Table 2.7. Condenser System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Thermodynamics	Pressure	Effect of loss of condenser pressure	41;42	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.2126; 2.2124
	Heat	Rate of heat loss by industrial condensed	43;44	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.2128
	Condensed	Condensate lost in the condensed heating process	38	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.2121

continuation

Table 2.7. Condenser System Index Indicators

concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Management	Local	Ideal dimension for boiler and production system operation	36;37	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.2123
	Isolation	Insulation to prevent heat loss from the condensed with the environment.	35;39; 40	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.2122
	Ventilation	Operation of the ventilation system to maintain the proper functioning and performance of the condenser	34	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.2124; 2.2135; 2.2136

Source: Own Authorship

2.6.5 Improvement index for the cooling tower

The cooling tower, as well as the condenser system, is part of the heat exchange technologies both have the function of cooling a given system. Specifically, in the thesis they are considered distinct technologies for the fuzzy system not to have more than 3 inputs at level 2.

The cooling tower is characterized by being an open circuit process. In this way, the heat from the water is dissipated by the air and by water evaporation. Then, the water is drained and returned to the production process, maintaining the cycle between heating and cooling (STOECKER; JABARDO, 2002).

The cooling tower has a preponderant role in ensuring industrial energy efficiency, because if the water is not cooled correctly, the equipment works constantly at high temperatures. In this way, it overloads the technology, potentially losing its productivity (WARTHMANN et al., 2018).

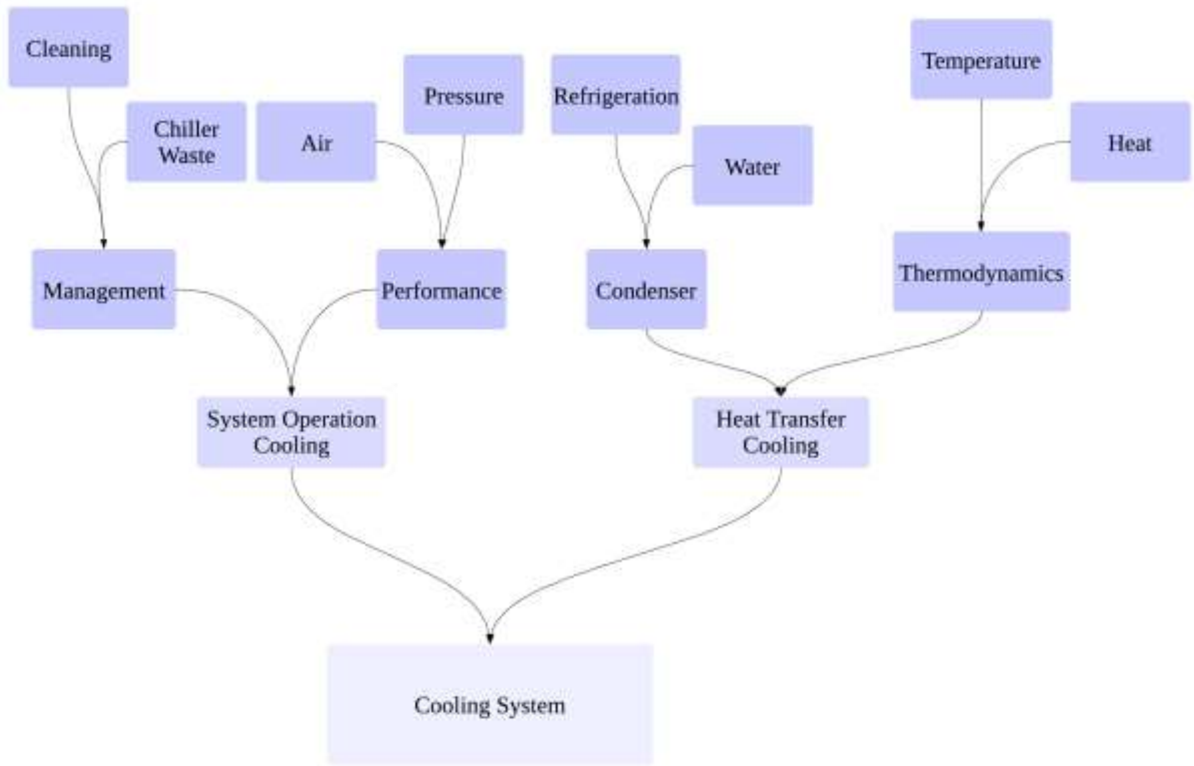
Figure 2.15 and Table 2.8 show the behavior of the improvement index for the Cooling Tower.

Table 2.8. Cooling Tower System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Performance	Use	Periodic use of compressed air	45;64	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Smaller-Better	2.4226; 2.4227
Management	Cleaning	Cleaning of compressed air in for the purpose to improve its performance	46; 47; 54	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Dirty; Medium Cleaning; Clean	Less-Worse	24.236
	Maintenance	Periodic maintenance of compressed air in order to reduce the number of repairs	52;53;55;54;56;57; 58;62	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.4225; 2.4235
	Moisture	Moisture removal to facilitate the operation process and improve the life of compressed air	48;49	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.4222
Thermodynamics	Temperature	Adjusting the gas pressure so that the compressed air intake is adequate.	60; 63	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Smaller-Better	2.4223
	Inlet Pressure Control	Estimation of the potential of the temperature that favors the efficiency of the air compressor	59; 61	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.4238

Source: Own Authorship

Figure 2.15. Improvement index Architecture for cooling tower



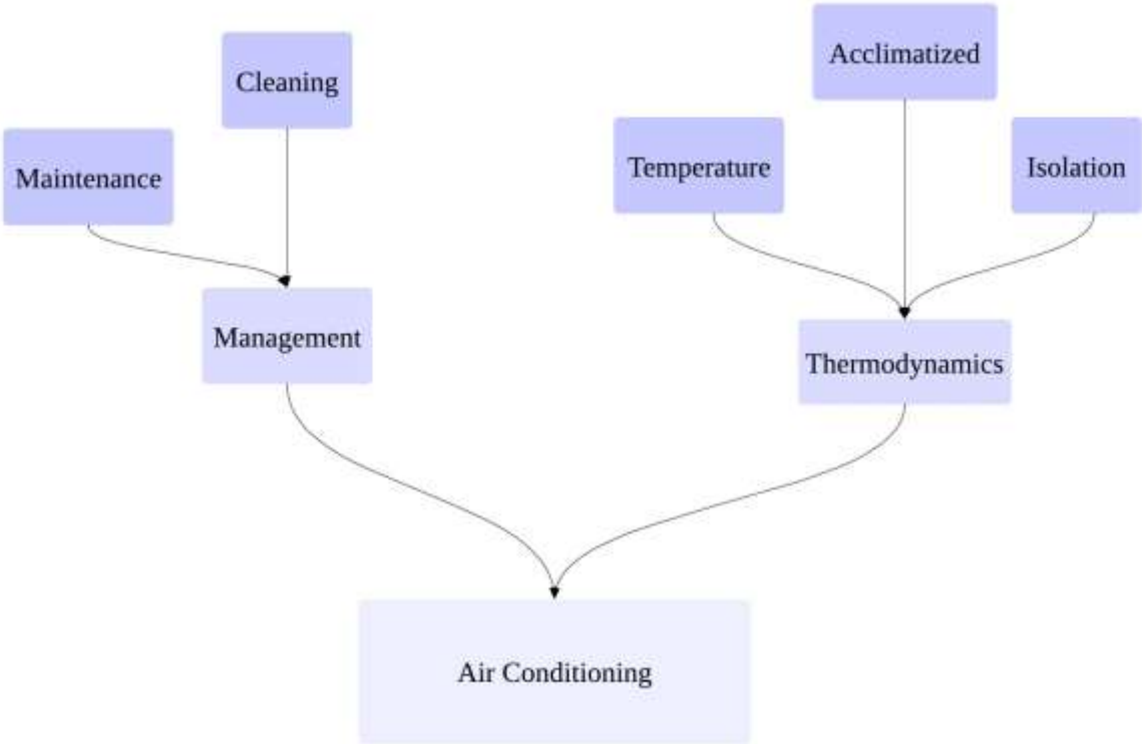
Source: Own Authorship

2.6.6 Improvement index for air-conditioning

Thermal comfort systems spend around 15% of energy consumption in the industrial sector. The first step to saving energy in the air conditioning system is its proper design. Also, this cross-cutting technology is essential for employee comfort, so developing a cleaning schedule becomes a necessary part of EE improvement for this equipment and for the proper functioning of the industrial system (KHAN; HADDARA, 2003; KHAN; RYAN; ABEBE, 2017).

The Figure 2.16 and Table 2.9 show the behavior of the improvement index for air conditioning.

Figure 2.16. Improvement index Architecture for air-conditioning



Source: Own Authorship

Table 2.9. Air Conditioning System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Management	Maintenance	Periodic inspection of the air conditioner to reduce the number of repairs	22; 23; 27; 32	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Dirty; Dirty; Middle Cleaning; Clean; Very Clean	Less-Worse	27.273
	Cleaning	Cleaning the air conditioner to improve its performance	33	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	27.224

continuation

Table 2.9. Air Conditioning System Index Indicators

concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Thermodynamics	Acclimatization	Temperature range suitable for ambient comfort	28	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.7221; 2.7243; 2.7311; 2.7312
	Temperature	Estimation of the temperature potential to favor the exchange of heat with the external environment	25; 26	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.7264
	Isolation	Insulation to prevent heat loss, from air conditioning, with the environment	24; 29; 30;31	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.7222; 2.7223; 2.7224

Source: Own Authorship

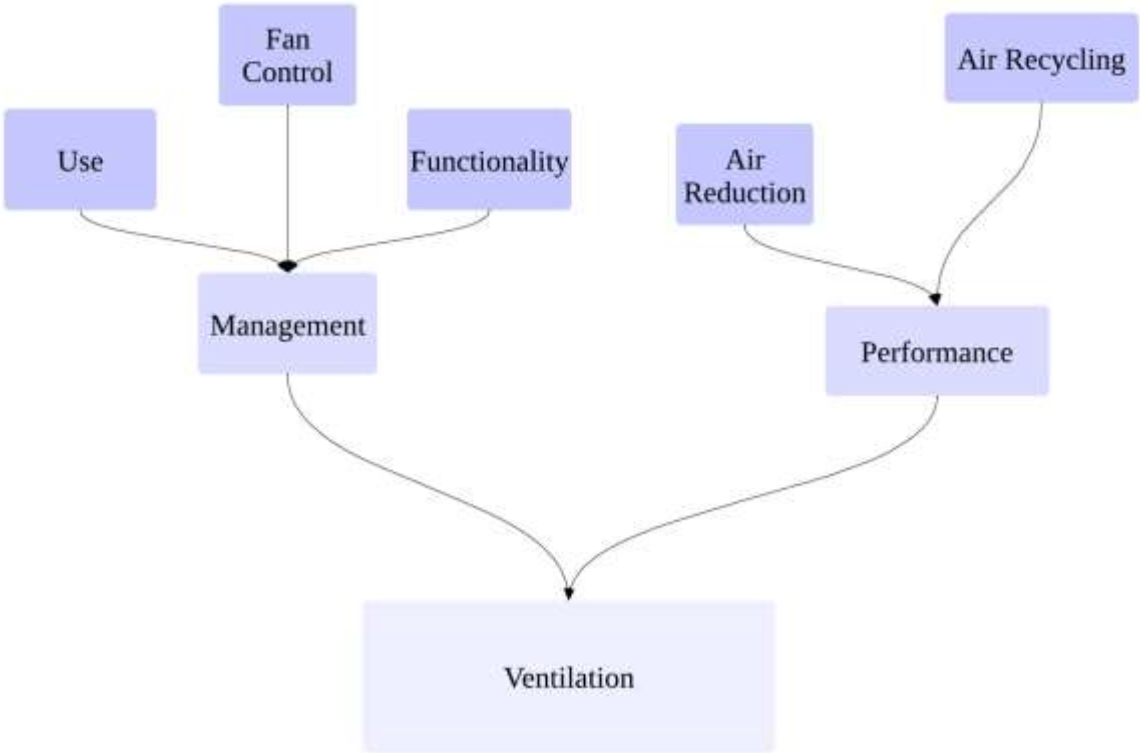
2.6.7 Improvement index for ventilation system

The ventilation is a cross-cutting technology that has the function of taking the gas from a closed place to an open place. It is used to bring an amount of fresh air into an environment (BRUNDAGE et al., 2014).

The ventilation system represents around up to 70% in energy consumption reduction with energy efficiency measures (LIU et al., 2020). How to maintain and operate dampers in addition to system flow control. In the case of specific combustion fans, they represent a reduction in energy savings through the quality of burning and economy of the fuel used.

Figure 2.17 and Table 2.10 show the behavior of the improvement index for the ventilation system.

Figure 2.17. Improvement index Architecture for Ventilation System



Source: Own Authorship

Table 2.10. Ventilation System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Performance	Air Reduction	External air compensation when the ventilation system is not in use	102	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.7314
	Air Recycling	Air recycling to improve comfort and ambient temperature	104	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.7313

continuation

Table 2.10. Ventilation System Index Indicators

concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Management	Use	Turn off the ventilation system when the room is not in use	101	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.7311
	Fan control	Centralization of fan control to ensure its operation	103	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Bad; Moderate; Good	Less-Worse	2.7316
	Functionality	Establishment of a monitoring program to ensure the functioning of the ventilation system	106;107	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.7316

Source: Own Authorship

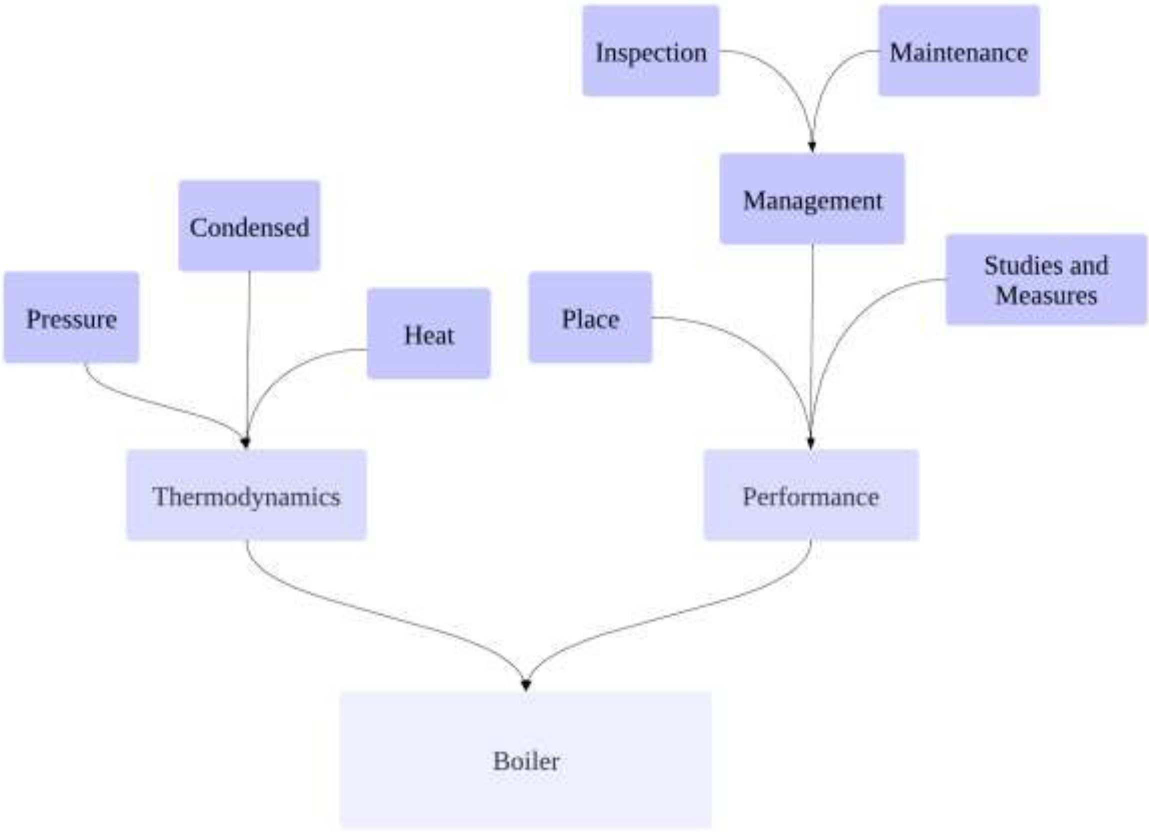
2.6.8 Boiler improvement index

The boiler is a cross-cutting technology whose purpose is to produce steam with pressure above atmospheric pressure using various energy sources such as coal and biomass. The steam produced in the boilers is used to feed turbo generators, evaporators and distilleries (YIN, 2015).

The energy stored by fuel sources is transferred to water and then to the product in the form of thermal energy. In industrial sectors that has the boiler as the main technology, it consumes almost 90% of the sector's total energy, especially when measures to control energy consumption are not being carried out with some constancy (CARVALHO et al., 2013).

The Figure 2.18 and Table 2.11 show the behavior of the improvement index for the boiler.

Figure 2.18. Improvement index Architecture for Boiler System



Source: Own Authorship

Table 2.11. Boiler System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Thermodynamics	Pressure	Amount of heat produced by the complete combustion of a unit from mass fuel	76	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	21.242
	Heat	Rate of heat loss by industrial boiler	88	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.1212; 2.1213; 2.1243
	Condensed	Condensate lost in the boiler heating process	85	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	21.224

continuation

Table 2.11. Boiler System Index Indicators

concluded

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Performance	Place	Ideal dimension for boiler and production system operation	75	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	21.211
	Studies and measures	Periodicity of studies and measures to evaluate the standard boiler performance	89	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; Much	Less-Worse	2.1222; 2.1223; 2.1224
	Inspection	Inspection of the operational performance of the boiler to avoid loss of functionality	79; 80; 86;87	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	21.233
	Maintenance	Periodic maintenance of the boiler to reduce the number of repairs	77; 78; 81;82; 83	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.1221; 2.1231; 2.1232; 2.1233

Source: Own Authorship

2.6.9 Improvement index for heaters/dryers

Despite having a higher energy efficiency compared to the boiler (section 2.2.8), in the direct heater the combustion products remain at an ambient temperature, making it have less heat transfer and, consequently, a greater possibility of energy savings (KHAN; RYAN; ABEBE, 2017; SARKAR; BHATTACHARYYA, 2012).

In indirect heating systems, heat is transferred from the burnt fuel to the drying air through heat transfer. As a result, the combustion products are not mixed to the content to be heated.

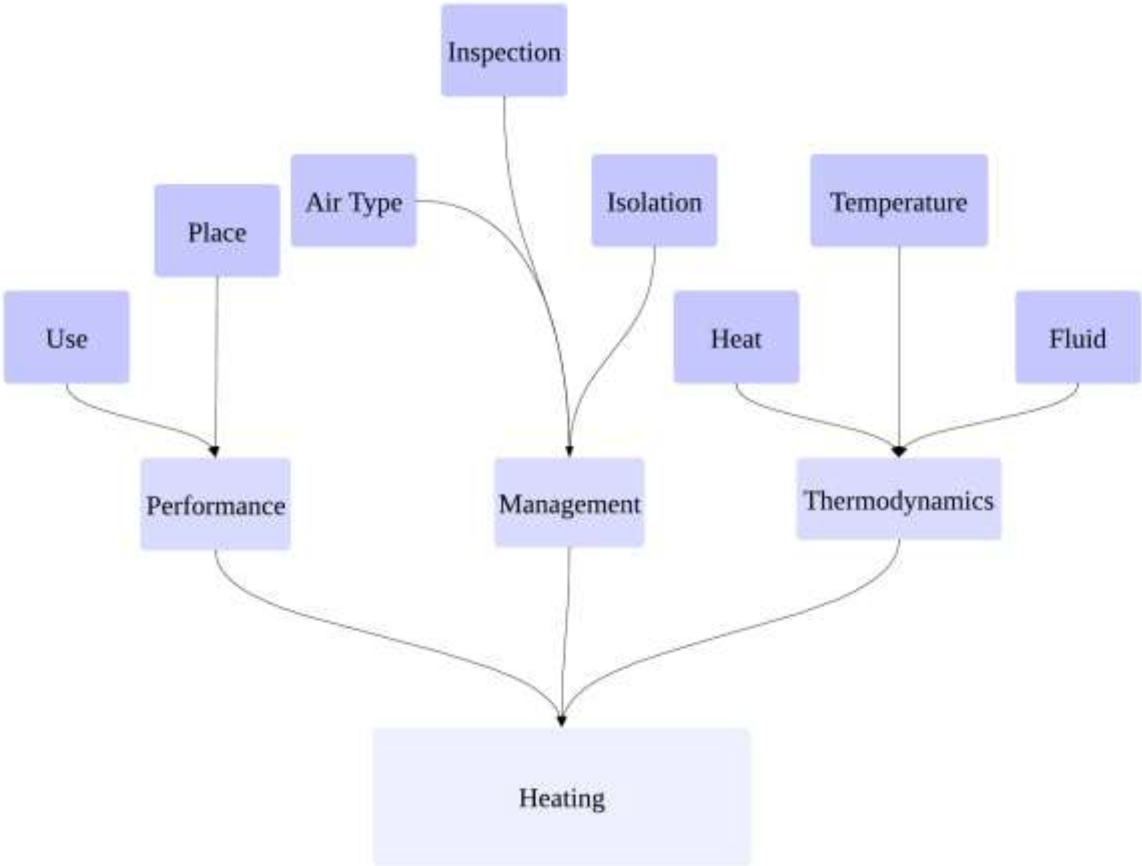
The Figure 2.19 and Table 2.12 how the improvement index behavior for the heater.

Table 2.12. Heating System Index Indicators

Issue	Indicator	Description	Question	Fuzzy Sets	Linguistic Terms	Rules	ARC
Thermodynamics	Temperature	Estimate of the temperature potential to favor heat exchange with the external environment	67	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Smaller-Better	2.2211
	Heat	Rate of heat loss by industrial heater	73	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.2421; 2.2428
	Fluid	Fluids used for heating operation	72	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Low; Medium; High	Less-Worse	2.2426
Performance	Use	Periodic use of the heater	65;68	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Smaller-Better	2.532
	Place	Dimension of the location for the optimal functioning of the heater and the production system	66	[0; 0; 1; 3]; [1; 3; 5]; [3; 5; 7]; [5; 7; 9]; [7; 9; 10;10]	Very Low; Low; Middle; High; Very High	Less-Worse	2.2314
Management	Air type	Regulation of the air outlet for the proper functioning of the heater	69	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Little; Proper; Much	Less-Worse	2.2426
	Inspection	Heater operational performance inspection to avoid loss of functionality	74	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Little; Medium; Much	Less-Worse	2.2531
	Isolation	Insulation to prevent heat loss from the heater with the environment	70;71	[0; 0; 2.5; 5]; [2.5; 5;7.5]; [5; 7.5; 10; 10]	Few; Medium; Much	Less-Worse	2.51; 2.511; 2.514;

Source: Own Authorship

Figure 2.19. Improvement index Architecture for Heater System



Source: Own Authorship

2.6.10 Improvement index model

The selection of indicators for each technology was made through the technology recommendations report, which the industrial assessment center makes available to US companies (INDUSTRIAL ASSESSMENTER CENTER, 2020).

The construction of the domain of each indicator was similar to the improvement index developed by (CAGNO et al., 2010). In the first questionnaire, it was verified which technologies the companies use in their production system, then, through the database of the industrial assessment center, data was collected to proceed with the construction of the fuzzy domain (section 3.2). For the selection, the following points were considered:

i. Industrial sector

The company in each industrial sector has a different energy consumption than the others. The retrieval of data that specify this sector gives greater reliability. In cases where the sector is extremely specific, data from similar sectors was collected.

ii. Data Age

Through technological progress, there may be variation in energy consumption, thus, data from recent years were collected

iii. Number of employees

The general use of each piece of equipment is specifically related to the size of the company.

For each indicator shown in Tables 2.4 and 2.12, the electricity demand for each indicator of cross-cutting technologies was verified and captured in the industrial assessment center's database, in addition to its electricity use.

Following the three filters highlighted above, data were collected for each indicator. As the IAC database is extensive, more than one company that followed the same model studied in the thesis was selected. Thus, the Equations (2.6, 2.7 and 2.8) were used to arrive at an input for the fuzzification process

The Equation 2.6 shows the general capacity and load usage of the indicators for each technology.

$$ECCi = DMi - UEEi \tag{2.6}$$

Where ECCi is electrical capacity of the indicator; DMi is electricity demand (KW-month/year) for each indicator and electricity usage (UEEi) in KWh for each indicator

The Equation 3.7 shows the standardized electrical capacity

$$ECCk = \frac{ECCi}{\sum ECCi} \tag{2.7}$$

Where ECCk is a standardized electrical capacity

And the Equation 3.8 shows the technological gap for each indicator

$$GAT = Is\ x\ EECg \tag{2.8}$$

where EECg is a median of each ECCK, Is is a escore of the likert scale

Equation 2.6 shows the general capacity and load usage of the indicators for each technology.

where DMi is electricity demand (KW-month/year) for each indicator and electricity usage (UEEi) in KWh for each indicator

It was chosen to use the electrical capacity index of the transversal technologies indicator, as it is a measure that does not vary in numbers between countries, for each piece of equipment. Unlike (CAGNO et al., 2010), who used the value of monetary savings in dollars with the implementation of recommendations to reduce energy consumption.

Then, Equation 2.7 is made to obtain the standardized electrical capacity of each indicator

In a subsequent stage, to verify the company's technological gap, the second questionnaire (section 3) was sent, constructed through a Likert analysis that contained four questions. it was chosen for a Likert scale even for companies that did not answer the median question, as is conventional in questionnaires of this nature. Table 2.13 shows the worst-to-best dynamics.

Table 2.13. Likert Scale scores for the Technological Gap

Punctuation	Scale
0	Terrible
3.3	Bad
6.6	Good
10	Excellent

Source: Adaptade Cagno et al.(2010)

In this way, the following relationship of the technological gap can be constructed for each indicator of cross-cutting technologies, verified by Equation 2.8.

Thus, the GAT score is used as an input value for the fuzzification of each indicator.

An example. Two data taken from the industrial assessment center for the local indicator.

UEE_{i1} =23; UEE_{i2} =111; DM_{i1} =384; DM_{i2}=1332 and 3.3 likert score

EEC_{i1} =384 - 23 =361

EEC_{i2} =1332 - 111 = 1221

$\sum EEC_{1,2}$= 361 + 1221 =1582

ECC_{k1}= 361/1582= 0.228

ECC_{k2} = 1221/1582= 0.77

EEC_{g} = 0.5 (median)

GAT = 3.3 x 0.5

GAT=1.65

In fuzzification, as in topic 2.3, the precepts that aim to address the aggregation with data from different aspects, such as qualitative and quantitative, described in sector 2.1, were followed.

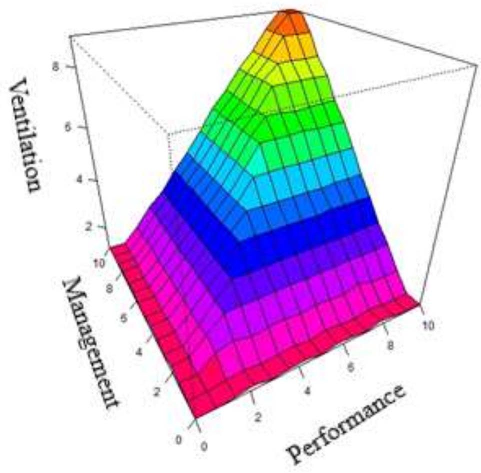
For the Improvement Index is considered that each cross-cutting technology has independence, that is, there was no general improvement index. Thus, the architectures that make up the improvement index for electric motor, compressed air, lighting system, condenser, cooling tower, air conditioning, ventilation system, boilers and heaters/dryers are found respectively in Figures 2.11 to 2.19.

Linguistic terms were assigned to each cross-cutting technology, and as well as in the criticality index, trapezoidal functions at the ends and triangular at the middles were used, shown, in an analogous way, as in Figure 2.8. In the fuzzifications of the final levels, which result in each of the nine improvement indices, there are two specific characteristics. In which the knowledge base for two indicators results in 25 rules, as 5 fuzzy sets were used for input and 5 fuzzy sets for output. And for 3 indicators, 5 input and 5 output fuzzy sets were used, totaling 125 rules (APPENDIX 3.1). For the nine cross-cutting technologies, the worst input case was always considered as an answer, to understand the context of where the energy efficiency of the studied company will have to be improved. And in defuzzification, the mass center of gravity was considered.

The surface resulting from the criticality index (Figure 2.20 and 2.21) shows that the appropriate becomes the exception within the system, since all the other indexes that make up this output must have the only rule: better situation and better situation or better situation, best situation and best situation, respectively, for technologies with two input indicators and with 3 input indicators. Therefore, the criticality will be the most common point of support for the surface.

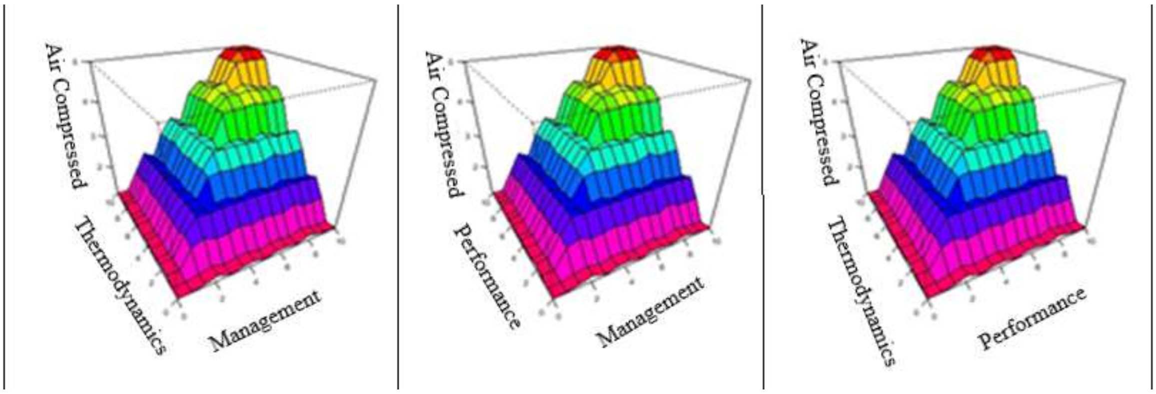
Thus, as in the criticality index, the same Mamdani inference method was followed for the development of improvement indices. For each of the nine improvement indices of the transversal technologies, fictitious data were used as a complement to the real data, thus, it is possible to verify if all the rule entries are robust and, therefore, the nine improvement indices are adequate. These results will be presented in chapter 4.

Figure 2.20. Surface on the Ventilation System (2 indicators)



Source: Own Authorship

Figure 2.21. Compressed Air System Surface (3 indicators)

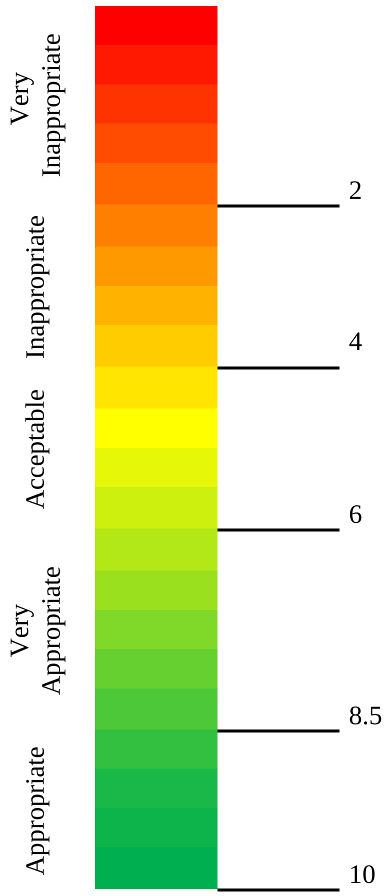


Source: Own Authorship

Soon after, a classification range (Figure 2.22) was built for each technology, with universal colors that show the red tone for the worst situation and the green for the best situation, an example is presented below.

As highlighted in section 2.3, cross-cutting technologies have peculiarities that make the industrial system not use them in an operationally aggregated way, that is, the operation of a certain technology such as the engine does not influence the operation of the lighting system. Thus, the energy consumption of transversal technologies are not similar. Table 2.14 shows the energy consumption ratio of the technologies used in the thesis.

Figure 2.22. Improvement Index Rating Range



Source: Own Authorship

Table 2.14. Energy consumption classification of cross-cutting technologies

Classification	Technology	Justification
1	Boiler	In industrial use, they can be responsible for 90% of internal consumption
2	Cooling towers	In the use of some industrial sectors such as food and beverages, it can reach 50% of energy consumption
3	Heat	Compared with sectors that use the heating system together with the refrigeration system, it assumes 15% of total energy consumption.
4	Condenser	The condenser, like the cooling towers, is part of the refrigeration system and represents 50% of the total energy consumption in some industrial sectors.

continuation

Table 2.14. Energy consumption classification of cross-cutting technologies

concluded

Classification	Technology	Justification
5	Motor	Although engine systems are responsible for 70% of the world's industrial energy consumption, when compared to heat transfer technologies it drops to 20%
6	Compressed air	Compressed air represents 23% of consumption in an industry. Despite being a little larger than the engine, it has a smaller amount of technology.
7	Ventilation system	The ventilation system is responsible for 12% of energy consumption when used in parallel with other cross-cutting technologies
8	Air conditioning	Air conditioning accounts for 10% of energy consumption when used with other cross-cutting technologies
9	Lighting system	The lighting system is responsible for 5% energy when used with other cross-cutting technologies

Source: Own Authorship

The order of decision of priorities for each transversal technology, to develop the improvement of energy consumption, will depend on the position it is found in Table 2.14.

2.7 CONCLUSIONS

Chapter 2 had the proposal to present the development of the fuzzy model that will generate the energy efficiency methodology for small and medium-sized companies.

First, the definition of indicators to support the EE methodology in SMEs was discussed. It is noteworthy that the indicators that served as support for the development of the index tried to relate in two aspects: 1) establishing the critical relationship considering the aspects of environmental quality and management for costs and industrial, and 2) a criterion to direct the improvement of technologies that consume excessive energy load. In this way, with both indexes, it is possible to verify the priority that the company will have to face.

The fuzzy model shown in sections 2.3 and 2.4 results in a new methodology that expresses EE in SMEs, having as the central objective of this research. There is, therefore, a new approach to support decisions related to measuring energy consumption in small and medium-sized companies, in which, through the color palette, a priority analysis can be made of which is the main critical point and which technology the energy efficiency gap will be improved.

Therefore, this approach proposed here should also enable new forms of planning, as well as subsidize the implementation of energy consumption reduction programs in micro, small and medium-sized companies.

3 CASE STUDIES

The main goal of this chapter is to present how the proposed methodology can guide seven (7) companies in the implementation of measures to reduce energy consumption, considering the main environmental, economic and managerial critical points and their respective cross cutting technologies. And then, show which industrial actions and energy consumption reduction that this methodology can generate in the company.

3.1 Descreption

Due to its exploratory nature, the case study method was chosen to analyze the seven companies. The in-depth study of a small number of companies is especially suited to give depth to the doctoral research analysis. In this way, it is possible to gain a deeper understanding of the behavior of each of the companies that made themselves available to participate in the research. And, consequently, provide a clear answer to the needs that companies need to solve the problem of excessive energy consumption.

With this guidance, seven manufacturing SMEs accepted to participate in the survey. The size of companies allows to verify that the fuzzy model is adjusted to the proposal of EE diagnosis in the manufacturing sector for SMEs.

Through key contacts existing in the companies, the first questionnaire on the consumption of energy management was answered, followed by the second questionnaire on the evaluation of the energy consumption of industrial technologies. And so, with the data collected, a priority index was developed for each company participating in the study.

The three filters described in section 2.4.10 were considered to collect the data to generate the report of Companies A-G. Which have the following characteristics, for the size of the companies, the data obtained by (BRASIL, 2013) contained in Table 3.1 were considered.

Table 3.1. Size of Companies according to the number of employees

Size	Industry
Micro enterprise	Up to 19 employees
Small business	From 20 to 99 employees
midsize company	From 100 to 499 employees
Large-sized company	500 or more employees

Source: Adapted from (BRASIL, 2013)

a) Company A has a total of up to 19 employees and operates in the chemical sector. It does not have any type of energy efficiency management system or active waste emission reduction program.

b) Company B has around 20 to 99 employees and operates in the paper and plastic sector. There are no energy efficiency actions, but there is a plan to implement energy efficiency measures in a period of 2 to 5 years, such as the free energy market. And the environmental improvement program is characterized by the recovery of grains.

c) Company C has around 20 to 99 employees and operates in the packaging sector. No energy efficiency actions or energy consumption management programs.

d) Company D operates in the blown plastic packaging sector and has around 20 to 99 employees. The company adopts peak shaving as an action to reduce energy consumption, and within 2 to 5 years it intends to adopt energy efficiency measures. Also, they consume recycled materials and there is reuse of production inputs.

e) Company E operates in the chemical sector and has a total of 20 to 99 employees. There are no energy efficiency actions, however within a period of up to 2 years to implement energy efficiency measures to reduce costs with higher expenses.

f) Company F operates in the chemical products sector and has around 19 employees. Although they use variable speed drives for the electrical motors, they intend to deepen energy efficiency measures within a period of up to 2 years, such as the purchase of equipment with adequate energy consumption. In addition, there is reuse of leftovers from the production process.

g) Company G operates in the machinery and equipment sector, it has around 19 employees and there are no energy efficiency actions.

Thus, with the survey of data from companies A and G (section 3.2), criticality and improvement indices were developed to analyze the critical points of the seven companies. Table 2.2 presents the results for the criticality index and the three indices that are the inputs of the criticality index's fuzzy model.

As shown in section 3.3, the criticality index has the characteristic of finding the main critical points for the EE improvement considering aspects of environmental quality, cost management and industrial management. It is important to emphasize that the result of defuzzification, which is the criticality index, is always the result of the worst entry, at level 4 (Figure 2.7). Therefore, according to Table 3.2, the industrial management index is the worst entry for all the seven companies and determined the criticality index result

Table 2.2. Criticality Index of Companies A-G

	Criticality Index	Environmental Quality	Costs Management	Industrial Management
Company A	2.86	10.00	7.54	3.22
Company B	2.28	8.32	7.54	2.80
Company C	5	10.00	7.54	5.00
Company D	5	8.42	7.54	5.00
Company E	0.87	10.00	7.54	1.48
Company F	4.01	10.00	7.54	4.28
Company G	6.13	10.00	7.54	5.87

Subtitle

Critical	0	2
Potentially Critical	2	4
Acceptable	4	6
Potentially Uncritical	6	8.5
Uncritical	8.5	10

Source: Own Authorship

As shown in section 3.3, the criticality index has the characteristic of finding the main critical points for the EE improvement considering aspects of environmental quality, cost management and industrial management. It is important to emphasize that the result of defuzzification, which is the criticality index, is always the result of the worst entry, at level 4 (Figure 2.7). Therefore, according to Table 3.2, the industrial management index is the worst entry for all the seven companies and determined the criticality index result.

It is observed that company E is within the range of potentially critical, while companies A and B are potentially critical, company C, D and F acceptable, and company G potentially uncritical.

Table 3.3 presents the Improvement Index results.

The blanks in Table 3.3 indicate that companies do not have these technologies. As a result of the companies being small and, for the most part, not having an adequate energy management system, they were classified between very inappropriate and inappropriate, showing the need for an analysis system that enables EE.

Considering Tables 3.14, 3.2 and 3.3, it is possible to trace an order of priority for energy management and consequently improve energy efficiency. Priority is given to the cross-cutting technologies that consume the most energy (Table 3.14), in which the priorities are those that exchange the greatest amount of heat with the environment and that are more difficult to maintain.

Table 3.3. A-G Companies Improvement Index

	Company A	Company B	Company C	Company D	Company E	Company F	Company G
Motor System Index	-	1.93	3.81	3.05	-	1.93	-
Air compressor System Index	-	0.21	0.23	0.16	0.21	-	-
Light System Index	0.08	0.12	0	0.12	-	-	-
Condenser System Index	-	-	-	0.01	-	-	0
Refrigeration System Index	-	-	-	5	-	-	-
Air conditioning Index	1.98	0.11	-	-	-	-	0.2
Ventilation System Index	-	-	-	-	-	-	-
Boiler System Index	-	-	-	-	-	-	-
Heating System Index	-	-	0.23	0.16	1.32	-	-

Subtitle

Very Inappropriate	0	2
Inappropriate	2	4
Acceptable	4	6
Potentially Appropriate	6	8.5
Appropriate	8.5	10

Source: Own Authorship

Tables 3.4, 3.6, 3.8, 3.10, 3.12, 3.14 and 3.16 show the indicators of the criticality index that need to be improved (highlighted in red) in A-G companies. And Tables 3.5, 3.7, 39, 3.11, 3.13, 3.15 and 3.17 present the improvement index indicators the need to be improved (also highlighted in red) in the seven companies.

Regarding the cross-cutting technologies, the priority of improvement is configured as follows for companies A-G:

Company A: 1st Air conditioning system and 2nd lighting system

Company B: 1st Motor System, 2nd Air Compressor System, 3rd Air Conditioning System and 4th Lighting System.

Company C: 1st Heating System, 2nd Air Compressor System, 3rd Lighting System and 4th Motor System

Company D: 1st Heating System, 2nd Condenser System, 3rd Air Compressor System, 4th Lighting System, 5th Engine System, 6th Cooling System.

Company E: 1st Heater System and 2nd Air Compressor System

Company F: 1st Motor System

Company G: 1st Air Conditioning System and 2nd Lighting System

Company A Priorities

Table 3.4. Priority Indicators of the Criticality Index of Company A

Index		Indicators
Criticality (2.86)	Environmental Quality (10)	Renewable energy source (100)
		Non-renewable energy sources (0)
		Solubility (0)
		Toxicity (0)
	Costs Management (7.54)	Technological investment (2.5)
		Investment in process (2.5)
		Investment in types of power generation (2.5)
		Electricity expenses (2.5)
	Industrial Management (3.22)	Degree of skill of employees (2)
		Management strategy (1)
		Corrective (13.75)
		Predictive operation (9.75)
		Technology data collection (4)
		Instrumentation (2.5)
		Operation sensitivity (15)
		Mean time between failures (2.5)
		Availability of repair personnel (12.5)
		Working Load (12.5)
		Average repair time (12.5)
		Availability of required parts (15)

Source: Own Authorship

Table 3.5. Priority Indicators of Company A Improvement Index

Index		Indicators
Improvement	Lighting Systems (0.08)	Reactor (3.3)
		Operating system (1.65)
		Cleaning (0.01)
		Constructure Structure (0.6)
	Air conditioning (1.98)	Maintenance (3.3)
		Cleaning (3.3)
		Acclimatization (0.825)
		Temperature (0)
		Isolation (0.23)

Source: Own Authorship

Company B Priorities

Table 3.6. Priority Indicators of the Criticality Index of Company B

Index		Indicators
Criticality (2.28)	Environmental Quality (8.32)	Renewable energy source (50)
		Non-renewable energy sources (50)
		Solubility (6)
		Toxicity (13)
	Costs Management (7.54)	Technological investment (2.5)
		Investment in process (2.5)
		Investment in types of power generation (12.5)
		Electricity expenses (2.5)
	Industrial Management (2.8)	Degree of skill of employees (5)
		Management strategy (3.5)
		Corrective (30)
		Predictive operation (4.5)
		Technology data collection (2.83)
		Instrumentation (9)
		Operation sensitivity (0)
		Mean time between failures (11)
		Availability of repair personnel (31.5)
		Working Load (90)
		Average repair time (21)
		Availability of required parts (19)

Source: Own Authorship

Table 3.7. Priority Indicators of the Improvement Index of Company B

Index		Indicators
Improvement	Motor (1.93)	Ventilation (1.36)
		Operation Regime (8.3)
		Noise / vibrations (0)
		Cleaning (4.15)
		Maintenance (1.91)
		Moisture (0)
		Temperature (5.87)

continuation

Table 3.7. Priority Indicators of the Improvement Index of Company B

concluded

Index		Indicators
Improvement	Lighting Systems (0.12)	Reactor (0.5)
		Operating system (6.6)
		Cleaning (0.51)
		Constructure Structure (0.24)
	Air conditioning (0.11)	Maintenance (0.06)
		Cleaning (0)
		Acclimatization (0)
		Temperature (1.88)
		Isolation (0.15)
	Compressed Air (0.21)	Cleaning (2.5)
		Maintenance (0)
		Moisture (4.15)
		Temperature (2.5)
		Inlet Pressure Control (6.65)
		Local (2.475)
		Use (0.007)

Source: Own Authorship

Company C Priorities

Table 3.8. Priority Indicators of the Criticality Index of Company C

Index		Indicators
Criticality (5)	Industrial Management (5)	Degree of skill of employees (5)
		Management strategy (3.5)
		Corrective (30)
		Predictive operation (4.5)
		Technology data collection (2.83)
		Instrumentation (9)
		Operation sensitivity (0)
		Mean time between failures (11)
		Availability of repair personnel (31.5)
		Working Load (90)
		Average repair time (21)
		Availability of required parts (19)

continuation

Table 3.8. Priority Indicators of the Criticality Index of Company C

concluded

Index		Indicators
Criticality (5)	Environmental Quality (10)	Renewable energy source (100)
		Non-renewable energy sources (0)
		Solubility (5)
		Toxicity (15)
	Costs Management (7.54)	Technological investment (2.5)
		Investment in process (2.5)
		Investment in types of power generation (12.5)
		Electricity expenses (2.5)

Source: Own Authorship

Table 3.9. Priority Indicators of Company C Improvement Index

Index		Indicators
Improvement	Compressed Air (0.23)	Cleaning (2.5)
		Maintenance (0.37)
		Moisture (0)
		Temperature (3.3)
		Inlet Pressure Control (2.5)
		Local (5)
		Use (0)
	Motor (3.81)	Ventilation (0)
		Operation Regime (3.325)
		Noise / vibrations (1.36)
		Cleaning (5)
		Maintenance (0.95)
		Moisture (0)
		Temperature (4.95)
	Lighting Systems (0)	Reactor (0.75)
		Operating system (5)
		Cleaning (0.77)
		Constructure Structure (0.31)
	Heating Systems (0,2)	Temperature (3.3)
		Heat (0)
		Fluid (10)
		Use (10)
		Place (3.3)
		Air type (0)
		Inspection (0)
		Isolation (0.73)

Source: Own Authorship

Company D Priorities

Table 3.10. Priority Indicators of the Criticality Index of Company D

Index		Indicators
Criticality (5)	Environmental Quality (8.42)	Renewable energy source (50)
		Non-renewable energy sources (50)
		Solubility (5)
		Toxicity (15)
	Costs Management (7.54)	Technological investment (2.5)
		Investment in process (2.5)
		Investment in types of power generation (12.5)
		Electricity expenses (2.5)
	Industrial Management (5)	Degree of skill of employees (0)
		Management strategy (1.2)
		Corrective (2.5)
		Predictive operation (6.6)
		Technology data collection (6.9)
		Instrumentation (7.5)
		Operation sensitivity (9)
		Mean time between failures (6.25)
		Availability of repair personnel (6.8)
		Working Load (90)
		Average repair time (7.5)
		Availability of required parts (7.8)

Source: Own Authorship

Table 3.11. Company D Improvement Index Priority Indicators

Index		Indicators
Improvement	Compressed Air (0.16)	Cleaning (0.34)
		Maintenance (0.9)
		Moisture (1.55)
		Temperature (5)
		Inlet Pressure Control (0.97)
		Local (1.65)
		Use (0.4)
	Motor (3.05)	Ventilation (0)
		Operation Regime (2.5)
		Noise / vibrations (1.36)
		Cleaning (0)
		Maintenance (1.59)
		Moisture (0)
		Temperature (4.12)

continuation

Table 3.11. Company D Improvement Index Priority Indicators

concluded

Index		Indicators
Improvement	Lighting Systems (0.12)	Reactor (0)
		Operating system (3.3)
		Cleaning (0)
		Constructure Structure (0.18)
	Heating Systems (0.16)	Temperature (0.3)
		Heat (5)
		Fluid (0)
		Use (1.5)
		Place (0.08)
		Air type (3.3)
		Inspection (2.2)
		Isolation (1.1)
	Condenser (0.008)	Pressure (10)
		Heat (5)
		Condensed (3.3)
		Local (4.95)
		Isolation (0)
		Ventilation (10)
	Cooling Systems (5)	Temperature (1.44)
		Heat (3.3)
		Refrigeration (1.65)
		Water (0.1)
		Air (0.83)
		Pressure (1.15)
		Chiller Waste (1.28)
		Cleaning (0.55)

Source: Own Authorship

Company E Priorities

Table 3.12. Priority Indicators of the Criticality Index of Company E

Index		Indicators
Criticality (0.87)	Environmental Quality (10)	Renewable energy source (95)
		Non-renewable energy sources (5)
		Solubility (5)
		Toxicity (13)

continuation

Table 3.12. Priority Indicators of the Criticality Index of Company E

concluded

Index		Indicators
Criticality (0.87)	Costs Management (7.54)	Technological investment (2.5)
		Investment in process (2.5)
		Investment in types of power generation (2.5)
		Electricity expenses (2.5)
	Industrial Management (1.48)	Degree of skill of employees (2.5)
		Management strategy (1.75)
		Corrective (2.5)
		Predictive operation (0.5)
		Technology data collection (4.125)
		Instrumentation (2.5)
		Operation sensitivity (24)
		Mean time between failures (2.5)
		Availability of repair personnel (13.25)
		Working Load (65)
		Average repair time (9.375)
		Availability of required parts (1.25)

Source: Own Authorship

Table 3.13. Priority Indicators of Company E Improvement Index

Index		Indicators
Improvement	Compressed Air (0.21)	Cleaning (2.475)
		Maintenance (0.45)
		Moisture (0.825)
		Temperature (2.5)
		Inlet Pressure Control (2.5)
		Local (1.65)
		Use (0.015)
	Heating Systems (1.32)	Temperature (0.05)
		Heat (3.3)
		Fluid (5)
		Use (1.32)
		Place (0.8)
		Air type (6.6)
		Inspection (1.65)
		Isolation (0.2)

Source: Own Authorship

Company F Priorities

Table 3.14. Priority Indicators of the Criticality Index of Company F

Index		Indicators
Criticality (4.01)	Environmental Quality (10)	Renewable energy source (100)
		Non-renewable energy sources (0)
		Solubility (0)
		Toxicity (0)
	Costs Management (7.54)	Technological investment (12.5)
		Investment in process (2.5)
		Investment in types of power generation (2.5)
		Electricity expenses (2.5)
	Industrial Management (4.28)	Degree of skill of employees (4)
		Management strategy (3)
		Corrective (30)
		Predictive operation (4.5)
		Technology data collection (4.5)
		Instrumentation (12.5)
		Operation sensitivity (9)
		Mean time between failures (12)
		Availability of repair personnel (22.5)
		Working Load (90)
		Average repair time (24)
		Availability of required parts (9)

Source: Own Authorship

Table 3.15. Company F Improvement Index Priority Indicators

Index		Indicators
Improvement	Motor (1.93)	Ventilation (0)
		Operation Regime (0.63)
		Noise / vibrations (1.87)
		Cleaning (1.69)
		Maintenance (0.45)
		Moisture (0)
		Temperature (4.12)

Source: Own Authorship

Company G Priorities

Table 3.16. Priority Indicators of the Criticality Index of the Company G

Index		Indicators
Criticality (6.13)	Environmental Quality (10)	Renewable energy source (100)
		Non-renewable energy sources (0)
		Solubility (0)
		Toxicity (0)
	Costs Management (7.54)	Technological investment (2.5)
		Investment in process (2.5)
		Investment in types of power generation (2.5)
		Electricity expenses (2.5)
	Industrial Management (5.57)	Degree of skill of employees (5)
		Management strategy (3)
		Corrective (30)
		Predictive operation (10.5)
		Technology data collection (0)
		Instrumentation (90)
		Operation sensitivity (6.75)
		Mean time between failures (12)
		Availability of repair personnel (2.5)
		Working Load (50)
		Average repair time (12.5)
		Availability of required parts (9)

Source: Own Authorship

Table 3.17. Priority Indicators of the Company Improvement Index G

Index		Indicators
Improvement	Lighting Systems (0)	Reactor (5)
		Operating system (5)
		Cleaning (0.33)
		Constructure Structure (0.8)
	Air conditioning (0.20)	Maintenance (1.65)
		Cleaning (0)
		Acclimatization (3.3)
		Temperature (0.825)
		Isolation (0.23)

Source: Own Authorship

It is important to recall that, from Tables 3.1-3.3 for the criticality index and 3.4-3.17 (chapter 3) for the improvement indicators, they show the characteristic of their expert knowledge base in which if the rules is better-worse and better -best. And as shown in Figure

3.7, the Electricity expenses indicator enters the second level of fuzzification, somewhat oriented towards the cost management index.

3.2 Discussion

The main problem of A-G companies in the criticality index is related to the industrial management index. As the study focuses on Brazilian SMEs, they do not have the characteristics of having a strategy for maintaining their cross-cutting technologies both in a preventive and predictive manner. And most of the time maintenance is done in the least adequate way, which is corrective maintenance (KHANLARI; MOHAMMADI; SOHRABI, 2008). The intrinsic characteristic of SMEs has become something cultural and determines a process that is difficult to break (SCHULZE et al., 2016). Therefore, it is necessary that the entities that guide companies develop projects and campaigns that raise awareness of the need to develop programs aimed at preventive and predictive maintenance (LUNG; NIMBALKAR; WENNING, 2019), such as the model proposed and developed in this thesis. Thus, by developing this cultural break, the energy consumption coming from the various cross-cutting technologies will decrease, reducing energy costs and, consequently, in terms of monetary value, the technologies will last longer and will function properly in companies (BENEDETTI et al., 2019). As already highlighted in the taxonomy of chapter 1 and by (MORGAN, 1997), EE actions are assigned to organizational departments and not top management, thus making it difficult to provide resources and support, thereby losing EE opportunities. And with the endorsement of (MARTIN et al., 2012), which also shows that criteria for an adequate organizational structure are directly related to management practices associated with greater productivity in senior management, with improved cultural practice. Complemented by (APEANING; THOLLANDER, 2013), the lack of specific economic structure for EE in the industry makes it difficult to develop an efficient organizational structure to reduce energy consumption.

Both the cost management and environmental quality index had a compatible score. In case of environmental quality it is due to the use of electricity coming from the grid, considered renewable, and because they do not produce materials that may contain environmental solubility and toxicological risks. As for the cost management index, although the investment is low for the process, in new technologies that consume less energy and internal renewable energy generation the energy cost is low, which helps in a higher score within the fuzzy model.

Also, linked to this low score on the industrial management index linked to low energy consumption, it directly implies the investment of companies in maintenance programs. For environmental quality, due to the characteristics of the seven companies studied, they did not emit any waste considerably risky to the environment. However, the companies would only implement a program if there was the need through of legislation, as highlighted by (NEVES; SALGADO; BEIJO, 2017).

The improvement index shows that there is no frequency of actions that enable the proper functioning of the cross-cutting technologies. For example, there is little cleaning in parts that are essential to the operation of the engine or air compressor. Thus, the accumulation of dirt does not make its operation unfeasible and, consequently, there will be a lower yield with a higher consumption of energy. Among other actions that are highlighted in Table 3.18, 3.19, 3.20, 3.21, 3.22 and 3.23 for companies A- G,

In both the seven cases discussed, the model showed its proposed functionality, highlighting all the important factors that companies should adopt to achieve industrial energy efficiency. Furthermore, the methodology sheds light on additional aspects that are largely neglected and that can result in positive impacts, such as the constant maintenance of technologies and investments in the production process, leading decision makers to take a comprehensive view of industrial improvement.

Energy efficiency gaps for cross-cutting technologies have been discussed in the world literature for a long period, but the adoption of EE measures is apparently low. The evidence, as shown in the reports of companies A-G, is not limited to Brazil, the target of this thesis' study. However, as highlighted by the (IEA/INTERNATIONAL ENERGY AGENCY, 2020b), there is a need for reducing industrial energy consumption linked to the equipment that makes up the production process, even due to the moment of climatic urgency that the ecosystem is going through.

Table 3.18. EE measurement actions for Company A

Lighting System		
Indicators	Suggested Actions	ARC
Cleaning	Keep lamps and reflectors clean	2.7123
	Installation of Lower Light in High Ceiling Areas	2.7141
Construction Structure	Use daylight whenever possible in a place where there is artificial light	2.7121
	Reduce lighting to minimum necessary levels	2.7111
Operating System	Disconnect the Ballasts	2.7122
	Turn off lamps when not needed	2.7124
Reactor	Install sensors in an underused area	2.7132

continuation

Table 3.18. EE measurement actions for Company A

concluded

Air conditioning		
Indicators	Suggested Actions	ARC
Maintenance	Install humidity control system	2.7273
Cleaning	Review the cleanliness of the air conditioning sheets	2.7244
Acclimatization	Keep the lowest temperature during the winter season and Vice-versa	2.7221
	Improve air circulation with destratification ventilations	2.7243
Isolation	Install or upgrade insulation in pipe distribution systems	2.7212

Source: Adapted from IAC

Table 3.19. EE Measurement Actions for Company B

Lighting System		
Indicators	Suggested Actions	ARC
Cleaning	Keep lamps and reflectors clean	2.7123
Construction Structure	Installation of Lower Light in High Ceiling Areas	2.7141
	Use daylight whenever possible in a place where there is artificial light	2.7121
Air conditioning		
Indicators	Suggested Actions	ARC
Maintenance	Install humidity control system	2.7273
Cleaning	Review the cleanliness of the air conditioning sheets	2.7244
Acclimatization	Keep the lowest temperature during the winter season and vice versa	2.7221
	Improve air circulation with destratification ventilations	2.7243
Isolation	Install or upgrade insulation in pipe distribution systems	2.7212
Compressed air		
Indicators	Suggested Actions	ARC
Cleaning	Clean air compressor filters	2.4227
Maintenance	Provide proper maintenance of air compressor motors	2.4313
	Eliminate leaks in the lines	2.4236
	Remove or close unnecessary compressed air lines	2.4235
Moisture	Install proper dryers on air lines	2.4222
Inlet pressure control	Install direct actions at the pressure location in compressed air	2.4223
Motor		
Indicators	Suggested Actions	ARC
Maintenance	Use parts originating from certified stores	2.4152
	Standardize motors inventory	2.4155
	Develop a preventive maintenance program	2.4156
	Establish a predictive maintenance program	2.4157
Cleaning	Develop an engine repair and cleaning policy	2.4151
Operation	Use energy efficient belts and other improved mechanisms	2.4111
	Install the voltage controller	2.4113
	Use electric motors with peak operating efficiency	2.4132
Ventilation	Develop a preventive maintenance program to improve ventilation	2.4156
	Develop a predictive maintenance program to improve ventilation	2.4157

Source: Adapted from IAC

Table 3.20. EE Measurement Actions for Company C

Heater		
Indicators	Suggested Actions	ARC
Use	Use minimum safe ventilation	2.2212
	Use Tank Immersion Heating	2.2221
Place	Use specifically certified fire-fighting furniture	2.2313
Air Type	Use gases from the heater to heat the local air	2.2426
Isolation	Use insulation thickness	2.2514
Heat	Recover heat residue during heating	2.2437
Temperature	Use Optimum Temperature	2.2211
Waste	Install boiler waste to produce steam	2.2423
Motor		
Indicators	Suggested Actions	ARC
Maintenance	Use parts originating from certified stores	2.4152
	Develop a preventive maintenance program	2.4156
	Establish a predictive maintenance program	2.4157
Cleaning	Develop an engine repair and cleaning policy	2.4151
Ventilation	Develop a preventive maintenance program to improve ventilation	2.4156
	Develop a predictive maintenance program to improve ventilation	2.4157
Compressed Air		
Indicators	Suggested Actions	ARC
Cleaning	Clean air compressor filters	2.4227
Maintenance	Provide proper maintenance of air compressor motors	2.4313
	Eliminate leaks in lines	2.4236
	Remove or close unnecessary compressed air lines	2.4235
Moisture	Install suitable dryers on air lines	2.4222
Local	Install the air inlets in the coolest places	2.4221
Lighting System		
Indicators	Suggested Actions	ARC
Cleaning	Keep reflector lamps clean	2.7123
Construction	Installation of lower light in high ceiling areas	2.7141
Structure	Use daylight whenever possible where there is artificial light	2.7121

Source: Adapted from IAC

Table 3.21. EE Measurement Actions for Company D

Heater		
Indicators	Suggested Actions	ARC
Use	Use minimum safe ventilation	2.2212
	Use Tank Immersion Heating	2.2221
Place	Use specifically certified fire-fighting furniture	2.2313
Air Type	Use gases from the heater to heat the local air	2.2426
Inspection	Use insulation thickness	2.2414
Isolation	Reduce load openings or add cover or movable door	2.2524
	Use insulation thickness	2.2525

continuation

Table 3.21. EE Measurement Actions for Company D

concluded

Motor		
Indicators	Suggested Actions	ARC
Maintenance	Use parts originating from certified stores	2.4152
	Patronize the engine stock	2.4155
	Develop a preventive maintenance program	2.4156
	Establish a predictive maintenance program	2.4157
Operation	Use energy efficient belts and other improved mechanisms	2.4111
	Install the voltage controller	2.4113
	Use electric motors with peak operating efficiency	2.4132
Ventilation	Develop a preventive maintenance program to improve ventilation	2.4156
	Develop a predictive maintenance program to improve ventilation	2.4157
Compressed air		
Indicators	Suggested Actions	ARC
Cleaning	Clean air compressor filters	2.4227
Maintenance	Provide proper maintenance of air compressor engines	2.4313
	Eliminate leaks in lines	2.4236
	Remove or close unnecessary compressed air lines	2.4235
Local	Install the air inlets in the coolest places	2.4221
Inlet pressure control	Install direct actions at the pressure location in compressed air	2.4223
Lighting System		
Indicators	Suggested Actions	ARC
Cleaning	Keep lamps and coolers clean	2.7123
Construction Structure	Installation of lower light in high ceiling areas	2.7141
	Use daylight whenever possible where there is artificial light	2.7121
Operating System	Reduce lighting to minimum necessary levels	2.7111
	Disconnect the Ballasts	2.7122
	Turn off lamps when not needed	2.7124
Cooling Tower		
Indicators	Suggested Actions	ARC
Temperature	Cooling tower outlet temperature moderate	2.2611
	Minimize condenser cooling water temperature	2.2623
Heat	Use waste heat from steam for steam absorption	2.2693
Chiller Waste	Use excess cold process fluid for industry refrigeration needs	2.2696
Cleaning	Clean cooling system types	2.2615
Condenser		
Indicators	Suggested Actions	ARC
Heat	Use a less expensive cooling method	2.2628
Local	Insulate cooling water tank	2.2123
Ventilation	Repair and eliminate vent leaks	2.2135

Source: Adapted from IAC

Table 3.22. EE Measurement Actions for Company E

Compressed Air		
Indicators	Suggested Actions	ARC
Local	Install the air inlets in the coolest places	2.4221
Cleaning	Clean air compressor filters	2.4227
Maintenance	Eliminate leaks in lines	2.4236
	Remove or close unnecessary compressed air lines	2.4235
Inlet pressure control	Install direct actions at the pressure location in compressed air	2.4223
Temperature	Cold compressor air inlet with heat exchange	2.4234
Heater		
Indicators	Suggested Actions	ARC
Place	Use specifically certified fire-fighting furniture	2.2313
Air Type	Use gases from the heater to heat the local air	2.2426
Inspection	Use insulation thickness	2.2514
Isolation	Reduce loading gaps or add cover or movable door	2.2524
	Use insulation thickness	2.2525
Heat	Recover heat residue during heating	2.2437
Temperature	Use optimum temperature	2.2211

Source: Adapted from IAC

Table 3.23. EE Measurement Actions for Company F

Motor		
Indicators	Suggested Actions	ARC
Maintenance	Use parts originating from certified stores	2.4152
	Patronize the motor stock	2.4155
	Develop a preventive maintenance program	2.4156
	Establish a predictive maintenance program	2.4157
Operation	Use energy efficient belts and other improved mechanisms	2.4111
	Install the voltage controller	2.4113
	Use electric motors with peak operating efficiency	2.4132
Ventilation	Develop a preventive maintenance program to improve ventilation	2.4156
	Develop a predictive maintenance program to improve ventilation	2.4157
Cleaning	Develop an engine repair and cleaning policy	2.4151

Source: Adapted from IAC

Table 3.24. EE Measurement Actions for Company G

Air conditioner		
Indicators	Suggested Actions	ARC
Maintenance	Install humidity control system	2.7273
Cleaning	Review the cleanliness of the air conditioning sheets	2.7244
Acclimatization	Keep the lowest temperature during the winter season and vice versa	2.7221
	Improve air circulation with destratification fans	2.7243
Isolation	Install or upgrade insulation in pipe distribution systems	2.7212

continuation

Table 3.24. EE Measurement Actions for Company G

concluded

Lighting System		
Indicators	Suggested Actions	ARC
Cleaning	Keep lamps and coolers clean	2.7123
Construction Structure	Installation of Lower Light in High Ceiling Areas	2.7141
	Use daylight whenever possible in a place where there is artificial light	2.7121
Operating System	Reduce lighting to minimum necessary levels	2.7111
	Disconnect the Ballasts	2.7122
	Turn off lamps when not needed	2.7124
	Install sensors in an underused area	2.7132
Reactor	Install occupancy sensors	2.7135
	Use sensors in places where ambient lighting can be used	2.7133

Source: Adapted from IAC

(TRIANNI; CAGNO; FARNÉ, 2016) portrays that, overall, the trends in adopting EE measures should not be treated in a one-dimensional, imposing way, as each measure can impact decision makers in different ways, at different times and with different impacts. Convincing decision makers that implementation will be financially and productively viable would facilitate the implementation of energy efficiency measures (RASMUSSEN; WILSON; HINDLE, 2014; TRIANNI; CAGNO; FARNÉ, 2016).

Still, adding to (TRIANNI; CAGNO; FARNÉ, 2016), the methodology developed in the thesis advances in a direction that is being consolidated in the literature, in new frameworks of energy efficiency. The development of this structure that enables the implementation of measures to reduce energy consumption will encompass management practices that until then are unknown by most SMEs, especially in countries that are considered to be developing, such as Brazil, in addition to energy knowledge that are related to EE (GORDIĆ et al., 2010; PALM; THOLLANDER, 2010).

Specifically, in the Brazilian case, as there is not a great practice of monitoring energy use due to management commitment barriers, energy awareness, cost and organizational behavior will tend to be overcome. In this way, they will meet the indication of the IPCC report (INTERNATIONAL PAINEL ON CLIMATE CHANGE, 2021a) as a significant tool for reducing energy consumption and GHG emissions and will also be bound by the law nº. 10.295.

In addition to the facts considered above, the current lack of power management is due to the current implementations being based on fast and piecemeal point aspects of EE measures. The companies, in general, are not concerned with the implementation, as the cultural and operational aspects in the companies have not yet been fully absorbed, due to the difficulties in understanding how the assimilation of EEMs should happen. The EE methodology for SMEs breaks this paradigm since there is a targeting of the main indicators and with the result in a clear organization of interpretation.

In addition, from a commercial point of view, the methodology can be an alternative to certifications such as ISO 50001 and, depending on the problem to be solved, ISO 14001, as they are expensive certifications to implement, thus being able to guarantee greater efficiency of energy resources. of companies with little financial availability. When the methodology is presented either through a platform or an application, it can be more accessible to several companies, so that they reach the main objective, which is the reduction of energy consumption.

3.3 Industrial implications

The industrial implications in the implementation and planning of priorities of EEMs, both critical and related to transversal technologies, allow measuring the improvement in energy consumption in the organization. The diagnoses contained in the reports in Tables 3.4-3.17 can help to establish an ongoing energy policy for these companies' energy management systems.

In the improvement index to achieve priority, the potential for reducing energy consumption is associated with the functional aspects of each equipment. The objective is to establish adequate operational and performance parameters from the point of view of energy performance, so that there are real savings in energy consumption. Furthermore, thermodynamic aspects shown in Figures 2.11 to 2.13, 2.14, 2.15, 2.17 3.2.9 and 2.18 are the biggest energy consumers, especially those related to heat transfer due to the characteristic heat process of the equipment. In industry, as described in topic 3.1, energy management processes must be supported by a methodology, such as the one developed in this PhD research, that meets the criteria raised in the criticality index and in the improvement indices of cross-cutting and consequently, facilitates to identify the main priorities to be develop (YIN, 2015).

The processes and actions addressed (Tables 3.4-3.17) are based on operational adjustments, including continuous monitoring of energy use related to transversal technologies and critical aspects of industrial technologies. With that, SMEs will be able to have a diagnosis of priorities that each company will have to face in order to be able to implement EEMs.

The model acts as a control strategy within the company, as a small and medium-sized company constantly does not have an internal structure capable of being focused on energy consumption, and even has no opportunity to implement energy reduction measures, since the owners of these projects or those responsible must fulfill a series of different functions for the functionality of small and medium industry. In this way, energy consumption is just one of several issues, not being a specific focus of it. Furthermore, the financial barrier identified in several studies shows that there is a certain amount of caution in implementing measures that reduce energy consumption, as shown in the literature (CAGNO et al., 2010; KATIC; TRIANNI, 2020; NAGESHA; BALACHANDRA, 2006; NEVES et al., 2020; THOLLANDER; DANESTIG; ROHDIN, 2007), being even considered prohibitive due to the financial and investment support. The energy efficiency model developed in this study overcomes this barrier as its availability is agile and easily accessible. (TRIANNI et al., 2013) already showed that the association of barriers with this type of characteristic within the industrial plant shows an intrinsic characteristic of difficulty in overcoming it, in addition to the barriers of technological origin, as many companies see an obstacle to changing the entire technological framework for energy efficiency.

Contradicting the barriers, the drivers shown by (SA; THOLLANDER; RAFIEE, 2018) which finds that the optimization and proper replacement of parts of cross-cutting technologies can save energy used, consequently, there will be a financial gain and a lower production cost (HASAN; TRIANNI, 2020; HASANBEIGI; PRICE, 2012; MALINAUSKAITE et al., 2019).

In short, the model developed advances to break the main barriers imposed to the adoption of measures that reduce energy consumption, such as financial, organizational and cultural, as its use will facilitate a diagnosis and subsequent development of energy efficiency measures. Therefore, as it is quite hard for SMEs to implement EE criteria, the model, when implemented for A-G companies, will also develop a social and even innovative assessment for both industries.

Also, as highlighted in section IV, the model confirms a capacity for innovation due to its solidity of the proposed evaluative framework, together with the organizational and even commercial interests of the industries. In terms of innovation, the framework highlights the importance of industrial gaps. In addition to the relevance of a new approach in what the literature says (JOVANOVIĆ; FILIPOVIĆ, 2016), as well as a set of models that mostly include specific approaches such as business (BENEDETTI et al., 2015; KINDSTRÖM; OTTOSSON, 2016).

3.4 CONCLUSIONS

This chapter of the thesis contributes to the PhD research, in the following ways: The investigated sample revealed an energy efficiency potential above the average in companies A-G. This important finding requires a greater effort to formulate internal policies to reduce energy consumption. Still, the chapter pointed out that, in the investigated context, companies can be challenged beyond the environmental aspects and cost management, but primarily to improve industrial management. The results suggest that further efforts in integrating constant maintenance with energy management into the organizational structures of industries A-G will work in the continued improvement of EE.

Still, the other contributions also cooperate in the development of the thesis as follows:

i. Demonstrates the functionality of the Industrial EE enhancement model.

ii. Presents an extensive list of priority actions through the reports. Thus, there is an effective targeting of the main interventions that the seven companies must face.

iii. It exposes the priorities of energy interventions from a critical point of view regarding the improvement of cross-cutting technologies that companies must face to achieve energy efficiency. And,

iv. It shows the main industrial implications that the implementation of priorities for energy efficiency measures can influence the improvement of energy consumption of each of the seven companies studied.

The transparency characteristics of the industrial energy EE model have the potential to reform practices within the manufacturing industry to support its technological advances and align it with other industries that have effective energy consumption control. This will allow the industry to better manage resources and help in financial survival, which enables to validate the hypothesis of this research, that is, fuzzy inference systems allow the development of a diagnosis aimed at improving EE in SMEs.

4 CONCLUSION

The identification of industrial energy consumption points is essential for many purposes, both economic, environmental and organizational.

Thus, this research developed a methodology to analyse possible measures to improve energy efficiency for small and medium-sized companies considering the peculiarities of Brazil and also to assist in the implementation of measures that include internal policies in sectors such as the environment, cost management and management industrial, and finally, addressing the main technological gaps that need to be overcome in order to reach energy consumption that is adequate to its standards.

In chapter 1, the panorama of energy efficiency was addressed with a specific focus on the industrial sector, considering national and international aspects. A taxonomy of the literature was developed, showing the behavior of industrial energy efficiency, showing that the implementation of measures to reduce energy consumption is primarily due to an economic and organizational scope.

Afterwards, the central point of the doctorate was discussed, which is the development of an energy efficiency assessment method for small and medium-sized companies using fuzzy logic. It was demonstrated to be effective for offering a methodology that abstracts subjectivities, inherent to the indicators found to compose the measure for both companies.

For the specific objectives achieved, as shown by the results of the model, the potential for improvement of each company is diagnosed, as well as the technological gaps beyond the critical points considering the relationships of environmental quality, cost management and industrial management. In this way, A-G companies can dedicate themselves and adapt their production and service system to improve their energy consumption, by solving gaps with suggestions for viable techniques and practices to ensure the best level of effectively acceptable energy efficiency. It is noteworthy that the list of actions presented to improve energy consumption is indicated according to the amount of energy in kW per technology, compared by the database of the Industrial Assessment Center.

Finally, the social aspect contributes to the proposed methodology for SMEs that do not have the economic conditions to develop energy management programs. From an academic point of view, there is an advance in the study of energy efficiency linked to a decision-making method. For the authorities, a generalized application that allows, through the developed structure, to create implementation actions in small and medium companies, helping the authorities to point out a list of actions that should be implemented and boosted to the energy efficiency of the industrial sector, in addition to helping the PADs to achieve the proposed 24% temperature reduction established by the IPCC for the year 2050.

And for future work, in the academy, use other techniques such as decision trees and neural networks to verify if there are related indicators for an even greater refinement of the methodology for evaluating industrial energy efficiency. It is proposed to develop a "tropicalization" of the data used from the industrial assessment center for the improvement indices of cross-cutting technologies. In addition to developing the cost-benefit ratio (CBR) with and without retrofit from the industrial energy efficiency assessment methodology, furthermore, it encourages the development of a specific framework for each industrial sector.

From a commercial point of view, the tool serves as a support for Energy services companies (ESCOs) or a power utility, to be distributed uniformly and in large quantities to Brazilian SMEs

In short, it is concluded that the methodology, supported by the Theory of Fuzzy Sets, is considerably viable, satisfactory and useful. Therefore, it allows new forms of planning for effective programs to implement energy efficiency in SMEs.

REFERENCES

ABE, S. **Pattern Classification. Neuro-Fuzzy Methods and Their Comparison**. 1. ed. [s.l: s.n.].

AHMAD, M. M.; DHAFR, N. Establishing and improving manufacturing performance measures. **Robotics and Computer-Integrated Manufacturing**, [s. l.], v. 18, n. 3–4, p. 171–176, 2002.

ALSOFYANI, I. M.; IDRIS, N. R. N. A review on sensorless techniques for sustainable reliablity and efficient variable frequency drives of induction motors. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 24, p. 111–121, 2013. Disponível em: <http://dx.doi.org/10.1016/j.rser.2013.03.051>

AMERICAN SOCIETY OF HEATING REFRIGERATION AND AIR CONDITIONING ENGINEERS. **How HVAC&R Changed the World**. 2020. Disponível em: <https://www.ashrae.org/file library/technical resources/ashrae journal/125thanniversaryarticles/34-49_nagengast.pdf>.

ANDERSON, S. T.; NEWELL, R. G. Information programs for technology adoption: The case of energy-efficiency audits. **Resource and Energy Economics**, [s. l.], v. 26, n. 1, p. 27–50, 2004.

ANDERSSON, E.; THOLLANDER, P. Key performance indicators for energy management in the Swedish pulp and paper industry. **Energy Strategy Reviews**, [s. l.], v. 24, n. April, p. 229–235, 2019. Disponível em: <https://doi.org/10.1016/j.esr.2019.03.004>

ANDRADE, C. T. de C.; PONTES, R. S. T. Economic analysis of Brazilian policies for energy efficient electric motors. **Energy Policy**, [s. l.], v. 106, n. April, p. 315–325, 2017. Disponível em: <http://dx.doi.org/10.1016/j.enpol.2017.03.029>

APEANING, R. W.; THOLLANDER, P. Barriers to and driving forces for industrial energy efficiency improvements in African industries - A case study of Ghana’s largest industrial area. **Journal of Cleaner Production**, [s. l.], v. 53, p. 204–213, 2013. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2013.04.003>

ARAÚJO, S. L. J. C. **Estudo de Metodologia Para Otimização da Eficiência Energética de Consumidores Residenciais e Micro e Pequenas Empresas**. 2017. Universidade Federal do Maranhão, [s. l.], 2017.

AZIZIFAR, S.; BANOONI, S. Modeling and optimization of industrial multistage compressed air system using actual variable effectiveness in hot regions. **Advances in Mechanical Engineering**, [s. l.], v. 8, n. 5, p. 1–10, 2016.

BAKER, R. W.; FREEMAN, B.; KNIEP, J.; WEI, X.; MERKEL, T. CO2 capture from natural gas power plants using selective exhaust gas recycle membrane designs. **International Journal of Greenhouse Gas Control**, [s. l.], v. 66, n. August, p. 35–47, 2017. Disponível em: <http://dx.doi.org/10.1016/j.ijggc.2017.08.016>

BALOCH, A. A.; SHAIKH, P. H.; SHAIKH, F.; LEGHARI, Z. H.; MIRJAT, N. H.; UQAILI, M. A. Simulation tools application for artificial lighting in buildings. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 82, p. 3007–3026, 2018. Disponível em: <https://doi.org/10.1016/j.rser.2017.10.035>

BARROS, L. C.; BASSANEZI, R. C. **Tópicos de Lógica Fuzzy e Biomatemática**. 5. ed. Campinas.

BARROS, L. C.; BASSANEZI, R. C.; LODWICK, W. A. **A First Course in Fuzzy Logic, Fuzzy Dynamical Systems, and Biomathematics**. [s.l: s.n.].

BENEDETTI, M.; BONFÀ, F.; INTRONA, V.; SANTOLAMAZZA, A.; UBERTINI, S. Real time energy performance control for industrial compressed air systems: Methodology and applications †. **Energies**, [s. l.], v. 12, n. 20, p. 1158–1179, 2019.

BENEDETTI, M.; CESAROTTI, V.; HOLGADO, M.; INTRONA, V.; MACCHI, M. A proposal for energy services’ classification including a product service systems perspective.

Procedia CIRP, [s. l.], v. 30, p. 251–256, 2015. Disponível em: <http://dx.doi.org/10.1016/j.procir.2015.02.121>

BERELSON, B. **Content Analysis in Communications Research**. New York.

BERNDT, E. R. AGGREGATE ENERGY, EFFICIENCY, AND PRODUCTIVITY MEASUREMENT. **Annual Reviews Energy**, [s. l.], v. 3, p. 225–273, 1978.

BLOMQVIST, E.; THOLLANDER, P. An integrated dataset of energy efficiency measures published as linked open data. **Energy Efficiency**, [s. l.], v. 8, n. 6, p. 1125–1147, 2015.

BOHARB, A.; ALLOUHI, A.; SAIDUR, R.; KOUSKSOU, T.; JAMIL, A.; MOURAD, Y.; BENBASSOU, A. Auditing and analysis of energy consumption of an industrial site in Morocco. **Energy**, [s. l.], v. 101, p. 332–342, 2016. Disponível em: <http://dx.doi.org/10.1016/j.energy.2016.02.035>

BORTONI, E. C.; MAGALHÃES, L. P.; NOGUEIRA, L. A. H.; BAJAY, S. V.; CASSULA, A. M. An assessment of energy efficient motors application by scenarios evaluation. **Energy Policy**, [s. l.], v. 140, p. 1114–1122, 2020.

BORTONI, E. C.; NOGUEIRA, L. A. H.; CARDOSO, R. B.; HADDAD, J.; SOUZA, E. P.; DIAS, M. V. X.; YAMACHITA, R. A. Assessment of the achieved savings from induction motors energy efficiency labeling in Brazil. **Energy Conversion and Management**, [s. l.], v. 75, p. 734–740, 2013. Disponível em: <http://dx.doi.org/10.1016/j.enconman.2013.08.034>

BRASIL. **National Conservation Policy and Rational Use of Energy and Decree 4059**. 2001. Disponível em: <http://www2.camara.leg.br/legin/fed/lei/2001/lei-10295-17-outubro-2001-408176-norma-pl.html>.

BRASIL. **Anuário do Trabalho na Micro e Pequena Empresa**. Brasilia. Disponível em: <https://www.sebrae.com.br/Sebrae/Portal Sebrae/Anexos/Anuario do Trabalho Na Micro e Pequena Empresa_2013.pdf>.

BRASIL. **Plano Nacional de Eficiência Energética**. Brasilia. Disponível em:

<http://cmsdespoluir.cnt.org.br/Documents/PDFs/Plano_Nacional_de_Eficixncia_Energxtica_-_PNEf_-_final.pdf>.

BRASIL. **Estudas da Demanda de Energia 2050**. Brasilia. Disponível em: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-227/topico-458/DEA 13-15 Demanda de Energia 2050.pdf>.

BRASIL. **Relatório Anual. Instituto Brasileiro de Geografia e Estatiítica**. 2017a. Disponível em: <https://ww2.ibge.gov.br/home/estatistica/indicadores/industria/pimpf_pimes/notas_tecnicas.shtm>. Acesso em: 23 abr. 2019.

BRASIL. Eficiência Energética para motores, Procel2017b.

BRASIL. **Balanço Energético Nacional**. Brasilia. Disponível em: <https://www.epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-479/topico-521/Relatório Síntese BEN 2020-ab 2019_Final.pdf>.

BRASIL. **Apresentação da Contribuição Nacionalmente Determinada do Brasil perante o Acordo de Paris. Ministério das Relações Exteriores**. 2020b. Disponível em: <https://www.gov.br/mre/pt-br/canais_atendimento/imprensa/notas-a-imprensa/2020/apresentacao-da-contribuicao-nacionalmente-determinada-do-brasil-perante-o-acordo-de-paris>. Acesso em: 20 dez. 2020.

BRASIL. **Sebrae: Painel de Empresas**. 2021. Disponível em: <https://datasebrae.com.br/totaldeempresas-11-05-2020/>. Acesso em: 4 ago. 2021.

BRASIL. **Procel Info: Centro Brasileiro de Informação de Eficiência Energética**. 2022. Disponível em: <http://www.procelinfo.com.br/main.asp?View=%7B5A08CAF0-06D1-4FFE-B335-95D83F8DFB98%7D&Team=&params=itemID=%7B4139A7E2-0383-4DC5-

892C-438AB182F9C8%7D;&UIPartUID=%7B05734935-6950-4E3F-A182-629352E9EB18%7D>. Acesso em: 27 mar. 2022.

BRASIL, I.-R. E. **Declaração Conjunta de Associação entre o Governo da República Federativa do Brasil e a Agencia Internacional de Energia**. 2017c. Disponível em: <http://www.itamaraty.gov.br/pt-BR/notas-a-imprensa/17762-declaracao-conjunta-de-associacao-entre-o-governo-da-republica-federativa-do-brasil-e-a-agencia-internacional-de-energia-brasilia-31-de-outubro-de-2017>. Acesso em: 22 abr. 2018.

BRASIL, R. S. C. **ABNT, Normal Brasileira 10004**. [s.l: s.n.].

BRIEF, C. **Analysis: Which countries met the UN's 2020 deadline to raise 'climate ambition'?** 2020. Disponível em: <https://www.carbonbrief.org/analysis-which-countries-met-the-uns-2020-deadline-to-raise-climate-ambition>.

BROWN, M. A. Market failures and barriers as a basis for clean energy policies. **Energy Policy**, [s. l.], v. 29, n. 14, p. 1197–1207, 2001.

BRUNDAGE, M. P.; CHANG, Q.; LI, Y.; XIAO, G.; ARINEZ, J. Energy efficiency management of an integrated serial production line and HVAC system. **IEEE Transactions on Automation Science and Engineering**, [s. l.], v. 11, n. 3, p. 789–797, 2014.

BRUNKE, J. C.; JOHANSSON, M.; THOLLANDER, P. Empirical investigation of barriers and drivers to the adoption of energy conservation measures, energy management practices and energy services in the Swedish iron and steel industry. **Journal of Cleaner Production**, [s. l.], v. 84, n. 1, p. 509–525, 2014. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2014.04.078>

BUNSE, K.; VODICKA, M.; SCHÖNSLEBEN, P.; BRÜLHART, M.; ERNST, F. O. Integrating energy efficiency performance in production management - Gap analysis between industrial needs and scientific literature. **Journal of Cleaner Production**, [s. l.], v. 19, n. 6–7, p. 667–679, 2011. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2010.11.011>

CABELLO ERAS, J. J.; SAGASTUME GUTIÉRREZ, A.; SOUSA SANTOS, V.; CABELLO ULLOA, M. J. Energy management of compressed air systems. Assessing the production and use of compressed air in industry. **Energy**, [s. l.], v. 213, p. 1186–1202, 2020.

CAGNO, E.; MOSCHETTA, D.; TRIANNI, A. Only non-energy benefits from the adoption of energy efficiency measures? A novel framework. **Journal of Cleaner Production**, [s. l.], v. 212, p. 1319–1333, 2019.

CAGNO, E.; NERI, A.; HOWARD, M.; BRENNA, G.; TRIANNI, A. Industrial sustainability performance measurement systems: A novel framework. **Journal of Cleaner Production**, [s. l.], v. 230, p. 1354–1375, 2019. Disponível em: <https://doi.org/10.1016/j.jclepro.2019.05.021>

CAGNO, E.; TRIANNI, A. Analysis of the most effective energy efficiency opportunities in manufacturing primary metals, plastics, and textiles small- and medium-sized enterprises. **Journal of Energy Resources Technology, Transactions of the ASME**, [s. l.], v. 134, n. 2, p. 1–9, 2012.

CAGNO, E.; TRIANNI, A. Exploring drivers for energy efficiency within small- and medium-sized enterprises: First evidences from Italian manufacturing enterprises. **Applied Energy**, [s. l.], v. 104, p. 276–285, 2013. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2012.10.053>

CAGNO, E.; TRIANNI, A. Evaluating the barriers to specific industrial energy efficiency measures: An exploratory study in small and medium-sized enterprises. **Journal of Cleaner Production**, [s. l.], v. 82, p. 70–83, 2014.

CAGNO, E.; TRIANNI, A.; SPALLINA, G.; MARCHESANI, F. Drivers for energy efficiency and their effect on barriers: empirical evidence from Italian manufacturing enterprises. **Energy Efficiency**, [s. l.], v. 10, n. 4, p. 855–869, 2017.

CAGNO, E.; TRUCCO, P.; TRIANNI, A.; SALA, G. Quick-E-scan: A methodology for the energy scan of SMEs. **Energy**, [s. l.], v. 35, n. 5, p. 1916–1926, 2010. Disponível em: <http://dx.doi.org/10.1016/j.energy.2010.01.003>

CAGNO, E.; WORRELL, E.; TRIANNI, A.; PUGLIESE, G. A novel approach for barriers to industrial energy efficiency. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 19, p. 290–308, 2013.

CAMERON, K.; WHETTEN, D.; BOZEMAN, B. **Organizational Effectiveness: A Comparison of Multiple Models**. [s.l: s.n.]. v. 3

CARLSSON, B. Management of flexible manufacturing: An international comparison. **Omega**, [s. l.], v. 20, n. 1, p. 11–22, 1992.

CARVALHO, L.; WOPIENKA, E.; POINTNER, C.; LUNDGREN, J.; VERMA, V. K.; HASLINGER, W.; SCHMIDL, C. Performance of a pellet boiler fired with agricultural fuels. **Applied Energy**, [s. l.], v. 104, n. 2013, p. 286–296, 2013. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2012.10.058>

CHAI, K. H.; YEO, C. Overcoming energy efficiency barriers through systems approach-A conceptual framework. **Energy Policy**, [s. l.], v. 46, p. 460–472, 2012. Disponível em: <http://dx.doi.org/10.1016/j.enpol.2012.04.012>

CHEN, C. C. An objective-oriented and product-line-based manufacturing performance measurement. **International Journal of Production Economics**, [s. l.], v. 112, n. 1, p. 380–390, 2008.

CHOI, J. K.; EOM, J.; MCCLORY, E. Economic and environmental impacts of local utility-delivered industrial energy-efficiency rebate programs. **Energy Policy**, [s. l.], v. 123, p. 289–298, 2018. Disponível em: <https://doi.org/10.1016/j.enpol.2018.08.066>

CHUANG, C. C.; SUE, D. C. Performance effects of combined cycle power plant with variable condenser pressure and loading. **Energy**, [s. l.], v. 30, n. 10, p. 1793–1801, 2005.

CHWIF, L.; MEDINA, A. **Modelagens e Simulação de Eventos Discretos**. 4. ed. São Paulo.

COILIN, Ó.; QUINN, G.; CONNOLLY, R.; CONNOLLY, M. Energy and Climate Policy — An Evaluation of Global. **Energies**, [s. l.], v. 13, n. 18, p. 4839, 2020. Disponível em: <https://www.mdpi.com/1996-1073/13/18/4839>

CRESWELL, J. W. .; PLANO CLARK, V. L. **Designing and Conducting Mixed Methods Research**. 3. ed. [s.l: s.n.].

DECANIO, S. J. The efficiency paradox: bureaucratic and organizational barriers to profitable energy-saving investments. **Energy Policy**, [s. l.], v. 26, n. 5, p. 441–454, 1998.

DINOLOV, O. Training methodology in energy efficiency evaluation of induction motor drives and systems for enhancing educational programs. **International Journal of Electrical Engineering Education**, [s. l.], v. 0, n. 0, p. 1–23, 2020.

FLEITER, T.; HIRZEL, S.; WORRELL, E. The characteristics of energy-efficiency measures - a neglected dimension. **Energy Policy**, [s. l.], v. 51, p. 502–513, 2012. Disponível em: <http://dx.doi.org/10.1016/j.enpol.2012.08.054>

FREITAS, L. C. De; GOMES, A. C.; SORIANO, F. R.; MONTEIRO, F. A. M.; CORTES, L. R. C.; MATOS, V. S.; WANDERLEY, V. de S. A. Programa Brasileiro De Etiquetagem: Breve Panorama. **Engenharia Elétrica e de Computação: Atividades Relacionadas com o Setor Científico e Tecnológico 4**, [s. l.], p. 77–87, 2020.

GAHM, C.; DENZ, F.; DIRR, M.; TUMA, A. Energy-efficient scheduling in manufacturing companies: A review and research framework. **European Journal of Operational Research**, [s. l.], v. 248, n. 3, p. 744–757, 2016. Disponível em: <http://dx.doi.org/10.1016/j.ejor.2015.07.017>

GARCIA, A. G. P.; SZKLO, A. S.; SCHAEFFER, R.; MCNEIL, M. A. Energy-efficiency standards for electric motors in Brazilian industry. **Energy Policy**, [s. l.], v. 35, n. 6, p. 3424–3439, 2007.

GILLINGHAM, K.; NEWELL, R. G.; PALMER, K. Energy Efficiency Economics and

Policy. **Annual Review of Resource Economics**, [s. l.], v. 1, p. 597–620, 2009.

GOLDSCHMIDT, R. R. **Uma Introdução à Inteligência Computacional: fundamentos, ferramentas e aplicações**. Rio de Janeiro.

GORDIĆ, D.; BABIĆ, M.; JOVIČIĆ, N.; ŠUŠTERŠIČ, V.; KONČALOVIĆ, D.; JELIĆ, D. Development of energy management system - Case study of Serbian car manufacturer. **Energy Conversion and Management**, [s. l.], v. 51, n. 12, p. 2783–2790, 2010.

GUDWIN, R. R.; GOMIDE, F. A. C. Context adaptation in fuzzy processing. In: 1ST BRAZIL-JAPAN JOINT SYMPOSIUM IN FUZZY SYSTEMS 1994, **Anais**... [s.l: s.n.]

HADDAD, J. **a Lei De Eficiência Energética E Os Possíveis Impactos Nos Setores Produtivos**. [s.l: s.n.].

HAJIAN, M.; ARAB MARKADEH, G. R.; SOLTANI, J.; HOSEINNIA, S. Energy optimized sliding-mode control of sensorless induction motor drives. **Energy Conversion and Management**, [s. l.], v. 50, n. 9, p. 2296–2306, 2009. Disponível em: <http://dx.doi.org/10.1016/j.enconman.2009.05.006>

HAN, Y.; ZHOU, R.; GENG, Z.; BAI, J.; MA, B.; FAN, J. A novel data envelopment analysis cross-model integrating interpretative structural model and analytic hierarchy process for energy efficiency evaluation and optimization modeling: Application to ethylene industries. **Journal of Cleaner Production**, [s. l.], v. 246, 2020.

HASAN, A. S. M. M.; TRIANNI, A. A review of energy management assessment models for industrial energy efficiency. **Energies**, [s. l.], v. 13, n. 21, 2020.

HASANBEIGI, A.; PRICE, L. A review of energy use and energy efficiency technologies for the textile industry. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 16, n. 6, p. 3648–3665, 2012. Disponível em: <http://dx.doi.org/10.1016/j.rser.2012.03.029>

HENRIQUES, J.; CATARINO, J. Motivating towards energy efficiency in small and medium enterprises. **Journal of Cleaner Production**, [s. l.], v. 139, n. 2016, p. 42–50, 2016.

HIRST, E.; BROWN, M. Closing the efficiency gap: barriers to the efficient use of energy. **Resources, Conservation and Recycling**, [s. l.], v. 3, p. 267–281, 1990.

HUANG, Z.; WEI, Y. M.; WANG, K.; LIAO, H. Energy economics and climate policy modeling. **Annals of Operations Research**, [s. l.], v. 255, n. 1–2, p. 1–7, 2017.

IBGE. **Pesquisa Industrial Anual**. 2021. Disponível em: <https://www.ibge.gov.br/estatisticas/economicas/industria/9042-pesquisa-industrial-anual.html?=&t=destaques>. Acesso em: 10 fev. 2022.

IEA/INTERNATIONAL ENERGY AGENCY. **Energy-Efficiency Policy Opportunities for Electric Motor-Driven Systems**. 2011.

IEA/INTERNATIONAL ENERGY AGENCY. **Word Energy Outlook**. 2017. Disponível em: <https://www.iea.org/reports/world-energy-outlook-2017>. Acesso em: 20 ago. 2018.

IEA/INTERNATIONAL ENERGY AGENCY. **report by the Global energy & CO2 Status Report 2019**. 2019a. Disponível em: <https://www.iea.org/reports/global-energy-co2-status-report-2019>. Acesso em: 22 set. 2020.

IEA/INTERNATIONAL ENERGY AGENCY. **Data**. 2019b. Disponível em: <https://www.iea.org/reports/world-energy-outlook-2019>.

IEA/INTERNATIONAL ENERGY AGENCY. **Data**. 2020a. Disponível em: <https://www.iea.org/data-and-statistics?country=WORLD&fuel=Energy supply&indicator=TPESbySource>. Acesso em: 20 nov. 2020.

IEA/INTERNATIONAL ENERGY AGENCY. **World Energy Outlook**. 2020b. Disponível em: <https://www.iea.org/reports/world-energy-outlook-2020>. Acesso em: 2 jan. 2020.

IEA/INTERNATIONAL ENERGY AGENCY. **Energy Efficiency Indicators**. 2021a. Disponível em: <https://www.iea.org/data-and-statistics/data-product/energy-efficiency-indicators>. Acesso em: 4 ago. 2021.

IEA/INTERNATIONAL ENERGY AGENCY. **Carbon capture, utilisation and storage**.

2021b. Disponível em: <https://www.iea.org/fuels-and-technologies/carbon-capture-utilisation-and-storage>. Acesso em: 10 fev. 2022.

IEA. **Light’s labour’s lost: Policies for Energy-Efficient Lighting, Energy Efficiency Policy Profiles**. 2006.

INDUSTRIAL ASSESSMENTER CENTER. **Assessment Recommendation Codes (ARC)**. [s.l: s.n.]. Disponível em: <https://iac.university/technicalDocs/ARC List - V19.1.pdf>.

INDUSTRIAL ASSESSMENTER CENTER. **Search IAC Recommendations**. 2020. Disponível em: <https://iac.university/searchRecommendations>. Acesso em: 2 jan. 2021.

INDUSTRIAL ASSESSMENTER CENTER. **Saving Energy and Reducing Costs at Small and Medium-sized US Manufacturers**. 2021.

INTERNATIONAL PAINEL ON CLIMATE CHANGE. **Report Global Warning 1.5°C**. 2018. Disponível em: <https://www.ipcc.ch/sr15/>. Acesso em: 25 out. 2019.

INTERNATIONAL PAINEL ON CLIMATE CHANGE. **Climate Change 2021 The Physical Science Basis**. [s.l: s.n.]. Disponível em: <https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_SPM_final.pdf>.

INTERNATIONAL PAINEL ON CLIMATE CHANGE. **Sixth Assessment Report FACT SHEET**. [s.l: s.n.].

ISO. **ISO survey**. 2020. Disponível em: <https://isotc.iso.org/livelink/livelink?func=ll&objId=18808772&objAction=browse&viewType=1>. Acesso em: 20 jan. 2020.

JAFFE, A. B.; STAVINS, R. N. The energy-efficiency gap What does it mean? **Energy Policy**, [s. l.], v. 22, n. 10, p. 804–810, 1994.

JENSEN, M. C. Organization Theory and Methodology. **SSRN Electronic Journal**, [s. l.], v. 58, n. 2, p. 319–339, 2005.

JOHANSSON, M. T.; THOLLANDER, P. A review of barriers to and driving forces for improved energy efficiency in Swedish industry– Recommendations for successful in-house energy management. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 82, n. October 2017, p. 618–628, 2018. Disponível em: <http://dx.doi.org/10.1016/j.rser.2017.09.052>

JOVANOVIĆ, B.; FILIPOVIĆ, J. ISO 50001 standard-based energy management maturity model - Proposal and validation in industry. **Journal of Cleaner Production**, [s. l.], v. 112, p. 2744–2755, 2016.

KANNAN, R.; BOIE, W. Energy management practices in SME - Case study of a bakery in Germany. **Energy Conversion and Management**, [s. l.], v. 44, n. 6, p. 945–959, 2003.

KATIC, M.; TRIANNI, A. Energy efficiency measures and production resources: Towards an integrative classification framework for decision makers. **IEEE International Conference on Industrial Engineering and Engineering Management**, [s. l.], v. 2020- Decem, p. 225–229, 2020.

KESICKI, F.; YANAGISAWA, A. Modelling the potential for industrial energy efficiency in IEA's World Energy Outlook. **Energy Efficiency**, [s. l.], v. 8, n. 1, p. 155–169, 2014.

KHAN, F. I.; HADDARA, M. M. Risk-based maintenance (RBM): A quantitative approach for maintenance/inspection scheduling and planning. **Journal of Loss Prevention in the Process Industries**, [s. l.], v. 16, n. 6, p. 561–573, 2003.

KHAN, K. H.; RYAN, C.; ABEBE, E. Optimizing HVAC Energy Usage in Industrial Processes by Scheduling Based on Weather Data. **IEEE Access**, [s. l.], v. 5, p. 11228–11235, 2017.

KHANLARI, A.; MOHAMMADI, K.; SOHRABI, B. Prioritizing equipments for preventive maintenance (PM) activities using fuzzy rules. **Computers and Industrial Engineering**, [s. l.], v. 54, n. 2, p. 169–184, 2008.

KINDSTRÖM, D.; OTTOSSON, M. Local and regional energy companies offering energy services: Key activities and implications for the business model. **Applied Energy**, [s. l.], v.

171, p. 491–500, 2016.

LEE, A. H. W. Verification of electrical energy savings for lighting retrofits using short- and long-term monitoring. **Energy Conversion and Management**, [s. l.], v. 41, n. 18, p. 1999–2008, 2000.

LEE, C. C. Fuzzy Logic in Control Systems: Fuzzy Logic Controller, Part II. **IEEE Transactions on Systems, Man and Cybernetics**, [s. l.], v. 20, n. 2, p. 419–435, 1990.

LI, W. **Risk Assessment Of Power Systems: Models, Methods, and Applications**. [s.l: s.n.].

LIU, G.; GAO, J.; ZENG, L.; HOU, Y.; CAO, C.; TONG, L.; WANG, Y. On-demand ventilation and energy conservation of industrial exhaust systems based on stochastic modeling. **Energy and Buildings**, [s. l.], v. 223, p. 1101–1158, 2020. Disponível em: <https://doi.org/10.1016/j.enbuild.2020.110158>

LIU, P.; ZHOU, Y.; ZHOU, D. K.; XUE, L. Energy Performance Contract models for the diffusion of green-manufacturing technologies in China: A stakeholder analysis from SMEs' perspective. **Energy Policy**, [s. l.], v. 106, p. 59–67, 2017. Disponível em: <http://dx.doi.org/10.1016/j.enpol.2017.03.040>

LOVINS, A. B. Energy Efficiency, Taxonomic Overview. **Encyclopedia of Energy**, [s. l.], v. 2, p. 383–401, 2004.

LUNG, B.; NIMBALKAR, S.; WENNING, T. Multiple Benefits of Industrial Energy Efficiency - Lessons Learned and New Initiatives. In: INDUSTRIAL ENERGY TECHNOLOGY CONFERENCE (IETC) 2019, New Orleans, Louisiana, United States of America. **Anais**... New Orleans, Louisiana, United States of America

LUNG, R. B.; MCKANE, A.; LEACH, R.; MARSH, D. Ancillary savings and production benefits in the evaluation of industrial energy efficiency measures. In: PROCEEDINGS ACEEE SUMMER STUDY ON ENERGY EFFICIENCY IN INDUSTRY 2005, Berkeley.

US. **Anais**... Berkeley. US

MALINAUSKAITE, J.; JOUHARA, H.; AHMAD, L.; MILANI, M.; MONTORSI, L.; VENTURELLI, M. Energy efficiency in industry: EU and national policies in Italy and the UK. **Energy**, [s. l.], v. 172, n. 2019, p. 255–269, 2019. Disponível em: <https://doi.org/10.1016/j.energy.2019.01.130>

MARAZZA, D.; BANDINI, V.; CONTIN, A. Ranking environmental aspects in environmental management systems: A new method tested on local authorities. **Environment International**, [s. l.], v. 36, n. 2, p. 168–179, 2010. Disponível em: <http://dx.doi.org/10.1016/j.envint.2009.10.011>

MARTIN, M.; TONN, B.; SCHMOYER, R.; OVERLY, J.; SCHEXNAYDER, S.; JOHNSON, D. **Industrial Assessment Center Program Impact Evaluation**, 1999.

MARTIN, R.; MUÛLS, M.; DE PREUX, L. B.; WAGNER, U. J. Anatomy of a paradox: Management practices, organizational structure and energy efficiency. **Journal of Environmental Economics and Management**, [s. l.], v. 63, n. 2, p. 208–223, 2012.

MEKHILEF, S.; SAIDUR, R.; SAFARI, A. A review on solar energy use in industries. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 15, n. 4, p. 1777–1790, 2011.

MICKOVIC, A.; WOUTERS, M. Energy costs information in manufacturing companies: A systematic literature review. **Journal of Cleaner Production**, [s. l.], v. 254, p. 119927, 2020. Disponível em: <https://doi.org/10.1016/j.jclepro.2019.119927>

MILLS, E.; ROSENFELDS, A. R. T. Consumer Non-Energy Benefits Making Energy-Efficiency Improvements. **Energy**, [s. l.], v. 21, n. 7/8, p. 707–720, 1996.

MISHRA, S. B.; ALOK, S. **Handbook of Research Methodology A Compendium for Scholars & Researchers**. 1. ed. New Delhi/ India.

MOKHTAR, A.; NASOOTI, M. A decision support tool for cement industry to select energy efficiency measures. **Energy Strategy Reviews**, [s. l.], v. 28, n. November 2016, p. 27, 2020.

Disponível em: <https://doi.org/10.1016/j.esr.2020.100458>

MORAIS, D.; GASPAR, P. D.; SILVA, P. D.; ANDRADE, L. P.; NUNES, J. Energy consumption and efficiency measures in the Portuguese food processing industry. **Journal of Food Processing and Preservation**, [s. l.], n. May, p. 1–9, 2020.

MORGAN, R. E. Export stimuli and export barriers: Evidence from empirical research studies. **European Business Review**, [s. l.], v. 97, n. 2, p. 68–79, 1997.

NAGESHA, N.; BALACHANDRA, P. Barriers to energy efficiency in small industry clusters: Multi-criteria-based prioritization using the analytic hierarchy process. **Energy**, [s. l.], v. 31, n. 12, p. 1969–1983, 2006.

NEHLER, T. Linking energy efficiency measures in industrial compressed air systems with non-energy benefits – A review. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 89, p. 72–87, 2018. Disponível em: <https://doi.org/10.1016/j.rser.2018.02.018>

NEHLER, T.; PARRA, R.; THOLLANDER, P. Implementation of energy efficiency measures in compressed air systems: barriers, drivers and non-energy benefits. **Energy Efficiency**, [s. l.], v. 11, n. 5, p. 1281–1302, 2018.

NEVES, F. D. O.; EWBANK, H.; ROVEDA, J. A. F.; TRIANNI, A.; MARAFÃO, F. P.; ROVEDA, S. R. M. M. Economic, Environmental and Productive Practices Influence on the Industrial Energetic Efficiency. **Revista Gestão & Sustentabilidade Ambiental**, [s. l.], v. 9, n. esp, p. 513, 2020.

NEVES, F. de O.; EWBANK, H.; ROVEDA, J. A. F.; TRIANNI, A.; MARAFÃO, F. P.; ROVEDA, S. R. M. M. Economic and Production-Related Implications for Industrial Energy Efficiency: A Logistic Regression Analysis on Cross-Cutting Technologies. **Energies**, [s. l.], v. 15, n. 4, p. 1–21, 2022.

NEVES, F. de O.; SALGADO, E. G.; BEIJO, L. A. Analysis of the Environmental Management System based on ISO 14001 on the American continent. **Journal of**

Environmental Management, [s. l.], v. 199, n. 2, p. 251–262, 2017.

NICHOLS, A. L. Demand-side management Overcoming market barriers or obscuring real costs? **Energy Policy**, [s. l.], v. 22, n. 10, p. 840–847, 1994.

OH, S.; REVANKAR, S. T. Analysis of the complete condensation in a vertical tube passive condenser. **International Communications in Heat and Mass Transfer**, [s. l.], v. 32, n. 6, p. 716–727, 2005.

PALM, J.; BACKMAN, F. Energy efficiency in SMEs: overcoming the communication barrier. **Energy Efficiency**, [s. l.], v. 13, n. 5, p. 809–821, 2020.

PALM, J.; THOLLANDER, P. An interdisciplinary perspective on industrial energy efficiency. **Applied Energy**, [s. l.], v. 87, n. 10, p. 3255–3261, 2010. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2010.04.019>

PATTERSON, M. G. What is energy efficiency? Concepts, indicators and methodological issues. **Energy Policy**, [s. l.], v. 24, n. 5, p. 377–390, 1996.

PIMENTEL, F. **O Fim da Era do Petróleo e a Mudança do Paradigma Energético Mundial: Perspectivas e Desafios para a Atuação Diplomática Brasileira**. 1. ed. Rio de Janeiro. Disponível em: <http://funag.gov.br/loja/download/838-Fim_da_Era_do_Petroleo_e_a_Mudanca_do_Paradigma_Energetico_Mundial_O.pdf>

PIRES, F. L. C.; SOUTO, R. S.; SILVA, P. H. P. Ações de eficiência energética no setor industrial do Brasil. **Revista Tecnologia**, [s. l.], v. 41, n. 2, p. 1–15, 2020.

PRASHAR, A. Adopting PDCA (Plan-Do-Check-Act) cycle for energy optimization in energy-intensive SMEs. **Journal of Cleaner Production**, [s. l.], v. 145, p. 277–293, 2017. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2017.01.068>

PYE, M.; MCKANE, A. Making a stronger case for industrial energy efficiency by quantifying non-energy benefits. **Resources, Conservation and Recycling**, [s. l.], v. 28, n. 3–4, p. 171–183, 2000.

RASMUSSEN, K.; WILSON, A.; HINDLE, A. Green mining: Energy consumption of advertisement blocking methods. **3rd International Workshop on Green and Sustainable Software, GREENS 2014 - Proceedings**, [s. l.], p. 38–45, 2014.

REIS, A. V.; NEVES, F. de O.; HIKICHI, S. E.; SALGADO, E. G.; BEIJO, L. A. Is ISO 14001 certification really good to the company? A critical analysis. **Producao**, [s. l.], v. 28, 2018.

ROHDIN, P. **Energy efficiency and ventilation in Swedish industries**. [s.l: s.n.].

ROHDIN, P.; THOLLANDER, P. Barriers to and driving forces for energy efficiency in the non-energy intensive manufacturing industry in Sweden. **Energy**, [s. l.], v. 31, n. 12, p. 1836–1844, 2006.

ROHDIN, P.; THOLLANDER, P.; SOLDING, P. Barriers to and drivers for energy efficiency in the Swedish foundry industry. **Energy Policy**, [s. l.], v. 35, n. 1, p. 672–677, 2007.

SA, A.; THOLLANDER, P.; RAFIEE, M. Industrial energy management systems and energy-related decision-making. **Energies**, [s. l.], v. 11, n. 10, p. 1–12, 2018.

SAFARZADEH, S.; RASTI-BARZOKI, M.; HEJAZI, S. R. A review of optimal energy policy instruments on industrial energy efficiency programs, rebound effects, and government policies. **Energy Policy**, [s. l.], v. 139, n. February, p. 111342, 2020. Disponível em: <https://doi.org/10.1016/j.enpol.2020.111342>

SAIDUR, R.; HASANUZZAMAN, M.; RAHIM, N. A. Energy, economic, and environmental analysis of the Malaysian industrial compressed-air systems. **Clean Technologies and Environmental Policy**, [s. l.], v. 14, n. 2, p. 195–210, 2012.

SAIDUR, R.; RAHIM, N. A.; HASANUZZAMAN, M. A review on compressed-air energy use and energy savings. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 14, n. 4, p. 1135–1153, 2010. Disponível em: <http://dx.doi.org/10.1016/j.rser.2009.11.013>

SANDBERG, P.; SÖDERSTRÖM, M. Industrial energy efficiency: The need for investment decision support from a manager perspective. **Energy Policy**, [s. l.], v. 31, n. 15, p. 1623–1634, 2003.

SANYA, M.; BART, K. Adaptive Joint fuzzy Sets for Function Approximation. In: PROCEEDINGS OF INTERNATIONAL CONFERENCE ON NEURAL NETWORKS (ICNN’97) 2004, Houston, TX, USA. **Anais**... Houston, TX, USA

SARKAR, J.; BHATTACHARYYA, S. Application of graphene and graphene-based materials in clean energy-related devices Minghui. **Archives of Thermodynamics**, [s. l.], v. 33, n. 4, p. 23–40, 2012.

SCHLEICH, J.; GASSMANN, X.; FAURE, C.; MEISSNER, T. Making the implicit explicit: A look inside the implicit discount rate. **Energy Policy**, [s. l.], v. 97, p. 321–331, 2016. Disponível em: <http://dx.doi.org/10.1016/j.enpol.2016.07.044>

SCHULZE, M.; NEHLER, H.; OTTOSSON, M.; THOLLANDER, P. Energy management in industry - A systematic review of previous findings and an integrative conceptual framework. **Journal of Cleaner Production**, [s. l.], v. 112, p. 3692–3708, 2016. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2015.06.060>

SHAW, W.; MATHEWS, M.; MARAIS, J. Using specific energy as a metric to characterise compressor system performance. **Sustainable Energy Technologies and Assessments**, [s. l.], v. 31, p. 329–338, 2019. Disponível em: <https://doi.org/10.1016/j.seta.2018.12.017>

SHI, Y.; ZENG, Y.; ENGO, J.; HAN, B.; LI, Y.; MUEHLEISEN, R. T. Leveraging inter-firm influence in the diffusion of energy efficiency technologies: An agent-based model. **Applied Energy**, [s. l.], v. 263, n. January, p. 114641, 2020. Disponível em: <https://doi.org/10.1016/j.apenergy.2020.114641>

SHOVE, E. Gaps, barriers and conceptual chasms: theories of technology transfer and energy in buildings. **Energy Policy**, [s. l.], v. 26, n. 15, p. 1105–1112, 1998.

SIHN, W.; SOBOTTKA, T.; HEINZL, B.; KAMHUBER, F. Interdisciplinary multi-criteria optimization using hybrid simulation to pursue energy efficiency through production planning. **CIRP Annals**, [s. l.], v. 67, n. 1, p. 447–450, 2018. Disponível em: <https://doi.org/10.1016/j.cirp.2018.04.059>

SILVA, A. B. de O. e; MATHEUS, R. F.; PARREIRAS, F. S.; PARREIRAS, T. A. S. Análise de redes sociais como metodologia de apoio para a discussão da interdisciplinaridade na ciência da informação. **Ciência da Informação**, [s. l.], v. 35, n. 1, p. 72–93, 2006.

SIMÕES, M. G.; SHAW, I. s. **Controle e Modelagem Fuzzy**. 1. ed. São Paulo.

SKUMATZ, L. A.; DICKERSON, C. A. **Extra! Extra! Non-Energy Benefits Swamp Load Impacts For PG&E Program!**, 1998.

SKUMATZ, L. A.; GARDNER, J. **Methods and results for measuring non-energy benefits in the commercial and industrial sectors**, 2005.

SORRELL, S.; SCHLEICH, D. J.; SCOTT, D. S.; O'MALLEY, E.; TRACE, F.; BOEDE, U.; OSTERTAG, K.; RADGEN, D. P. **REDUCING BARRIERS TO ENERGY EFFICIENCY IN PUBLIC AND PRIVATE ORGANISATIONSResearch funded in part by THE EUROPEAN COMMISSION in the framework of the Non Nuclear Energy Programme**. [s.l: s.n.].

STEGER, S.; BLEISCHWITZ, R. Drivers for the use of materials across countries. **Journal of Cleaner Production**, [s. l.], v. 19, n. 8, p. 816–826, 2011. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2010.08.016>

STOECKER, W. .; JABARDO, J. . S. **Refrigeração Industrial (LIVRO COMPLETO) - Jabardo_e_Stoecker.pdf**, 2002. Disponível em: <http://ftp.demec.ufpr.br/disciplinas/EngMec_NOTURNO/TM374/Refrigera%E7%E3o Industrial (LIVRO COMPLETO) -Jabardo_e_Stoecker.pdf>

SUDHAKARA REDDY, B. Barriers and drivers to energy efficiency - A new taxonomical approach. **Energy Conversion and Management**, [s. l.], v. 74, p. 403–416, 2013. Disponível em: <http://dx.doi.org/10.1016/j.enconman.2013.06.040>

SUDHAKARA REDDY, B.; KUMAR RAY, B. Understanding industrial energy use: Physical energy intensity changes in Indian manufacturing sector. **Energy Policy**, [s. l.], v. 39, n. 11, p. 7234–7243, 2011. Disponível em: <http://dx.doi.org/10.1016/j.enpol.2011.08.044>

SUGENO, M. An introductory survey of fuzzy control. **Information Sciences**, [s. l.], v. 36, n. 1–2, p. 59–83, 1985.

SUN, Y.; GU, L.; WU, C. F. J.; AUGENBROE, G. Exploring HVAC system sizing under uncertainty. **Energy and Buildings**, [s. l.], v. 81, p. 243–252, 2014.

SY, M. V. U. Drivers of corporate social responsibility leading to sustainable development. **Industrial Engineering and Management Systems**, [s. l.], v. 13, n. 3, p. 342–355, 2014.

TANAKA, K. Assessment of energy efficiency performance measures in industry and their application for policy. **Energy Policy**, [s. l.], v. 36, n. 8, p. 2887–2902, 2008.

TAYLAN, O.; KAYA, D.; DEMIRBAS, A. An integrated multi attribute decision model for energy efficiency processes in petrochemical industry applying fuzzy set theory. **Energy Conversion and Management**, [s. l.], v. 117, p. 501–512, 2016. Disponível em: <http://dx.doi.org/10.1016/j.enconman.2016.03.048>

TEKE, A.; TIMUR, O. Assessing the energy efficiency improvement potentials of HVAC systems considering economic and environmental aspects at the hospitals. **Renewable and Sustainable Energy Reviews**, [s. l.], v. 33, p. 224–235, 2014.

THIEDE, S.; BOGDANSKI, G.; HERRMANN, C. A systematic method for increasing the energy and resource efficiency in manufacturing companies. **Procedia CIRP**, [s. l.], v. 2, n. 1, p. 28–33, 2012. Disponível em: <http://dx.doi.org/10.1016/j.procir.2012.05.034>

THOLLANDER, P.; DANESTIG, M.; ROHDIN, P. Energy policies for increased industrial energy efficiency: Evaluation of a local energy programme for manufacturing SMEs. **Energy Policy**, [s. l.], v. 35, n. 11, p. 5774–5783, 2007.

THOLLANDER, P.; OTTOSSON, M. An energy efficient Swedish pulp and paper industry - Exploring barriers to and driving forces for cost-effective energy efficiency investments. **Energy Efficiency**, [s. l.], v. 1, n. 1, p. 21–34, 2008.

THOLLANDER, P.; OTTOSSON, M. Energy management practices in Swedish energy-intensive industries. **Journal of Cleaner Production**, [s. l.], v. 18, n. 12, p. 1125–1133, 2010. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2010.04.011>

TRIANNI, A.; CAGNO, E. Dealing with barriers to energy efficiency and SMEs: Some empirical evidences. **Energy**, [s. l.], v. 37, n. 1, p. 494–504, 2012. Disponível em: <http://dx.doi.org/10.1016/j.energy.2011.11.005>

TRIANNI, A.; CAGNO, E.; BERTOLOTTI, M.; THOLLANDER, P.; ANDERSSON, E. Energy management: A practice-based assessment model. **Applied Energy**, [s. l.], v. 235, n. March 2018, p. 1614–1636, 2019. Disponível em: <https://doi.org/10.1016/j.apenergy.2018.11.032>

TRIANNI, A.; CAGNO, E.; DE DONATIS, A. A framework to characterize energy efficiency measures. **Applied Energy**, [s. l.], v. 118, p. 207–220, 2014. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2013.12.042>

TRIANNI, A.; CAGNO, E.; FARNÉ, S. Barriers, drivers and decision-making process for industrial energy efficiency: A broad study among manufacturing small and medium-sized enterprises. **Applied Energy**, [s. l.], v. 162, p. 1537–1551, 2016. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2015.02.078>

TRIANNI, A.; CAGNO, E.; FARNÈ, S. An empirical investigation of barriers, drivers and practices for energy efficiency in primary metals manufacturing SMEs. **Energy Procedia**, [s. l.], v. 61, p. 1252–1255, 2014. Disponível em:

<http://dx.doi.org/10.1016/j.egypro.2014.11.1071>

TRIANNI, A.; CAGNO, E.; MARCHESANI, F.; SPALLINA, G. Classification of drivers for industrial energy efficiency and their effect on the barriers affecting the investment decision-making process. **Energy Efficiency**, [s. l.], v. 10, n. 1, p. 199–215, 2017.

TRIANNI, A.; CAGNO, E.; THOLLANDER, P.; BACKLUND, S. Barriers to industrial energy efficiency in foundries: A European comparison. **Journal of Cleaner Production**, [s. l.], v. 40, p. 161–176, 2013. Disponível em: <http://dx.doi.org/10.1016/j.jclepro.2012.08.040>

USDOE-US. **Department of Energy. Determine cost of compressed air for your plant, compressed air tip**. [s.l: s.n.].

VAN RUIJVEN, B. J.; DE CIAN, E.; SUE WING, I. Amplification of future energy demand growth due to climate change. **Nature Communications**, [s. l.], v. 10, n. 1, p. 1–12, 2019.

VIDMAR, K. Importance of finding and defining energy conservation measures. **World Energy Engineering Congress 2009, WEEC 2009**, [s. l.], v. 3, n. 2, p. 1167–1175, 2008.

WAGNER, H. J.; MATHUR, J. Economics and Policy Issues. **Green Energy and Technology**, [s. l.], n. 9783642329753, p. 73–84, 2013.

WARTHMANN, A.; WÖLKI, D.; METZMACHER, H.; VAN TREECK, C. Personal climatization systems-a review on existing and upcoming concepts. **Applied Sciences (Switzerland)**, [s. l.], v. 9, n. 1, 2018.

WEBER, L. Some reflections on barriers to the efficient use of energy. **Energy Policy**, [s. l.], v. 25, n. 10, p. 833–835, 1997.

WORRELL, E.; BERNSTEIN, L.; ROY, J.; PRICE, L.; HARNISCH, J. Industrial energy efficiency and climate change mitigation. **Energy Efficiency**, [s. l.], v. 2, n. 2, p. 109–123, 2009.

WORRELL, E.; BIERMANS, G. Move over! Stock turnover, retrofit and industrial energy efficiency. **Energy Policy**, [s. l.], v. 33, n. 7, p. 949–962, 2005.

WORRELL, E.; LAITNER, J. A.; RUTH, M.; FINMAN, H. Productivity benefits of industrial energy efficiency measures. **Energy**, [s. l.], v. 28, n. 11, p. 1081–1098, 2003.

WU, Y. Scientific management- the first step of building energy efficiency. **2009 International Conference on Information Management, Innovation Management and Industrial Engineering, ICIII 2009**, [s. l.], v. 4, p. 619–622, 2009.

YIN, C. On gas and particle radiation in pulverized fuel combustion furnaces. **Applied Energy**, [s. l.], v. 157, p. 554–561, 2015. Disponível em: <http://dx.doi.org/10.1016/j.apenergy.2015.01.142>

YONEYAMA, J.; NISHIKAWA, M.; KATAYAMA, H.; ICHIKAWA, A. Output stabilization of Takagi-Sugeno fuzzy systems. **Fuzzy Sets and Systems**, [s. l.], v. 111, n. 2, p. 253–266, 2000.

YOSHINO, R. T. **Barreiras ao uso Racional de Energia em micro, pequenas e médias empresas**. 2003. Universidade Estadual de Campinas, [s. l.], 2003.

ZADEH, L. A. F u z z y s e t s as a basis f o r a theory of possibility* l.a. z a d e h. **Fuzzy Sets and Systems**, [s. l.], v. 1, n. 1, p. 3–28, 1978.

ZHANG, L.; LONG, R.; CHEN, H.; HUANG, X. Performance changes analysis of industrial enterprises under energy constraints. **Resources, Conservation and Recycling**, [s. l.], v. 136, n. September 2017, p. 248–256, 2018.

ZHOU, Y.; XU, G.; MINSHALL, T.; LIU, P. How do Public Demonstration Projects Promote Green-Manufacturing Technologies? A Case Study from China. **Sustainable Development**, [s. l.], v. 23, n. 4, p. 217–231, 2015.

ZILL, D. G.; CULLEN, M. R. **Matemática Avançada para Engenharia: Equações diferenciais elementares e transformada de laplace**. 3. ed. São Paulo.

ZIMMERMANN, H.-J. **Fuzzy set and Theory**. 4. ed. [s.l: s.n.]. v. 4

Appendix 2.1: Most cited words in barrier articles

Organizational	Institutional	Financial	Behavioral	Competences	Policy	Awareness
Aneel	Analysis	Speed	Strategy	Process	Institutional	Policy
Basic	Backup	Instrument	Greenhouse	Routine	Network	Framework
Technology	Back pressure	Group	Substitute	Institutional	Instrument	Discussion
base cost effect	Production	Flow	Pressure	Government	Backup	Environmental
Barrier Specific	Attitudinal	Greenhouse	Stress	Impact	Discussion	Governmental
Actor	Associations	Growth	Regulatory	Balance	Technology	Product
Analysis	Aspects Proposed	Production	Administration	Opportunities	Environmental	Process
Ballast	Advisory	Substitute	Institutional	Aspects Proposed	Energy	Individuals
Back Pressure	Aneel	Program	Appropriate	Energy	Cleaner	Appropriate
Authoritarian	Process	Cleaner	Social	Multi attributes	Actor	Pressure
Assumption	Balance	Opportunities	Stimulus	Routine	Process	Energy Efficiency
Appropriate	Cleaner	Regulatory	Society	Discussion	Product	Consumption
Administration	Energy	Group	Routine	Instrument	Greenhouse	Attitudinal
Background	Opportunities	Back pressure	Process	Information Relation	Machinery	Limit
Energy	Preliminaries	Energy	Movement	Individuals	Governmental	Machinery
Challenged	Regulatory	Assumption	Impact	Environmental	Individuals	Regulatory
Ecoefficiency	Relationship	Success	Government	Energy Intensive	Relationship	Balance
Instrument	Limit	Process	Energy Efficiency	Production	Framework	Process
Institutional	Instrument	Pressure	Discussion	Administration	GDP	Cleaner
Network	Group	Machinery	nonenergy	Ecoefficiency	Interactional	Challenged

Source: Own Authorship

Appendix 2.2: Most cited words in drivers articles

Corporate involvement	Economy	Competences	Strategy	Market	Technology
Industrial	Process	Product	Manufacture	Growth	Amount
Process	Industrial	Government	Process	Financial	Machine
Product	Behavior	Industrial	Decision Maker	Amount	Diffusion
Companies	Criterion	Decision maker	Administration	Ecoefficiency	Agreement
Stimulus	Diffusion	Companies	Technology	Stimulus	Cost effect
policymaker	Identify	Obstacle	Greenhouse	Instrument	Need
Method	Growth	agreement	Preliminary	Program	Answer
Information Relationship	Product	Independence	Financial	Climate	Reflect
Protocolar	Ecoefficiency	Effect	Imperfect	Development	Manufacturing
Government	Cost effect	Manufacture	Obstacle	Benchmark	Energy relation
Focus	Government	Behavior	Machine	Communication	Recommended
Identify	Intervention	Machine	Pollution	Environment	Adopt
Economy	Obstacle	Opportunities	Information Relationship	Recommended	Progress
Diffusion	Greenhouse	Framework	Sector	Opportunities	Argument
Greenhouse	Energy efficiency	Program	Opportunities	Around	Pollution
Climate	Focus	Financial	Behavior	Scenario	Sector
Account	Feedstock	Greenhouse	Instrument	Progress	Greenhouse
Obstacle	Opportunities	Recommended	Climate	Technology	Obstacle
Ecoefficiency	Machine	Multi attribute	Economic	Information Relationship	Behavior
Need	Climate	Growth	Stimulus	Feedstock	Focus

Source: Own Authorship

Appendix 2.3(a): Most cited words in atributtes articles

Payback	Costs	Energy	Environmental	Productivity	Operation	Strategy	Culture
Technology	Efficiency	Industry	Efficiency	Efficiency	Efficiency	Industry	Efficiency
Industry	Industry	Efficiency	Industry	Industry	Industry	Efficiency	Barrier
Energy Efficiency	Product	Sector	Sector	Product	Product	Use	Industry
Use	Emission	Product	Product	Sector	Use	Sector	Use
Cost	Technology	Emission	Technology	Technology	Consumption	Emission	Technology
Product	Measure	Technology	Model	Consumption	Barrier	Consumption	Policy
Model	Policy	Consumption	Improvement	Analysis	Process	Heat	Cost
Process	Scenario	Model	Consumption	Process	Cost	Save	Studies
Audit	Consumption	Region	Emission	Indicator	Technology	Product	Information
Investment	Electricity	Improvement	Development	Cost	Sector	Electricity	Difference
System	Improvement	Potential	Region	Technical	Heat	Scenario	Measure
Policy	Process	Differentiate	Indicator	Chang	Emission	Demand	Consumption
Economy	Include	Manufacturing	Process	Benefit	Measure	System	Product
Improvement	Reduction	Environmental	Electricity	Potential	Improvement	Improvement	Research
Measure	Development	Policy	Chang	Frontier	Manufacturing	Policies	Management
Plant	Economy	Effect	Scenario	Plant	Development	Technology	Process
Analyzing	Intensive	Demand	Manufacturing	Development	Management	Intensively	Companies
Emission	Manufacturing	Development	System	Differentiate	Steel	Increase	Manufacturing
Reduction	System	Process	Economy	Reduction	System	Target	Sector
Project	Investments	Scenario	Analysis	Policy	Model	Economy	Development

Source: Own Authorship

Appendix 2.3(b): Most cited words in atributtes articles

Process	Involvement	Acceptance	Check-up	Effects	Risk	Impact
Industry	Efficiency	Efficiency	Efficiency	Industry	Efficiency	Efficiency
Efficiency	Industry	Use	Companies	Efficiency	Industry	Industry
Use	Investment	Build	Factor	Use	Sector	Technology
Sector	Use	Measure	System	Technology	Barrier	Sector
Technology	Product	Policy	Product	Sector	Use	Product
Product	Effect	Industry	Industry	Product	Policy	Use
Heat	Technology	Technology	Sustainable	Policy	Cost	Model
Emission	Sector	Consumption	Implement	Model	Product	Cost
Consumption	Consumption	System	Cost	Improvement	Investment	Improvement
Measure	Build	Perceive	Operation	Studies	Measure	Measure
Electricity	Model	Companies	Process	Results	Emission	Consumption
Model	Project	Level	Management	Measure	Management	Barrier
Potentially	Development	Saved	Technology	Consumption	Companies	Policy
Improvement	Cost	Heat	Adopt	Development	Information	Studies
Economy	Policy	Management	Difference	Manufacturing	Technology	Economy
Increase	Increase	Studies	Considerer	Economy	Process	Process
Scenario	Result	Implemented	Saved	Estimative	Studies	Difference
Manufacturing	Economy	Result	Reduction	Difference	Saved	Factor
Demand	Cost	Cost	Waste	Saved	Program	Manufacturing
Target	System	Research	Related	Increase	Target	Increase

Source: Own Authorship

Appendix 2.4: Most cited words in cross-cutting articles

Motor	Air compressor	Light	Ventilation	Boiler	Cooling	Condenser	Heating	Air conditioning
System	Use	Led	System	Industry	System	Heat	Industry	Use
Use	Saved	Build	Use	Use	Heat	Water	Process	System
Efficiency	System	Saved	Build	Efficiency	Temperature	System	System	Industry
Industry	Industry	Use	Consumption	Emission	Use	Temperature	Use	Cost
Control	Heat	System	Heat	Heat	Efficiency	Use	Solar	Electricity
Electricity	Efficiency	Electricity	Control	Fuel	Condenser	Cooling	Sector	Cooler
Saved	Pressure	Lamp	Desiccant	Saved	Exergy	Evaporation	Water	Heat
Speed	Consumption	Efficiency	Model	Cost	Performance	Pipe	Product	Efficiency
Operation	Power	Control	Flow	System	Increase	Flow	Temperature	Sector
Development	Electricity	Power	Conditioner	Reduction	Cycle	Solar	Potential	Interrupt
Power	Speed	Cost	Pressure	Technology	Work	Increase	Demand	Demand
Pump	Reduction	Case	Difference	Process	Evaporation	Performance	Thermal	Service
Measure	Operation	Consumption	Operation	Production	Flow	Chiller	Electricity	Power
Model	Cost	Technology	Plant	Gas	Compressor	Load	Fuel	Refrigerator
Maintenance	Temperature	Green	Temperature	Consumption	Conditional	Operation	Cost	Increase
Induction	Period	Management	Process	Electricity	Pressure	Transferring	Consumption	Development
Potential	Cycle	Voltage	Electricity	Exergy	Difference	Efficiency	Collector	Consumption
Technology	Flow	Emission	Efficiency	Economy	Operation	Difference	Difference	Generation
Improvement	Emission	Reduction	Area	Scenario	Transfer	Industry	Emission	Studies
Voltage	Sector	Sector	airflow	Steam	Effect	Pressure	Studies	Technology

Source: Own Authorship

Appendix 3.1: Criticality Index Rules

Environmental Quality	Costs Management	Industrial Management	Criticality Index
Inappropriate	Inappropriate	Inappropriate	Inappropriate
Inappropriate	Inappropriate	Potentially Inappropriate	Inappropriate
Inappropriate	Inappropriate	Acceptable	Inappropriate
Inappropriate	Inappropriate	Potentially Appropriate	Inappropriate
Inappropriate	Inappropriate	Appropriate	Inappropriate
Inappropriate	Potentially Inappropriate	Inappropriate	Inappropriate
Inappropriate	Potentially Inappropriate	Potentially Inappropriate	Inappropriate
Inappropriate	Potentially Inappropriate	Acceptable	Inappropriate
Inappropriate	Potentially Inappropriate	Potentially Appropriate	Inappropriate
Inappropriate	Potentially Inappropriate	Appropriate	Inappropriate
Inappropriate	Acceptable	Inappropriate	Inappropriate
Inappropriate	Acceptable	Potentially Inappropriate	Inappropriate
Inappropriate	Acceptable	Acceptable	Inappropriate
Inappropriate	Acceptable	Potentially Appropriate	Inappropriate
Inappropriate	Acceptable	Appropriate	Inappropriate
Inappropriate	Potentially Appropriate	Inappropriate	Inappropriate
Inappropriate	Potentially Appropriate	Potentially Inappropriate	Inappropriate
Inappropriate	Potentially Appropriate	Acceptable	Inappropriate
Inappropriate	Potentially Appropriate	Potentially Appropriate	Inappropriate
Inappropriate	Potentially Appropriate	Appropriate	Inappropriate
Inappropriate	Appropriate	Inappropriate	Inappropriate
Inappropriate	Appropriate	Potentially Inappropriate	Inappropriate
Inappropriate	Appropriate	Acceptable	Inappropriate
Inappropriate	Appropriate	Potentially Appropriate	Inappropriate
Inappropriate	Appropriate	Appropriate	Inappropriate

continuation

Appendix 3.1: Criticality Index Rules

Environmental Quality	Costs Management	Industrial Management	Criticality Index
Potentially Inappropriate	Inappropriate	Inappropriate	Inappropriate
Potentially Inappropriate	Inappropriate	Potentially Inappropriate	Inappropriate
Potentially Inappropriate	Inappropriate	Acceptable	Inappropriate
Potentially Inappropriate	Inappropriate	Potentially Appropriate	Inappropriate
Potentially Inappropriate	Inappropriate	Appropriate	Inappropriate
Potentially Inappropriate	Potentially Inappropriate	Inappropriate	Inappropriate
Potentially Inappropriate	Potentially Inappropriate	Potentially Inappropriate	Potentially Inappropriate
Potentially Inappropriate	Potentially Inappropriate	Acceptable	Potentially Inappropriate
Potentially Inappropriate	Potentially Inappropriate	Potentially Appropriate	Potentially Inappropriate
Potentially Inappropriate	Potentially Inappropriate	Appropriate	Potentially Inappropriate
Potentially Inappropriate	Acceptable	Inappropriate	Inappropriate
Potentially Inappropriate	Acceptable	Potentially Inappropriate	Potentially Inappropriate
Potentially Inappropriate	Acceptable	Acceptable	Potentially Inappropriate
Potentially Inappropriate	Acceptable	Potentially Appropriate	Potentially Inappropriate
Potentially Inappropriate	Acceptable	Appropriate	Potentially Inappropriate
Potentially Inappropriate	Potentially Appropriate	Inappropriate	Inappropriate
Potentially Inappropriate	Potentially Appropriate	Potentially Inappropriate	Potentially Inappropriate
Potentially Inappropriate	Potentially Appropriate	Acceptable	Potentially Inappropriate
Potentially Inappropriate	Potentially Appropriate	Potentially Appropriate	Potentially Inappropriate
Potentially Inappropriate	Potentially Appropriate	Appropriate	Potentially Inappropriate
Potentially Inappropriate	Appropriate	Inappropriate	Inappropriate
Potentially Inappropriate	Appropriate	Potentially Inappropriate	Potentially Inappropriate

continuation

Appendix 3.1: Criticality Index Rules

Environmental Quality	Costs Management	Industrial Management	Criticality Index
Potentially Inappropriate	Appropriate	Acceptable	Potentially Inappropriate
Potentially Inappropriate	Appropriate	Potentially Appropriate	Potentially Inappropriate
Potentially Inappropriate	Appropriate	Appropriate	Potentially Inappropriate
Acceptable	Inappropriate	Inappropriate	Inappropriate
Acceptable	Inappropriate	Potentially Inappropriate	Inappropriate
Acceptable	Inappropriate	Acceptable	Inappropriate
Acceptable	Inappropriate	Potentially Appropriate	Inappropriate
Acceptable	Inappropriate	Appropriate	Inappropriate
Acceptable	Potentially Inappropriate	Inappropriate	Inappropriate
Acceptable	Potentially Inappropriate	Potentially Inappropriate	Potentially Inappropriate
Acceptable	Potentially Inappropriate	Acceptable	Potentially Inappropriate
Acceptable	Potentially Inappropriate	Potentially Appropriate	Potentially Inappropriate
Acceptable	Potentially Inappropriate	Appropriate	Potentially Inappropriate
Acceptable	Acceptable	Inappropriate	Inappropriate
Acceptable	Acceptable	Potentially Inappropriate	Potentially Inappropriate
Acceptable	Acceptable	Acceptable	Acceptable
Acceptable	Acceptable	Potentially Appropriate	Acceptable
Acceptable	Acceptable	Appropriate	Acceptable
Acceptable	Potentially Appropriate	Inappropriate	Inappropriate
Acceptable	Potentially Appropriate	Potentially Inappropriate	Potentially Inappropriate
Acceptable	Potentially Appropriate	Acceptable	Acceptable
Acceptable	Potentially Appropriate	Potentially Appropriate	Acceptable
Acceptable	Potentially Appropriate	Appropriate	Acceptable

continuation

Appendix 3.1: Criticality Index Rules

Environmental Quality	Costs Management	Industrial Management	Criticality Index
Acceptable	Appropriate	Inappropriate	Inappropriate
Acceptable	Appropriate	Potentially Inappropriate	Potentially Inappropriate
Acceptable	Appropriate	Acceptable	Acceptable
Acceptable	Appropriate	Potentially Appropriate	Acceptable
Acceptable	Appropriate	Appropriate	Acceptable
Potentially Appropriate	Inappropriate	Inappropriate	Inappropriate
Potentially Appropriate	Inappropriate	Potentially Inappropriate	Potentially Inappropriate
Potentially Appropriate	Inappropriate	Acceptable	Inappropriate
Potentially Appropriate	Inappropriate	Potentially Appropriate	Inappropriate
Potentially Appropriate	Inappropriate	Appropriate	Inappropriate
Potentially Appropriate	Potentially Inappropriate	Inappropriate	Inappropriate
Potentially Appropriate	Potentially Inappropriate	Potentially Inappropriate	Potentially Inappropriate
Potentially Appropriate	Potentially Inappropriate	Acceptable	Acceptable
Potentially Appropriate	Potentially Inappropriate	Potentially Appropriate	Potentially Inappropriate
Potentially Appropriate	Potentially Inappropriate	Appropriate	Potentially Inappropriate
Potentially Appropriate	Acceptable	Inappropriate	Inappropriate
Potentially Appropriate	Acceptable	Potentially Inappropriate	Potentially Inappropriate
Potentially Appropriate	Acceptable	Acceptable	Acceptable
Potentially Appropriate	Acceptable	Potentially Appropriate	Acceptable
Potentially Appropriate	Acceptable	Appropriate	Acceptable
Potentially Appropriate	Potentially Appropriate	Inappropriate	Inappropriate
Potentially Appropriate	Potentially Appropriate	Potentially Inappropriate	Potentially Inappropriate
Potentially Appropriate	Potentially Appropriate	Acceptable	Acceptable

continuation

Appendix 3.1: Criticality Index Rules

Environmental Quality	Costs Management	Industrial Management	Criticality Index
Potentially Appropriate	Potentially Appropriate	Potentially Appropriate	Potentially Appropriate
Potentially Appropriate	Potentially Appropriate	Appropriate	Potentially Appropriate
Potentially Appropriate	Appropriate	Inappropriate	Inappropriate
Potentially Appropriate	Appropriate	Potentially Inappropriate	Potentially Inappropriate
Potentially Appropriate	Appropriate	Acceptable	Acceptable
Potentially Appropriate	Appropriate	Potentially Appropriate	Potentially Appropriate
Potentially Appropriate	Appropriate	Appropriate	Potentially Appropriate
Appropriate	Inappropriate	Inappropriate	Inappropriate
Appropriate	Inappropriate	Potentially Inappropriate	Inappropriate
Appropriate	Inappropriate	Acceptable	Inappropriate
Appropriate	Inappropriate	Potentially Appropriate	Inappropriate
Appropriate	Inappropriate	Appropriate	Inappropriate
Appropriate	Potentially Inappropriate	Inappropriate	Inappropriate
Appropriate	Potentially Inappropriate	Potentially Inappropriate	Potentially Inappropriate
Appropriate	Potentially Inappropriate	Acceptable	Potentially Inappropriate
Appropriate	Potentially Inappropriate	Potentially Appropriate	Potentially Inappropriate
Appropriate	Potentially Inappropriate	Appropriate	Potentially Inappropriate
Appropriate	Acceptable	Inappropriate	Inappropriate
Appropriate	Acceptable	Potentially Inappropriate	Potentially Inappropriate
Appropriate	Acceptable	Acceptable	Acceptable
Appropriate	Acceptable	Potentially Appropriate	Acceptable
Appropriate	Acceptable	Appropriate	Acceptable
Appropriate	Potentially Appropriate	Inappropriate	Inappropriate
Appropriate	Potentially Appropriate	Potentially Inappropriate	Potentially Inappropriate
Appropriate	Potentially Appropriate	Acceptable	Acceptable
Appropriate	Potentially Appropriate	Potentially Appropriate	Potentially Appropriate

continuation

Appendix 3.1: Criticality Index Rules

concluded

Environmental Quality	Costs Management	Industrial Management	Criticality Index
Appropriate	Potentially Appropriate	Appropriate	Potentially Appropriate
Appropriate	Appropriate	Inappropriate	Inappropriate
Appropriate	Appropriate	Potentially Inappropriate	Potentially Inappropriate
Appropriate	Appropriate	Acceptable	Acceptable
Appropriate	Appropriate	Potentially Appropriate	Potentially Appropriate
Appropriate	Appropriate	Appropriate	Appropriate

Source: Own Authorship