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PERSEU PADRE DE MACEDO

SUPPORTING GOVERNMENT'S ACTIONS TO REACH ENERGY EFFICIENCY: the motor replacement problem

Recife
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SUPPORTING GOVERNMENT'S ACTIONS TO REACH ENERGY EFFICIENCY: the motor replacement problem

A thesis presented to the Federal University of Pernambuco to the achievement of PhD degree as part of the requirements from Postgraduate Program in Production Engineering.

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ABSTRACT

Considering current policies and trends, world energy consumption will increase by 28% by 2040. In Brazil, the industrial sector consumes approximately 40% of all national electrical power, and the complexity of energy industrial system demands appropriate energy management. To address this problem, the government with its energy efficiency law, established minimum energy performance standard for motors manufactured since December 2009 to ensure adequate energy consumption. However, with current mechanisms, companies continue to practice motor rewinding, increasing their lifespan and reducing the efficiency, consequently increasing the energy costs and emission of polluting gases into the atmosphere. The public policies to encourage the motors replacement are unattractive and there is low participation of companies, making it difficult for the government to achieve its energy efficiency goals. Moreover, companies need suitable tools to support their strategies to meet energy efficiency regulations and promote energy gains. In this way, this thesis proposes to build models to support energy efficiency decisions with regard to motor replacement projects. Two models were developed, the first, based on the FITradeoff method, seeks to support the companies to prioritize their non-efficient motors and build a replacement plan in the face of conflicting criteria, budget constraints and limited available data. The second one is based on ACUTA method, an holistic approach, different from classic negotiation direct rating models, used to support a negotiation process between the power utilities and companies, in order to align current incentive options of the Public Calls for motor replacement with their preferences, making the options more attractive to increase companies participation on energy efficiency projects. As for the applicability of the models, both were applied in real-life situations through two different case studies and were able to deal with conflicting criteria against a range of options. They deal with the data inaccuracy, are agile, interactive and flexible; also, they reduced the cognitive effort of the decision-maker/negotiator while conducting the analytical process by achieving robust results with scarce data. The results were satisfactory and showed an adequate direction to promote energy efficiency in organizations.

Keywords: Energy efficiency. Multicriteria decision analysis. Negotiation. Scoring system. Holistic approach.

RESUMO

Considerando as políticas e tendências atuais, o consumo mundial de energia aumentará em 28% até 2040. No Brasil, o setor industrial consome aproximadamente 40% de toda a energia elétrica nacional e a complexidade do sistema industrial de energia exige um gerenciamento adequado de energia. Para resolver esse problema e garantir o consumo adequado de energia, o governo, com sua lei de eficiência energética, estabeleceu um padrão mínimo de desempenho energético para motores fabricados desde dezembro de 2009. No entanto, com os mecanismos atuais, as indústrias continuam praticando o rebobinamento de motores, aumentando sua vida útil e reduzindo a eficiência, consequentemente aumentando os custos de energia e a emissão de gases poluentes na atmosfera. As políticas públicas para incentivar a substituição de motores são pouco atraentes e há baixa adesão das indústrias, dificultando ao governo atingir suas metas de eficiência energética. Além disso, as indústrias precisam de ferramentas adequadas para apoiar suas estratégias para atender às regulamentações de eficiência energética e promover ganhos de energia. Dessa forma, esta pesquisa propõe a construção de modelos de decisão para apoiar as decisões de eficiência energética quanto aos projetos de substituição de motores. Dois modelos foram desenvolvidos, o primeiro, baseado no método FITradeoff, visa apoiar as indústrias a priorizarem seus motores não eficientes e construir um plano de substituição diante de critérios conflitantes, restrições orçamentárias e dados disponíveis limitados. O segundo é baseado no método ACUTA, uma abordagem holística, diferente dos modelos de classificação direta de negociação, usada para apoiar um processo de negociação entre concessionárias e indústrias, a fim de alinhar, com suas preferências, as atuais opções de incentivo das Chamadas Públicas para substituição de motores, tornando as opções mais atrativas para aumentar a adesão das indústrias aos projetos de eficiência energética. Quanto à aplicabilidade dos modelos, ambos foram aplicados em situações reais por meio de dois estudos de caso diferentes e foram capazes de lidar com critérios conflitantes contra uma gama de opções. Eles lidam com a imprecisão dos dados, são ágeis, interativos e flexíveis; além disso, eles reduziram o esforço cognitivo do decisor/negociador enquanto conduziam o processo, obtendo resultados robustos com dados escassos. Os resultados foram satisfatórios e mostraram uma direção adequada para promover a eficiência energética nas organizações

Palavras-chave: Política de eficiência energética. Análise de decisão multicritério. Negociação. Sistema de pontuação. Aproximação holística.

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1 INTRODUCTION

Considering current policies and trends, world energy consumption will increase by 28% by 2040, with more than half attributed to non-member countries of the Organization for Economic Cooperation and Development, primarily China and India (EIA, 2016). In order to promote efficient energy use and economic growth, governments must adopt energy efficiency politics as one of their main strategies. This invisible and underappreciated factor has the potential to improve social development, promote environmental sustainability and ensure energy security in the legal framework (IEA, 2013).

There are several ways to improve energy efficiency. This can be done through readjustment of the end-use power system, insertion of automation and control devices, awareness programs, training for energy conserving actions, among others (SOLA; MOTA; KOVALESKI, 2011).

In Brazil, the government's National Energy Plan 2030 proposed a strategy for expansion of the energy supply, however, current Brazilian market mechanisms are not sufficient to promote desirable efficiency improvements in the end-use of energy. Brazilian industrial sector consume approximately 40% of all national electrical power, with most of this electricity being demanded by motor systems, represented by the collective use of electric motors in production processes (EPE, 2016).

To support this strategy, in 2009, the Brazilian government amended the Law nº 10.295 of 2001, known as the Energy Efficiency Law, which established the minimum energy performance standards for energy-using technologies. However, considering that motors have a lifespan of more than 15 years and the practice of motor rewinding and reuse, companies will continue using non-efficient motors given the lack of awareness about energy efficiency and its benefits. Therefore, companies need to assess financial implications, technical aspects and environmental impacts, encouraging the replacement of non-efficient motors by those that meet the minimum efficiency levels defined by the Law.

To support the adoption of high efficiency motors, the government proposed some energy efficiency programs to promote motor replacement. Through Public Calls, energy power utilities select companies to receive bonuses by fulfilling a replacement project. However, with current incentive options, low adherence to replacement projects has been observed. Thus, power utilities should look for ways to understand the company's preferences to increase their participation in the energy efficiency programs, assisting the government with its energy policies.

In this context, the diversity of analytical approaches, methods and techniques of the decision theory supports the decision-makers in analyzing multicriteria ranking, selection and sorting problems (FIGUEIRA; GRECO; EHRGOTT, 2005). Multicriteria evaluation is useful to analyze the complex problem of replacing motors, enabling an integrated assessment of the problem (DE ALMEIDA et al., 2015). This will allow companies to explore their different criteria and alternatives to increase their productivity, consume less electricity and minimize the practice of motor reconditioning, reduce greenhouse gas (GHG) emissions and increase the State economy, promoting sustainable development (MUNDA, 2008).

Also, negotiation is another useful tool to reach an agreement through complex issues and different intervals of resolution options. The negotiation process allows power utilities to understand the company’s preferences and align the incentive options to reach the Government’s energy efficiency goals and allow companies to minimize the practice of motor rewinding. Therefore, the negotiations are often supported by multicriteria decision-making (MCDM) techniques to facilitate the parties in finding mutually satisfying, fair and efficient compromises (RAIFFA; RICHARDSON; METCALFE, 2002). In addition, multicriteria analysis can support the negotiation procedure during the pre-negotiation phase, eliciting negotiators' preferences and constructing scoring systems (GORECKA et al., 2016).

In this context, this study aims to build models to support the decision making of companies and power utilities, given the complexity of the energy efficiency problem faced by the country, especially the problems related with the motor replacement. The use of interactive, flexible, agile, easy-to-understand models capable of dealing with complex problems, involving multiple criteria and issues, numerous alternatives and resolution options, contribute to the dissemination of tools that promote energy efficiency in business; spread energy awareness; and align incentive options. In addition, these models can promote increased adherence of consumer units to public energy efficiency policies, meeting the minimum standards set by the Energy Efficiency Law and contributing to the government's 2030 strategy with its National Energy Plan.

1.1 STUDY RELEVANCE

Electricity consumption in industries is expected to grow to more than one-third of all energy produced on the planet, and are opportune targets for achieving energy efficiency. This will require technologies that reduce energy consumption and emission of polluting gases (SOLA; MOTA, 2012).

Thus, to promote energy efficiency, several energy policies are being adopted in the world. In Brazil, for example, one of the policies adopted voluntarily set minimum efficiency standards for electric motors. However, after estimation, it was observed that only 10% of all motors in the industrial park met this standard, even with incentives in favor of its replacement, making the voluntary standard mandatory. Since then, Brazilian manufacturers have offered motors that comply with the law (GARCIA et al., 2007).

However, it is worth noting that: the current Brazilian energy efficiency law does not imply on the other side of the supply chain and new actions are needed for customers, especially the industries and decision-makers therein. Also, old motors can still be used for a long time, considering their useful life and the rewinding process. At last, since the offerings of the Brazilian high-efficiency motor market are more expensive than the standard model, the motor replacement may be neglected if decision-makers do not have sufficient information about the feasibility of replacing their technologies (SOLA; MOTA, 2012).

In this context, decision-making is often unviable due to lack of understanding of the problem faced. To support government actions, industries and power utilities should align their efforts and increase their contribution to solving energy efficiency problems. However, facing market changes and their complexity, the decisions to be made are complex due to the need to consider conflicting criteria and a considerable range of alternatives to prioritize, in addition to the changing marketplace. Mostly, these decisions are made subjectively, based on common sense, which can result in improper choices that negatively impact government strategic objectives.

Therefore, to minimize the subjectivity of current practices, there is a need to use structured tools for problem solving, especially those for the motor replacement to comply with the Brazilian energy efficiency law. It is important to develop structured and realistic models that can handle complex situations and help industries, power utilities and the government to make appropriate decisions. To support the development and achieve robust results, it is important to identify the methods that will be used; understand the criteria (or issues) and alternatives (or options) involved in the problem; and represent the preferences of the decision maker (or negotiator).

Thus, this thesis stands out in exploring the relationship between energy efficiency, the industrial motor system and the energy policies adopted by the Brazilian government to replace non-efficient motors, and address the barriers faced by companies and power utilities to meet the government's energy efficiency actions.

For this, this study explores the usability and efficiency of the multicriteria decision aiding and the negotiation analysis in supporting the aforementioned decisions. The proposed models are distinguished from the others by reducing the cognitive effort of the decision-maker/negotiator and supporting the decision-making/negotiation process comprehensively.

The first model, the multicriteria-based one, seeks to support industries in making an internal selection of motors to prioritize their replacement. The goal is to meet the minimum energy efficiency standards set by law. This model is important because it considers conflicting criteria when replacing motors located at strategic areas in production, overcoming organizational barriers and promoting an alternative to motor rewinding processes, promoting gains in energy efficiency, productivity, cost reduction and the emission of polluting gases. The model stands out for reducing the cognitive effort of the decision-maker in conducting the decision process, besides being interactive, flexible and agile.

The second one, the holistic-based negotiation model, seeks to support power utilities in aligning Public Call’s incentive options and making them more attractive to industries in order to increase their adherence to motor replacement programs and promote energy efficiency in the country, according to national energy efficiency plan. This model emerges as an alternative to the current government procedure. It elicits negotiators’ preferences with a holistic method (oppositely to conventional models that use direct rating). It also proposes the assessment of conflicting issues given different resolution options ranges, as well as the exploration of a considerable amount of negotiation packages that will assist the parties during the negotiation process. In addition to being interactive, flexible and agile, the model stands out for proposing the use of a holistic method to support negotiation and reduce negotiators' cognitive effort to understand the problem.

Furthermore, this thesis provides a systematic review of existing holistic approaches to support the construction of negotiation models, supporting researchers to find a more compelling and reliable compilation of alternatives present in relevant databases. This systematic review does not recommend the best holistic method to support negotiation, as each has different characteristics and objectives; however, it provides a reference basis for the usefulness and application of the methods in various scenarios over time.

Thus, given the lack of efficiency of current government mechanisms, it is important to propose models that support the government in achieving its energy policies more appropriately, particularly those of involving motor replacement to promote energy efficiency.

1.2 OBJECTIVES

The main objective of this thesis is to support energy efficiency decisions concerning motor replacement projects by providing decision models for companies and power utilities. The first model consists of a multicriteria decision model and the second one consists of a negotiation model.

The specific objectives are:

- Identify the relationship between energy efficiency and industrial motors.
- Identify policies that the country adopts to promote energy efficiency by replacing motors.
- Conduct a research on multicriteria methods and how they can support the negotiation process.
- Identify the applicability of the holistic approaches in negotiation

1.3 MATERIALS AND METHODS

This section presents the methodological aspects of the research.

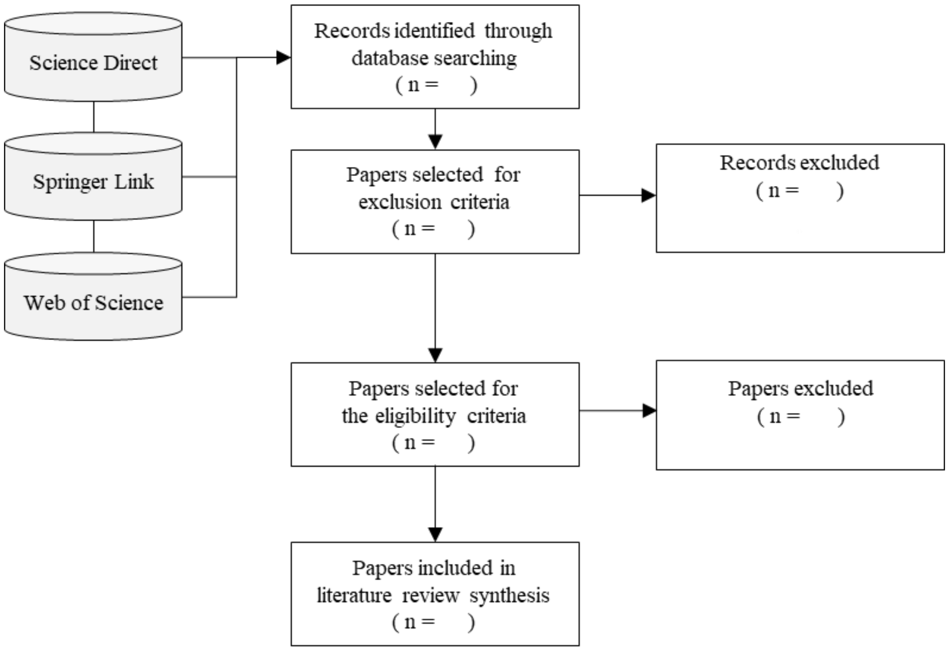
1.3.1 Systematic review

Systematic reviews are useful tools to synthesize published research findings and provide a critical overview of the topic under study (DE ALMEIDA et al., 2016; LEE et al., 2017). The review was conducted in a replicable way, improving the clarity and transparency of this research. This research follows the five-stage procedure proposed by (DENYER; TRANFIELD, 2009).

a) Stage 1: Formulation of the question. Questions should be built clearly, in order to direct the focus of the study. For this, the CIMO-Logic (DENYER; TRANFIELD; VAN AKEN, 2008) is used, which combines the problem in a context (C) of a specified intervention (I), with identified mechanisms (M) that were observed to produce results (O).
b) Stage 2: Locating studies. This stage must be conducted in a structured way. To locate, select and evaluate relevant records, it is important to define a recognized scientific database. It is worth noting that the screening time and the keywords to be used should be defined, as well as the use of Boolean logic to combine them. Keywords should guide research to answer the previously asked question.

c) Stage 3: Study selection and evaluation. To select and evaluate the relevant records, a filtering process with inclusion/exclusion criteria must be defined. In order to ensure the research quality, the following filtering process was conducted (Figure 1):

Figure 1 – Filtering process



Source: The author (2020).

d) Stage 4: Analysis and synthesis. To extract unified information, it is recommended to use the designed question from Stage 1, which allows to describe the records and classifying them better.

e) Stage 5: Results report. The result of the literature review must be reported. This stage specifies what is known and unknown regarding the questions studied in the review. At last, it should provide a brief summary of the review, present the limitations encountered and suggest directions for future works.

1.3.2 Building MCDM models

The modeling of a decision problem consists of several steps which includes assumptions, choices regarding the approach and simplifications. This will allow the transformation of inaccurate and disorganized information into a structured problem (BELTON; STEWART, 2002; DE ALMEIDA et al., 2015).

To support the construction of the models proposed in this thesis, the 12-step procedure proposed by DE ALMEIDA et al. (2015) was used. It is divided in 3 phases: Preliminary, Preference modeling and method selection, and Conclusion.

Initially, in the Preliminary Phase, decision-makers must be identified, as well as their involvement in the decision-making process must be clearly characterized. Then the objectives must be identified, as they will have a big influence on the final model. For each set of objectives, criteria should be constructed to represent them in the quantitative modeling process. They should be constructed in such a way that help the decision maker to establish the structure of the action space and generate the alternatives that will be evaluated. In the fifth step, the uncontrolled factors must be identified that the variables outside of the decision-maker control.

To begin the Preference Modeling and Method Choice Phase, it is important to find the most appropriate preference structure to represent the decision maker's preferences. Next, the intra-criterion evaluation needs to be performed, which will depend on the type of method used. It consists of evaluating each alternative according to each criterion, leading to a value function. In the eighth step, based on the multicriteria method already established, the method is parameterized.

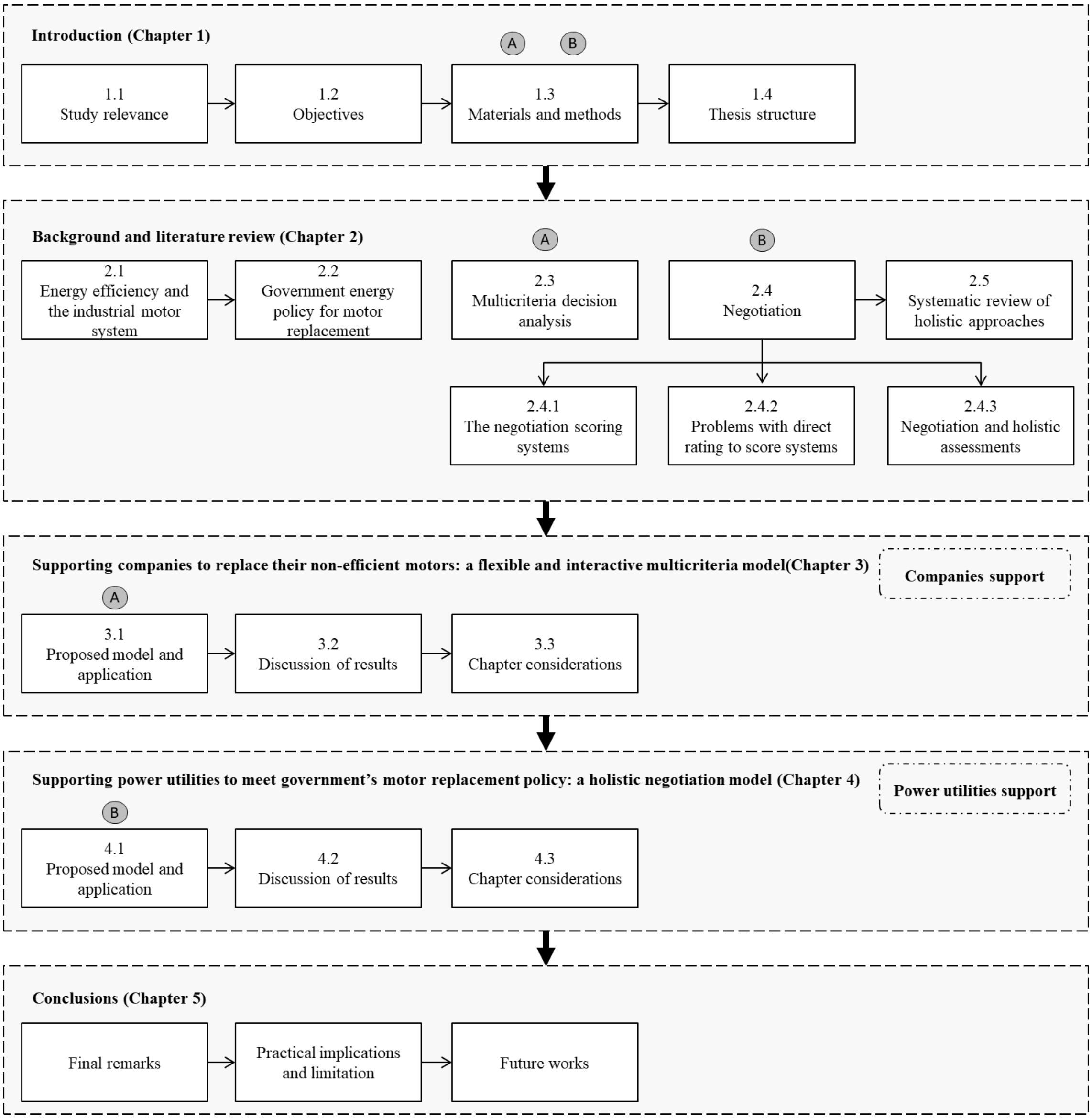
Finally, during the Conclusion Phase, to confront the robustness of the consolidated decision model with respect to the input data and the parameters employed in the decision model, a sensitivity analysis should be conducted. Then, when there is no need to return to the previous steps, the final analysis of the results and the recommendation to the decision maker are made. Finally, the twelfth stage of the model consists of the implementation of the action itself or the adoption of procedures on the set of indicated actions, according to the problem addressed.

During the construction of decision models, the present research used the FITradeoff and ACUTA methods, which will be described in the next chapter and implemented in chapters 3 and 4, respectively.

1.4 THESIS STRUCTURE

The thesis is structured in five chapters. The chapters, as well as the relationship between them, are set out in Figure 2.

Figure 2 – Thesis structure



Source: The author (2020).

Chapter 1: Introduction. It presents the introduction of the thesis. First, it is presented the contextualization of the scenario faced by the country to achieve its strategic goal of energy efficiency regarding the motor replacement problem, as well as the definition of the main and specific objectives of the research. Then, the materials and methods used are presented, with the exposure of the procedure to build MCDM models and the systematic review method. Finally, the thesis structure is presented.

Chapter 2: Background and literature review. It presents the importance of the industrial motor systems and the energy efficiency problem, the Government energy efficiency policy and its effectiveness. Next, the FITradeoff and ACUTA methods that were used in the construction of the models of this thesis were presented. Also, this chapter shows a theoretical foundation of multicriteria decision analysis, negotiation process, the importance of negotiation scoring systems and the problems related to the use of direct rating techniques. At last, presents a systematic review of the applicability of various holistic approaches in the pre-negotiation phase and a descriptive analysis of the identified approaches.

Chapter 3: Supporting companies to replace their non-efficient motors: a flexible and interactive multicriteria model. It describes the proposed FITradeoff-based model to support industries to solve the problem of motor replacement and presents an application of the proposed model followed by a sensitivity analysis and discussion of results.

Chapter 4: Supporting power utilities to meet the government's motor replacement policy: a holistic negotiation model. It describes the proposed negotiation model based on the holistic method ACUTA, to support concessionaries to align governmental actions by adjusting incentive options and making them more attractive. Its goal is to increase the company's adherence to energy efficiency programs, in particular the project of replacing non-efficient motors. Also, it presents an application of the proposed model and discussion of results.

Chapter 5: Conclusions. It presents the final remarks and indicates future directions of the study.

2 BACKGROUND AND LITERATURE REVIEW

This chapter aims to present the theoretical foundations used by this thesis, as well as the results of the systematic literature review on the holistic approach in decision models.

2.1 ENERGY EFFICIENCY AND THE INDUSTRIAL MOTOR SYSTEM

The concept of energy efficiency is quite general, with no explicit quantitative measure. Typically, it refers to using less energy to produce the same amount of services or output (PATTERSON, 1996). Compared to final use of energy, energy efficiency can be defined as the ratio of the amount of energy consumed to the amount of energy required (SOLA; MOTA, 2012; WANG et al, 2009).

The importance of energy efficiency as a policy objective is linked to energy security and industrial competitiveness, as well as economic, environmental, social and cultural benefits (EPE, 2015; SAIDUR et al., 2010; STEFANO, 2000). In addition, energy efficiency has been promoted as a risk management tool (RUSSELL, 2004). The industrial energy system plays a key role in the energy efficiency process owing to its complexity in terms of economics, organizational structure and technologies. It is divided into motor systems, steam generation, fired heaters, refrigeration and cooling systems, power generation and cogeneration (ENERGETICS, 2004).

Motor systems are represented by the collective use of electric motors in production processes. They play a critical role in the industry because they are responsible for most of the electricity consumed, thereby present a great opportunity for energy saving (KAYA; CINAR, 2008; SAIDUR et al., 2010). In order to maintain industrial competitiveness, projects designed for energy efficiency helps industries to reduce their costs, raise their productivity and ensure other operational benefits.

There are several mechanisms to improve energy efficiency in motor systems including replacement of current technology, motor loading to adapt to the energy efficiency norms, speed control of induction motors, the use of capacitor banks, energy optimization devices, maintenance management, adequate information management as well as training programs and education (SOLA; MOTA, 2012). However, some organizational barriers have prevented the development of these projects due to inefficient decision-making processes, uncertainties in the information, lack of time and resources to collect and process information, failures in management tools, budget restrictions, outdated technologies, unqualified professionals, costs and risks of stopping production, as well as financial and economic responsibilities (WORRELL et al., 2001).

Although the practice of reconditioning old motors is common in industries, exceeding the useful lifetime of 15 years makes the motors lose their quality and effectiveness over time. Industries continue to recondition their non-efficient motors with experts as well as acquiring used motors at affordable prices. Thus, there is a large number of active motors with a compromised efficiency that do not meet the minimum efficiency levels defined by regulations (BORTONI, 2009). Consequently, in order to meet the minimum efficiency levels defined by regulations and to promote sustainable development, the industry needs to be encouraged by the State to replace non-efficient motors through more effective actions and raising awareness about energy efficiency.

2.2 ALIGNING THE MOTOR REPLACEMENT PROBLEM WITH GOVERNMENT ACTIONS

In Brazil, the industrial sector consumes 43.7% of all national electrical power and the motor system in operation uses 68% of this electricity (EPE, 2016). Hence, approximately 30% of all electricity in the country is consumed by electric motors. Therefore, Brazil amended the Law 10,295 of 2001, known as the Energy Efficiency Law, establishing the obligation of minimum efficiency levels for three-phase induction motors manufactured from December 2009, as well as those traded from June 2010, ensuring adequate energy expenditure.

However, with the advanced age of the motors and a natural loss of efficiency over time, industries acquire refurbished motors at an attractively lower price or they also request the rewinding of their old motors by specialized companies. Even at a lower price, motors undergoing this process have their efficiency compromised, their lifespan significantly shortened, and their energy consumption is excessively higher than currently allowed by regulation (MACEDO et al., 2018).

In the Brazilian industrial sector, the practice of rewinding old motors, manufactured before December 2009, has become increasingly significant. These motors, still in operation, do not meet the minimum efficiency levels defined by the aforementioned regulations, lead to an efficiency loss of approximately 7TWh for the country and have an average yield loss of 8.7% (SOUZA, 2013). Therefore, more incisive government action is required to encourage the replacement of old and inefficient engines, with engines that meet the current regulation of minimum energy efficiency standards and update the motor system.

Thus, in compliance with the clause of the Electricity Distribution Concession Agreement, Law No. 9,991 / 2000, Law No. 11,465 / 2007, Law No. 12,212 / 2010 and Law 13,280/2016, the power utilities and licensees of public services of electricity distribution should annually apply an amount equivalent of 0.50% of their annual net operating revenue in the development of programs to increase energy efficiency in the final use of electricity.

In addition, according to the Energy Efficiency Program Procedures – ProPEE (Procedimentos do Programa de Eficiência Energética), which establishes the guidelines for the selection and implementation of Energy Efficiency Program – PEE (Programa de Eficiência Energética) projects for all electricity distributors, according to their market profile, the distributor must invest at least 50% of the mandatory investment in consumer units of the two classes of consumption with the largest participation in its electricity market. However, if after the Public Call there is no proposal for qualified projects that include all available resources, the distributor may, on its own initiative and directly with the consumer, elaborate other projects in any sector (ELÉTRICA, 2018).

In compliance to their concession agreements and under regulation with Agência Nacional de Energia Elétrica – ANEEL, the electricity distribution companies promote the participation of society in their energy efficiency programs through Public Hearings, in which they present and discuss their results and projects in the area, and in Public Calls, in which they seek partners to carry out new actions.

Among the Public Calls made, highlighting those linked to Priority Project 002/2015 "Incentive for Electric Motor Replacement: Promoting Energy Efficiency in the Motor System" (SPDE, 2015), which promotes the modernization of the Brazilian motor park, by granting subsidies for the replacement of old and inefficient motors, whether or not they have been rewinded, with more modern, more efficient motors that meet the current regulation of minimum efficiency standards.

By replacing non-efficient motors, it is possible to reduce power consumption and peak demand; reduce electricity bill costs for targeted consumers; spread the culture of energy efficiency; and bring the power utility closer to society. In addition, it reduces costs with the maintenance of obsolete equipment, combats energy waste and promotes the preservation of the environment.

According to the established technical rules, the Public Call promotes the replacement of three-phase motors, the power of which varies from 1 HP (horse-power) to 250 HP, manufactured by 2009 (SPDE, 2015). All old motors to be replaced must be in operation and have a minimum regime of 3,000 hours/year. New motors shall be in performance class IR2 (high performance) or IR3 (premium). Participation is restricted to captive consumers and free consumers (except those directly connected to the basic network), belonging to the Industrial, Public Power, Residential Condominiums, Public Services and Commerce/Services that are up to date with their business obligations to the power utility.

Thus, once the motors are changed and the supporting documents are presented to the distributor, the consumer will receive the pre-established bonus, according to the motor's power and performance class. In order to prevent old motors from being incorrectly discarded or reused, replaced equipment should be disposed of by specialized companies defined by the power utility or the new motor manufacturer.

For example, analyzing the administrative reports of the State of Pernambuco, based on the latest Public Calls aligned with the Priority Energy Efficiency Project, the region's electricity power utility, in partnership with the distributors of the states of Bahia and Rio Grande do Norte, made available in 2016 around $1.500.000 (assuming the quotation of 1 BRL to USD = 0.246569) bonus for replacing inefficient motors. With the result published in December of the same year, only 40.6% of the earmarked resources were used. During its application throughout 2017, 161 electric motors from 14 selected consumer units were replaced and subsidized in December 2016, generating energy savings of 438.33 MWh /year and a reduction in peak demand of 62.38 kW. The remaining resources were used in the 2017 public call, but no records of the results of the completed project were found.

The low adherence may have been a reflection of the economic crisis faced by the country in recent years, creating a barrier to the presentation of projects, but with the improvement of the economic moment, this scenario may change; and the incentive options present in Public Calls, which could be reviewed and aligned to the needs of companies, especially in the industrial sector, promoting greater gain in benefit-cost ratio.

It is also worth highlighting the low percentage of project investments for the Brazilian industrial sector, approximately 4%, reflecting a restriction imposed in the ProPEE Energy Performance Contract (ELÉTRICA, 2018), which prevents the transfer of public resources to consumer units, private ventures and without assistance purposes. However, this policy should be reviewed, given that when analyzing the consumption of electricity by end use, the Brazilian industrial sector is responsible for the highest consumption of electricity and motor system in operation (EPE, 2018).

2.3 MULTICRITERIA DECISION MANAGEMENT

A multicriteria decision problem consists of a situation where there are at least two alternatives to choose from, the choice must be driven by the desire to meet multiple objectives, often conflicting with each other (ALMEIDA, 2013). These objectives are associated with the consequences of the choice of alternatives; besides, they are associated with variables (criteria or attributes) that allow the evaluation of the alternatives. Thus, the multicriteria approach stands out in the field of decision support tools for its robustness and ability to analyze complex models.

The main goal of MCDM is to help decision-makers feel comfortable and confident through their preferences and decisions. These criteria can be understood as a means of judgment that hints at a standard by which a particular choice can be judged more desirable than others (BELTON; STEWART, 2002). These methods differ depending on the type of problem considered, available data and implement various approaches to elicit preferences.

In this context, the methods can be classified into four clusters of decision problematics (ROY, 1996). The choice problem involves choosing a subset of the action space. That is, it makes a choice from a set of alternatives. The classification problem aims to allocate each action to a certain class, defined a priori from rules applied to the set of actions. The ranking problem involves establishing a rank order of actions according to the decision-maker's preferences. At last, the description problem seeks to support the decision through a description of the actions and their consequences, in a structured and systematic way, facilitating the understanding of the decision maker.

As for the classification of multicriteria methods, they can be grouped as (ROY, 1974; VINCKE, 1992):

a) Single synthesis criterion method: consists of aggregating different points of view within a single synthesis function, which can be further optimized. In this case, the conditions of function aggregation and model construction should be analyzed. The examples of such methods are, the Multiatribute Utility Theory (KEENEY; RAIFFA, 1976) and the FITradeoff (DE ALMEIDA-FILHO et al., 2017)
b) Outranking Method: inspired by the French School, this family supports the construction of an outranking relationship, which represents the preferences established by the decision-maker. The second step is to explore the outranking relationship in such a way as to help the decision maker solve his problem. The best

known methods are those of the ELECTRE AND PROMETHEE family (BELTON; STEWART, 2002; ROY, 1974).

c) Interactive judgment approach: these are methods that use the trial and error approach and multi-objective mathematical programming structures.

2.3.1 FITradeoff

This section presents a review of the Flexible and Interactive Tradeoff Elicitation (FITradeoff) procedure (choice version) using the usual notations adopted in the elicitation of weights process (KEENEY; RAIFFA, 1976):

a) $X = \{x_1, x_2, \ldots, x_n\}$ represents the vector of consequences of an alternative, considering all *i* (*i =1,2,…,n*) criteria
b) k_i represents the weight (scale constant) for the criterion *i*
c) $v_i(x_i)$ represents the value function of the consequences x_i for the i-th criterion

One of the most relevant issues in a multicriteria decision problem is the elicitation of the scale constants for the aggregation process, such as the traditional tradeoff (KEENEY; RAIFFA, 1976) and SWING (Mustajoki, 2005).

The traditional tradeoff procedure has a more robust axiomatic structure, but has been shown to have certain inconsistencies. It requires a high cognitive effort from the DM to compare consequences when establishing an exact value for the criterion that promotes indifference between two consequences. Furthermore, especially in additive models, there is a problem in defining the weight of criteria because the DM does not understand the meaning of weight and does not have sufficient knowledge or information to define it (de Almeida, Almeida, Paula, Seixas, & Almeida-filho, 2016; Weber & Borcherding, 1993). Consequently, a new procedure was proposed to reduce the information required by the DM and make the cognitive process easier.

The FITradeoff procedure works with partial information from the DM, searching for potentially optimal alternatives inside a weight space φ, by solving linear programming problems (LPP) (DE ALMEIDA et al., 2016). It was developed for eliciting scale constants k_i, used to score alternatives according to the value function as in (1), assuming (2).

$$v(x) = \sum_{i=1}^{n} k_i . v_i(x_i) \quad (1)$$

$$\sum_{i=1}^{n} k_i = 1, k_i \geq 0 \quad (2)$$

Like the traditional tradeoff procedure, FITradeoff application is divided into two parts: (i) to obtain the order of the scale constants k_i using strict preference and (ii) to obtain values of k_i. The first part (i) allows the construction of a weigh space φ by (3) to rank the criteria from the most important to the least important (4).

$$\varphi = \{(k_1, k_2, \dots, k_n) | \sum_{i=1}^{n} k_i = 1; k_i \geq 0\} \tag{3}$$

$$k_1 > k_2 > \cdots > k_n \tag{4}$$

For the second part (ii), unlike traditional procedures, in FITradeoff, it is not necessary to find an indifference value between adjacent criteria and the DM does not need to provide imprecise or incomplete information *a priori*. The DM does not need to define an exact indifference value x_i^I (KEENEY; RAIFFA, 1976), which would denote the outcome of criterion *i* for which the indifference value is obtained between consequences. The FITradeoff requires the DM to specify a range from x_i' to x_i'' that represents the upper and lower limit that x_i^I can assume, respectively. In this way, given any criterion *i*, new relations can be established to x_i' (5) and x_i'' (6). As result, a new weight space φ^S (7) is obtained, which is a subspace of (3) (DE ALMEIDA et al., 2016; COSTA et al., 2016).

$$v_i(x_i') > \frac{k_{i+1}}{k_i} \tag{5}$$

$$v_i(x_i'') > \frac{k_{i+1}}{k_i} \tag{6}$$

$$\varphi^S = \left\{ \begin{array}{l} (k_1, k_2, \dots, k_n) | \sum_{i=1}^{n} k_i = 1; k_i \geq 0 \\ k_i v_1(x_1'') < k_2 < k_i v_1(x_1'); \dots; \\ k_i v_1(x_i'') < k_{i+1} < k_i v_1(x_i'); \dots; \\ k_{n-1} v_1(x_{n-1}'') < k_n < k_{n-1} v_1(x_{n-1}') \end{array} \right\} \tag{7}$$

With this, there is an attempt to minimize the DM's effort, finding an interval in which the indifference value is bounded by the interval $[v_i(x_i');v_i(x_i'')]$, which when reduced by changing one or both limits of the relationship between two adjacent criteria, restricts the number of potentially optimal alternatives, so that eventually, one alternative can be considered the best.

The FITradeoff is supported by a Decision Support System (DSS), which includes the following stages: intra-criteria evaluation; scale constant ranking; attempting to solve the problem using the available set of weights; and DM's preferences evaluation. If it is not possible to solve the problem using the available set of weights, FITradeoff evaluates the DM's preferences through these steps:

a) Setting values, with the analyst, for testing the distribution of scale constants
b) Asking the DM to state his preferences
c) Computing the LPP
d) Solving the problem

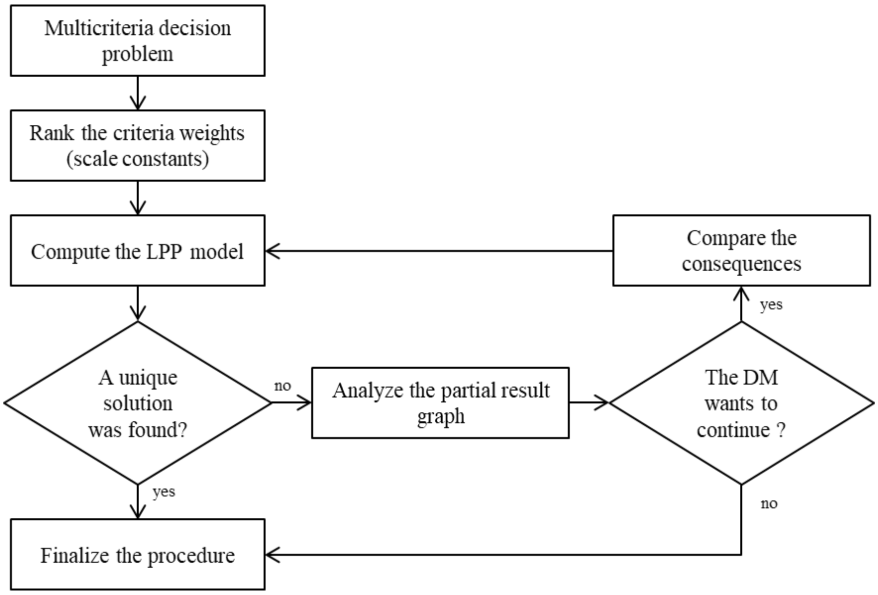
In (a), the aim of the FITradeoff heuristic is to compute the value of x_i, thereby minimizing the number of questions to the DM. The output of this step, and the input for the step (b) is a new set of values for x_i' and x_i''. The step (b) consists of asking the first question to DM, right after the criteria ranking, comparing the weight of the last criteria with half the weight of the first criteria. It is assumed that the DM may have more difficulty providing accurate answers at narrower intervals, considering that these two criteria are more distant in the ranking. So, only one question is asked for the relationship between these two criteria.

To answer the questions, the DM has three options, to analyze the partial results graphs, stop the procedure or to proceed making a choice between two consequences. Depending on the consequence chosen, either x_i' or x_i''obtains a new value. In the case of indifference, x_i^{I} assumes the x_i value. With this, starts the step (c). For each question in the problem, the FITradeoff seeks a solution through a LPP (8) to find a solution:

$$
\begin{aligned}
&\max_{k_1,k_2,\ldots,k_n} \sum_{i=1}^{n} k_i v_i(x_{ij}), j = 1,2,\ldots,m \\
&s.t. \\
&\sum_{i=1}^{n} k_i v_i(x_{ij}) \geq \sum_{i=1}^{n} k_i v_i(x_{iz}), z = 1,2,\ldots,m\,, z \neq j \\
&k_{i+1} \leq k_i v_i(x_i') - \varepsilon \text{ for } i = 1 \text{ to } n-1 \\
&k_{i+1} \geq k_i v_i(x_i'') + \varepsilon \text{ for } i = 1 \text{ to } n-1 \\
&\sum_{i=1}^{n} k_i = 1 \\
&k_i \geq 0, i = 1,2,\ldots n
\end{aligned}
\tag{8}
$$

If the LPP solution has more than one alternative, it means that one more question should be asked to the DM to reduce the interval of the relation between the weights of two adjacent criteria, changing the restrictions and repeating the questions until a new solution is found. This will mean that any combination of weights within the constraints will evaluate this alternative as the best (DE ALMEIDA et al., 2016). The FITradeoff procedure is summarized in Figure 3.

Figure 3 – FITradeoff procedure



Source: Macedo *et al.* (2018).

2.3.2 ACUTA

ACUTA (analytic center for UTA) is a MCDM technique which disaggregates preferences out of the holistic judgments, i.e. the rank order of some predefined alternatives. About its mathematical formulation, which essential advantage is the centrality and uniqueness of the solutions it produces; let us assume A to be the set of possible offers (alternatives) and $A_L = \{a_j, j = 1, \ldots, k\}$ the reference set. In A_L, offers are ranked in order of decreasing preference by the negotiator. The values of resolution levels of the n criteria denoted by $x_i(i = 1, \ldots, n)$, belong to the interval $[\overline{x_i}, \underline{x_i}]$ that, for each i, denotes the range between the worst and best values, in the set of possible offers. The purpose of this is to establish marginal value functions $v_i(x_i)$ for each issue, to model the perceived value of each issue. These value functions are piecewise linear and the range of resolution levels on each issue is divided into subintervals through a predefined number of α_i breakpoints such that $x_i = \{\underline{x_i} = x_i^1, \ldots, x_i^{\alpha_i} = x_i\}$. For resolution levels different than those defining the breakpoints it is possible to compute value functions by linear interpolation between the values of the neighboring breakpoints (BOUS et al., 2010). To define a value function, set $v_i\left(\underline{x_i}\right) = 0$ and

$$\sum_{i=1}^{n} v_i(\overline{x_i}) = 1 \quad (9)$$

By this way, $v_i(\overline{x_i})$ can be interpreted as the tradeoff associated with issue i. Besides, all value functions should be monotonic $v_i\left(x_i^{l+1}\right) - v_i\left(x_i^l\right) \geq \lambda$, ($\forall$ i and l =1,…, $\alpha_i - 1$), with $\lambda \geq 0$. The global value $v(x_p)$ of and alternative x_p is given by the sum of its marginal values, i.e. if the value of the p^{th} alternative on issue i is denoted by x_{ip}, the global value of x_p is given by

$$v(x_p) = \sum_{i=1}^{n} v(x_{ip}) \tag{10}$$

This analytic expression of an alternative's global value allows for modelling the preferences of the negotiator, as expressed in the ranking of the reference set, using linear constraints:

$$v(x_p) - v(x_{p+1}) \geq \delta \ if \ x_p \ is \ preferred \ to (\succ) \ x_{p+1} \tag{11}$$

$$v(x_p) - v(x_{p+1}) = 0 \ if \ x_p \ is \ indifferent \ to (\sim) \ x_{p+1} \tag{12}$$

At this point, δ is a positive number, the preference threshold. The evaluation of the $v_i\left(x_i^l\right)$ variables should be done in such a way that the deviation from the preferences expressed by the negotiator in the subset A_L is minimal.

The adaptation of the linear additive disaggregation model to the analytic center formulation is quite straightforward and gives rise to the ACUTA method, which leads to the following nonlinear optimization problem.

$$\begin{aligned}
& max \ \textstyle\sum_{j=1}^{k-1} \ln s_j + \sum_{i=1}^{n} \sum_{l=1}^{\alpha_i - 1} \ln s_{il} \,, \\
& \text{s.t. } v(a_j) - v(a_{j+1}) = 0 \qquad if \ a_j \sim a_{j+1} \,, \\
& (v(a_j) - v(a_{j+1}) - \delta = s_j \qquad if \ a_j \succ a_{j+1} \,, \\
& s_{il} = (v_i\left(x_i^{l+1}\right) - v_i\left(x_i^l\right) - \lambda \,, \\
& \textstyle\sum_{i=1}^{n} v_i(\overline{x_i}) = 1.
\end{aligned} \tag{13}$$

2.4 NEGOTIATION

The complexity of the negotiation process results from many negotiator's aspects that must be taken into account to solve the problem, such as decision-analytic, economic, psychological and social, and extends to its configuration, which can assume different geometries. Each of these groups' combinations poses particular challenges and may involve cases of a single-issue or a multi-issue to be treated in a distributive negotiation (win-lose) or integrative negotiation (win-win) (RAIFFA, 1982).

Therefore, the negotiation process is not uniform and depending on the level of conflict, different tasks will need to be performed. However, to support the negotiation process, that are various proposals of dividing the negotiation process into separate phases (GREENHALGH, 2001; MADRIGAL et al., 2009; TAFRESCHI et al., 2008). Among the existing proposals, a general categorization allows distinguishing the main negotiation phases, the prenegotiation phase; actual negotiation phase; and post-negotiation phase (GULLIVER, 1979).

In the prenegotiation phase the parties will prepare for the negotiation, evaluating the interests they wish to fulfill. First, the negotiators need to gather information to understand the conflict essence, leading to the construction of a negotiation space by an assessment of the options for agreement in the negotiation, a comparative analysis of the advantages/disadvantages of both sides, knowledge of reservation level and BATNAs (best alternative to a negotiated agreement) of the negotiators. At the end of this step, the negotiators and third party are chosen, and the agenda are prepared (RAIFFA; RICHARDSON; METCALFE, 2002).

Having completed the prenegotiation preparation, during the actual negotiation phase the negotiators can use the information collected to analyze the offers, in order to determine the counter-offers and, if possible, to discuss each reservation level. This phase is necessary to identify the true intentions, emotions and position of the sides, to assist the strategy to be used by the negotiators towards the desired agreement. Then, the negotiators start exchanging offers until the final compromise aiming at mutual agreement. At last, the post-negotiation phase consists in writing a contract and its execution. Besides that, the third party evaluates the agreement in order to find effective solutions that dominate the current compromise and summarizes the conclusions learned to use in other negotiations (LEWICKI et al., 2002; RAIFFA, 1982).

With technology, the negotiations are being conducted by means of electronic media to support the different tasks at different stages of negotiation process, facilitating, organizing and automating activities carried out by negotiators and third parties (KERSTEN; LAI, 2007). In particular, the negotiation support systems (NSS) implements some decision support tools in the software system to gather and visualize information from negotiators, acting on data processing, performing calculations and simulations or suggesting possible solutions to the problem.

2.4.1 The negotiation scoring systems

During the prenegotiation phase, the negotiation template is designed to structure the negotiation problem. In addition, this phase may also be responsible for building a negotiation scoring system. According to Gorecka et al. (2016), a negotiation scoring system is a system of quantitative ratings that represents the negotiators' preferences for all feasible negotiation solutions. This system allows the negotiator to evaluate the quality of offers. Also, the scoring systems can measure the scale of concessions; search for improvements in the negotiated contract or determine an fair solution for the negotiation problem during the post-negotiation analysis (RAIFFA, 1982).

Some negotiation tasks are typical of any MCDM problem, particularly the evaluation of the negotiation template from the point of view of one of the parties. Thus, a MCDM approach can be used to determine a negotiation scoring system (EHRGOTT et al., 2010; FIGUEIRA et al., 2005). In cases of multi-issue negotiation problems, the MCDM methods is commonly used to evaluate negotiation offers, supporting the construction of the scoring system (RAIFFA et al., 2002).

Furthermore, the negotiation process can use two paradigms, aggregation and disaggregation, to elicit the negotiators' preference and build the scoring system (FIGUEIRA et al., 2009). The aggregation approach utilizes a direct rating technique to obtain the definition of all the parameters from the problem. Direct rating techniques derive outcome scores by the direct assignment of a value to each indicator from a defined scale.

The simple additive weighting (SAW) based approach is the mostly used technique to determine the scoring systems (BEUTHE; SCANNELLA, 2001; OLSON, 2001). This technique requires a direct rating of the scores, assuming additive preferences and preferentially independent issues. In opposition to the traditional aggregation paradigm, the philosophy of disaggregation uses a holistic approach to infer indirectly the preference model from given global preference. This indirect approach requires predefined examples of negotiation offers to use them to infer the model parameters, as in, for instance, the UTilités Additives (UTA) family methods (GORECKA et al., 2016).

With the differences between the preference elicitation philosophies, e.g. in the ways of expressing the decision-makers' preferences (numerically or linguistically) and processing them (aggregating or disaggregating), different scoring systems that rank and rate the negotiation offers may be different depending on the chosen MCDM method. Besides that, there are behavioral factors (e.g., the negotiators' cognitive capabilities, their mathematical sense and decision-making experience) that can influence the way the negotiators use the decision-making tools impacting the accuracy and reliability of the scoring system (ROSZKOWSKA; WACHOWICZ, 2016). Thus, selecting a MCDM method to support negotiation process is a decision problem itself, a mix of factors need to be taken into account, such as, the methodological legitimacy, its capability for generating the scoring systems precisely reflecting the negotiators' preferences, usefulness and other (DAVIS, 1989).

To support the negotiation problem using the classical MCDM methods, it is important to consider that a negotiation package is an offer; an issue is a criterion; and an option is the criterion potential resolution level (ROSZKOWSKA; WACHOWICZ, 2012). It is worth noting that for scoring systems based on the disaggregation approach usually uses a reference set of potential negotiation packages in order to obtain the negotiators' holistic preference, instead using direct rating to score the negotiation parameters. (JACQUET-LAGREZE, 1990; JACQUET-LAGRÈZE; SISKOS, 2001b)

2.4.2 Problems with direct rating to score systems

Despite the direct rating (DR) techniques used in additive scoring system, such as SAW, SMART or even swaps approaches, seems to be technically and computationally simple to support the negotiation process, there are some theoretical and experimental studies in electronic negotiations that revealed some problems in interpreting the scores by the negotiators (GÓRECKA; ROSZKOWSKA; WACHOWICZ, 2016). For instance, sometimes the negotiators misused the DR technique by means of a misinterpretation of the cardinal utility scores, not representing their preferences accurately (WACHOWICZ; WU, 2010).

Also, through other experiments (KERSTEN; ROSZKOWSKA; WACHOWICZ, 2017; ROSZKOWSKA; WACHOWICZ, 2014), it was observed that most of the negotiators uses an imprecise and non-numeric evaluation to define their preferences in an intuitive way, they have difficulty in defining reference points and resolution levels for each issue. In addition, these experiments suggest that the negotiators may make mistakes when asked to express their preferences by means of cardinal ratings instead of more intuitive qualitative judgements. This affects the quality of the agreements and turns difficult to obtain a consistent scoring system.

Another identified problem lies in the fact that negotiators had difficult to assign accurately scores for the negotiation template and prefer a predefined ranking than their own subjectively defined one (WACHOWICZ et al. 2015; GÓRECKA et al. 2016). An inaccurate scoring system leads the negotiators to a wrong perception of the negotiation process. The negotiators are convinced that the agreement reached is the best according to their preferences; however, the ratings of their contracts are lower than their expectations.

In this way, these experiments shows that the potential determinants for the misuse of the DR techniques can be the holistic judgements related to fast thinking and the cognitive demand of the scoring procedures, due to the effect of negotiators low cognitive capabilities, limited number sense or scarce mathematical background (WACHOWICZ; ROSZKOWSKA, 2018). Based on the global preferences, the holistic approach aims at determining a quantitative scoring system in order to build a ranking. Working with holistic preference declaration can result in a scoring system less inaccurate than the ones obtained through DR; it is a useful approach to bypass the scoring system inaccuracy working as an additional toll to support the negotiation.

2.4.3 Negotiation and holistic assessments

As mentioned earlier, the issue of designing new public calls by the power utilities that would meet both the legal requirements and the companies needs and internal possibilities makes the situation to be a mutual decision-making problem. To be solved successfully, its consensual character should be taken into account and thus the negotiation approach seems to be the best solution here. Considering that the negotiation process as a decision making one (BRETT; THOMPSON, 2016) requires implementing some methods and techniques for decision support, and since most negotiations involve multiple issues, the multiple criteria decision management (MCDM) methods (FIGUEIRA; GRECO; EHRGOTT, 2005) are recommended to negotiation analysis and support.

The use of MCDM tools support negotiators to organize their prenegotiation preparation, bargaining and post-negotiation phases (RAIFFA; RICHARDSON; METCALFE, 2002). For example, multiple criteria decision aiding techniques may be used to structure the negotiation problem and elicit negotiator's preferences and build the negotiation offer scoring systems (i.e. the value functions) during the prenegotiation phase. Such a system helps the negotiator to evaluate the offers submitted during the negotiation process (bargaining), analyze the mutual concessions and their reciprocity or proactive suggest some efficient compromises. In case of deadlocks, it can be used to find the arbitration solution(DRUCKMAN; OLEKALNS, 2013; NASH, 1950; PRUITT; LEWIS, 1975) or in the post-negotiation phase – to find the improvements of the negotiated agreement.

The direct rating is most commonly used technique for eliciting the negotiators' preference and build a value function over the negotiation issues and their options (KEENEY; RAIFFA, 1976). It requires a subjective assignment of rating points by the negotiators to all the elements of the negotiation problem, that was adequately structured beforehand. The examples of such direct rating approach are SMARTS or SMARTER techniques (EDWARDS; BARRON, 1994). However, sometimes the negotiators misuse the direct rating technique, due to their limited cognitive capabilities, limited number sense or insufficient mathematical background or simple use of the heuristics resulting from fast thinking (STANOVICH; WEST, 2008; TVERSKY et al., 2008). One of the disadvantages of this technique is the assignment of numerical scores to all levels of resolution evaluated in the negotiation model (ROSZKOWSKA; WACHOWICZ, 2014).

Often, the negotiators have difficult to interpret numerical scores and use some heuristics, such as round numbers (KERSTEN; ROSZKOWSKA; WACHOWICZ, 2017); they are unable to determine the scoring systems that are accurate; the ratings used did not represent their preferences well and this inaccuracy significantly impacts the quality of contracts (ROSZKOWSKA; WACHOWICZ, 2015a). This indicates the need for search for an alternative prenegotiation preference elicitation protocol and technique.

In order to reduce the preference misrepresentation and promote more reliable decision support for the negotiators, some alternative approaches have been suggested, such as Even Swaps (as in SmartSettle system (THIESSEN; SOBERG, 2003)or Fuzzy TOPSIS negotiation mechanism (ROSZKOWSKA; WACHOWICZ, 2015c). These are however the protocols that assume the negotiators are able to declare their preferences at disaggregated level. The opposite approach that could be implemented to support negotiation can be designed based on the indirect preference elicitation by means of holistic judgments. Holistic approach to preference elicitation is considered to be cognitively less demanding, since it operates on the examples of complete alternatives (offers) and their natural evaluation by means of series of comparisons, allocations to the classes or rank orders (DESHAZO; FERMO, 2002; CIOMEK et al. 2017). The value functions, previously precisely defined by negotiators in series of direct ratings, here are inferred based on these indirect comparisons, assuming a particular form of the preference model (usually its additive form). Furthermore, the holistic approach is also considered as explaining the nature and structure of decision maker's preferences better (CORRENTE et al., 2013).

Finally, it is perceived as being naturally better suited to the context of the negotiation problems, as the comparison of offers (full packages considered as the contract proposals) is a typical task the negotiators need to perform during the bargaining phase when considering which of the offers submitted to the negotiation table is better and of how much. As presumably eliminating the negative effects of negotiators' lack of information and mathematical knowledge, the holistic approach has been suggested to support group decision making processes in early in 1980s (e.g. Mediator system (JARKE; JELASSI; SHAKUN, 1987)). Its accuracy with comparison to the use of direct rating mechanisms has also been recently empirically verified (ROSZKOWSKA; WACHOWICZ; KERSTEN, 2017). Therefore we decided to develop the negotiation support protocol that uses the holistic approach for the efficient prenegotiation preference elicitation process.

2.5 SYSTEMATIC REVIEW OF HOLISTIC APPROACHES

This section presents the systematic review, which addresses the use of holistic approaches to support decision making and how they can contribute to negotiations. Initially, it is presented the application of the systematic review model proposed by Denyer and Tranfield (2009), as explained in Chapter 1. This model consists of 4 stages: formulation of the question, study location, study selection and evaluation, analysis and synthesis. Then, the results of the review are presented by summarizing the methods found. Finally, a general discussion is presented, facing the question raised in the first stage of the model.

2.5.1 Application Stages

a) Stage 1: Formulation of the question

The first stage involved the formulation of questions to conduct the study, considering the negotiation discussion in the previous section. Hence, the question arise what preference elicitation mechanism could reduce the preference misrepresentation and promote more reliable decision support for the negotiators. For this, the indirect preference elicitation by means of holistic judgments seems to be most predisposed to eliminate the negative effects of negotiators' lack of information and mathematical knowledge (GORECKA et al., 2016; ROSZKOWSKA; WACHOWICZ, 2015b). The holistic approach is based on the disaggregation paradigm, which infer the preference's parameters and reduces the negotiator's cognitive effort. This approach may assess and rank the offers considered in the negotiation problem.

Based on the previous discussion of section 2.4, through the CIMO-Logic (DENYER; TRANFIELD; VAN AKEN, 2008) it is formulated the following statement to identify the four main elements: If a mediator aims to use other techniques instead direct rating to assess negotiators' preference information (C), it should evaluate other MCDM tools such as, the holistic approaches, (I) to identify their use implications (M) and provide a better support for the negotiators by building a more accurate negotiation scoring system (O).

With this statement, the following research questions were designed to support the study:

1. What holistic approaches are the most widely used in the multi-criteria decision-making?
2. What are the implications of using the identified holistic approaches to build negotiation scoring systems?

b) Stage 2: Locating studies

The second stage involved a research in a structured way through three databases: Elseviers' Science Direct, Springer Natures' Springer Link and Clarivate Analytics' Web of Science. The choice is reasonable and sufficient to identify suitable papers, because these bases are considered among the most prominent in academic institutions and are frequently used by other researchers.

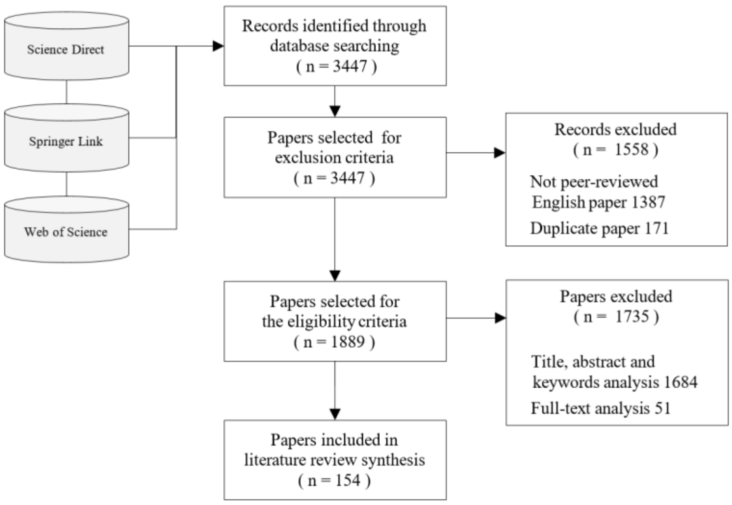
The research sought 8 keywords by using Boolean logic to group them to make the search more efficient. The research used the following combinations of keywords in all fields of each record: ("multi-criteria" OR "multicriteria" OR "multiple criteria") AND ("holistic approach" OR "holistic preference" OR "holistic evaluation" OR "holistic judgment"); and ("multi-criteria" OR "multicriteria" OR "multiple criteria") AND "disaggregation". The keywords were chosen to guarantee the relevance of the study with regard to holistic approaches, the multi-criteria methods and the non-direct rating techniques for preference elicitation. The searches were conducted on June 2018, with a screening from the last 25 years, that is, all records between 1993 and 2018 were verified.

c) Stage 3: Study selection and evaluation

As a result, after searching the databases, 3447 records were obtained. Then, a spreadsheet was arranged allowing the evaluation of each record individually. The spreadsheet made it possible the use of exclusion/eligibility criteria, in order to assess significant evidence of insights related to holistic approaches in MCDM.

In order to ensure the research quality, only peer-reviewed English papers were considered, excluding proceeding papers, reviews, book chapters, articles in press, editorials, reviews, short communications, reference works, opinion papers and magazine papers, resulting in the exclusion of 1387 records. Then, 171 duplicate papers were excluded, leaving 1889 papers to be evaluated by the eligibility criteria. Regarding the relevance of the papers, after reading the titles, abstracts and keywords of all papers, 1684 papers that are irrelevant with the research topic were excluded. Then, the remaining 208 papers were examined by a full-text analysis, excluding more 51 papers. At last, 154 papers in total were used in the literature review synthesis. To summarize the methodological processes of this review, Figure 4 shows the filtering process used with its different stages of exclusion and eligibility.

Figure 4 – Papers selection



Source: The author (2020).

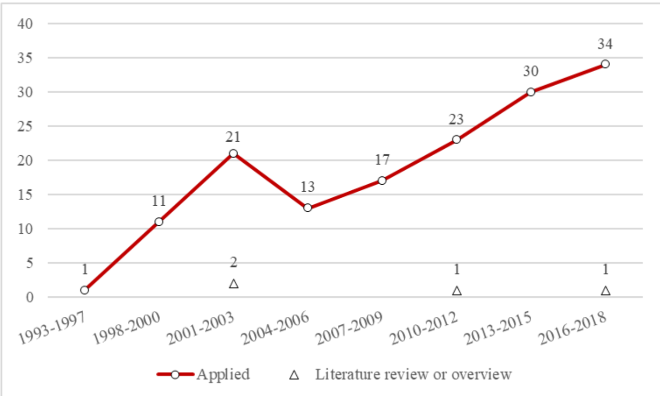
After the filtering process, each paper was categorized into one of the two groups according to its main focus: applied papers; literature review and overview papers. Applied papers group presents results of holistic approaches applications or experimental analysis. In addition, papers containing algorithms and decision support system (DSS) are included in group (a). 150 applied papers were identified. For each paper, the holistic methods were identified and in which context it was used.

Papers in group *b* includes literature reviews and overviews of one or more holistic approach. Papers in this category are researches that carried out a large review in a scientific database for an application or a methodology and methodological review of a specific approach or range of methods. 4 papers were identified in this group (DOUMPOS; ZOPOUNIDIS, 2011; EL GIBARI et al., 2018; JACQUET-LAGRÈZE; SISKOS, 2001a; MATSATSINIS; SAMARAS, 2001).

For the 154 English peer-reviewed papers retrieved through stages 1-3, the literature directly or indirectly addressing holistic approaches in MCDM has grew slowly, and only between the years 2013 and 2018 the growth represented around 40%, as can be seen in Figure 5 which shows the distribution of papers by year of publication. The papers were divided within three-year intervals, however, the first interval cover five years, since only few papers were found for the earliest years.

It was identified that the papers are distributed among 41 different journals, as shown in Table 1. The journal with most publications is *European Journal of Operational Research* (EJOR). This journal published three times more papers than the second journal listed, which is *Operational Research*. Most journals have only published one or two papers.

Figure 5 – Publishing trend for relevant papers



Source: The author (2020).

Table 1 – Research fields and papers considered in review

Main journals	Research field	Number of papers	Percentage
European Journal of Operational Research	Operational research	51	33.1%
Operational Research	Operational research	16	10.4%
Omega	Others	13	8.4%
Computers & Operations Research	Computer science	12	7.5%
Decision Support Systems	Decision analysis	7	4.5%
Annals of Operations Research	Operational research	5	3.2%
Group Decision and Negotiation	Decision analysis	5	3.2%
Journal of Global Optimization	Operational research	4	2.6%
Expert Systems with Applications	Computer science	3	1.9%
Others (with 2 papers each)	-	12	7.8%
Others (with 1 paper each)	-	26	16.8%

Source: The author (2020).

d) Stage 4: Analysis and synthesis

Based on the holistic preference information used in the disaggregation paradigm, numerous approaches were identified to support MCDM problems according to decision-maker cognitive style and capacities. Therefore, to organize the literature, each applied paper was divided into three main classes of preference models: utility (or value) functions; outranking relation; rule-based models. Such structure is meant to support the reader in understanding how the literature has addressed the holistic approaches, which were found to be similar in some respects.

The assignment of the papers to one category is subjective and depends on its context of application were defined. As the contexts of application, the following categorization was used (Table 2). To determine the most used preference model in different areas, Table 3 shows the distribution by preference model vs. context of application.

Table 2 – Context of application and problems addressed to each category

Context of application	Problems
Financial management	Assessment of stock performance, risk assessment of global investments, bankruptcy and financial distress predictions, buying decisions.
Experimental analysis	Numerical applications by a combination of experimental and simulation data, presentation of an algorithm, decision support system (DSS) application.
Marketing	Customers' satisfaction, the ranking of countries, cities and universities, assessment of job.
Environmental management	Risk assessment of environment and nuclear safety choices, nanoparticles synthesis, assessment of energy supply and policymaking, assessment of water quality, water supply and wastewater treatment.
Urban management	Urban planning, extension of metro lines, cities livability, transportation and location problems.
Education	Assessments of universities quality, students' performance and e learning.
Research and development	Applications involving innovation, the assessment of projects and project management
Operations management	Airline scheduling, employees' engagement, predictive maintenance, newsvendor problem.
Health	Health sector problems, psychological experiments.

Source: The author (2020).

Table 3 – Distribution of applied papers across the context of application

Context of application	All	%	Utility (or value) functions	%	Outranking relations	%	Rule-based models	%
Financial management	44	29.3	35	29.7	7	28.0	2	28.6
Experimental analysis	36	24.0	21	17.8	12	48.0	3	42.9
Marketing	26	17.3	25	21.2	1	4.0	0	0
Environmental management	11	7.3	10	8.5	1	4.0	0	0
Urban management	10	6.7	10	8.5	0	0	0	0
Education	9	6.0	5	4.2	2	8.0	2	28.6
R&D	5	3.3	4	3.4	1	4.0	0	0
Operations management	5	3.3	4	3.4	1	4.0	0	0
Health problem	4	2.7	4	3.4	0	0	0	0
Total	150	100	118	100	25	100	7	100

Source: The author (2020).

In order to stratify the information and to know the most used holistic methods, Appendix 1 shows the distribution of each holistic method with respect to the preference model and application context. Furthermore, some of the papers explore aspects of holistic assignments that cannot be associated with a specific method, but they provide some insights for holistic methods. These papers were named *Others*, in which the main focus lies in the construction of a representative set of parameters or preference relations, post-optimality analysis, robustness analysis and discussions to explain decision-makers preferences.

2.5.2 Review results

This section highlights some significant results of this literature review on the holistic approaches used to support MCDM

a) Utility (or value) functions: methods based on ordinal regression

The first method in the series, called UTA, evaluates the problem more quickly and less redundantly. This method is conducive to preferences' changes and requires only holistic preference declarations in a form or rank orders for different alternatives in a reference set. Later, different extensions were developed by incorporating other types of preference information and criteria discrimination, such as UTASTAR (SISKOS; YANNACOPOULOS, 1985) and UTADIS (ZOPOUNIDIS; DOUMPOS, 1999a). To make the UTA methods capable of processing fuzzy scores, Patiniotakis et al. (2011) extend the UTASTAR method through the Fuzzy UTASTAR, allowing to introduce the fuzzy utility functions.

Other approaches were developed to support the building of value functions compatible with holistic preferences and provide a more precise solution, such as ACUTA (BOUS et al., 2010). Later, Kadziński et al. (2013b) present the RUTA method which can handle with preference information in terms of rank statements and does not require a complete pre-order of reference alternatives. Karande and Chakraborty (2015) improve the UTA approach by accommodating the criteria weights in problem through the weighted utility additive (WUTA).

Besides additivity, part of UTA-based methods assumes piecewise linear and monotonic value functions (BECCACECE et al., 2015). However, on the one hand, rather than using a piecewise linear function, the piecewise linear assumption is relaxed in the method PUTADIS (CAI; LIAO; WANG, 2011) coupled the UTADIS method with a polynomial of the degree to represent the utility function. Later, the monotonic value function assumption is relaxed in the UTA-NM method (GHADERI; RUIZ; AGELL, 2015) and other approaches consider an evolutionary optimization process (DOUMPOS, 2012) and DEA modelling (CARAYANNIS; GRIGOROUDIS; GOLETSIS, 2016) in disaggregation environment.

Furthermore, a map-based interactive UTA implementation was developed, the Spatial UTA (S-UTA) (DEMESOUKA; VAVATSIKOS; ANAGNOSTOPOULOS, 2013), which provides results consistent with the other GIS-based techniques. Finally, Sobrie et al (2018) proposed two approaches that model value functions through polynomials (UTA-poly) and splines (UTA-splines) instead of piecewise linear functions, contributing to the field of preference. Both methods can also be used for ranking and sorting problems.

b) Utility (or value) functions: methods based on robust ordinal regression

The first Robust Ordinal Regression (ROR) method, called UTA^{GMS}, was presented by Greco et al. (2008) to deal with problems of ranking and choice. Afterwards, Figueira et al. (2009) extends the UTA^{GMS} method and propose the GRIP method to handle with the preferences' intensity between the alternatives, not only pairwise comparisons between them.

For sorting problems, Greco et al. (2010) extends the ROR through the $UTADIS^{GMS}$ method. Further, Greco et al. (2011b) introduces representative value function in the $UTADIS^{GMS}$ method, by assigning actions to pre-defined classes. Greco et al. (2012) extends this principle to group-decision problems through the UTA^{GMS} – GROUP and the $UTADIS^{GMS}$ – GROUP, supporting the decision-makers' to cooperate and making a collective decision. Next, Greco et al (2014) proposed a ranking method called UTA^{GMS} – INT, an alternative to Choquets' integral. Not least important, the ROR-UTADIS (KADZIŃSKI; CIOMEK; SŁOWIŃSKI, 2015) provides a more robust recommendations by building preference relations for a sorting decision problem.

c) Utility (or value) functions: MUSA-based methods

The Multicriteria Satisfaction Analysis (MUSA) evaluates the level of customer satisfaction for each criterion (ANGILELLA et al., 2014). As the main advantage, this method considers the customers' judgment and preferences in a qualitative way. (GRIGOROUDIS; SISKOS, 2002). MUSA has already been extended, e.g. in MUSA+, a refined MUSA method (GRIGOROUDIS et al., 2008); in MUSA-INT, which considers a positive and negative interaction between criteria, similarly to UTA^{GMS}-INT (Angilella et al. 2014); and in N-MUSA, where nonlinear form was implemented (NAYERI; MEHREGAN, 2018).

d) Utility (or value) functions: MARS method

Gorecka et al. (2016) presents the MARS (Measuring Attractiveness near Reference Situations) approach, which merges ZAPROS and MACBETH to support a negotiation problem by dealing with negotiators' holistic preferences when expressed in a verbal way. It supports the construction of value functions based on an interval scale derived from verbal judgments (BANA E COSTA; CARNERO; OLIVEIRA, 2012; BANA E COSTA et al., 2001).

e) Utility (or value) functions: decision support systems

Decision support system (DSS) is an interactive system that use models and data to support decision problems (TURBAN; ARONSON, 2001). Over the years, various systems were proposed to support the advancement of UTA approaches and enrich preference-modeling capabilities, e.g. the FINCLAS which incorporates financial modeling tools with preference disaggregation methods (ZOPOUNIDIS, 2006; ZOPOUNIDIS; DOUMPOS, 2001); and the PREFDIS system, to study sorting decision problems, which incorporate UTADIS methods and may use non-monotonic preferences (2000c). Later, by improving the global stock system (SAMARAS; MATSATSINIS; ZOPOUNIDIS, 2003, 2008), Samaras and Matsatsinis (2003) presents a DSS for portfolio management, called the INVESTOR system, which is based on UTASTAR, such as consumer-based system MARKEX (SISKOS; MATSATSINIS, 1993).

Furthermore, the MIIDAS systems implements UTA II method and contributes with the decision-maker through artificial intelligence and visual techniques to support the decision (SISKOS; SPYRIDAKOS; YANNACOPOULOS, 1999). In group decision context, Spyridakos and Yannacopoulos (2015) proposed the RACES system by incorporating collective voting functions to estimate a global pre-ranking of the alternatives. Recently, similar to TELOS system (Grigoroudis et al. 2000), in order to measure job satisfaction, Aouadni and

Rebai (2017) exceeds the limits of the MUSA method and proposes a DSS based on continuous genetic algorithm, called GMUSA.

f) Utility (or value) functions: Other applications

Researches on the issue of robustness using disaggregation techniques in order to build more robust multi-criteria decision models and obtain robust recommendations are currently very active. The first main approach consists of using analytical methodologies for preference relations elicitation and recommendations formulation, according to the characterization of the decision models compatible with the decision-makers' preferences on the reference set (SPYRIDAKOS et al., 2018). The second approach comprises the building of robust decision models, which best represent the information through the reference data. Such approach involves methods to deal with interactions' strength in a value function (BECCACECE et al., 2015), equity concerns (KARSU, 2016), heuristic selection for pairwise questions (CIOMEK; KADZIŃSKI; TERVONEN, 2017), expressiveness (KADZISKI et al., 2017), non-monotonic additive preference models inference (GHADERI; RUIZ; AGELL, 2017), and imbalanced set of assignment example (LIU et al., 2018).

The papers that perform experimental analyzes through comparisons between holistic methods were also identified (ÇELIK; KARASAKAL; İYIGÜN, 2015; DOUMPOS; ZOPOUNIDIS, 2002; MIHELČIĆ; BOHANEC, 2017; PASIOURAS; TANNA; ZOPOUNIDIS, 2007) and develops extensions of current techniques in several areas (BOLAND et al., 2009; KADZIŃSKI et al., 2018; YANG; LIAO; HUANG, 2014; ZHENG; LIENERT, 2018). Some extensions use the ordinal regression analysis based on the concept of regularization, such as Doumpos and Zopounidis (2007) which proposes to UTA and UTADIS methods. Further, Hurson and Siskos (2014) present a synergy of UTA, MAUT and MACBETH to assess additive models and extract robust conclusions.

With a similar perspective, some extensions use the robust ordinal regression analysis by introducing representative value function trough UTA^{GMS} and GRIP, which represents a set of value functions through just a single compatible value function for choice and ranking problems (KADZIŃSKI; GRECO; SŁOWIŃSKI, 2012a). Similarly, Kadziński et al. (2013a) generalize this concept to UTA^{GMS}-GROUP and UTADIS^{GMS}-GROUP methods in a group decision context, to support decision-makers' understanding of the robust results and overcome the conflicts between them. Further, Kadziński and Tervonen (2013) coupled ROR with SMAA, namely the Stochastic Ordinal Regression (SOR) which was extended later through several scoring procedures (KADZIŃSKI; MICHALSKI, 2016). To enhance the interpretability of the outcomes and increase the decision-maker acceptance of the recommendation without loss of generality, Kadziński et al. (2014) present a new approach to promotes the intuitive interpretation of numerical scores of alternatives and preference information for multi-criteria choice and ranking methods.

Some extensions were proposed to reduce the lack of preferential information in decision-making problems since the holistic framework does not require specific details on the parameters that define the criteria aggregation model. For example, an extension that describes preference information through a hierarchical structure, and allows decomposing problems into smaller dimensions, as well as handling intermediate levels of the hierarchy of criteria (CORRENTE et al., 2017; ÜLENGIN; ÜLENGIN; GÜVENÇ, 2001). Furthermore, Sarabando et al. (2013) develop approaches to support a mediator in a bilateral negotiation under incomplete information; and Branke et al. (2017) through the RORi framework, which permits the use of indifference declaration.

To handle the decisions under risk and uncertainty, Corrente et al. (2016) propose a methodology based on meaningful and manageable quantiles and ROR. These quantiles allow the decision-maker to reasonably understand the rich and complex information contained in a probability distribution by means of additive and non-additive probabilities. In addition, Liu et al. (2015) deal with uncertainty utilizing an evidential reasoning approach. Other approaches presented in this section use the non-conventional Choquets' integral forms (ANGILELLA; GRECO; MATARAZZO, 2010; BEAUDOUIN, 2015) and Tchebycheff utility function (SOYLU, 2011) to represent the interaction among criteria of the methods. One of the advantages of using a Tchebycheff utility function is that it reaches all the efficient alternatives.

g) Outranking relations

Research on the ELECTRE TRI method to infer some of the required parameters method through disaggregation approaches is currently very active. These range from the robustness analysis (DIAS et al., 2002; RANGEL-VALDEZ et al., 2018), non-discordance conditions (LOURENÇO; COSTA, 2004; MOUSSEAU; DIAS, 2004), inconsistencies among constraints of the parameters (MOUSSEAU et al., 2003; MOUSSEAU; DIAS; FIGUEIRA, 2006), veto-related parameters (DIAS; MOUSSEAU, 2006), progressive assistance (ROCHA; DIAS, 2008) and optimistic rule (ZHENG et al., 2014). To support interactively the disaggregation procedure based on outranking relations, some systems may be used such as:

the ELECCALC system (KISS; MARTEL; NADEAU, 1994), ELECTRE TRI Assistant (MOUSSEAU; SLOWINSKI; ZIELNIEWICZ, 2000) and IRIS (DAMART; DIAS; MOUSSEAU, 2007).

Regarding robust ordinal regression, Greco et al. (2011a) extends this principle to outranking models and developed the ELECTRE^{GKMS} method, which uses monotonic functions of marginal concordance indices. Later, Kadziński et al. (2012b) extends the ROR through an analysis of extreme ranking results, and proposes the PROMETHEE^{GKS} method. Also, Kadziński et al. (2012c) extends the ROR principle by using a representative set of preference model parameters to support outranking models. Some papers investigates the performance of outranking methods by developing models in different aspects, e.g. using fuzzy indifference relations(FERNANDEZ; NAVARRO; BERNAL, 2009) or through an evolutionary methodology (CORAZZA; FUNARI; GUSSO, 2015) to infer parameter values.

h) Rule-based models

The classical Rough Set theory (PAWLAK, 1982) has proved useful for dealing with the inconsistency of problems and inaccurate information. (GRECO et al., 2011a; GRECO; MATARAZZO; SLOWINSKI, 2001). However, generalizing this approach, the Dominance-based Rough Set Approach (DRSA) emerges being able to handle with the preference order in the value sets of condition, by using a dominance relation instead a indiscernibility one (SLOWINSKI; GRECO; MATARAZZO, 2012).

To support decisions, researches studies rule-based models are investigating the induction of rules and recommendations generated by them. These researches range from group decision classification problems (CHAKHAR; SAAD, 2012) to the additional constraints on the categories, like a balanced composition of the categories, through the DIS-CARD sorting method (KADZIŃSKI; SŁOWIŃSKI, 2013).

Later, DRSA has been coupled with ROR approach to provide a more accurate model and a better interpretation of the preference relations by considering a set of possible values of preference, close as possible to decision-makers’ preference (GRECO; SŁOWIŃSKI; ZIELNIEWICZ, 2013; KADZIŃSKI; GRECO; SŁOWIŃSKI, 2014; KADZIŃSKI; SŁOWIŃSKI; GRECO, 2015).

2.5.3 Systematic review discussion

Through the conducted literature review, this section identified how the holistic approaches can support the construction of negotiation scoring systems during the prenegotiation phase.

In the negotiation context, during the prenegotiation phase, the negotiator can build a negotiation scoring system taking into account his direct or indirect preference information. However, a negotiation problem involves a complex environment with conflicting criteria, imprecise knowledge and lack of information. To deal with ill-structured negotiation problems, it is more appropriate to model the problem through indirect preference information in order to evaluate and rank the negotiation packages by providing some examples from the negotiation offers and inducing the parameters of the preference model. For this problem, the holistic evaluation, which uses the disaggregation paradigm, is useful by knowing first the negotiators' global preferences from a subset of packages to infer an aggregation model from this information in order to rank the negotiation offers. Furthermore, according to Roszkowska and Wachowicz (2015), the holistic evaluation allows to build a scoring system based on complete or incomplete preferential information defined for a predefined set of reference packages, extending it for all feasible offers; the negotiators' preference can be obtained through intuitive linguistic terms; and eliminates the need to define the issues' weight.

The holistic approaches include two main situations, the first situation concerns the evaluation of the preference information from a global perspective on a reference set of alternatives, and the second situation is their interactive essence to support negotiators to understand and provide preferences. However, through the correct use of the holistic approaches according to their individual characteristics, it is possible to support negotiators to better understand the problem, identify reliably offer packages from the negotiators' preferences, as well as provide insights on the stability of the structural parameters of the model. The main advantages of the holistic approaches is the reduction of the negotiators' cognitive effort and evaluation of negotiation offers under an ill-structured negotiation problem.

It was observed that only Gorecka et al. (2016) proposed the use of a holistic approach to support a negotiation problem through the MARS method, where elements of ZAPROS and MACBETH were hybridized to elicit negotiators' preferences in multi-issue negotiations. This method compares the reference alternatives with those that differ from the ideal one in the issues' resolution level. However, there are many multi-criteria methods based on holistic approaches that can be applied in negotiation problems to support the preferences' elicitation and build negotiation scoring systems to evaluate qualitatively the offers submitted during the negotiation process.

From the methods based on utility (or value) theory, the UTA-based methods are the most researched ones and have been applied in many MCDM problems. However, UTA-based methods may produce not satisfactory scoring functions due to their dependence on the reference set. To overcome this shortcoming, ROR-based methods emerge as an alternative to ordinal regression-based methods, using additional information to compare the preferences between actions. For instance, ROR-based methods do not make older approaches obsolete. The UTA^{GMS} method is easy to explain to the decision-makers, however, the method requires more effort to develop the supporting tool for interactive elicitation, it also requires some knowledge about linear programing to infer the utilities. One advantage of GRIP, an extension of UTA^{GMS} method for choice and ranking problems, is that this method takes into account the intensity of preferences.

Indeed, UTA^{GMS} and GRIP appear as more rigorous and in some practical situations they may not provide adequate support for the problem, because if the set of compatible functions is large, it is possible to obtain less information from the negotiator, deriving poor robust conclusions (BOUS et al., 2010). Then, the negotiation process may be hampered if the negotiator is unable to provide additional data to enrich the information. Later, Kadziński et al. (2015a) present the ROR-UTADIS to provide robust recommendations by building two preference relations, a necessary and a possible one, for a sorting problem. Therewith, the analyst can take advantage of each method through their particular characteristics to not risk of biasing the process

To support the negotiation process, the traditional outranking methods are powerful for providing a negotiation scoring system, in cases of limited issues or packages, as they require a high amount of information and parameters to be established. To overcome this situation, through the concept of assignment examples provided by the ELECTRE^{GKMS} and PROMETHEE^{GKS}, these holistic methods require both less cognitive effort and time. For problems with many issues or packages, the methods based on utility (or value) theory are more suitable. However, ranking alternatives may be tiresome and problematic especially when the set of reference alternatives is relatively big to assure a certain level of scoring system accuracy. Furthermore, a negotiation problem can use methods based on rule decisions, mainly the DRSA, to assess negotiators' preferences information through rules induction and to better explain the recommendations in terms of rules involving conditions.

Another observed issue refers to biases and heuristics that may appear in the negotiation process, which can negatively influence the quality of the negotiation support and affect the accuracy of the negotiation scoring system. It is worth mentioning that mediators need to be aware of their holistic scoring systems inaccuracies and when possible, correct them by changing option ratings to improve accuracy. No papers were identified that evaluated the influence of biases in the negotiation given the use of a holistic assessment to conduct the prenegotiation phase.

At last, the selection of the most appropriate method to support the negotiation problem is a complex problem due to their individualities. To choose the most suitable one, it is important to consider its features, their computational complexity, the applicability, the number of issues and options, and thus comparing its advantages and disadvantages (BRZOSTOWSKI; ROSZKOWSKA; WACHOWICZ, 2011), and the preference elicitation process. Through the information presented in this literature review to support the negotiation process, the mediator can choose one of the holistic approaches studied and apply it in the negotiation template in order to build an accurate negotiation scoring system.

2.6 CHAPTER CONSIDERATIONS

Based on the literature review, it was possible to understand the relationship between the industrial motor system and energy efficiency. In this way, industries need suitable tools to support their strategies to meet energy efficiency regulations and promote energy gains. Among the decision support tools, it is possible to highlight the multicriteria methods that support decision-makers in finding acceptable solutions in conflicting situations for complex problems. To obtain robust results, it is necessary to properly elicit the preferences of the decision-makers, in addition, it is important to articulate the sectors of the industry to understand the criteria and alternatives of the problem, and thus appropriately select the multicriteria method and approach to be used

Also, another useful decision tool to reach an agreement through complex issues and different intervals of resolution options is negotiation. The multicriteria methods are shown to be useful tools to support the negotiation processes, mainly for evaluating the negotiation packages. The majority of methods that use holistic approaches are based on linear programming problems and present good computational efficiency. However, the algorithms of these methods present their own particularities of its usage, then the mediator needs to be aware of the characteristics of these methods to reduce holistic scoring systems inaccuracies when possible making the modifications in the negotiation model when necessary. In general, the holistic approaches when used in a negotiation context can allow a better assessment of negotiation offers under an ill-structured problem and reduce the negotiators' cognitive effort during the negotiation process by assessing his indirect preference information from global preferences.

Also, using relevant databases, a systematic review was carefully carried through 154 journal papers to study holistic approaches or related concepts from them. In total, 150 papers were assigned in the applied papers group and 4 papers were assigned in the literature review/overview papers group. The largest identified class of applied papers was the utility (or value) function, which includes 118 that were further categorized according to 7 subclasses. The UTA-based methods subclass represents the most used holistic approaches in the research; UTADIS and UTASTAR are the most used in this field. Moreover, the papers were classified according to the journal of publication, year of publication and the distribution by holistic approach vs. context of application. With respect to the context of application, financial management is the most-researched problem.

As this theme has not been much discussed in this context, this chapter has contributed to the literature by integrating knowledge from studies on energy efficiency, motor system, Brazil's motor replacement policy, multicriteria decision analysis, negotiation and the use of holistic approaches to support the negotiation process. Therefore, for those researchers seeking to conduct studies in this field, the outcomes of this chapter provide a good source of information to conduct studies and condenses high-quality peer-reviewed English papers available in relevant databases.

3 SUPPORTING COMPANIES TO REPLACE THEIR NON-EFFICIENT MOTORS: A FLEXIBLE AND INTERACTIVE MULTICRITERIA MODEL

This section sets out the building of a multicriteria decision model based on the FITradeoff procedure to solve a company's motor replacement problem. The studied company is located in the city of Ponta Grossa, Paraná (Brazil).

The industrial plant is powered by 380v and 150kW of average power consumed by the motor system, which represents about 80% of the total demand consumed. Voltage imbalance, that is, the difference between voltages in the three phases of the network, shows a variation of 2%, significantly below the recommended maximum of 10% to avoid electrical losses and operational problems. This shows the loss of energy efficiency in the company, it consumes a considerable amount of energy and has difficulty in meeting minimum levels of energy efficiency with their current motors.

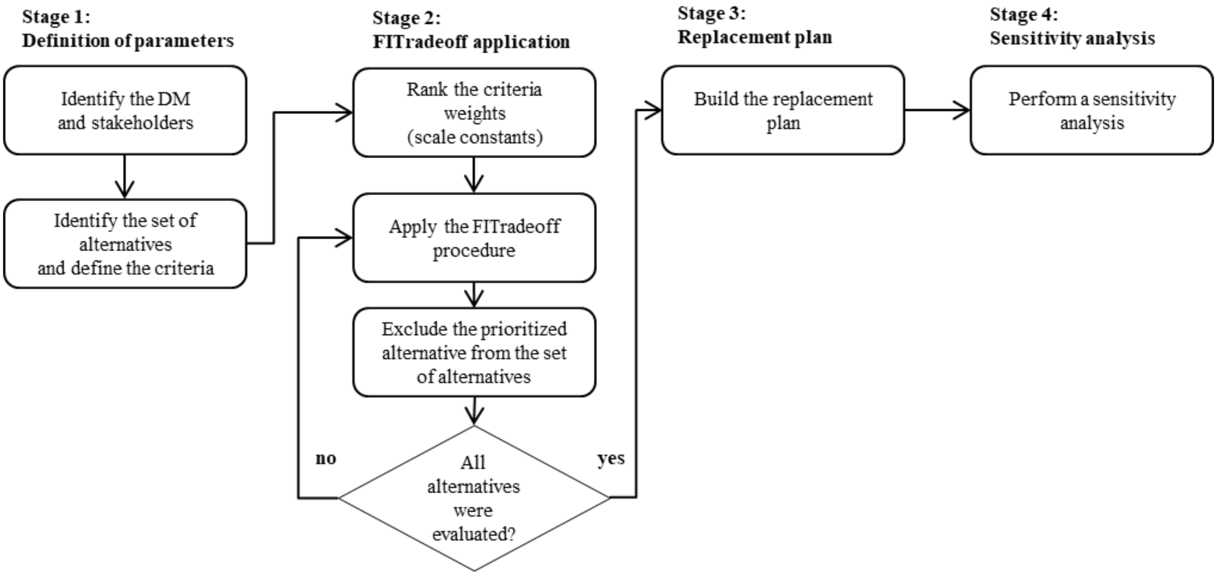
In addition, the company imposed two restrictions to develop this study: the available time for the application and the available budget for the replacement.

3.1 PROPOSED MODEL AND APPLICATION

The problem that is to be addressed is to build a motor replacement plan to fulfill the Brazilian Energy Efficiency Law, providing a minimum energy performance standard for energy-using equipment. For modeling this decision problem in a flexible, interactive, fast and efficient way, the knowledge level of the problem, the available information and organizational interest were considered. In addition, it was observed the principles of broad participation of the sectors involved, commitment, multidisciplinary, and data accuracy.

To reduce the DM's cognitive effort, time spent, inconsistencies and provide a more robust solution, the multicriteria decision model was proposed (Figure 6), which requires less information from the DM. In addition, it associates the inaccuracy of information to refine the results by means of a sensitivity analysis.

Figure 6 – Multicriteria model for motor replacement problem



Source: Macedo *et al.* (2018).

a) Stage 1: Definition of parameters.

In the first step of the model, the analyst responsible for conducting the interactive decision process identifies the DM and the stakeholders. In this problem, the DM is the industrial director of the company. The stakeholders involved in the decision problem are the managers of the production, maintenance and financial sectors that contribute by providing pertinent information for the motor replacement problem due to their daily routine, as specialists who can help with criteria and alternatives definition.

The second step is to identify the set of alternatives and criteria to be evaluated. The DM listed twenty motors as alternatives owing to their non-compliance with Brazilian Energy Efficiency Law. Thus, the set of alternatives is A = {Motor 1; Motor 2; Motor 3; Motor 4; Motor 5; Motor 6; Motor 7; Motor 8; Motor 9; Motor 10; Motor 11; Motor 12; Motor 13; Motor 14; Motor 15; Motor 16; Motor 17; Motor 18; Motor 19; Motor 20}.

Due to a lack of information and an adequate energy management system, it may be difficult to measure technical, financial and environmental criteria, to improve energy efficiency. However, there are three ways to measure the criteria, i.e. using natural, proxy and constructed attributes. The natural attribute directly measures the objective and generally is the most used metric for having common sense in its interpretation. The proxy attribute, despite sharing qualities of the natural attribute, does not directly measure the objective of the decision and it is used when it is difficult to select or measure the natural attribute. When it is not possible to obtain one of these two attributes, it is suggested to develop a measurement capable of indirectly measuring the objective, that is, the constructed attribute (KEENEY, 1992).

From a technical perspective, motors outside the specifications reduce the efficiency, useful life and negatively affects the saved amount of energy and motors in operation with high stop rates located in critical parts of the industrial process affects the process reliability due to failures or high product rejection rates (DOE, 2008; LUNG; MCKANE; OLSZEWSKI, 2005; MCCOY; DOUGLASS, 2000; NEMA, 2001). To represent the technical perspective, the DM chose four criteria: years in use, rewinding, number of failures and importance to production.

a) Years in use - reflects the running time of the motor. Preventive maintenance can extend motor life, but there is a loss of efficiency, so older motors should be prioritized for replacement. Information about the criterion is obtained from the maintenance sector.
b) Rewinding - indicates how many times the motor has undergone the rewinding process as the result of burning processes, usually due to overheating. This process reduces motor efficiency. Information obtained from the maintenance sector.
c) Number of failures - indicates the number of problems presented by the motor that caused stops of the machines, delaying the production process. The information was obtained from the maintenance sector.
d) Importance to production - reflects the degree of importance of the motor in the production system. It is defined by a constructed scale of 0 (least important) to 10 (most important) for motors located in critical parts of the production process. Information obtained from the production sector.

Owing to the link between sustainable development and the energy system (LIU et al., 2012), some criteria can be used to represent the environmental impact of non-efficient motors, such as greenhouse gas (GHG) emissions or GHG emission removal. However, due to the available information to assess the environmental impact, the stakeholders suggested the DM use technical data such as motor power (P_{HP}) and the motor load (γ).

a) Motor power - reflects the current power factor of the motor. One horsepower (HP) is equal to 0.746 kilowatts (kW). The higher the motor power, the greater the amount of energy saved by replacing the motor with a more efficient one. By means of this criterion, it is possible to estimate the reduction in the emission of carbon dioxide (CO_2) in the environment. Information obtained from the maintenance sector.

b) Motor load - indicates the loss of efficiency, considering the electric current, the nominal electric current and the electric current in a vacuum. When the engine runs at a higher power than is required to perform a task, it has a low load, which implies loss of power. This criterion allows the estimation of the reduction in the emission of CO_2 in the environment. Information obtained with the maintenance sector.

The value of the motor load (γ) is obtained through equation (14) and considers the motor real electrical current measured (I_R), the nominal electrical current (I_N) and the electrical current in the vacuum (I_O) (SOLA; XAVIER, 2007). Also, the α parameter of the electrical current curve is calculated according to equation (15). When the motor works with power much higher than necessary to perform the task, it presents low loading, implying loss of energy (SOLA; MOTA; KOVALESKI, 2011).

$$\gamma = 1 + \frac{1}{\alpha} ln\left(\frac{I_R}{I_N}\right) \quad (14)$$

$$\alpha = -ln\left(\frac{I_O}{I_N}\right) \quad (15)$$

Employing motor power and motor load criteria, it is possible to estimate the reduction in the emission of CO_2 in the environment by means of the Quantity of Energy Saved (QES) with the motor replacement, given by equation (16). The higher the motor power (P_{HP}) and the motor load (γ), the greater the QES. Consequently, by reducing energy consumption, there will be a reduction of GHG emission according to a valid conversion metric used by the International Energy Agency (GARCIA et al., 2007; IEA, 2010). In Brazil, the conversion metric is a reduction of 0.73 kg of carbon dioxide for each kW per hour consumed.

$$\text{QES} = \left[0.746 \cdot P_{HP} \cdot \gamma \cdot \left(\frac{1}{\eta_R} - \frac{1}{\eta_A}\right) \cdot t\right] \text{ kWh/yr} \quad (16)$$

Where η_R is the efficiency of the current motor in operation, defined as a ratio between the output power and the current power consumed (P_R), given by equation (17); η_A is the efficiency of a new motor given by the supplier; and *t* is the motor operation time (h/yr) (MCCOY; DOUGLASS, 2000).

$$\eta_R = \left(\frac{P_{Out}}{P_{In}}\right) = \frac{746 \cdot P_{HP} \cdot \gamma}{P_R} \ (\%) \quad (17)$$

With regard to financial reasons, is not interesting to consider only the Motor Investment Value (MIV) because the energy saved could be lower. A less expensive motor normally implies lower efficiency (GARCIA et al., 2007). In this way, the DM chose the criteria Net Present Value (NPV).

a) NPV - indicates the difference between the present value of the cash inflows and the present value of the cash outflows (LUNG; MCKANE; OLSZEWSKI, 2005; NEMA, 2001).

The values of NPV were estimated by the financial sector, considering a useful motor life equal to 15 years, with an interest rate of 12% per year and a constant energy cost per kilowatt-hour of R$0.55. Therewith, regarding the set of criteria to evaluate the alternatives, the DM, together with the stakeholders, defined seven criteria summarized in Table 4.

Table 4 – Selected criteria

Criteria	Unit	Objective	Attribute type
Years in use	Years	Maximize	Natural
Rewinding	Unit	Maximize	Natural
Number of failures	Unit/Year	Maximize	Natural
Importance to production	Grade	Maximize	Constructed
Motor power (P_{HP})	HP	Maximize	Natural
Motor load (γ)	%	Minimize	Natural
Net Present Value (NPV)	R$	Maximize	Natural

Source: Macedo *et al.* (2018).

To assist the energy efficiency analysis with the motor replacement, the analyst collected some information from the company’ suppliers regarding the potential alternatives, such as the electrical current in the vacuum (I_O), the nominal electrical current (I_N), the efficiencies (η_A) and investment values (MIV) for new motors. Furthermore, to obtain the efficiency of current motor in operation (η_R), the analyst measured the real electrical current (I_R) and the current power consumed (P_R) via a digital instrument able to measure active power, reactive power, power factor, voltage and electrical current.

At this point, it is possible to build the decision matrix with the performance of each alternative evaluated with respect to each criterion, as summarized in Table 5.

Table 5 – Decision matrix of the motor replacement problem

Criteria/ Alternative	Years in use	Rewinding	Number of failures	Importance to production	Motor load	Motor power	NPV
Motor 1	5	2	1	5	22	10	8,872
Motor 2	5	1	0.5	5	79	15	52,440
Motor 3	2	0	0	10	17	12.5	859
Motor 4	2	0	0	10	20	12.5	5,039
Motor 5	2	0	0	10	84	50	78,104
Motor 6	40	5	1	10	35	7.5	18,017
Motor 7	5	0	0	5	83	20	60,574
Motor 8	4	0	0	8	98	7.5	7,328
Motor 9	7	1	0.5	7	20	5	2,252
Motor 10	10	1	0.5	9	24	7.5	10,342
Motor 11	1	0	0	10	30	12.5	3,243
Motor 12	1	0	0	10	17	10	1,120
Motor 13	1	0	0	10	50	30	34,975
Motor 14	4	2	1	10	104	40	122,638
Motor 15	7	2	1	8	32	10	15,981
Motor 16	1	2	1	5	72	7.5	12,777
Motor 17	10	0	0	9	69	7.5	5,247
Motor 18	7	0	0	8	76	7.5	5,685
Motor 19	8	0	0	7	21	10	4,323
Motor 20	7	1	1	7	42	5	11,312

Source: Macedo *et al.* (2018).

b) Stage 2: FITradeoff application.

An important issue to point out here is one of the challenges of the decision-making problem, the DM's preference modeling and the incorporation of these preferences in the decision model (FIGUEIRA; GRECO; EHRGOTT, 2005; KEENEY, R.L.; RAIFFA, 1976). Thus, considering compensatory rationality, evaluating twenty alternatives in view of seven criteria makes this decision-making problem reasonably complex for preference modeling. However, the number of alternatives is not a relevant issue for FITradeoff procedure, because at the beginning of the FITradeoff process, the number of potentially optimal alternatives is reduced to between one and seven in more than 95% of cases based on simulations conducted (DE ALMEIDA-FILHO; DE ALMEIDA; COSTA, 2017).

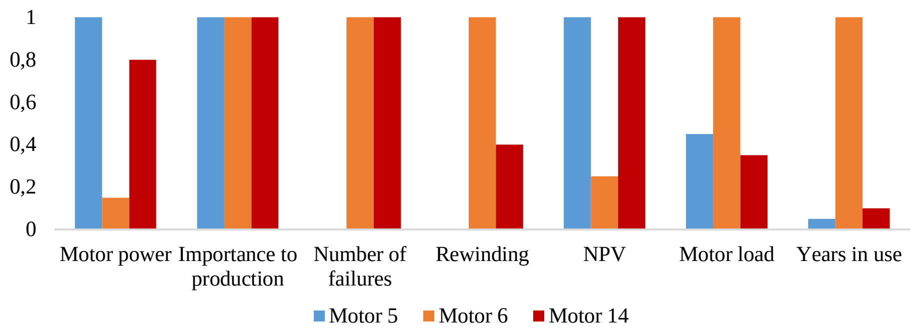
In the second stage of the application, the analyst conducted the preference modeling with the DM using FITradeoff (choice version), a successive refinement procedure, because it presents ways of dealing with some inconsistencies and complexities observed in the traditional tradeoff procedure (DE ALMEIDA et al., 2016). This stage was conducted by means of a DSS to assist the evaluation to prioritize the replacement of the alternatives. The DSS used in this application is available for download on request at htpp://fitradeoff.org/.

In this way, the third step of the model presented in Figure 6 consists of ranking criteria weights (scale constants), considering the DM's preferences. The DM holistically assessed the criteria to rank them according to his preference. The order obtained by the DM was:

(C1)$K_{MotorPower}$ > (C2)$K_{ImportanceToProduction}$ > (C3)$K_{NumberOfFailures}$ > (C4)$K_{Rewinding}$ > (C5)K_{NPV} > (C6)$K_{MotorLoad}$ > (C7)$K_{YearsInUse}$. At this point, the fourth stage of the model consists in applying the FITradeoff procedure (Figure 1). Following the FITradeoff heuristic, the LPP model is run to look for potentially optimal alternatives in the current space of weights, minimizing the number of questions asked to the DM.

From the twenty alternatives of the problem, there were three potential alternatives (Motors 5, 6 and 14) to occupy the first position in the replacement plan (see Figure 7). The bars represent the performance of the alternatives in each criterion.

Figure 7 – Partial result chart of non-dominated alternatives



Source: Macedo *et al.* (2018).

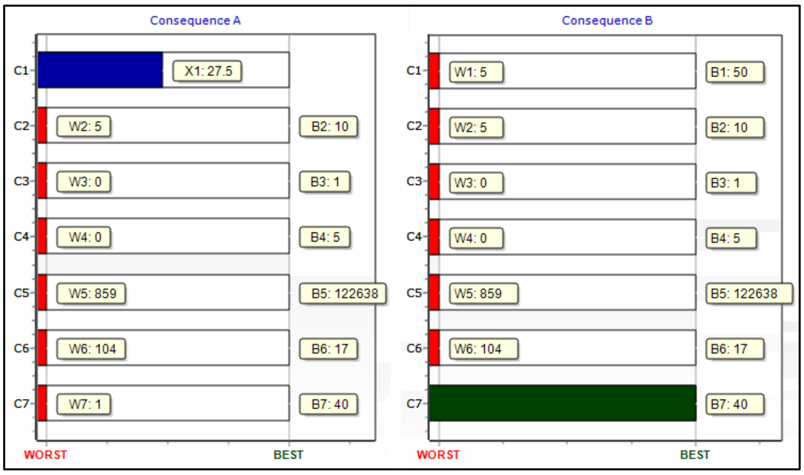
These three alternatives are technically tied in terms of *Importance to production* criterion. However, Motor 5 has an advantage over Motor 6 and Motor 14 in the *Motor power* criterion, whose scale constant is more attractive for the DM.

If the DM chooses to make a decision by evaluating the partial result chart holistically, which characterizes the flexibility of this method. The elicitation process would close and the first alternative to be prioritized for replacement would be chosen. If the DM chooses to continue the process, the pairwise comparison of the consequences is performed to restrict the consequences' space and find the optimal alternative. For this application in a motor replacement problem, instead of holistic evaluation through the chart (Figure 7), the DM chose to continue the elicitation process, because it was still cognitively difficult for him to decide since all three alternatives had appropriate outcomes for the problem. Thus, the DSS computed a new LPP following the FITradeoff heuristic, assuming an intermediate value for one criterion and the worst value for the others as Consequence A, and the best value for one criterion and the worst value for the others as Consequence B. The DM has four possible answers for the questions made by the DSS: preference for Consequence A; preference for Consequence B;

indifference between these two consequences; or not answer the comparison, so the model computes another question with no loss of information.

In this problem, as the first question put for the DM by the DSS was the following: Consequence A, with 27.5 HP value for the Motor Power criterion and worst value for the others, and Consequence B, with the best outcome for Years in Use, which is 40 years according to Table 3, and the worst outcome for the other criteria, as illustrated in Figure 8. The red bars W_i represents the worst outcome of criterion C_i, the blue bar X_i represents an outcome in between the best and worst of criterion C_i and B_i represents the best outcome of criterion C_i.

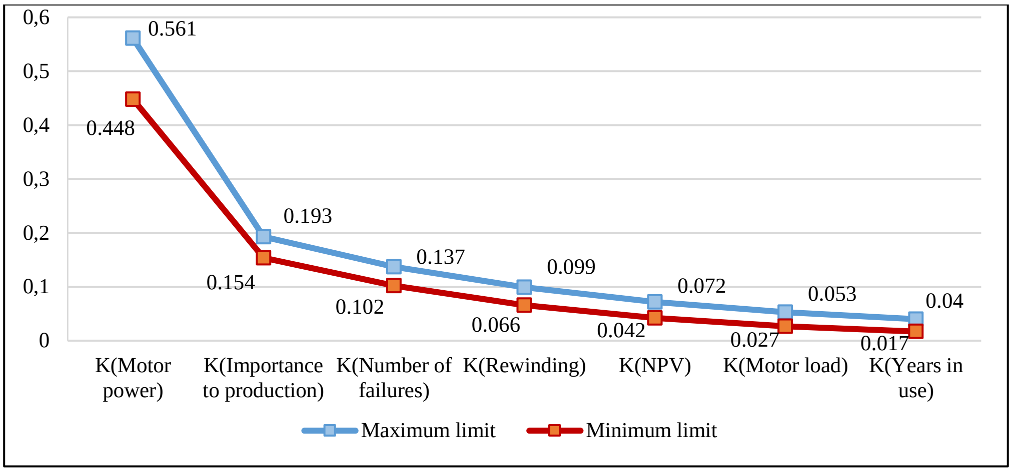
Figure 8 – Comparative chart of non-dominated alternatives



Source: Macedo *et al.* (2018).

Thus, the DM answered the first elicitation question, and the set of potentially optimal alternatives remained the same: Motors 5, 6 and 14. After answering some other comparisons and analyzing the partial result charts, a unique solution was found: Motor 14. The weight space obtained with this application is illustrated in Figure 9, represented by the maximum and minimum limits for each scaling constant. This means that for any set of weight vectors within this space, the overall value of the alternative (Motor 14) is greater than the overall value of the other alternatives, justifying the choice of this alternative as the replacement.

Figure 9 – Weight space obtained by the FITradeoff procedure



Source: Macedo *et al.* (2018).

The fifth step of the model excludes the prioritized alternative from the set of alternatives and performs the FITradeoff procedure with the remaining alternatives until all were prioritized to build the replacement plan. Thus, the replacement of the motors should start with Motor 14, followed by Motor 5, Motor 13, Motor 6, Motor 15, Motor 4, Motor 3, Motor 11, Motor 10, Motor 12, Motor 1, Motor 20, Motor 2, Motor 7, Motor 16, Motor 17, Motor 9, Motor 19, Motor 18, Motor 8.

c) Stage 3: Replacement plan.

The sixth step of the proposed model consists of elaborating on a motor replacement plan respecting the restrictions imposed by the problem. Due to budget constraints and the company' strategic planning, it is not possible to replace all motors simultaneously. According to the DM, the company has a replacement budget of R$10,000 per semester.

After the installation of the new efficient motors and the return they bring to the company, the other motors will be replaced until all of them meet the Brazilian Energy Efficiency Law, the prioritization obtained can be followed or the model can be applied again. Accordingly, a replacement plan was constructed using the FITradeoff solution and evaluating the MIV of new motors obtained with the financial sector. The replacement will occur over two and a half years at a cost of R$40,890 as summarized in Table 6.

Table 6 – Replacement plan

Time	Alternatives	MIV (R$)	Total (R$)
Year 1			
First semester	Motor 14	3,540	8,490
	Motor 5	4,950	
Second semester	Motor 13	3,100	8,370
	Motor 6	1,580	
	Motor 15	1,790	
	Motor 4	1,900	
Year 2			
First semester	Motor 3	1,900	9,070
	Motor 11	1,900	
	Motor 10	1,530	
	Motor 12	1,870	
	Motor 1	1,870	
Second semester	Motor 20	1,220	9,020
	Motor 2	2,100	
	Motor 7	2,460	
	Motor 16	1,580	
	Motor 17	1,530	
Year 3			
First semester	Motor 9	1,220	5,720
	Motor 19	1,790	
	Motor 18	1,530	
	Motor 8	3,540	

Source: Macedo *et al.* (2018).

d) Stage 4: Sensitivity analysis

Due to the lack of information, sometimes it is difficult to obtain accurate data from the DM, affecting the preferences elicitation, so the last step of the proposed model consists of a sensitivity analysis to ensure the consistency of the final decision.

Through sensitivity analysis, different "what-if" scenarios can be visualized which are helpful to observe the impact of changing criteria to the obtained replacement plan. Also, it allows the analyst and DM to observe how the final evaluation is likely to change, helping in measuring the changes made by deviations in criteria consequences.

To assist the sensitivity analysis and maintain the original limits of the consequence space, the DSS checked the minimum values of the consequence space generated with the percentage variation in the sensitivity analysis cycle and assigned it the nominal minimum value, doing the same for the nominal maximum value. The FITradeoff restrictions of weight space and criteria scaling constants ranking were met and the DM preferences were maintained. For example, for a variation of *D*%, the consequence value of each alternative *j* of the problem in this criterion will have a value $S_{j,criterion}$ such that $(\rho_{\mathrm{j,criterion}}) \cdot (1 - \mathrm{D}) \leq \mathrm{S}_{\mathrm{j,criterion}} \leq (\rho_{\mathrm{j,criterion}}) \cdot (1 + \mathrm{D})$, where $\rho_{j,criterion}$ correspond to its nominal value (original consequence matrix value).

In this case, simulation of sensitivity analysis was carried out by changes on *Net Present Value* criterion which presents inaccuracy information due to market inflation conditions. For the 1000 instances simulated, it was revealed that changing the value of *Net Present Value* criterion from 15% up to 25% had no significant effect; the probability of an alternative position change is small as shown in Table 7. However, there is a great chance for a significant change to the ninth motor of the replacement plan, when this replacement could be occupied by alternatives 10 or 1. Overall, based on the sensitivity analysis, it can be concluded that the final decision is consistent and reliable.

Table 7 – Sensitivity analysis for Net Present Value criterion

Position	15%	20%	25%
1	14	14	14
2	5	5 (99.5%); 6 (0.5%)	5 (92.8%); 6 (7.2%)
3	13	13	13
4	6	6	6
5	15	15	15
6	4	4	4
7	3	3	3
8	11	11	11
9	10 (50.7%); 1 (49.3%)	10 (51%); 1 (49%)	10 (52.8%); 1 (47.2%)
10	12	12	12
11	1 (59.3%); 2 (40.7%)	1 (58.4%); 2 (41.6%)	1 (58.1%); 2 (41.9%)
12	20 (63.2%); 2 (36.8%)	20 (60.8%); 2 (39.2%)	20 (61.2%); 2 (38.8%)
13	2 (81.1%); 16 (18.8%)	2 (70.5%); 16 (29.5%)	2 (64.2%); 16 (35.8%)
14	7 (66.3%); 16 (33.7%)	7 (62.2%); 16 (37.8%)	7 (58.9%); 16 (41.1%)
15	16 (63.9%); 19 (36.1%)	16 (63.7%); 19 (36.3%)	16 (62.5%); 19 (37.5%)
16	17 (81.4%); 8 (18.6%)	17 (77%); 8 (23%)	17 (77.2%); 8 (22.8%)
17	9 (96.8%); 18 (3.2%)	9 (85.2%); 18 (14.8%)	9 (74.5%); 18 (23.5%)
18	19	19	19
19	18 (93.2%); 8 (6.8%)	18 (92.8%); 8 (7.2%)	18 (92.6%); 8 (7.4%)
20	8	8	8

Source: Macedo *et al.* (2018).

In addition, another criterion that could undergo a sensitivity analysis was the "importance for production" due to its wide scale from 1 to 10 and the subjectivity associated with it. However, to overcome this problem, a suggestion would be to reduce the range of the constructed scale.

3.2 DISCUSSION OF RESULTS

Analyzing the result obtained with the model, according to Table 6, the alternatives prioritized in stage 1 are the largest motors (high motor power) located at critical points in the production process, whereas the criteria that represent *Motor Power* and *Importance to Production* were defined by DM during preference elicitation as the most important ones. In addition, Motor 14 and Motor 5 have the highest differences in their loads, consequently, their replacement will save greater amounts of energy annually. With a joint investment of R$8,490, a total of 16,032kWh/year will be saved, replacing the motors from stage 1 to meet the energy efficiency law. Motor 14 saves 2,069 kWh/year, with an investment of R$3,540 and the return of this investment would come in approximately three years. Also, considering a conversion metric valid for Brazil as 0.73 kg of CO_2 saved for each kWh consumed (IEA, 2010), this motor replacement promotes a reduction of 598.37 kg of CO_2 per year.

By conducting a sensitivity analysis as summarized in Table 7, it was possible to observe that the first positions of the replacement plan would not change for a relatively large range of weight values, indicating that the result obtained is reasonably robust. Also, for any set of weight vectors inside the obtained weight space for each round of FITradeoff application after removal of prioritized alternative from the set of alternatives, the global value of this solution will remain the same.

It is also interesting to highlight the importance of considering a multiple criteria decision analysis to deal with a motor replacement problem, instead of randomly choosing the motors to replace. The chosen scale constants ranking affects the whole decision process, prioritizing some alternatives over others due to their different consequences' values. In the worst case, the DM's preferences will be disregarded and the wrong replacement can lead to losses at technical, environmental and financial levels, not meeting the targets set by the company, postponing the fact of fulfilling the energy efficiency law by their motors, including fines and affecting the company' budget.

For example, instead of using the original scenario for motor replacement problem that considers the multicriteria decision analysis, the DM may choose to obtain the replacement plan just considering the MIV as criterion to prioritize the motors to be replaced, opting for those with smaller investments, the replacement plan would be different, as shown in Table 8. Thus, comparing the replacement plans from the original scenario and MIV scenario, the difference ratio between them gives the DM a clear idea about the difference of considering only a financial reason, instead of taking into account a multicriteria problem.

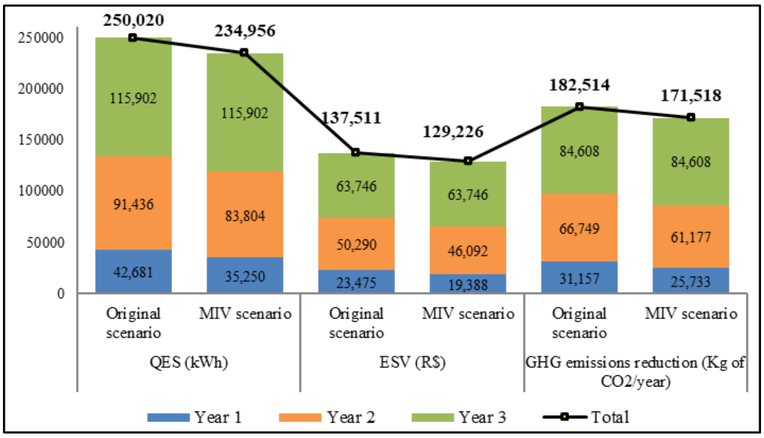
Table 8 – Comparative scenario analysis

Alternative	Original scenario plan	MIV scenario plan	Difference ratio
Motor 14	1	19	1
Motor 5	2	20	0.526
Motor 13	3	18	0.737
Motor 6	4	8	0.263
Motor 15	5	9	0.526
Motor 4	6	15	0.526
Motor 3	7	14	0.632
Motor 11	8	13	0.211
Motor 10	9	4	0.211
Motor 12	10	12	0.421
Motor 1	11	11	0
Motor 20	12	2	0.105
Motor 2	13	16	0.263
Motor 7	14	17	0.368
Motor 16	15	5	0.474
Motor 17	16	6	0.158
Motor 9	17	3	0.158
Motor 19	18	10	0.789
Motor 18	19	7	0.947
Motor 8	20	1	0.947

Source: Macedo *et al.* (2018).

Using data from this motor replacement problem, the gains in the quantity of energy saved (in kWh), energy saved value (in R$) and GHG emissions reduction per year, with the motor replacement plan application for two different scenarios, the original and the MIV ones were shown in Figure 10. Since the largest motors located in critical points of the productive process consume more energy and are the most expensive in the market, prioritizing their replacement will promote greater energy savings, and consequently the greater the reduction in the emission of GHG. Thus, considering the multicriteria problem presented in the original scenario, the gains will be higher than in the case of the second scenario which chooses to obtain the replacement plan only by a financial criterion.

Figure 10 – Gains comparison



Source: Macedo *et al.* (2018).

With regard to the applicability of the proposed model, the FITradeoff procedure did not require much cognitive effort from the DM to solve this problem. When the DM felt indifferent toward some consequences, he did not need to specify an indifference value. Unlike the traditional tradeoff procedure, in FITradeoff, the DM does not necessarily give indifference statements, but can do so if he desires because of the flexibility of this method. If the traditional tradeoff procedure was applied to solve this problem, at least 6 (number of criteria – 1) indifference statements would be mandatory to find a solution (FREJ et al., 2017).

Thus, according to the topology of the alternatives and the distribution of criteria weights, twenty-seven questions were necessary to compare the consequences between the criteria through FITradeoff Decision Support System for twenty alternatives and seven criteria. The result was a reduction in the number of questions and in the DM's cognitive effort. Lastly, companies are always looking to reduce the effort and time spent with decision-making, so this proposed model seems to be an appropriate multicriteria tool for them.

3.3 CHAPTER CONSIDERATIONS

Due to the current policies and trends towards efficient energy consumption, it is important to find tools able to handle limited information and shorten time spent on decision-making to promote energy gains and abide by current energy efficiency laws. This chapter presented an application of the FITradeoff procedure in the context of motor replacement in a chemical company, where a multicriteria model was proposed to build a replacement plan, instead of using only a financial criterion to meet the minimum energy performance standards established by the Brazilian Energy Efficiency Law. Through different types of attributes, seven criteria were selected to represent the objectives related to this problem, and twenty motors were evaluated with respect to these criteria. Within a compensatory approach, the preference modeling was conducted by the Flexible and Interactive Tradeoff (FITradeoff) procedure considering the industrial director's (DM) preferences.

The main motivation to apply this model and not the others is due to its robustness, flexibility and interactivity, allowing the information to converge in only a few iterations. Through the FITradeoff procedure, it was possible to obtain the result with less information than required in the traditional tradeoff procedure, because the procedure does not necessarily require indifferent statements, being cognitively easier for the DM during the preferences modeling, avoiding a tedious and long decision process.

The elicitation process was conducted with the DM through the FITradeoff Decision Support System. After twenty-seven questions were answered interactively by the DM, FITradeoff DSS found a solution for the problem, the alternatives were recognized by solving linear programming problems as proposed by FITradeoff. Next, a sensitivity analysis was conducted to test the robustness of the model due to criterion inaccuracy data. Later, a replacement plan was built to gradually replace the motors. This plan is divided into five stages, over two and a half years at a cost of R$40,890.

As to the management aspect, the model contributes by overcoming the barriers linked to decision-making in organizations, such as the asymmetry of information among sectors and lack of awareness for energy efficiency actions. It has promoted the broad participation of the sectors, commitment and multidisciplinary action between the sectors to align the strategic areas.

The following chapter presents a negotiation model to support power utilities and companies to reach an agreement on incentive options for replacing non-efficient motors.

4 SUPPORTING POWER UTILITIES TO MEET GOVERNMENT’S MOTOR REPLACEMENT POLICY: A HOLISTIC NEGOTIATION MODEL

Twenty years ago, the government proposed a strategy for expansion of the energy supply and promotion of the energy efficiency through the National Energy Plan 2030, however, current Brazilian market mechanisms are not sufficient to promote desirable efficiency improvements in end-use of energy (EPE, 2016).

Twenty years ago, the government proposed a strategy for expansion of the energy supply and promotion of energy efficiency through the National Energy Plan 2030, however, current Brazilian market mechanisms are not sufficient to promote desirable efficiency improvements in the end-use of energy (EPE, 2016).

To support this strategy, the Brazilian government amended the Law nº 10.295/2001, known as the Energy Efficiency Law, which established the minimum energy performance standards for energy-using technologies. However, considering that motors' lifespan and the practice of motor rewinding and reuse are common practices in Brazil, companies will continue using non-efficient motors given the lack of awareness about energy efficiency and its benefits. Therefore, companies need to assess financial implications, technical aspects and environmental impacts, encouraging the replacement of non-efficient motors by those that meet the minimum efficiency levels defined by the Law. In contrast, electric power utilities need to encourage energy efficiency programs in order to increase the company's willingness to exchange their inefficient motors. For this, the criteria considered in the projects must be attractive.

Therefore, to support Government’s motor replacement policy to meet the minimum energy performance standards established by the Brazilian Energy Efficiency Law, this section seeks to suggest an alternative to the current government-led process and increase companies' participation in this energy efficiency project by supporting the parties' individual and conflicting preferences and making incentive options more attractive.

By this way, this section proposes a negotiation model based on the ACUTA method (BOUS et al., 2010) to support a contract between a power utility and a company. This contract regards the participation of the company in the Public Call for non-efficient motors replacement, which involves different incentive options elaborated by the power utility. Through the ACUTA method, a holistic scoring system was built to support the parties in reaching a more effective agreement by identifying the most interesting combinations between different offer packages.

In this way, the ACUTA method was chosen to support the negotiation model, this indirect method is useful to calculate a unique, well-defined and central solution based on additive piecewise linear value functions compatible with a holistic evaluation of the negotiator's preferences. The concept of this method lies in the heart of interior-point methods for solving linear programming optimization problems and it is based on the principle of the analytic center of a polyhedron (BOUS et al., 2010). It benefits from theoretical advantages over the notion of centrally used in other UTA-based methods (WANG; MOUSSEAU; ZIO, 2013).

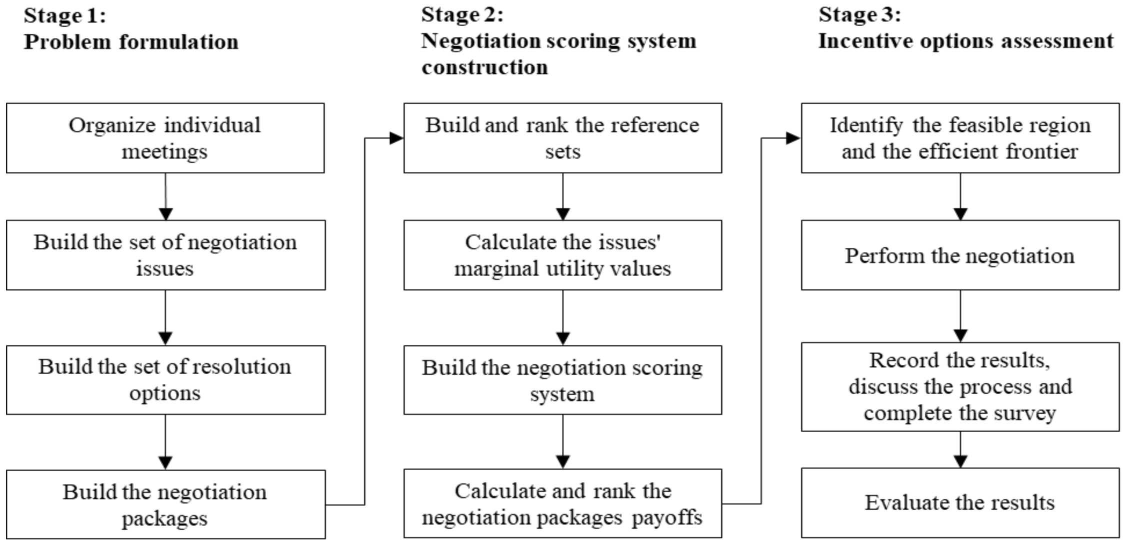
Also, ACUTA does not require the assessment of the criteria weights, it is done by holistic pairwise comparisons of negotiation packages, where the negotiator decides if one offer is better than another, evaluating the tradeoff of complete packages. The comparisons could cover different levels of the negotiation space.

4.1 PROPOSED MODEL AND APPLICATION

To analyze the complex problem of motor replacement and enabling and integrated assessment of the situation, we propose a holistic model based on the ACUTA method (BOUS et al., 2010) to identify the most interesting negotiation packages and reach an agreement, as shown in Figure 11. The model allows the power utilities to assess the companies' preferences for the incentive options of the Public Calls through a negotiation space, align these options to make them more attractive and increase the companies' participation in energy efficiency projects, allowing this way the country to reach its goal with the National Energy Plan 2030.

In addition, due to the use of an indirect elicitation method, the cognitive requirements would be minimized as well as the expectation towards the mathematical skills and decision-making knowledge of the negotiators. Consequently, the negotiation process may become more intuitive and agile.

Figure 11 – Holistic model based on ACUTA approach



Source: The author (2020).

a) Stage 1: Problem formulation

The problem formulation requires a design of the negotiation template, which is a precise definition of the structure of the negotiation problem. To do this, it is necessary to determine the set of negotiation issues and the set of resolution levels (options) for each issue before building the negotiation packages. With this information, it will be possible to define the negotiation space in a simplified way.

Initially, individual meetings were held with the parties (power utility manager and company manager) to gather all the data and facts describing the present situation between them and the essence of conflict. In this way, by grouping the issues raised by them, five negotiation issues were identified:

a) x_1 = Benefit-Cost Ratio (grade);
b) x_2 = Energy Saved (MWh);
c) x_3 = Project Duration (months);
d) x_4 = Bonus Adjustment (%);
e) x_5 = Suitability (days).

The first issue x_1, Benefit-Cost Ratio (BCR), is a parameter used by power distributors to carry out an economic evaluation of projects. In the state of Pernambuco, companies will only be eligible to participate in the government's energy efficiency incentive if they submit a proposal for motor replacement with a BCR of 0.75 or less. Additionally, they need to fulfill all commercial obligations to the power utilities and meet all parameters defined in the Public Call. Also, for BCR calculation, companies are not allowed to acquire new motors through rental or leasing, i.e. new motors to be installed must be purchased as part of the company's assets. The BCR is automatically calculated on the project registration portal and follows the methodology described in ANEEL's Energy Efficiency Program – PROPEE (Procedimentos do Programa de Eficiência Energética) (ELÉTRICA, 2018), as follows:

$$BCR = \frac{AC_T}{AB_T} \tag{18}$$

Where: AC_T = Total annualized cost (\$/year), AB_T = Annualized benefit (\$/year). Also, to obtain AC_T:

$$AC_T = \sum_n AC_n \tag{19}$$

Where: AC_n = Annualized cost of each equipment including costs related (labor, etc.) (\$/year). The AC_n is obtained by:

$$AC_n = EC_n \times \frac{TC}{EC_T} \times CRF_u \tag{20}$$

Where: EC_n= Cost of each equipment (\$), TC= Total project cost (\$), EC_T= Total equipment cost (\$), CRF_u= Capital recovery factor for *u* years (1/year), u= Equipment life (year). To obtain CRF_u:

$$CRF_u = \frac{i(1+i)^u}{(1+i)^u - 1} \tag{21}$$

Where: *i* = Discount rate. The *i* considered is the same as that specified in the National Energy Plan in force on the date of project submission.

At last, to obtain the AB_T:

$$AB_T = (AES \times EUC) + (APD \times CAD) \tag{22}$$

Where: *AES* = Annual energy saved (MWh/year), *EUC* = Energy unit cost (\$/MWh), *APD* = Avoided peak demand (kW), *CAD* = Unit cost avoided from demand (\$/kW·year). When a project is implemented for more than a year, the expenses of each year must be brought to present value at the same discount rate used in the BCR calculation.

The second issue x_2, Energy Saved, reflects an observation made regarding the construction of the previous issue. If the AB_T is not large enough to cover the AC_T of the project, the BCR will be high and will not fit the power utilities' requirements. This may limit the development of large projects, which require more investment, to promote greater energy savings. These projects may relate to the replacement of huge motors, which are usually located in strategic areas of the production process and therefore undergo frequent rewinding processes, losing energy efficiency. In addition, the power utility should pay attention in these cases, because the energy savings can be maximized and response to public calls can increase, contributing to the country's energy efficiency plan. Thereby, this issue represents the amount of energy saved with the project in MWh.

The third issue x_3, Project Duration, represents the time frame the company has to complete the replacement project. After analyzing the project and agreeing to the BCR, the power utility select the projects and the company must contract with it within 20 days. If the deadline is not met, the provisioned resources will be available to another participant. After signing the contract, the company has a period of 5 months to carry out the motor replacement project and present the documents supporting the right to the bonus. In case of non-compliance with this deadline, the agreement may be terminated by the power utility and the provisioned funds may be released to another participant without implying any right to indemnity or fines from the company. Project execution is the sole responsibility of the company.

The fourth issue x_4, Bonus Adjustment, represents a percentage adjustment in bonuses paid. Currently, the contract between the power utility and the company details the bonus that the company may receive after project execution. The values are presented according to electric motor nominal power in horse-power (HP), either three-phase motors class IR2 or IR3, or single-phase motors class IR1. Also, the bonuses are limited to replacing motors manufactured up to 2009. Based on the exchange rate for the day (1 BRL to USD = 0.246569), the minimum bonuses offered by the power utilities are shown in Table 9 below:

Table 9 – Bonus values per motor

Motor Nominal Power (HP)	Single-Phase Motors	Three-Phase Motors	
	IR 1	IR2	IR3
1	$ 61.70	$ 60.22	$ 88.85
1.5	$ 61.70	$ 60.22	$ 114.27
2	$ 77.27	$ 103.66	$ 146.36
3	$ 77.27	$ 146.85	$ 216.70
4	$ 77.27	$ 178.20	$ 269.51
5	$ 111.43	$ 193.00	$ 269.51
6	$ 111.43	$ 193.00	$ 285.06
7.5	$ 112.55	$ 193.00	$ 305.05
10	$ 112.55	$ 266.55	$ 414.64
12.5	$ 112.55	$ 283.09	$ 513.36
15	$ 135.07	$ 283.09	$ 513.36
20	$ -	$ 283.09	$ 591.11
25	$ -	$ 370.46	$ 666.38
30	$ -	$ 370.46	$ 707.11
40	$ -	$ 478.81	$ 932.19
50	$ -	$ 478.81	$ 988.47
60	$ -	$ 733.51	$ 1,276.99
75	$ -	$ 950.21	$ 1,562.54
100	$ -	$ 1,065.72	$ 1,838.47
125	$ -	$ 1,900.67	$ 2,980.95
150	$ -	$ 2,265.95	$ 3,487.65
175	$ -	$ 2,587.54	$ 3,843.30
200	$ -	$ 2,587.54	$ 3,877.36
250	$ -	$ 3,899.08	$ 5,468.53

Source: The author (2020).

At last, the fifth issue x_5, Suitability, reflects the project's nonconformity adjustment period after the inspection process. Enrollment and selection do not guarantee the company will receive the bonus. The power utility will be able to supervise the execution of the project, including pre-scheduled on-site visits, and to evaluate the information granted by the company. Currently, in case of any discrepancy between the information provided by the company upon enrollment and in the contract with that obtained during the inspection, the contract may be terminated by the distributor and the provisioned funds may be released to another company, without any right to indemnity or fines by company. Thus, by conducting the project inspection process from this new incentive perspective, allowing companies to correct non-conformities within a defined timeframe, their participation to the Brazilian energy efficiency program may increase.

Continuing the Stage 1, besides raising the negotiation issues during the meetings, each negotiator also defined its negotiation space. They declared different resolutions levels (options) for each issue, and then the information was compiled. The following space was considered for both parties (Table 10):

Table 10 – Negotiation space

Issues to negotiate	Preference direction		Negotiation space	Resolution options
	Power utility	Company		
BCR	Cost	Benefit	[0.7, 0.85]	(0.7, 0.75, 0.8, 0.85)
Energy saved	Benefit	Benefit	[25, 100]	(25, 50, 75, 100)
Project duration	Cost	Benefit	[4, 6]	(4, 5, 6)
Bonus adjustment	Cost	Benefit	[5, 7]	(5, 5.5, 6, 6.5, 7)
Suitability period	Cost	Benefit	[15, 45]	(15, 30, 45)

Source: The author (2020).

It is important to highlight that, with these options, the scoring system will consist of 720 different negotiation packages for each negotiator. Thus, for the power utility, the most desirable and undesirable packages are respectively (0.70, 100, 4, 5, 15) and (0.85, 25, 6, 7, 45), so for the company (0.85, 100, 6, 7, 45) and (0.7, 25, 4, 5, 15).

b) Stage 2: Negotiation scoring system construction.

During Stage 2, the negotiators' holistic preferences must be obtained to build a reference set from the negotiation packages. This holistic procedure is intuitive and requires a small cognitive effort from the negotiators. Since, ACUTA does not require the assessment of the criteria weights, the evaluation is made by holistic pairwise comparisons of negotiation packages. To support this holistic assessment, the negotiators need to build a reference set from the negotiation package set, by selecting some negotiation packages and ranking them from most desirable to least desirable. Then, the parties defined their own reference set of packages, as shown in Table 11.

Table 11 – Reference set of packages

Desirability	Rank	Power utility	Company
Most desirable contracts	1	(0.7, 100, 4, 5, 15)	(0.85, 100, 6, 7, 45)
	2	(0.75, 100, 4, 5, 15)	(0.85, 100, 6, 7, 30)
	3	(0.7, 100, 4, 5, 30)	(0.85, 100, 6, 6.5, 15)
	4	(0.75, 100, 5, 5.5, 15)	(0.8, 100, 6, 7, 30)
	5	(0.7, 75, 4, 5.5, 45)	(0.8, 75, 5, 6.5, 30)
Feasible contracts	6	(0.75, 75, 5, 6, 15)	(0.8, 75, 5, 6.5, 15)
	7	(0.75, 75, 5, 6, 30)	(0.75, 75, 5, 6.5, 15)
	8	(0.8, 50, 5, 6, 30)	(0.75, 50, 5, 6, 45)
	9	(0.8, 50, 5, 6.5, 30)	(0.75, 50, 5, 6, 30)
Undesirable contracts	10	(0.8, 50, 6, 6.5, 45)	(0.75, 50, 5, 5.5, 15)
	11	(0.8, 25, 6, 7, 30)	(0.75, 50, 4, 5.5, 30)
	12	(0.85, 25, 6, 7, 15)	(0.75, 25, 4, 5, 30)
	13	(0.85, 25, 6, 7, 30)	(0.7, 25, 4, 5, 30)
	14	(0.85, 25, 6, 7, 45)	(0.7, 25, 4, 5, 15)

Source: The author (2020).

After building the reference set of packages and ranking them from the most acceptable offer to the least acceptable, the next step is to structure the negotiation scoring system. For this, it is necessary to identify a value function compatible with the negotiator's preferences. The ACUTA will find a compatible set of additive value functions for the negotiation problem. For each issue, a non-decreasing marginal value function will be found, allowing to assign scores to each negotiation options. Thus, negotiation packages can be assessed using an additive value function. In addition, ACUTA allows negotiators to choose as many linear parts of the marginal utility function as they wish to model their marginal utilities. Thereby, to proceed with the model purpose, it is important to assume that the negotiators' preferences are mutually independent.

Then, with the negotiation template built, to support ACUTA method practical computations, the Diviz software (MEYER, 2012) was used, a tool based on algorithmic components, designed for executing multicriteria methods by building complex workflows. Once the execution is completed, the outputs of the different components can be visualized to support the construction of the negotiation scoring system.

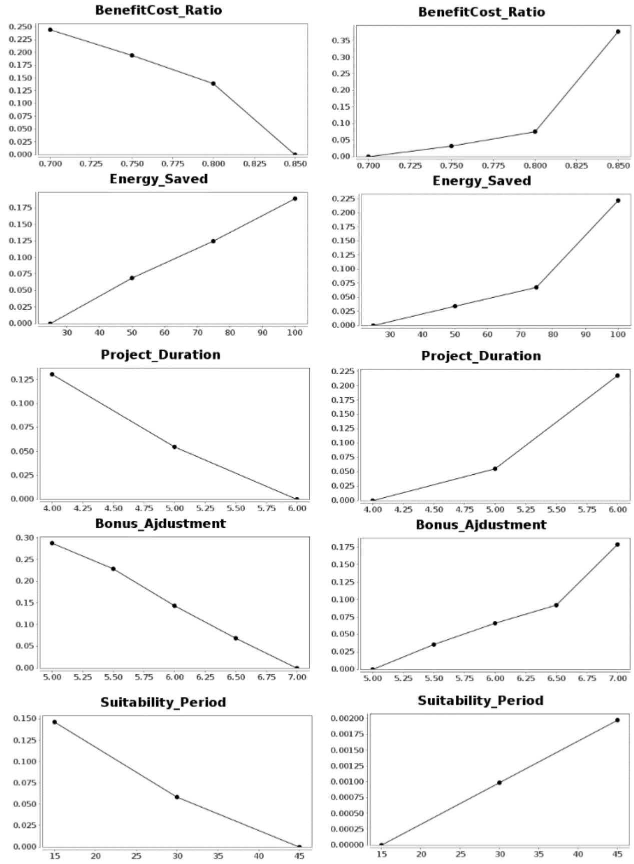
Based on the negotiation template and the issue's utility functions, ACUTA generates the marginal utility values of the corresponding issues, as shown in Table 12, and the piecewise linear marginal utility values, as shown in Figure 12.

Table 12 – Issues' marginal utility values

Issues	Option	Power utility	Company
BCR	0.7	0.24493	0
	0.75	0.19463	0.03165
	0.8	0.13929	0.07547
	0.85	0	0.37826
Energy Saved	25	0	0
	50	0.069	0.03402
	75	0.12434	0.06776
	100	0.18952	0.22254
Project Duration	4	0.1308	0
	5	0.05476	0.05521
	6	0	0.21788
Bonus Adjustment	5	0.28818	0
	5.5	0.22874	0.03526
	6	0.14306	0.06587
	6.5	0.069	0.09169
	7	0	0.17933
Suitability Period	15	0.14658	0
	30	0.05826	0.00099
	45	0	0.00198

Source: The author (2020).

Figure 12 – Piecewise linear marginal utility values



Source: The author (2020).

To conclude this stage, the negotiation scoring system allows to score all possible offers with comprehensive values by means of the global values given by the sum of the issues' marginal utility values. It allows to find out the best negotiation packages and support the negotiators to maximize their gains to reach an acceptable agreement. In the end, the parties will obtain a ranking of all negotiation packages according to their holistic preferences.

Each ranking obtained is individually integrated into the negotiation process to support the parties in choosing the most interesting negotiating packages to pursue the agreement. The 720 negotiation packages are ranked for each negotiator according to Table 13 and Table 14.

Table 13 – Negotiation packages ranking (power utility)

Rank	Package number	Package	BCR	Energy Saved	Project Duration	Bonus Adjustment	Suitability Period	Payoff
1	1	(0.7, 100, 4, 5, 15)	0.7	100	4	5	15	1.00001
2	181	(0.75, 100, 4, 5, 15)	0.75	100	4	5	15	0.94971
3	4	(0.7, 100, 4, 5.5, 15)	0.7	100	4	5.5	15	0.94057
4	46	(0.7, 75, 4, 5, 15)	0.7	75	4	5	15	0.93483
5	16	(0.7, 100, 5, 5, 15)	0.7	100	5	5	15	0.92397
6	2	(0.7, 100, 4, 5, 30)	0.7	100	4	5	30	0.91169
7	361	(0.8, 100, 4, 5, 15)	0.8	100	4	5	15	0.89437
8	184	(0.75, 100, 4, 5.5, 15)	0.75	100	4	5.5	15	0.89027
9	226	(0.75, 75, 4, 5, 15)	0.75	75	4	5	15	0.88453
10	91	(0.7, 50, 4, 5, 15)	0.7	50	4	5	15	0.87949
11	49	(0.7, 75, 4, 5.5, 15)	0.7	75	4	5.5	15	0.87539
12	196	(0.75, 100, 5, 5, 15)	0.75	100	5	5	15	0.87367
13	31	(0.7, 100, 6, 5, 15)	0.7	100	6	5	15	0.86921
14	19	(0.7, 100, 5, 5.5, 15)	0.7	100	5	5.5	15	0.86453
15	182	(0.75, 100, 4, 5, 30)	0.75	100	4	5	30	0.86139
16	61	(0.7, 75, 5, 5, 15)	0.7	75	5	5	15	0.85879
17	7	(0.7, 100, 4, 6, 15)	0.7	100	4	6	15	0.85489
18	3	(0.7, 100, 4, 5, 45)	0.7	100	4	5	45	0.85343
				⋮				
702	659	(0.85, 50, 5, 7, 30)	0.85	50	5	7	30	0.18202
703	701	(0.85, 25, 5, 6.5, 30)	0.85	25	5	6.5	30	0.18202
704	615	(0.85, 75, 5, 7, 45)	0.85	75	5	7	45	0.1791
705	718	(0.85, 25, 6, 7, 15)	0.85	25	6	7	15	0.14658
706	714	(0.85, 25, 6, 6, 45)	0.85	25	6	6	45	0.14306
707	540	(0.8, 25, 6, 7, 45)	0.8	25	6	7	45	0.13929
708	672	(0.85, 50, 6, 6.5, 45)	0.85	50	6	6.5	45	0.138
709	690	(0.85, 25, 4, 7, 45)	0.85	25	4	7	45	0.1308
710	674	(0.85, 50, 6, 7, 30)	0.85	50	6	7	30	0.12726
711	716	(0.85, 25, 6, 6.5, 30)	0.85	25	6	6.5	30	0.12726
712	630	(0.85, 75, 6, 7, 45)	0.85	75	6	7	45	0.12434
713	660	(0.85, 50, 5, 7, 45)	0.85	50	5	7	45	0.12376
714	702	(0.85, 25, 5, 6.5, 45)	0.85	25	5	6.5	45	0.12376
715	704	(0.85, 25, 5, 7, 30)	0.85	25	5	7	30	0.11302
716	675	(0.85, 50, 6, 7, 45)	0.85	50	6	7	45	0.069
717	717	(0.85, 25, 6, 6.5, 45)	0.85	25	6	6.5	45	0.069
718	719	(0.85, 25, 6, 7, 30)	0.85	25	6	7	30	0.05826
719	705	(0.85, 25, 5, 7, 45)	0.85	25	5	7	45	0.05476
720	720	(0.85, 25, 6, 7, 45)	0.85	25	6	7	45	0

Source: The author (2020).

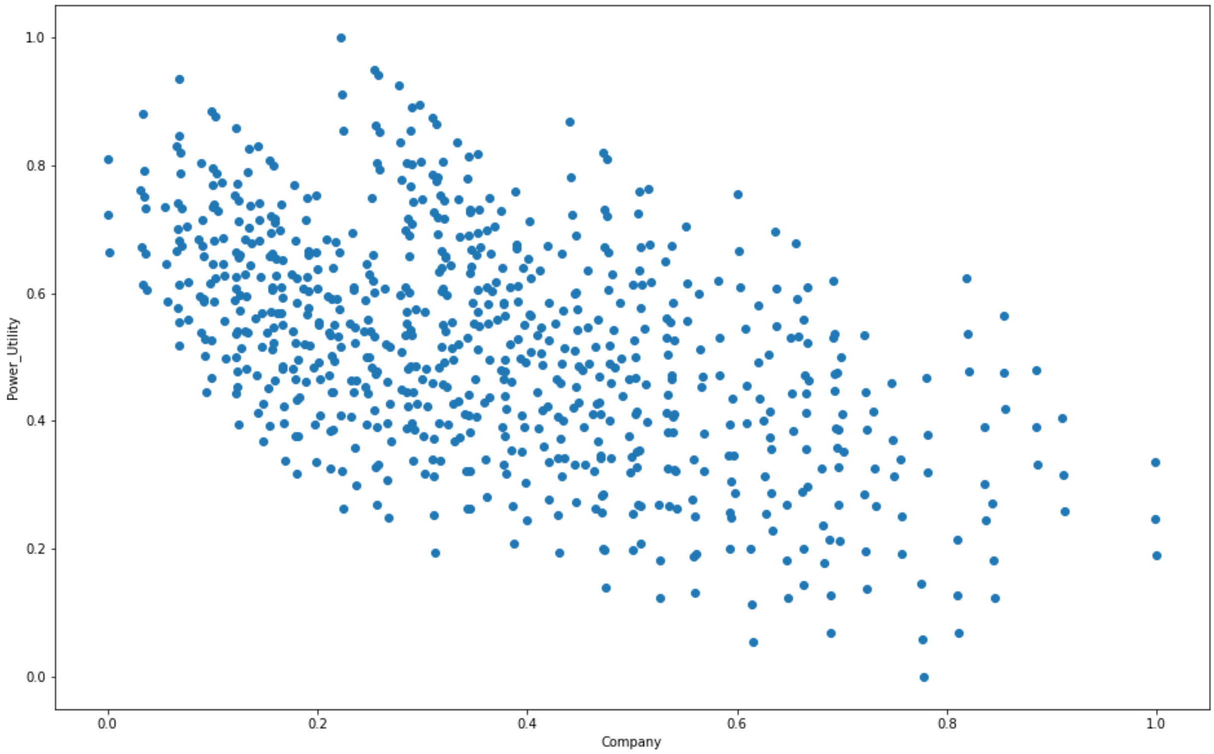
Table 14 – Negotiation packages ranking (company)

Rank	Package number	Package	BCR	Energy Saved	Project Duration	Bonus Adjustment	Suitability Period	Payoff
1	585	(0.85, 100, 6, 7, 45)	0.85	100	6	7	45	0.99999
2	584	(0.85, 100, 6, 7, 30)	0.85	100	6	7	30	0.999
3	583	(0.85, 100, 6, 7, 15)	0.85	100	6	7	15	0.99801
4	582	(0.85, 100, 6, 6.5, 45)	0.85	100	6	6.5	45	0.91235
5	581	(0.85, 100, 6, 6.5, 30)	0.85	100	6	6.5	30	0.91136
6	580	(0.85, 100, 6, 6.5, 15)	0.85	100	6	6.5	15	0.91037
7	579	(0.85, 100, 6, 6, 45)	0.85	100	6	6	45	0.88653
8	578	(0.85, 100, 6, 6, 30)	0.85	100	6	6	30	0.88554
9	577	(0.85, 100, 6, 6, 15)	0.85	100	6	6	15	0.88455
10	576	(0.85, 100, 6, 5.5, 45)	0.85	100	6	5.5	45	0.85592
11	575	(0.85, 100, 6, 5.5, 30)	0.85	100	6	5.5	30	0.85493
12	574	(0.85, 100, 6, 5.5, 15)	0.85	100	6	5.5	15	0.85394
13	630	(0.85, 75, 6, 7, 45)	0.85	75	6	7	45	0.84521
14	629	(0.85, 75, 6, 7, 30)	0.85	75	6	7	30	0.84422
15	628	(0.85, 75, 6, 7, 15)	0.85	75	6	7	15	0.84323
16	570	(0.85, 100, 5, 7, 45)	0.85	100	5	7	45	0.83732
17	569	(0.85, 100, 5, 7, 30)	0.85	100	5	7	30	0.83633
18	568	(0.85, 100, 5, 7, 15)	0.85	100	5	7	15	0.83534
					⋮			
702	143	(0.7, 25, 4, 6, 30)	0.7	25	4	6	30	0.06686
703	272	(0.75, 50, 4, 5, 30)	0.75	50	4	5	30	0.06666
704	142	(0.7, 25, 4, 6, 15)	0.7	25	4	6	15	0.06587
705	271	(0.75, 50, 4, 5, 15)	0.75	50	4	5	15	0.06567
706	153	(0.7, 25, 5, 5, 45)	0.7	25	5	5	45	0.05719
707	152	(0.7, 25, 5, 5, 30)	0.7	25	5	5	30	0.0562
708	151	(0.7, 25, 5, 5, 15)	0.7	25	5	5	15	0.05521
709	141	(0.7, 25, 4, 5.5, 45)	0.7	25	4	5.5	45	0.03724
710	140	(0.7, 25, 4, 5.5, 30)	0.7	25	4	5.5	30	0.03625
711	93	(0.7, 50, 4, 5, 45)	0.7	50	4	5	45	0.036
712	139	(0.7, 25, 4, 5.5, 15)	0.7	25	4	5.5	15	0.03526
713	92	(0.7, 50, 4, 5, 30)	0.7	50	4	5	30	0.03501
714	91	(0.7, 50, 4, 5, 15)	0.7	50	4	5	15	0.03402
715	318	(0.75, 25, 4, 5, 45)	0.75	25	4	5	45	0.03363
716	317	(0.75, 25, 4, 5, 30)	0.75	25	4	5	30	0.03264
717	316	(0.75, 25, 4, 5, 15)	0.75	25	4	5	15	0.03165
718	138	(0.7, 25, 4, 5, 45)	0.7	25	4	5	45	0.00198
719	137	(0.7, 25, 4, 5, 30)	0.7	25	4	5	30	0.00099
720	136	(0.7, 25, 4, 5, 15)	0.7	25	4	5	15	0

Source: The author (2020).

Also, to understand the preferences of the negotiators, a graph was built with the distribution of packages conveying their utility values, from the most attractive to the least attractive, as Figure 13 shows:

Figure 13 – Graph of negotiation packages (payoffs)



Source: The author (2020).

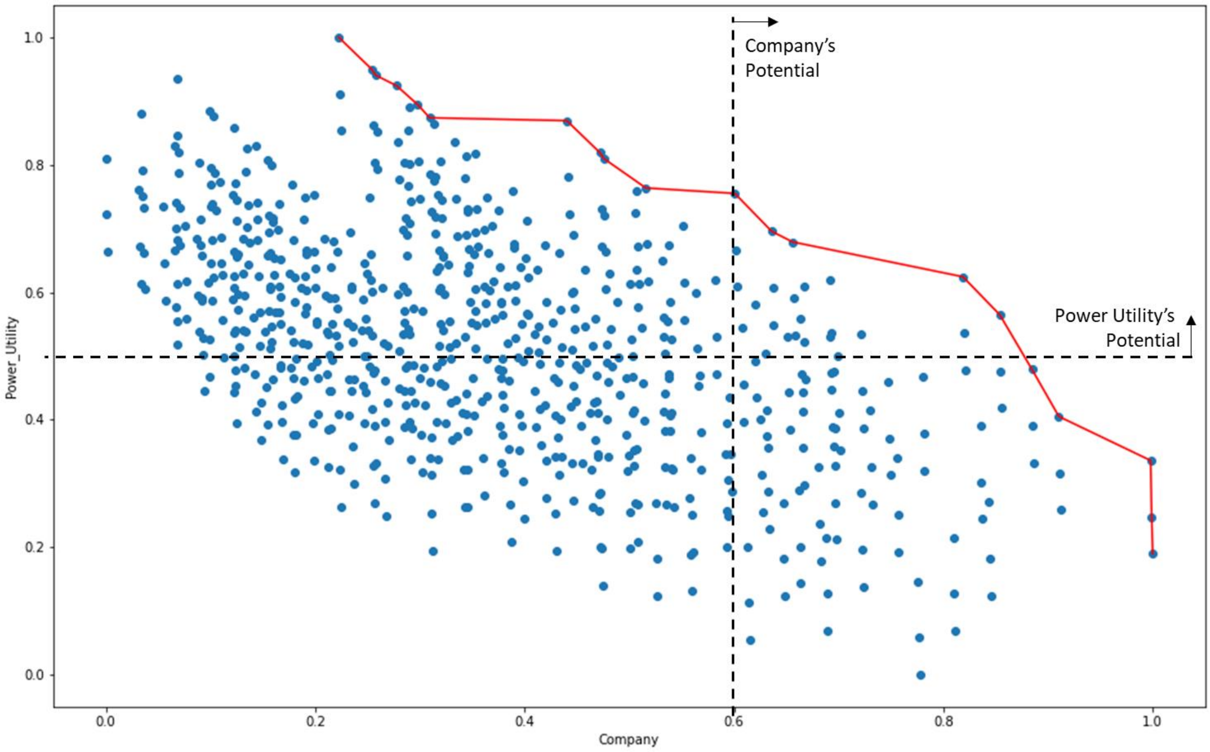
c) Stage 3: Incentive options assessment

In Stage 3, the negotiators start the negotiation process to reach an agreement. To support them, the model reduces the negotiators' cognitive effort to understand which negotiation offers are most attractive to maximize their gains, by individually providing negotiation packages rankings and their respective utilities.

After the holistic formulation of the problem and the construction of the negotiation scoring system, an integrative negotiation process between the parties was conducted to reach an agreement that could meet the parties' requirements in the presence of a conflict of interest and limited information. However, before starting the negotiation, to enable the parties to strategically explore a better deal, the proposed model suggests setting up a reservation level (RES_u) that will reduce the region of viable packages for negotiation.The RES_u is the utility value subjectively defined by the negotiator below which the settlement is unacceptable. At this time, the parties requested assistance to support this decision and after discussing individually with the mediator, derived from both BATNA's, the company chose to work with a reservation value of 0.4 and the power utility with 0.5.

Thus, the power utility will have 387 packages with a utility range [0.5001, 1] to negotiate with the company, which has 111 packages with a utility range [0.6008, 1]. Taken together, the number of viable negotiation packages was reduced to 23 packages, a 96,8% reduction in inefficient concessions (Figure 14). The maximum joint payoff obtainable is 1.4430 and the minimum is 1.134. However, negotiators are unaware of each other's payoff, which will allow bids and counter bids to be made until they reach an attractive deal for both. This process is also known as the dance of packages. Besides that, the model suggests feasible negotiation packages for each negotiator, allowing them to get the maximum payoff from their packages.

Figure 14 – Feasible region and the efficient frontier



Source: The author (2020).

The packages closest to the efficient frontier have the largest joint payoffs. Among the packages of the feasible region stand out (Table 15):

Table 15 – Closest packages to the efficient frontier

Rank	Package number	Package	Power utility payoff	Company payoff	Joint payoff (JP)	Difference from the most valuable JP
1	571	(0.85; 100; 6; 5; 15)	0.62428	0.81868	1.44296	0
2	574	(0.85; 100; 6; 5.5; 15)	0.56484	0.85394	1.41878	0.02418
3	541	(0.85; 100; 4; 5; 15)	0.75508	0.6008	1.35588	0.08708
4	572	(0.85; 100; 6; 5; 30)	0.53596	0.81967	1.35563	0.08733
5	556	(0.85; 100; 5; 5; 15)	0.67904	0.65601	1.33505	0.10791
6	544	(0.85; 100; 4; 5.5; 15)	0.69564	0.63606	1.3317	0.11126
7	559	(0.85; 100; 5; 5.5; 15)	0.6196	0.69127	1.31087	0.13209
8	547	(0.85; 100; 4; 6; 15)	0.60996	0.66667	1.27663	0.16633
9	542	(0.85; 100; 4; 5; 30)	0.66676	0.60179	1.26855	0.17441
10	562	(0.85; 100; 5; 6; 15)	0.53392	0.72188	1.2558	0.18716
11	557	(0.85; 100; 5; 5; 30)	0.59072	0.657	1.24772	0.19524
12	545	(0.85; 100; 4; 5.5; 30)	0.60732	0.63705	1.24437	0.19859
13	550	(0.85; 100; 4; 6.5; 15)	0.5359	0.69249	1.22839	0.21457
14	560	(0.85; 100; 5; 5.5; 30)	0.53128	0.69226	1.22354	0.21942
15	616	(0.85; 75; 6; 5; 15)	0.5591	0.6639	1.223	0.21996
16	543	(0.85; 100; 4; 5; 45)	0.6085	0.60278	1.21128	0.23168
17	43	(0.7; 100; 6; 7; 15)	0.58103	0.61975	1.20078	0.24218
18	558	(0.85; 100; 5; 5; 45)	0.53246	0.65799	1.19045	0.25251
19	548	(0.85; 100; 4; 6; 30)	0.52164	0.66766	1.1893	0.25366
20	546	(0.85; 100; 4; 5.5; 45)	0.54906	0.63804	1.1871	0.25586
21	223	(0.75; 100; 6; 7; 15)	0.53073	0.6514	1.18213	0.26083
22	400	(0.8; 100; 6; 6.5; 15)	0.54439	0.60758	1.15197	0.29099
23	661	(0.85; 50; 6; 5; 15)	0.50376	0.63016	1.13392	0.30904

Source: The author (2020).

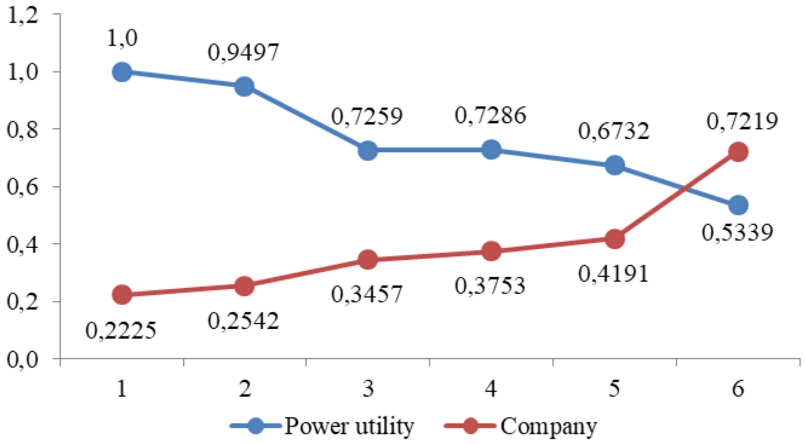
After the definition of the RES_u, negotiators started concessions in search of an agreement. The holistic model suggests packages that maximize their joint gains, however, the parties' individual preferences will lead to an agreement or not. Table 16 shows the concessions made in this negotiation and the individual points of view of this process in Figures 15 and 16.

Table 16 – Negotiation concessions

Concession		Package number	BCR	Energy Saved	Project Duration	Bonus Adjustment	Suitability Period	Payoff
1	Power utility	1	0.7	100	4	5	15	1.00001
	Company	585	0.85	100	6	7	45	0.99999
2	Power utility	181	0.75	100	4	5	15	0.94971
	Company	570	0.85	100	5	7	45	0.83732
3	Power utility	200	0.75	100	5	5.5	30	0.72591
	Company	565	0.85	100	5	6.5	15	0.7477
4	Power utility	202	0.75	100	5	6	15	0.72855
	Company	563	0.85	100	5	6	30	0.72287
5	Power utility	382	0.8	100	5	6	15	0.67321
	Company	575	0.85	100	6	5.5	30	0.8549
6	Power utility	562	0.85	100	5	6	15	0.53392
	Company	562	0.85	100	5	6	15	0.72188

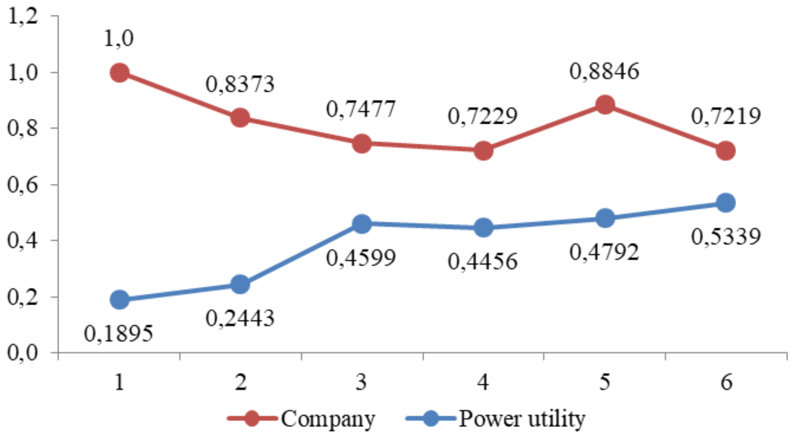
Source: The author (2020).

Figure 15 – Concession path – power utility viewpoint



Source: The author (2020).

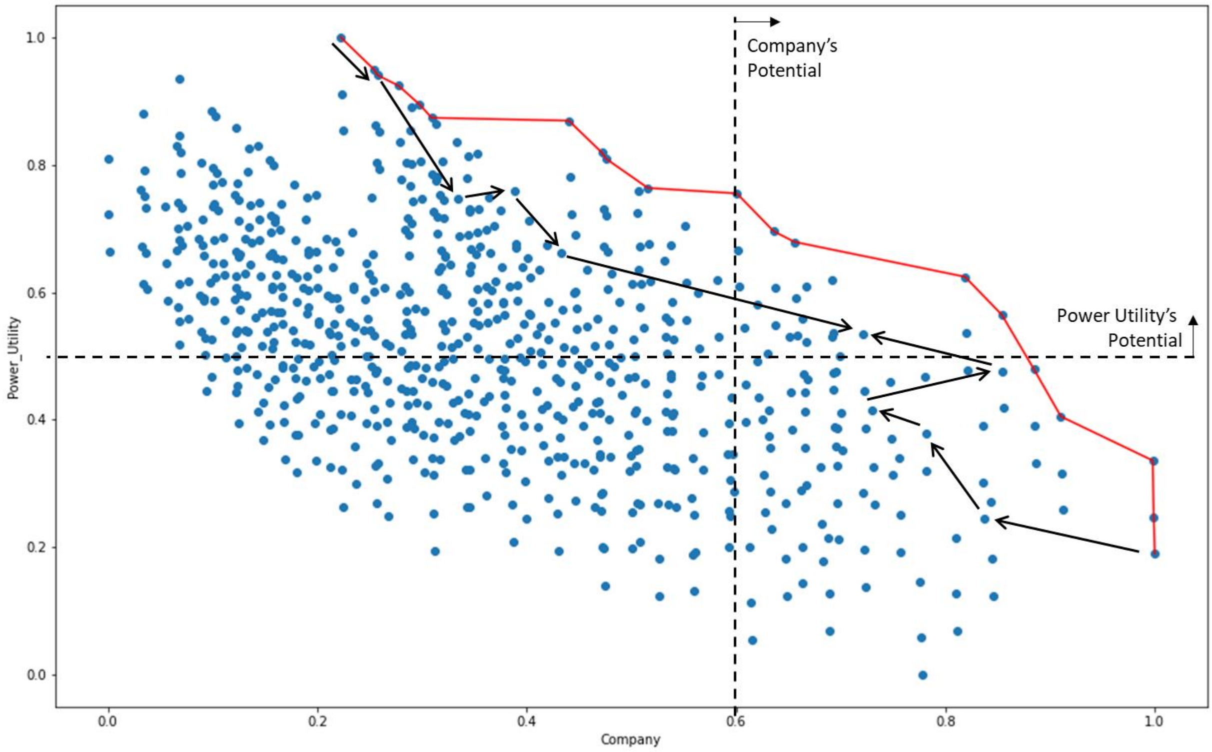
Figure 16 – Concession path – company viewpoint



Source: The author (2020).

The parties reached an agreement with the package 562 (0.85, 100, 5, 6, 15) and a joint payoff of 1.2558, this package have the 10th largest joint payoff of the 23 packages present in the feasible region. Figure 17 shows the dance of packages for this negotiation.

Figure 17 – Dance of packages



Source: The author (2020).

It is worth noting that the package achieved loses in joint payoff to the most valuable, 571 (0.85, 100, 6, 5, 15), at 0.1872. This reflects that a one-month increase in project duration would result in a greater joint gain, however, analyzing the negotiation, it is clear that the power utility was not interested in developing projects with terms longer than 6 months, considering the suitability period. Analyzing this, with the mediator's intervention to expose the possibility of increasing their joint gains in this negotiation, the other 9 most interesting packages were exposed so that they could reach an agreement. When analyzing them, it was observed that to achieve the results of the best package to be negotiated, negotiators should evaluate the possibility of increasing the Project Duration by 1 month, from 5 to 6, at the expense of reducing the Bonus Adjustment by 1 %, going from 6 to 5. The parties talked and analyzed the situation, even agreeing with the proposed adjustment to maximize their gains. Thus, the final agreement was reached with package 571.

With the negotiation concluded, during the post-negotiation, the negotiators were asked to record their agreement, discuss the process and complete a questionnaire (Table 17) with their perceptions about the negotiation process. Also, during the debrief, the parties were told to keep their experiences in this research confidential.

Table 17 – Negotiation questionnaire

Negotiation questionnaire

Instructions:
- After reaching the agreement and concluding the negotiation, answer the following questions from your experience with the negotiation model used.
- This questionnaire is designed solely for academic purposes. Your results are confidential.
- Answer all the questions, there are no right or wrong answers. Thanks.

Label:
1 = Disagree 2 = Partially disagree 3 = Indifferent 4 = Partially agree 5 = Agree

Question		1	2	3	4	5
1.	The problem to be negotiated was exposed clearly and accurately?					
2.	Are you satisfied with the structuring of the negotiation problem?					
3.	Are you satisfied with the result achieved?					
4.	In relation to your initial expectation, are you satisfied with the result?					
5.	Did the model support you to make concessions faster?					
6.	The interaction with the model was clear and understandable?					
7.	Would you use the model for future negotiations?					
8.	Did the model support your negotiation strategy?					
9.	Did the model support predict the behavior of the other party?					
10.	Did the concessions from the other party influenced your concessions?					

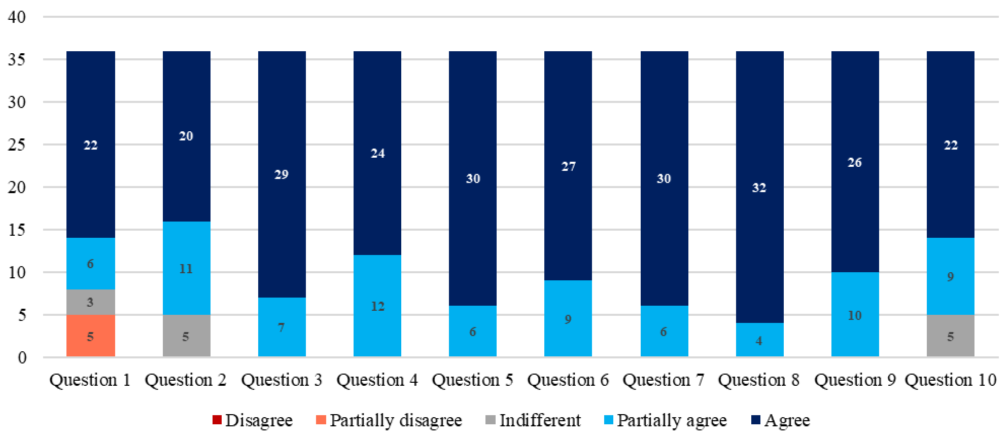
Source: The author (2020).

With the results of the questionnaire, it was possible to verify the understanding of the negotiated problem and the satisfaction of the parties in the structuring of the negotiation. Both parties agreed with the result obtained and found it fair. The model supported them with their negotiation strategy in a clear and understandable way, allowing concessions to be carried out more quickly and comprehensively during the negotiation process. At last, they would also use the model for future negotiations.

The power utility evaluated the negotiation process to support other negotiations and adjust their incentive options according to company's individual preferences, in order to increase companies' participation in government's energy efficiency project. Also, the power utility was able to compare current practices and what the companies expected from the Public Calls, being able to promote more attractive incentive plans. The power utility approved this negotiation procedure in light of the way it conducts the current process of public policy; found it efficient and would like the process to be computerized to streamline actions with other companies.

At last, for evaluative purposes to test the model usability, a bilateral negotiation experiment was conducted with 36 students from Brazil using the proposed negotiation model based on the motor replacement policy case. Thus, 18 experimental negotiations were conducted. In this negotiation, the participants were asked to play the roles of managers of the power utility and the company. The negotiators were provided with private information about the goals, expectations and priorities of the principals they represented. The negotiation problem was defined by means of the same negotiation issues and resolution options; however, they built their own reference sets and reservation utilities. Thus, each party obtained a negotiation scoring system based on their own holistic preferences to score the negotiation packages and support them during the negotiations to reach an agreement, suggesting individually the packages with higher payoffs. After the negotiation, the students were asked to fill out the evaluation questionnaire of the proposed model. The data was summarized in Figure 18.

Figure 18 – Model evaluation



Source: The author (2020).

Thus, analyzing the data obtained with the questionnaires, the result did not differ from what was raised with the real case. The model was considered easy to apply and understand. It also allowed for satisfactory agreements to be reached. In addition, it was noted that approximately 14% of participants did not understand the problem well, but this did not negatively affect the use of the proposed model.

4.2 DISCUSSION OF RESULTS

Analyzing the results obtained with the model, the agreement reached by the parties reflects a 13.33% increase in the benefit-cost ratio, from 0.75 to 0.85. In addition, taking into account the energy saved issue, it was noted that the company participating in the negotiation has the preference of carrying out high-cost projects that promote greater energy savings, reflecting its preference for a high BCR.

With the current economic scenario, the company calls for a fair adjustment to the benefit given by the power utility, so the agreement closed with an adjustment of 6% over the current price. Finally, compared to other power utilities in the country, which work with adequacy deadlines, the power utility of this research does not work this way. Currently, companies that do not comply with the contract signed, lose the transfer of the benefit, having to bear the costs they had, which ends up reducing adherence to public calls in the state. However, a 15-day period was found to be ideal. This suitability period should be used to adjust nonconformities identified by the power utility after the completion of the project.

Nonetheless, the negotiation carried out does not reflect the State companies as a whole. For this, the power utility must apply the model with other companies to refine the negotiation space and build more concise incentive options according to the company's characteristics.

It is also interesting to highlight the importance of considering this holistic model to support the construction of incentive options for Public Calls, instead of considering only the Government's preferences, but evaluating power utilities and companies' perspectives. The construction of the negotiation template, through the set of negotiation issues, resolution levels and negotiation packages, and the choice of the holistic approach will directly affect the negotiation scoring system. In addition, the negotiator's preferences affect the packages' subset selection, which also serves as input for ACUTA's mathematical calculations. Thus, the utility function values found are aligned with this information. However, to avoid agreements that are inconsistent with the negotiator's preferences, the negotiators should be familiar with the problem under study to provide consistent data.

With regard to the applicability of the proposed model, unlike the direct rating used to conduct the negotiations, the construction of the negotiation scoring system based on a holistic approach did not require much cognitive effort from the parties and allowed them to conduct the negotiation in an easier way by analyzing the utilities of negotiation packages while the offers and counter-offers were made.

Thus, according to the topology of the issues and the considered resolution levels, from the 720 negotiation packages possible to be chosen for each negotiator it was necessary a few interactions between them during the negotiation, a reduction in the number of possible interactions and in the negotiator's cognitive effort. In addition, due to the disaggregation procedure, it was not necessary to rank all negotiation packages to find the utility function.

Through a set of packages, it was possible to quickly obtain a satisfactory negotiation scoring system to support the parties during the negotiation. Moreover, negotiators are always looking to reduce the effort and time spent with negotiations, so this proposed model is an appropriate tool to support negotiation problems.

This model allows to aligning the obtained results with future Public Calls and others Government's actions. Lastly, it serves as an alternative procedure to the one currently used by the government, supporting the construction of new incentive options; increasing the companies' participation with motor replacement projects; learning to conduct future negotiations; building more accurate negotiation options; and refining the negotiation scoring system with the reapplication of the model with other negotiators. It also promotes the Government's energy efficiency development and provides support for companies meeting the minimum energy performance standards established by the Brazilian Energy Efficiency Law for their motors.

4.3 CHAPTER CONSIDERATIONS

Due to the country's current energy efficiency policies, mainly those aimed at replacing non-efficient motors, to overcome the problem of low adherence of consumer units to the Brazilian Energy Efficiency Law it is important to align public policies with attractive incentive options. This chapter presented the problem faced by Brazil in encouraging companies to meet the minimum energy efficiency standards for their motors, and a holistic negotiation model to support power utilities to align their actions with the companies and develop better incentive options on their Public Calls.

Through five complex issues and different intervals of resolution options to represent the problem's objectives, 720 negotiation packages were evaluated with respect their utility functions obtained through an ACUTA-based negotiation scoring system. The indirect model supported the parties (power utility and company) to conduct the negotiation considering their individual holistic preferences.

During the negotiation, after 6 changes of offers and counter-offers, the parties reached an agreement, through the package (0.85, 100, 5, 6, 15) with a joint payoff of 1.2558, 0.5339 for the power utility and 0.7219 for the company. Next, after mediator's intervention to expose the possibility of increasing their joint gains, the negotiators discussed and agreed to adjust some issues, reaching an agreement through the package (0.85, 100, 6, 5, 15) with a joint payoff of 1.44296. It was possible to observe a discrepancy with the incentive options currently practiced by the power utility, enabling it to align its motor replacement policy with more attractive incentive options, in order to increase the participation of the companies to the energy efficiency program and to support the country with its energy goals.

The main motivation to propose this model is its flexibility, interactivity and robustness to reduce the time spent in negotiation and cognitive effort of negotiators during the process. Furthermore, the ACUTA method, which is based on the computation of the analytic center of a polyhedron, guarantees the uniqueness of the provided solution through a non-linear objective function.

Also, for this negotiation process, the model supported the parties to find the utility functions of negotiation packages intuitively through a holistic negotiation scoring system, instead of assigning the scores to options, as direct rating approaches suggest. The negotiation process, in a practical way, becomes easier by allowing the parties to understand the packages through their utility functions and reaching a more consistent agreement.

5 CONCLUSIONS

This section concludes the thesis by presenting the final remarks, the practical implications and limitations, as well as directions for future studies.

5.1 FINAL REMARKS

This thesis proposes to support energy efficiency decisions concerning motor replacement projects by providing decision models for companies and power utilities. The first model consisted of a multicriteria decision model based on FITradeoff procedure and the second model consisted of a negotiation model based on ACUTA method, both to support government actions in achieving their energy efficiency goals by replacing non-efficient motors.

First, to support model development, a study was carried out to identify the relationship of energy efficiency and industrial motors, followed by research to identify policies that Brazil adopts to promote energy efficiency through motor replacement, since the industrial sector is responsible for the largest consumption of electricity in the country. It has been observed that current mechanisms are not attractive to change the perception of companies about the need for efficient motors. This reflects the low participation of companies to Public Calls that guarantee bonuses for motor replacement projects, even with the enactment of the energy efficiency Law, which compels companies to adjust their motors to minimum efficiency standards.

However, current incentive options end up restricting the participation of some companies, making them perform rewinding processes, reducing motor efficiency and extending motor lifespan rather than acquiring more efficient motors. This reflects the conflicting criteria related to its replacement, such as the strategic location of the motors in the productive sector and the net present value with its replacement; and in structuring the issues of current Public Calls. As can be seen in Chapter 4, companies have divergent preferences over current Public Calls, prefer a higher BCR to carry out high investment projects, but also pursue less restrictive and punitive options such as increased project lead time, readjustment in the values of bonuses and the creation of a project suitability period, given future unforeseen events that may occur and the country’s inflation. In the current Public Calls, there is no suitability period, if the company does not meet the project, the bonus is not passed.

Thus, companies and power utilities need suitable tools to deal with conflicting situations for complex problems, in order to support their strategies to meet energy efficiency regulations and promote energy gains. Also, the government can increase adherence to energy efficiency projects and meet its goals for the national energy plan. Among the decision support tools, it is possible to highlight the multicriteria methods and negotiation. The multicriteria methods are shown to be useful tools to support the negotiation processes.

Regarding the proposed models, the FITradeoff-based model allowed industries to prioritize motors in their production processes and build an efficient replacement plan. The other, through a holistic negotiation model, allowed the power utilities to align the incentive options to the results obtained, in order to create more attractive Public Calls and increase the companies' participation in the motor replacement projects. The models also allow refining the results through a sensitivity analysis and understanding of the different companies’ profiles. They are able to promote the development of government energy efficiency actions for motor replacement problems and provide support for companies to meet the minimum energy performance standards set by the Brazilian Energy Efficiency Law.

As for the applicability of the models, both were applied in real-life situations and were able to deal with conflicting criteria against a considerable range of options. The models were agile, interactive and flexible; In addition, they reduced the cognitive effort of the decision-maker/ negotiators while conducting the process, achieving robust results and reducing the amount of preference information to be imparted by DM. The FITradeoff-based model does not necessarily require indifferent statements, being cognitively easier for the decision-maker during preference modeling, avoiding a tedious and lengthy decision process. In addition, by using holistic preferences to create an efficient negotiation scoring system and support the negotiation process, the ACUTA-based model finds utility functions more intuitively through a reference set of negotiation packages. In addition, the parties could assess their own negotiation packages scores to reach a better payoff during the negotiation. Also, the proposed negotiation model is a useful tool and serves as an alternative to the current procedure used by the government to conduct its energy efficiency project, regarding the replacement of non-efficient industrial motors.

Furthermore, this thesis contributed to the literature by integrating the knowledge of studies on holistic approaches to support their use in the negotiation process. A systematic review of holistic approaches was performed, identifying how these approaches could support the construction of negotiation scoring systems during the pre-negotiation phase, according to articles published from 1993 to 2018. Papers were categorized according to their methodologies, investigating which holistic methods were mostly used to support the multicriteria decision, as well as their implications for the construction of negotiation scoring systems. The results revealed a series of holistic techniques, with their own particularities of use to support the negotiation process

Last but not least, as for the impacts in economic, social, environmental and financial terms, the thesis contributes to: reduction of organizational barriers related to decision-making; awareness of actions aimed at energy efficiency; the increase of the productivity in the industrial sector; reduction of electricity consumption; reduction of motors reconditioning practices; reduction of pollutant gas emissions; and promotion of the competitiveness of industries in their field of activity

5.2 PRACTICAL IMPLICATIONS AND LIMITATIONS

During this research, some practical implications and limitations were found. In the following points, some aspects of the systematic review and models developed to support the achievement of energy efficiency will be highlighted.

a) The systematic review depends on the keywords chosen initially. Despite the efforts during the filtering process to identify papers related to the topic of this study, the research cannot state that all relevant papers have been included. In fact, the research directed its efforts on papers that were focused on the holistic approaches used in MCDM scenarios, as these tools were used to support the negotiation process.

b) Given the specificity of each negotiation, negotiator's limited knowledge and scarce information, the quality of the negotiation process can be negatively influenced. It is recommended that mediators adapt their negotiations model according to each holistic approach, to challenge their technical limitations in order to improve the accuracy of the negotiation scoring systems and better support of the negotiation processes.

c) Given the specificity of each negotiation, negotiator's limited knowledge and scarce information, the quality of the negotiation process can negatively influence. It is recommended that mediators adapt their negotiations' model according to each holistic approach, to face their technical limitation in order to improve the accuracy of the negotiation scoring systems and better support the negotiation processes.

d) The results obtained with the ACUTA-based method cannot be generalized as the best incentive options to be adopted by the government in its Public Calls. Even involving real negotiators, the negotiation was restricted to applying the model to just one time. Thus, it was not possible to make an adequate analysis of the profiles of companies and their preferences. More data is needed to explore the negotiation space.

e) One difficulty encountered was holding meetings to gather information for the negotiation and finding a time when both could meet to conduct the process. Had an NSS been developed, it would not have been a barrier.

f) Another difficulty was organizing experimental negotiations with students due to their lack of understanding of decision making and negotiation. The time available for conducting this activity was a limiting factor as well

5.3 FUTURE DIRECTIONS

As future works, it is suggested:

a) The outcomes of this literature review provide insights to study the issues of inaccuracy in negotiation problems during the prenegotiation phase. It is necessary to conduct experiments to evaluate the use of holistic approaches in the negotiation process, e.g. definition of the negotiation offer packages, in order to measure the accuracy index compared with other direct rating techniques.

b) Furthermore, some biases and heuristics may appear in the negotiation process, so it is important to consider these aspects and evaluate their influence in the construction of negotiation scoring systems. It is important to choose the more suitable methodology for the negotiation problem, taking into account negotiator’s technical limitations and making the appropriate changes to conduct the negotiation process.

c) It would be useful to conduct comparative studies with the application of different holistic approaches and studies to explore the conflicting factors in the prenegotiation phase.

d) About the FITradeoff-based model, it would be useful to apply the model in other scenarios. Also, some opportunities can be explored to promote energy efficiency, energy savings and emission reduction, such as the implementation of an energy management system, dissemination of the proposed model, adoption of sustainable policies and new production techniques. In addition, it would be interesting to conduct another sensitivity analysis involving the other criteria, among them the "Importance to production" criterion, due to its build scale.

e) About the ACUTA-based model, future work may focus on applying the proposed model with other companies, in order to map their respective preference profiles and refine the negotiation space, allowing power utilities to propose more robust incentive options, closer to the current industrial sector scenario. In addition, it would be interesting to conduct an application of a direct rating negotiation model, e.g. SAW-based ones, to compare the results with the proposed holistic model.

f) In many organizations, decisions are made by a group of individuals, the developed models can be extended for group decision/negotiation, whether consensus is needed or not.

g) Development of a system of decision/negotiation to support data parameterization.

h) Implementation of the model in a system to support organizations.

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APPENDIX A - HOLISTIC APPROACHES AND CONTEXT OF APPLICATION

Table A.1 – Holistic approaches and context of application

Method	Total	%	Context of application	Authors
Utility (or value) functions	118	78.7		
UTA-based				
[Ordinal Regression]	38	32.2		
UTADIS	13	11.0	Financial management	(ZOPOUNIDIS; DOUMPOS, 1999a), (ZOPOUNIDIS; DOUMPOS; ZANAKIS, 1999), (ZOPOUNIDIS; DOUMPOS, 1999b), (DOUMPOS, 2002) (KOSMIDOU et al., 2004) (PASIOURAS; GAGANIS; ZOPOUNIDIS, 2010), (COHEN et al., 2012), (ANDRIOSOPOULOS et al., 2012), (DOUMPOS; ZOPOUNIDIS; FRAGIADAKIS, 2016),
			Experimental analysis	(DOUMPOS; ZOPOUNIDIS, 2004)
			Environmental management	(DIAKOULAKI et al., 1999)
			R&D	(KARASAKAL; AKER, 2017)
			Health	(DOUMPOS et al., 2010)
UTASTAR	10	8.5	Financial management	(ZOPOUNIDIS, 2001), (MASTORAKIS; SISKOS, 2016)
			Marketing	(GHADERI; RUIZ; AGELL, 2015)
			Environmental management	(HAIDER et al., 2015), (PAPAPOSTOLOU et al., 2016)
			Urban management	(PATINIOTAKIS; APOSTOLOU; MENTZAS, 2011)
			R&D	(MATSATSINIS; GRIGOROUDIS; SAMARAS, 2005), (CARAYANNIS; GRIGOROUDIS; GOLETSIS, 2016)
			Health problem	(GRIGOROUDIS; ORFANOUDAKI; ZOPOUNIDIS, 2012), (GRIGOROUDIS; ZOPOUNIDIS, 2012)
UTA	7	5.9	Experimental analysis	(SISKOS; ASKOUNIS; PSARRAS, 2014)
			Environmental management	(ANDROULAKI; PSARRAS, 2016), (MARINAKIS et al., 2017)
			Urban management	(CHHIPI-SHRESTHA et al., 2018)
			Education	(MANOUSELIS; SAMPSON, 2002), (MATSATSINIS; FORTSAS, 2005), (SISKOS et al., 2007)
ACUTA	2	1.7	Experimental analysis	(BOUS et al., 2010)
			Operations management	(KHALED et al., 2018)
PUTADIS	2	1.7	Experimental analysis	(CAI; LIAO; WANG, 2011)
			Health problem	(ESMAELIAN; SHAHMORADI; VALI, 2016)
RUTA	1	0.8	Financial management	(KADZIŃSKI; GRECO; SŁOWIŃSKI, 2013b)
S-UTA	1	0.8	Environmental management	(DEMESOUKA; VAVATSIKOS; ANAGNOSTOPOULOS, 2013)
UTA-poly / UTA-splines	1	0.8	Financial management	(SOBRIE et al., 2018)
W UTA	1	0.8	Financial management	(KARANDE; CHAKRABORTY, 2015)
UTA-based				
[Robust Ordinal Regression]	7	4.7		
$UTADIS^{GMS}$	2	1.3	Marketing	(GRECO; KADZIŃSKI; SŁOWIŃSKI, 2011)
			Urban management	(GRECO; MOUSSEAU; SŁOWIŃSKI, 2010)
UTA^{GMS}	1	0.7	Experimental analysis	(GRECO; MOUSSEAU; SŁOWIŃSKI, 2008)
GRIP	1	0.7	Experimental analysis	(FIGUEIRA; GRECO; SŁOWIŃSKI, 2009)
UTA^{GMS}-GROUP / $UTADIS^{GMS}$-GROUP	1	0.7	Financial management	(GRECO et al., 2012)
UTA^{GMS}-INT	1	0.7	Education	(GRECO; MOUSSEAU; SŁOWIŃSKI, 2014)
ROR-UTADIS	1	0.7	Urban management	(KADZIŃSKI; CIOMEK; SŁOWIŃSKI, 2015)
MUSA-based	17	11.3		
MUSA	14	9.3	Financial management	(MIHELIS et al., 2001)
			Marketing	(GRIGOROUDIS; SISKOS, 2002), (GRIGOROUDIS; SPYRIDAKI, 2003), (GRIGOROUDIS; SISKOS, 2004) (POLITIS; SISKOS, 2004), (KOILIAS, 2005), (DIAMANTIS; BENOS, 2007), (KYRIAZOPOULOS et al., 2007) (IPSILANDIS; SAMARAS; MPLANAS, 2008), (ARABATZIS; GRIGOROUDIS, 2010), (KOILIAS; TOURNA; KOUKOULETSOS, 2012), (KIPENIS; ASKOUNIS, 2016), (ZERVA et al., 2018), (TSAFARAKIS; KOKOTAS; PANTOUVAKIS, 2018)

Table A.1 – Holistic approaches and context of application (continuation)

Method	Total	%	Context of application	Authors
Utility (or value) functions	118	78.7		
MUSA-INT	1	0.7	Marketing	(ANGILELLA et al., 2014)
MUSA +	1	0.7	Marketing	(GRIGOROUDIS et al., 2008)
N-MUSA	1	0.7	Experimental analysis	(NAYERI; MEHREGAN, 2018)
MARS	1	0.7	Financial management	(GORECKA et al., 2016)
Decision Support Systems	12	8.0	Financial management	(SISKOS; SPYRIDAKOS; YANNACOPOULOS, 1999)(ZOPOUNIDIS; DOUMPOS, 2001) (SAMARAS; MATSATSINIS, 2003) (SAMARAS; MATSATSINIS; ZOPOUNIDIS, 2003), (SAMARAS; MATSATSINIS; ZOPOUNIDIS, 2008)
			Experimental analysis	(ZOPOUNIDIS, 2006)
			Marketing	(GRIGOROUDIS; SISKOS; SAURAIS, 2000)(SPYRIDAKOS; YANNACOPOULOS, 2015)(AOUADNI; REBAI, 2017)
			Environmental management	(SISKOS; MATSATSINIS; BAOURAKIS, 2001)(SPYRIDAKOS et al., 2001)
			Urban management	(ZOPOUNIDIS; DOUMPOS, 2000b)
Other applications	43	28.7	Financial management	(DOUMPOS; ZANAKIS; ZOPOUNIDIS, 2001), (DOUMPOS; ZOPOUNIDIS, 2001), (DOUMPOS et al., 2002), (ZOPOUNIDIS; DOUMPOS, 2002), (DOUMPOS; ZOPOUNIDIS, 2002), (PASIOURAS; TANNA; ZOPOUNIDIS, 2007), (DOUMPOS, 2012), (SARABANDO; DIAS; VETSCHERA, 2013), (YANG; LIAO; HUANG, 2014), (BECCACECE et al., 2015), (CORRENTE et al., 2017)
Other applications	43	28.7	Financial management	(DOUMPOS; ZANAKIS; ZOPOUNIDIS, 2001), (DOUMPOS; ZOPOUNIDIS, 2001), (DOUMPOS et al., 2002), (ZOPOUNIDIS; DOUMPOS, 2002), (DOUMPOS; ZOPOUNIDIS, 2002), (PASIOURAS; TANNA; ZOPOUNIDIS, 2007), (DOUMPOS, 2012), (SARABANDO; DIAS; VETSCHERA, 2013), (YANG; LIAO; HUANG, 2014), (BECCACECE et al., 2015), (CORRENTE et al., 2017)
			Experimental analysis	(ZOPOUNIDIS; DOUMPOS, 2000a), (DOUMPOS; ZOPOUNIDIS, 2007), (BOLAND et al., 2009), (SOYLU, 2011), (DOUMPOS; ZOPOUNIDIS; GALARIOTIS, 2014), (ÇELIK; KARASAKAL; İYIGÜN, 2015), (KADZIŃSKI; MICHALSKI, 2016), (KARSU, 2016), (BRANKE et al., 2017), (CIOMEK; KADZIŃSKI; TERVONEN, 2017), (KADZISKI et al., 2017), (GHADERI; RUIZ; AGELL, 2017) (MIHELČIĆ; BOHANEC, 2017), (LIU et al., 2018)
			Marketing	(SISKOS et al., 1998), (KADZIŃSKI; GRECO; SŁOWIŃSKI, 2012a), (KADZIŃSKI; GRECO; SŁOWIŃSKI, 2013a), (LIU; LIAO; YANG, 2015)
			Environmental management	(CHEN; MARC KILGOUR; HIPEL, 2008), (BEAUDOUIN, 2015), (KADZIŃSKI et al., 2018), (ZHENG; LIENERT, 2018)
			Urban management	(BANA E COSTA; NUNES DA SILVA; VANSNICK, 2001), (ÜLENGIN, et al., 2001), (HURSON; SISKOS, 2014), (KADZIŃSKI et al., 2014), (SPYRIDAKOS et al., 2018)
			Education	(KADZIŃSKI; TERVONEN, 2013)
			R&D	(CORRENTE et al., 2013)
			Operations management	(ANGILELLA; GRECO; MATARAZZO, 2010), (BANA E COSTA et al., 2012), (CORRENTE et al., 2016)
Outranking relations	25	16.7		
ELECTRE TRI	11	7.3	Financial management	(DIAS et al., 2002), (MOUSSEAU et al., 2003), (DIAS; MOUSSEAU, 2006), (ROCHA; DIAS, 2008), (DOUMPOS et al., 2009)
			Experimental analysis	(MOUSSEAU; SLOWINSKI, 1998), (MOUSSEAU; FIGUEIRA; NAUX, 2001), (LOURENÇO; COSTA, 2004), (MOUSSEAU; DIAS; FIGUEIRA, 2006), (ZHENG et al., 2014)
			Environmental management	(KADZIŃSKI; TERVONEN; RUI FIGUEIRA, 2015)
ELECTRE^{GKMS}	1	0.7	Experimental analysis	(GRECO et al., 2011b)
PROMETHEE^{GKS}	1	0.7	Operations management	(KADZIŃSKI; GRECO; SŁOWIŃSKI, 2012b)
Decision Support Systems	3	2.0	Financial management	(DAMART; DIAS; MOUSSEAU, 2007)
			Experimental analysis	(KISS et al., 1994), (MOUSSEAU et al.,2000)

Table A.1 – Holistic approaches and context of application (continuation)

Method	Total	%	Context of application	Authors
Outranking relations	25	16.7		
Other applications	9	6.0	Financial management	(CORAZZA; FUNARI; GUSSO, 2015)
			Experimental analysis	(MOUSSEAU; DIAS, 2004), (BREGAR; GYÖRKÖS; JURIČ, 2008), (COVANTES; FERNÁNDEZ; NAVARRO, 2016), (RANGEL-VALDEZ et al., 2018)
			Marketing	(KADZIŃSKI; GRECO; SŁOWIŃSKI, 2012c)
			Education	(KADZIŃSKI; SŁOWIŃSKI, 2015), (KADZIŃSKI; CIOMEK, 2016)
			R&D	(FERNANDEZ; NAVARRO; BERNAL, 2009)
Rule-based models	7	4.7		
DRSA	5	3.3	Financial management	(KADZIŃSKI; SŁOWIŃSKI, 2013)
			Experimental analysis	(CHAKHAR; SAAD, 2012), (KADZIŃSKI; GRECO; SŁOWIŃSKI, 2014), (KADZIŃSKI; SŁOWIŃSKI; GRECO, 2015)
			Education	(GRECO; SŁOWIŃSKI; ZIELNIEWICZ, 2013)
Rough set	2	1.7	Financial management	(GRECO et al., 2011a)
			Education	(GRECO; MATARAZZO; SLOWINSKI, 2001)