Models to Deal With Uncertainties in Energy Commercialization in a Deregulated Market

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Area de concentração: Engenharia Elétrica

Orientador: Rodney Rezende Saldanha
Coorientador: Douglas Alexandre Gomes Vieira

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Tese de Doutorado submetida à Banca Examinadora designada pelo Colegiado do Programa de Pós-Graduação em Engenharia Elétrica da Escola de Engenharia da Universidade Federal de Minas Gerais, como requisito para obtenção do grau de Doutor em Engenharia Elétrica.

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Este trabalho é dedicado às crianças adultas que,
quando pequenas, sonharam em se tornar cientistas.

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achievements.

"Where there's a will, there's a way."

(...)

Resumo

Em todo o mundo, os mercados de energia passam por uma reestruturação significativa, fomentando a desregulamentação e a concorrência. Essa reestruturação transformou a indústria de serviços públicos em agentes privados que competem para vender energia a empresas de distribuição independentes e clientes finais. Os agentes devem ser capazes de analisar e modelar o comportamento do mercado para tomar boas decisões, às vezes com baixos níveis de informação disponível. Sob um mercado mais descentralizado, os agentes devem assumir mais riscos e responsabilidades em suas próprias decisões para lidar com um ambiente incerto.

Este trabalho teve como objetivo modelar, processar e analisar problemas relacionados ao comércio de energia, com foco nas dificuldades do pequeno consumidor. Especificamente, tratou de questões percebidas na representação de incertezas, falta de dados históricos robustos disponíveis para processar, informações de natureza qualitativa, nível de conhecimento dos especialistas e previsão de cargas. Este trabalho tratou dessas questões de forma a reduzir ao máximo os riscos do comércio de energia. Algumas dessas questões são parcialmente creditadas à estrutura do mercado de energia brasileiro. O mercado mudou, mas a maioria dos consumidores não. Historicamente, as empresas de geração e distribuição de energia detêm as informações e as melhores técnicas para a comercializar energia já que a comercialização de energia é seu principal negócio. Por outro lado, o consumidor final não domina essa disciplina. Geralmente, faltam dados robustos e, na maioria dos casos, não possuem recursos ou conhecimento para subsidiar uma pesquisa neste sentido.

Como resultado, neste trabalho são projetados dois procedimentos metodológicos úteis para facilitar o processo de compra de energia. Eles visam representar a incerteza e os riscos (qualitativos e quantitativos). Estes métodos melhoram o entendimento das opções de comercialização de energia e levam o consumidor a tomar uma decisão melhor. Além disso, como inovação adicional, desenvolveu-se uma formulação de CVaR que considera as informações qualitativas e quantitativas, lidando com os dois tipos de risco. Os métodos contribuem para flexibilizar a coleta de informações, melhoram o entendimento dos problemas associados à compra de energia e também avaliam a qualidade dos conselhos dos especialistas de forma justificada e tornando a decisão robusta.

Palavras-chave: Risco Qualitativo, Risco Quantitativo, CVaR, Mercados de Energia, Leilões, Otimização Multiobjetivo, Predição de cargas, Decisão Multicritério.

Abstract

Throughout the world, the electricity markets are undergoing significant restructuring towards deregulation and competition. This restructuring has broken the utility industry into agents that compete to sell power to independent distribution firms and final customers. The agents should be able to analyses and to model the market behavior to make good decisions, at times, having low levels of information. Under a more decentralized market, the agents must assume more risk and responsibility on their own decisions dealing with an uncertain environment.

This work aims at modeling, processing, and analyzing problems regarded to the energy trade, focusing on the difficulties of the small consumer. Specifically, it deals with issues perceived in the representation of uncertainties, lack of robust historical data to process, information of qualitative nature, level of knowledge of the specialists, and forecasting. This work had handled these issues to make the risks of the energy trade as low as possible. Some of these issues are partially credited to the Brazilian energy market structure. The market changed, but most consumers did not. Historically, the energy generation and distribution companies hold the information and top-rated techniques to trade energy since energy commercialization is its core business. On the other hand, the final consumer does not dominate this discipline. Usually, it lacks robust data, and can't afford the research in most cases.

As the outcome, it is designed two methodological procedures that are useful in facilitating the energy buying process. They aimed at representing the uncertainty and the risks (qualitative and numeric). That improves the energy trade heading the consumer to make a better decision. Also, as additional innovation, it had developed a CVaR formulation that regards the qualitative as well as quantitative information, dealing with both kinds of risk. The methods contribute loosening the collection of information, improves the understanding of the issues associated with energy buying, also evaluating the quality of the specialists' advice, heading to a substantiated decision.

Keywords: Qualitative risk, Quantitative risk, CVaR, Energy Markets, Auctions, Multiobjective Optimization, Forecasting, Multicriteria Decision Making.

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Acronyms list

ACR Ambiente de Contratação Regulada

ANEEL Agência Brasileira de Energia Elétrica

CCEE Câmara de Comercialização de Energia Elétrica

CM Capacity Market

CFD Contracts for Difference

CPF Carbon Price Floor

CVaR Conditional Value at Risk

EDR Electricity Demand Reduction

EMR Electricity Market Reform

EPS Emissions Performance Standard

FLR Fuzzy Logical Relationship

FTS Fuzzy Time Series

LHS Left hand side of a Fuzzy Logical Relationship

MME Ministério das Minas e Energia

Ofgem Office of Gas and Electricity Markets

PV Photo-voltaic

RHS Right hand side of a Fuzzy Logical Relationship

SIN Sistema Integrado Nacional

VaR Value at Risk

List of symbols

A, B, D	a fuzzy set defined by the membership function $\mu_A(x) : X \rightarrow [0, 1]$
α	significance level
B_a	Left hand side of a Fuzzy Logical Relationship (LHS)
B_b	Right hand side of a Fuzzy Logical Relationship (RHS)
b_i	i^{th} greatest value in a set
$\mathrm{CVaR}_\alpha, \phi_\alpha$	Conditional Value at Risk (CVaR)
c_i	i^{th} evaluation criteria
Δ_τ	weight of importance of the τ^{th} risk
$E(.)$	risk expected value
$F(t)$	FTS defined on $\gamma(t)$
$F(t–1) \rightarrow F(t)$	Fuzzy Logical Relationship (FLR)
$F_i(x_l)$	fuzzy estimations
Γ	a set of all possible states of π
h, g	numbers of fuzzy sets in the RHS sequences
$\mu_{I_i}(x_k, x_l)$	pertinence function of a fuzzy indifference preference relation that represents the pair of alternatives (x_k, x_l) for the i^{th} criteria
$ICMP(x_k, x_l)$	comparability index between alternatives x_k and x_l
$IDSC_i^{y,z}(x_k, x_l)$	discordance index between the specialists e_y and e_z for the i^{th} criteria

$IDSCM_i^{y,z}(x_k, x_l)$ mean discordance between the specialists e_y and e_z for the i^{th} criteria. it is calculated considering just the judgments with an aceptable level of incomparability

$IDM_i^{v,G}$ mean discordance of the group of specialists for the i^{th} criteria, considering just the judgments with and acceptable level of incomparability

$ICNC_i^{y,z}(x_k, x_l)$ concordance index between the specialist e_y and e_z for the i^{th} criteria

$ICNCM_i^{y,z}(x_k, x_l)$ mean concordance between the specialist e_y and e_z for the i^{th} criteria

$ICNS_i(x_k, x_l)$ consensus index for the i^{th} criteria

$\mu_{J_i}(x_k, x_l)$ pertinence function of a fuzzy incomparability preference relation that represents the pair of alternatives (x_k, x_l) for the i^{th} criteria

J fuzzy incomparability relation

$J(x_k, x_l)$ value of fuzzy incomparability relation between alternatives x_k and x_l

J_i fuzzy incomparability relation associated to the i^{th} criteria

$J_{i,y}$ fuzzy incomparability relation associated to the i^{th} criteria, provided by the y^{th} specialist

$LT(c_i)$ linguistic term of criteria c_i

$\mu_A(x)$ membership function of x in the fuzzy set A

$\mu_j(t)$ fuzzy set

$\mu_{F_i}(x_k)$ fuzzy estimation

$\mu_R(x_k, x_l)$ pertinence of a bi-dimensional fuzzy set

$\mu_{R_i}(x_k, x_l)$ pertinence function of a fuzzy non-strict preference relation that represents the pair of alternatives (x_k, x_l) for the i^{th} criteria

$\mu_R(x_k, x_l)$ pertinence of a bi-dimensional fuzzy set

$\mu_{R_i}(x_k, x_l)$ pertinence function of a fuzzy non-strict preference relation that represents the pair of alternatives (x_k, x_l) for the i^{th} criteria

$\mu_{R_i,G}(x_k, x_l)$ pertinence function of the collective fuzzy preference relation

$\mu_{ND_i}(x_k, x_l)$ pertinence function of a fuzzy set of non-dominated solution defined by the i^{th} criteria

XND	solution set of the problem
n	number of energy sources (alternatives in the set X
π	a random variable
$p(.)$	a probability function
$p(\mathbf{y})$	a probability functions of the price scenario $\mathbf{y}$
$\boldsymbol{\Psi}$	vector of qualitative risk
ψ	lower/upper bound of qualitative risk
Ψ_k	risk susceptibility for the k^{th} energy provider
$\mu_{P_i}(x_k, x_l)$	pertinence function of a fuzzy strict preference relation that represents the pair of alternatives (x_k, x_l) for the i^{th} criteria
P	fuzzy strict preference relation
$P(x_k, x_l)$	value of the strict preference relation between alternatives x_k and x_l
P_i	fuzzy strict preference relation associated to i^{th} criteria
$P_{i,G}$	fuzzy strict preference relation that represents the group preferences for the i^{th} criteria
$P_{i,y}$	fuzzy strict preference relation associated to i^{th} criteria, provided by the y^{th} specialist
q	q is the number of matrix of preference relations to be evaluated
$R(t–1, t)$	fuzzy relationship
ρ	lower bound on expected return
r_τ	the impact of τ^{th} risk for the k^{th} asset (energy provider) considering the advice of a specialist
$RM_i(x_l, x_k)$	multiplicative preference relations
R	fuzzy non-strict preference relation
R^c	complement of the fuzzy non-strict preference relation R
R^d	dual relation of the fuzzy non-strict preference relation R
R^{-1}	inverse relation of the fuzzy non-strict preference relation R

$R(x_k, x_l)$	fuzzy non-strict preference relation value for the pair of alternatives (x_k, x_l)
$\mu_{R^{-1}}(x_k, x_l)$	inverse relation between the solution x_k and x_l
R_i	fuzzy non-strict preference relation associated to i^{th} criteria
$R_{i,y}$	fuzzy non-strict preference relation associated to i^{th} criteria, provided by the y_{th} specialist
$R_{i,G}$	fuzzy non-strict preference relation associated to group of specialists and i^{th} criteria
s	a scenario
T_{in}	intersection. Class of nebulous operator known as T-norm
T_{ne}	negation T-norm
T_{un}	union T-norm
t	time
$(.)^T$	transposed
$(.)^+$	the subset greater than 0
τ	the number of qualitative risks considered in a energy buying
$u(.)$	a step function
$U_i(x)$	a utility function of i^{th} criteria
$\text{VaR}_\alpha, \zeta_\alpha$	Value at Risk (VaR) for a confidence level α
v	number of specialists in set E
$f(\omega, \mathbf{y})$	loss function
ω	decision vector (a portfolio of n assets)
$w_{i,y}$	weight of i^{th} criteria for the decision
X	Universe set
x	element of X
x, y, w, z	elements of X regarded the T-norm
x_k	k^{th} energy provider

x_k, x_l, x_m	elements to be evaluated (k^{th} alternative of solution)
$\gamma(t)$	universe of discourse in $\mathbb{R}$
$\mathbf{y}$	random vector of prices for the portfolio $\mathbf{x}$
y, v	$y = 1, 2, \ldots, v$ is the number of specialists
Z_b	stands for the defuzzified value of B_a
$\succ$	better than
$\prec$	worse than

Contents

Chapter 1

Introduction

In the last decade, the energy markets dynamics has increased by adopting a decentralized structure between generators, distributors, and final consumers. Distributed generation has strengthened as a trend against the old model of centralized power generation (WU, 2013), and the interactions among agents became more intense with the popularization increase of smart grids. In some markets, such as the North American and English ones, the energy purchase has become daily, with the dynamic choice of energy providers by the final consumer, turning itsef into a world trend (WANG et al., 2015).

In 2000s two markets were created in the Brazilian model: the regulated market (ACR - Ambiente de Contratação Regulada), which follows strict market rules stipulated by the government and is already well known by the agents, and the free market (ACL - Ambiente de Contratação Livre). The latter needing further research as pointed out in (BALTA-OZKAN et al., 2013). The regulated market is already well exploited by large companies and, thus, a number of methodologies have been developed to improve the energy matrix and the customer portfolio of generators as pointed out in (AFŞAR et al., 2016). In these works, (AFŞAR et al., 2016)(BALTA-OZKAN et al., 2013), the energy purchases take place by public auctions with long periods of supply.

The free market has made much progress favoring the competition among agents, but few are the formal methods developed for the energy commercialization in this environment, minimizing risks, dealing with uncertainties, and increasing the system reliability, in particular for small agents operating with renewable sources (STEEGER; BARROSO; REBENNACK, 2014). The deficiency of a unified formula for electricity deregulation shows the need for more research as pointed in (NANDURI; DAS, 2009), where it is addressed to the research communities the challenge of developing models to establish a competitive structure for deregulated electricity markets and exposing its real social benefits.

Currently, in Brazil, the energy purchase in free market can be done: by the consumer's initiative, through means of specialized companies or a combination of both. All methods are deficient. In the first one, since it is outside its core business and done without an appropriate tool, the energy purchase is informal, without a structured process of buying. The second method lacks transparency since the consulting company offers a standard product, that may not take advantage of the benefits of market competition through auctions, as distributors do in the regulated market. The development of a power trade model, risk constrained, and physical reliable has become imperative (BRASIL, 2016).

The authors in (NANDURI; DAS, 2009) point out several challenges in developing a bespoke marketing method that meets the needs of consumers and generators in the deregulated market. It ought to face challenges such as price and demand forecasting, bilateral contracts specifications, determination of auction types and optimal bidding strategies, and determination of Nash equilibria. Besides, we consider essential the seasonal behavior of each energy generation as well as the seasonal behavior of loads.

The potential value of using probabilistic forecasting to estimate loads is increasingly recognized among system operators and market participants (SILVA et al., 2019). Methods such as quantiles regression, fuzzy inference, or kernel density, can be used to make a conditional statistical estimate of the uncertainty around the point forecast (JONES, 2017). In (AVEN et al., 2013) it is pointed out the need for seeing beyond probability to research uncertainties in risk assessment context, also showing an alternative representation of uncertainty through interval probabilities and possibility theory. This has led to the evolution of the work proposed by the author in (BERNARDES; FERREIRA; SALDANHA, 2016), including the probabilistic approach with the recommended Fuzzy Time Series (FTS) to make a robust prediction.

Once the agent knows how much and when to buy the energy, it is needed to trade the energy. The auction is a good mechanism to do this since it encourages competition among agents to reduce the energy cost. This environment is tackled in the literature usually by the Auction Theory, Game Theory, Stackelberg equilibrium (DUSSE et al., 2015), Fuzzy Bayesian Games, and Hierarchical Games (DENG et al., 2015). These last ones, in special, pointed out that the case of multiple energy sources and the competition among them have been drawing, so far, very little attention in the literature.

The Brazilian model of a deregulated market has as substantial benefits allowing the free-consumer to creates its strategy and terms to negotiate the energy in a custom-made way. But, creating your own strategy to optimize energy buying leads to a kind of tailor-made challenges as well. This work introduces a methodology to address the benefits, streamlining the process of energy commercialization and, at the same time, designing strategies to reduce the quantitative risk, qualitative risk (uncertainty), and energy price. The methodology aims at exploring the features of the free market and creating countermeasures for the consequent threats of the migration, in particular for the small consumer. The purchase ought to be organized by the final consumer or generators, and not by the government, as occurs in the regulated market. Thus, it is possible to create custom rules that fit better to consumer needs.

The proposed method is an evolution of the works developed in the first part of this thesis, which the most relevant are: (BERNARDES; CARVALHO; SALDANHA, 2017) where was used the Game Theory to deal the energy trade; (BERNARDES; FERREIRA; SALDANHA, 2016) where it was implemented a Fuzzy Time Series mechanism to predict the consumer load using the seasonal complementarity of the energy generation; (PARREIRAS; EKEL; BERNARDES, 2012) where it was proposed a new consensus scheme that allows us to classify the electrical companies reliability; (BERNARDES; FERREIRA; SALDANHA, 2017) a manuscript still under review that discuss how to evaluate wind plants to trade energy in deregulated market. This papers and the present project aims at filling a poorly exploited market niche and lack appropriate methods to deal with the current market paradigm.

Summing up, this thesis improves the energy commercialization, by developing methods to represent and minimize the risks and uncertainties intrinsic to the energy markets. For achieving this goal, is also proposed a partnership in a sandwich internship at Coventry University, UK. In addition to the highly experienced researchers at Coventry, the English energy market has always been a model to the Brazilian one, being the inspiration for some of the present changes in regulation. Much can be learned from a successful market that has faced the deregulation and competition years before the Brazilian one (EXELBY, 1993).

1.1 Objectives

1.1.1 Main Objectives

The main objective of this project is to develop a tool to improve the energy trade results to the standard consumer. It aims at modeling the challenges faced by the energy consumer, improving the uncertainties representation, and reducing the qualitative and numeric risks.

The literature drive less effort to solve problems faced by the standard energy consumers than it is driven to distribution company energy buying problems. The proposed methods contributes to fulfilling this lack of knowledge presenting ways to devise the energy buying strategy for a regular consumer (small consumer) and also to enrich the distribution companies energy trade process.

1.1.2 Specific Objectives

a) Identify the main approaches for tackling the uncertainties regarding to the seasonal behavior of the energy generation and consumer demand;

b) Propose methods that enhances the energy trade dealing with qualitative and quantitative risks;

c) Propose a tool to afford the choice of sources that best fit the consumer's needs in the deregulated market improving the national energy matrix;

d) Enhance research partnerships among UFMG, COVENTRY University, CEFETMG, and ENACOM.

1.2 Project relevance

The law projects (CÂMARA, 2015) and (SENADO, 2016), which are in negotiations by the Deputies Chamber and the Brazilian Senate, proposes the expansion of Brazilian deregulated energy market through the adoption of portability (access to deregulated market) for all. It gives the consumer the possibility to choose their energy supplier, regardless of the amount contracted. It is a world trend, already implemented in the North American and European markets (ENERGYSHOP, 2017). It allows reducing costs for the final consumer while, at the same time, promoting a significant increase in competition and sector efficiency (ABRACEEL, 2016). The Ministerial Order (MME, 2019a) and (MME, 2019b) lays down profound changes in the energy price formulation for the spot market, starting in early 2020. Although, now, there is no tool suitable to afford those new regulation features in the Brazilian market. It is essential to develop a bespoke technology that could be used by the small consumer to have the benefits proposed by the new regulation. As described in (MEIJER et al., 2019) (FOXON et al., 2005) a limited attention is given to end-users. Designing this kind of methodology is one of the improvements which were developed in this research.

Accelerating the transition to a low-carbon competitive economy is both an urgent necessity and a tremendous opportunity for Europe (KOWALSKA-PYZALSKA, 2018), so do it in Brazil. Photo-voltaic (PV) panels technology has achieved maturity and is in expansion in Brazil (WÜSTENHAGEN; MENICHETTI, 2012). Together with the regulation changes, it creates a new consumer profile, that ought to develop strategies to manage its energy trade. These strategies are not available in retail.

In the deregulated market, the consumer must have the capacity of forecasting their own energy consumption, defining his own energy buying strategy and taking its own purchase decisions (ABRACEEL, 2016). It is not an easy task even to the big consumers as could be seen in the literature. As can be seen in (BRONZATTI; NETO, 2008) and (WEIJERMARS et al., 2012) the electric sector planing itself is a complex task. Both by the number of companies and stakeholders (FILARDI; LEITE; TORRES, 2014) as by the number of variables that can interfere in the choice of generation and energy transmission (RIBEIRO; MACEDO; MARQUES, 2012). There is an interaction of a large number of stakeholders in the energy market such as: government, regulatory agencies, generation companies, traders and consumers (ONS, 2013)(BRONZATTI; NETO, 2014). A large number of uncertainties such as economic, logistical, demand, installed capacity, environmental impact (FREITAS; DATHEIN, 2015). The existing planning tools are limited to simplified aspects of reality that do not represent technological evolution and its potential benefits (MONTOYA; LOPES; GUILHOTO, 2014)(PCE, 2014).

The optimal combination of sources in the energy matrix is a complicated optimization problem (WEIJERMARS et al., 2012). The choice of the energy matrix to be implemented is a decision of great responsibility (TOLMASQUIM; GUERREIRO; GORINI, 2007) that generates long-term impacts throughout society. Its repercussions result in varied disturbances in the environment and the country economy (TOLMASQUIM, 2012). The better the choice of the energy matrix and the understanding of its impacts, the greater are the benefits that can be generated. It is hoped that, with better computational tools, such that forecasting techniques and uncertainty representation instead of point estimations at the disposal of researchers and consumers, price evolution in electricity markets will be better understood over a time period (AGGARWAL; SAINI; KUMAR, 2009). In this context, the literature lacks methods that deals with risk and uncertainty (AVEN, 2016). It points out that the critical challenge in the risk management field is related to the lack of knowledge characterizations instead of accurate risk estimations and predictions.

Energy auctions have been the main form of energy commercialization in the regulated market, but there is a lack of research that tackle the problem of trade energy in the deregulated market, representing both the risk and uncertainties of generation and demand (KAGIANNAS; ASKOUNIS; PSARRAS, 2004). Due to the problem complexity, the solution importance and the lack of an optimal way to trade the energy, this work aims at contributing to fill this gap improving the system reliability proposing a new suitable mechanism that represents the uncertainties in the forecasts and agents' iteration in a systematic way through the energy market, creating:

- a mechanism that represents risks in the agents' strategies over a deregulated energy market;
- a representation of the uncertainties of the energy trade process;
- models that represents the energy trade market variables simulating their behavior, and allowing the decision maker to be technically based.

1.3 Publications

This work contributions has resulted in the following papers:

Journal papers

- Bernardes, Fernando and Vieira, Douglas and Saldanha, Rodney; Quantitative and Qualitative risks for energy commercialization using CVaR and multicriteria decision making. **Energy, Elsevier**. **(draft under submission process)**;

- Bernardes, Fernando and Vieira, Douglas and Palade, Vasile and Saldanha, Rodney; Winds of Change: How Up-To-Date Forecasting Methods Could Help Change Brazilian Wind Energy Policy and Save Billions of US$. **Energies**, v. 11, n. 11, p. 2952, 2018, doi.org/10.3390/en11112952;

Conferences

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- BERNARDES, Fernando Gontijo; FERREIRA, Leonardo Augusto; SALDANHA, Rodney Rezende. Optimal energy portfolios with demand prediction and distributed generation sources. In: **2016 Eighteenth International Middle East Power Systems Conference (MEPCON).** IEEE, 2016. p. 318-323, doi 10.1109/MEPCON.2016.7836909;

- F. Bernardes Jr.; Rodrigo de Carvalho; Saldanha, R. R..; Escolha de estratégia ótima para competição em leilões de energia em um mercado de geração distribuída; **SIMPEP XXIV**, p. 1331-1340, 2016;

- Queiroz, M. O.; F. Bernardes Jr.. Despacho econômico em sistema de seis barras com modulagem de usinas Térmicas e Eólicas, **CIEEMAT II**, 2016 (poster);

- F. Bernardes Jr.; Ferreira, Leonardo Augusto; Saldanha, R. R.. Otimização de portfólios de energia não despachável, **SBPO XLVIII**, p. 3263, 2016 (poster);

Book chapters

- F. Bernardes Jr.; Rodrigo de Carvalho; Saldanha, R. R.. Escolha de estratégia ótima para competição em leilões de energia em um mercado de geração distribuída; **Coletânea Nacional Sobre Engenharia de Produção 5**, 2017, dx.doi.org/10.22533/at.ed.2571004;

1.4 Thesis structure

The work is organized as follows.

Chapter 1 introduces the work presenting its context, the relevance of this thesis, the objectives, the methodologies, schedule, and the work structure.

Chapter 2 introduces the energy markets, making a review of the markets throughout the world, pointing out the improvement opportunities and new challenges.

Chapter 3 presents the challenges in energy and loads forecasting, introducing the concepts of uncertainties, fuzzy logic, and fuzzy time series.

Chapter 4 reviews the quantitative risk concepts presenting the most common techniques to deal with the risk. The chapter focus on the quantitative risk model applied in the Brazilian market.

Chapter 5 reviews the qualitative risk. It proposes methods to deal with the qualitative risk, improving the uncertainty representation in the energy commercialization.

Chapter 6 presents the experiments using the methods designed to improve the energy buying for the small consumer.

Chapter 7 concludes the work, summarizes its contributions, and suggests issues for future investigations.

Chapter 2

Energy Markets

2.1 Markets Over the World

The Energy market is the trading environment where all the energy industry agents interact to negotiate electricity (ANEEL, 2017). This industry is composed by a chain of assets to regulate, produce, transport, and trade energy, including consumers.

The energy industry is characterized by long-term investments, with a high degree of asset specificity and the presence of sunk costs. That explains the initial state monopoly in this industry until the '70s. Also, the electrical energy is a not a storable asset or, at least, so far, a hardly storable one. It brings the need for policy energy environments aiming at organizing the interaction among the agents and the energy flow. It results in a very peculiar energy policy environment in each country, sharing only a few common characteristics among them. As pointed out in (SANTANA, 2012): electric power does not have a economic viability of being stored so far; supply and demand must be balanced, instantaneously; due to production process intrinsic uncertainties the energy quantities generated and consumed during the day rarely coincide with what was planned the day before; it is not possible to associate the energy consumed by a given user with a specific supplier once it electric flow along the networks obeys the laws o physics, so; this demands a settlement mechanism to deal the differences usually called spot market.

This section reviews the energy market evolution throughout the world, aiming at understanding the Brazilian situation. The UK market is one of the ancientest, influencing many others. Recently, it introduced the Electricity Market Reform (EMR) (ENERGY; UK, 2014), a government policy to encourage investment in secure, low-carbon electricity, improving the security of Great Britain's electricity supply, and improving affordability for consumers. It is an effort to narrow the UK generation mix in a way to deal with the challenge of climate change. The main mechanisms included by this policy were:

- Capacity Market (CM), that helps ensure security of electricity supply at the least cost to the consumer.

- Contracts for Difference (CFD), that provide long-term revenue stabilization for new low carbon initiatives.
- Electricity Demand Reduction (EDR) pilot, that encourages the implementation of more efficiency equipments in the demand side.

Also a minimum price to the carbon dioxide emission was also implemented - and it is named the Carbon Price Floor Carbon Price Floor (CPF). This is used to tax the emission of the non-renewable power plants. And the Emissions Performance Standard (EPS), an index to measure this carbon emission.

These changes were implemented in 2014 and aim at achieving £100 billion of capital investment in UK electricity infrastructure until 2030 to accommodate projected future increases in electricity demand and to replace ageing power stations. The EMR could be described as Figure 1.

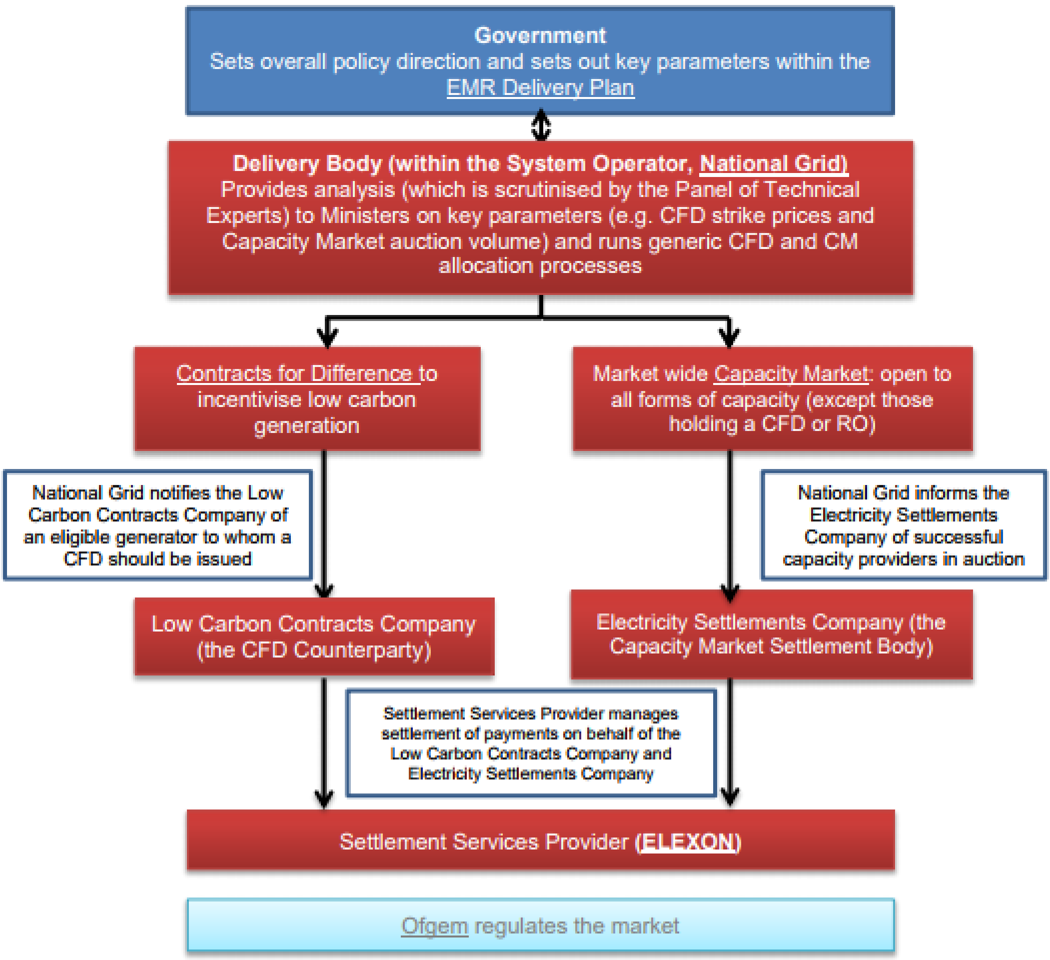


Figure 1 – EMR chart

Source: Energy e UK (2014, p. 20)

The stakeholders present the following attributions:

- Government – Sets the policy framework, provides sponsorship, leads design and legislative action.
- Office of Gas and Electricity Markets (Ofgem) – Regulates the electricity market, provides design advice, analysis and regulation.
- National Grid – Delivery Body, administrator of CFD allocation and the Capacity Market auction and provides advice to the Government.
- Low Carbon Contracts Company (the CFD Counterparty) - Administers and acts as counterparty to the CFD, manages the supplier obligation.
- Electricity Settlements Company (the Capacity Market Settlement Body) – Makes capacity payments and retains overall accountability and control of the Capacity Market settlement process.
- Settlement Services Provider – Carries out the settlement of CFDs on behalf of the CFD Counterparty and the settlement of Capacity Market agreements on behalf of the Capacity Market Settlement Body.
- Devolved Administrations – Oversee implementation and monitoring of EMR with DECC.
- Generators – Participants and parties to CFD and Capacity Market agreements.
- Suppliers – Contributors to CFD and Capacity Market funding arrangements.

It is a very flexible market. The energy trading can take place bilaterally or on exchanges, and contracts for electricity can be struck over time scales ranging from several years ahead to intraday trading markets.

The deregulation started in the UK on 1986 with the British Gas Corporation privatization. At this time, it was created the Office of Gas and Electricity Markets (Ofgem) to supervise the prices, protecting against abuse. Country's Electricity Boards was privatized in 1990 and the gas markets were opened in 1996. The gas market opening gave to the consumers the opportunity to choose the gas provider for the first time. By 1998 the system becomes fully free, with the electricity markets opening. The Electrical companies could now acquire customers from each other, while British Gas was free to take on electricity customers. In 2001, Ofgem introduced the New Electricity Trading Arrangement (NETA) aimed at finalizing the deregulation process finishing with the price regulation.

Now, theoretically, it is quite simple to change supplier. Besides the price reduction switching to a cheaper one, some suppliers offer incentives such as cash back and points in fidelity programs. The prices of each supplier are public and fixed. So, its doesn't matter the way you contact the supplier. The distribution companies buy energy through auctions in the Wholesale market and the final consumer is free to chose the supplier in the retail.

In some sites like UK (ENERGYSHOP, 2017) and USA (ELECTRICCHOICE, 2017) there are tools which are available to estimate the energy consumption and chose the provider of gas and energy. In some places, you count on even with prepaid energy cards.

However, there is still some difficulties. In accordance with (ENERGYSHOP, 2017) most of the billing process is still estimated by the energy supplier, not measured. Moreover, it takes a long time to switch, about 4 weeks, and it is common to have some penalties, since the suppliers can charge the consumer for leaving.

Chile was the first in deregulating the energy market. It created in 1978 market conditions to afford competition in generation and to share the transmission fees among the system agents (BERNSTEIN, 1988). It was followed by the United kingdom and the North America deregulation (HEALD, 1989). In markets like the USA, deregulation started in 80's but still now there is no state where it is fully deregulated. The most deregulated is Texas, which achieved 85% of the market (ELECTRICCHOICE, 2017). The states in favour to deregulation cite the fact that deregulated energy rates have fallen significantly more than regulated rates since 2008. The ones against claim problems like market manipulation, like the one in California 2001 (ROBERTS, 2013). The USA market is very complex, some markets like Colorado, Idaho, and Kentucky are fully regulated, with vertically-integrated utilities that own or control the entire flow of electricity from generation to meter. California was deregulated and after 2013 becomes regulated again, and others, such as the states from Northeast, Mid-Atlantic, and Texas are partially deregulated, so it coexists many topologies in this country.

In South America, power market reforms have always been driven by the need of attracting investments (STEEGER; BARROSO; REBENNACK, 2014). In fact, it seems to be the main reason all over the world. Some countries like Paraguay, Venezuela, Guyana, Suriname, and French Guyana follow a vertically integrated regulated monopoly. Paraguay, Bolivia, and Ecuador adopt a vertically integrated utility plus Independent Power Producers (IPPs). The ones such as Brazil, Argentina, Chile, Peru and Panama have a wholesale market mainly through auctions and Colombia adopts a Wholesale market plus a retail competition (IRENA, 2016) as seen in Figure 2.

Chile was a worldwide pioneer in energy market deregulation (RUDNICK, 1994). It had introduced a policy regulation that favors an open market encouraging the coming of new agents to the electrical system. In this system prevails a centralized scheduling generation and transmission plan and the agents are hourly marginal-cost remunerated (BATLLE; BARROSO; PÉREZ-ARRIAGA, 2010). In this market the captive consumers also need to be fully covered by long term contracts procured by auctions. But, the auctions are decentralized. Each distribution company do it by itself and inform the Regulator. Besides there is not an index to ensure the contracts capacity but the generators

Figure 2 – Electricity market structures in Latin America

Source: IRENA (2016, p. 36)

need to inform to the Regulator how they intend to meet the contract requirements.

Colombia implemented a fully regulated auction mechanism. The auctions are centralized by the Regulator and adopt a special rule with a negative-slope demand curve to clear the auction. This aims at dealing with the Threat of New Entrants in an effort to improve the competition without harming companies that are already in the market.

Peru adopts two auction frameworks (HANCHER; HOUTECLOCQUE; SADOWSKA, 2015). One has a fully decentralized designed to deal with the distribution company needs and the captive consumers. The auction fixes the price at which the energy will be remunerated, while the capacity payment, still calculated by the Regulator, enters the energy contract through the associated capacity calculation (MASTROPIETRO et al., 2016). The second, centralized and managed by the State, is designed to procure large power projects, mainly regarded to hidropower projects. These frameworks was introduced in 2006 aiming at fostering large investments in hidropower plants.

In Brazil, free competition was adopted in the electricity generation and commercialization segments. The transmission and distribution segments are characterized as natural monopolies, where the regulatory action is accentuated in the tariff modality direction. On a complementary basis it is forbidden the distribution segment vertical integration, that means, a distribution agent can not own transmission or generation assets, but need to ensure the free access to the network to generation companies and consumers. In the wholesale the distribution companies buy energy through auctions organized by government, what makes this practice the major way of energy trade.

2.2 Auctions

About auctions, one lesson that emerges is that details clearly do matter. Every design has to be adapted to the specificities of each power system (MAURER; BARROSO, 2011). To enable an effective outcome in terms of least-cost procurement of electricity, different renewable technologies should ideally compete on a level-playing-field basis.

Figure 3 summarizes the main auctions types in South America Mastropietro et al. (2016, p. 1109) .

	Brazil A1	Brazil A3	Brazil A5	Chile	Colombia OEF	Colombia GPPS	Peru Law 28.832	Peru Proinversión
Buying side	Captive demand			Captive demand	All system demand		Captive demand	
Selling side	Existing plants	New plants	New plants	Existing and new plants	Existing and new plants	New plants	Existing and new plants	New hydro plants
Auction process	Centralized			Decentralized	Centralized		Decentralized	Centralized
Demand forecasting	Decentralized			Decentralized	Centralized		Decentralized	Centralized
Lag period	1 year	3 years	5 years	> 3 years	4 years	> 4 years	> 3 years (90%)	> 3 years
Contract duration	3 to 8 years	15 years (thermal) and 30 years (hydro)		< 15 years	< 20 years	< 20 years	> 5 years (75%)	> 10 years
Contract type	Forward (hydro) and option (thermal)			Forward	Option		Forward	

Figure 3 – Comparison of the design elements of long-term electricity auctions in the four South American countries implementing them

Source: Mastropietro et al. (2016, p. 1109)

Figure 4 overviews the auction mechanisms over the world (MAURER; BARROSO, 2011).

However, if governments have a preference for particular technologies driven by energy policy concerns, this element should be reflected in the auction design. Figure 5 and Figure 6 shows the auctions result of wind and solar plants from 2010 to 2016 in many countries. As could be seen, the price reduction is a trend, this could be explained by the technologies matureness and also by the market competition. The auction regulator should take advantage of this situation when designing the auction. The selection of a particular technology is often driven by energy or economic policy considerations. A good review of auction mechanisms was present in (Renewable Energy Agency, 2016) and (MAURER; BARROSO, 2011).

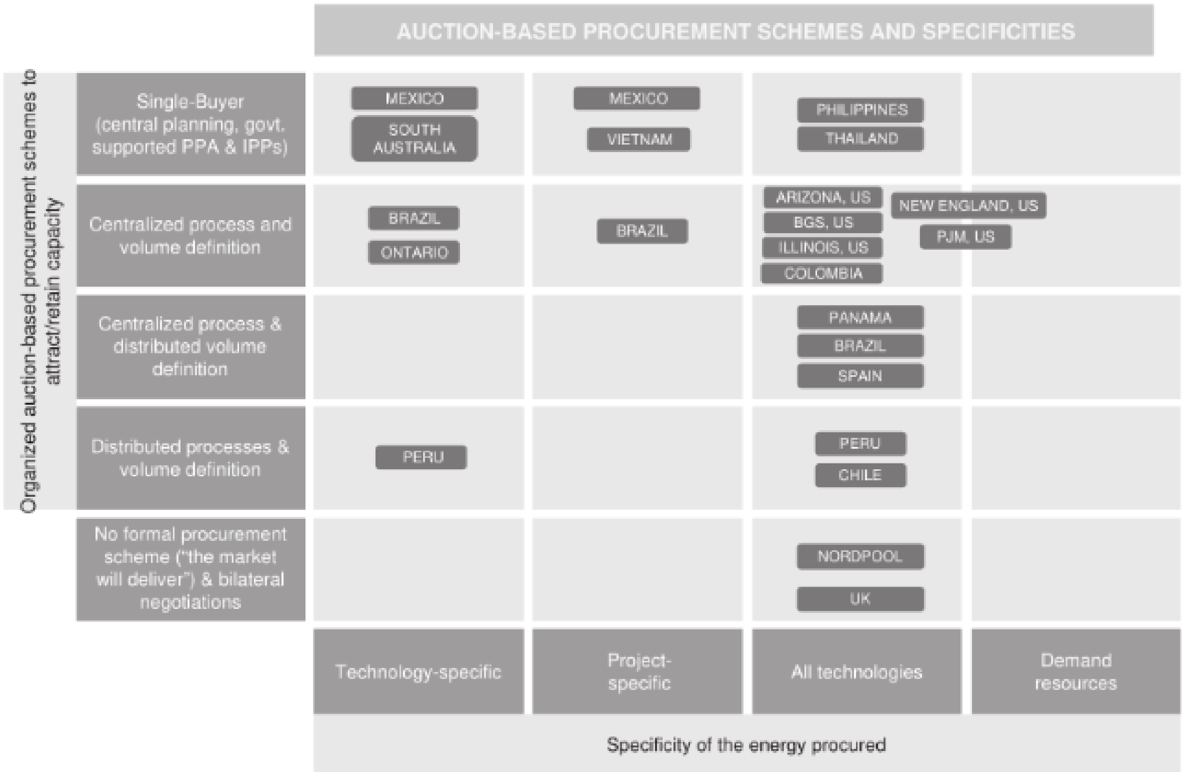


Figure 4 – Energy auction Organization over the world

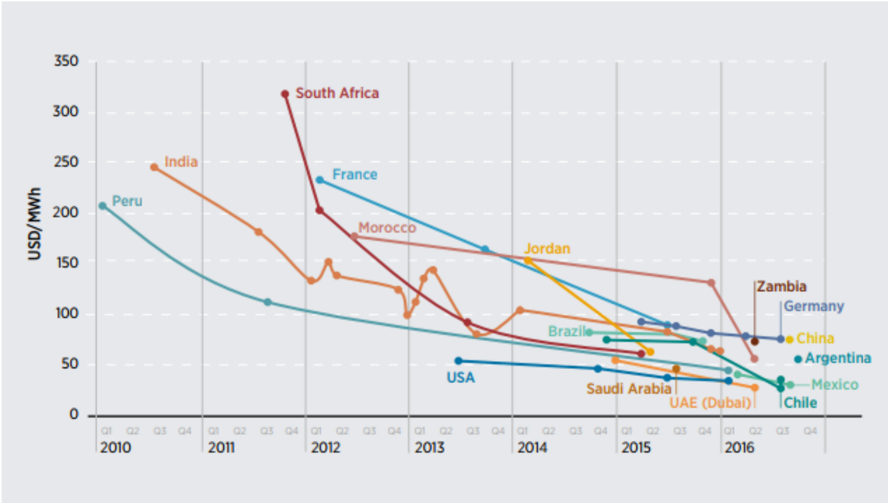
Source: Maurer e Barroso (2011, p. 15)

In Brazil, the electric power auction in the Ambiente de Contratação Regulada (ACR) is a competition promoted by the public power with a view to obtaining electricity in the future (predetermined in terms of a bidding) or by the construction from new power generation plants, transmission lines to the consumer centers or even the energy that is generated in operating plants and with their investments already paid, known as "old energy".

Auctions are the main form of acquiring energy in Brazil. Through this mechanism, the Sistema Integrado Nacional (SIN) agents (concessionaires, permit holders and distribution companies) provide the energy to the final customers. In terms of hierarchical coordination, all public auctions of energy go through the coordination and control of the electric sector Regulatory Agency, the Agência Brasileira de Energia Elétrica (ANEEL), connected to the Ministério das Minas e Energia (MME).

In the public auction of energy purchase, generation companies interact with each other to supply the energy to the distributors, and ANEEL organizes the auction so that the distributors obtain the necessary power to their consumers in the most advantageous condition. Auctions are designed to attend specific requirements, such as improving the variety of generators in the energy matrix or reducing the energy price. At other times

Figure 3 Evolution of average solar prices in auctions, January 2010-September 2016

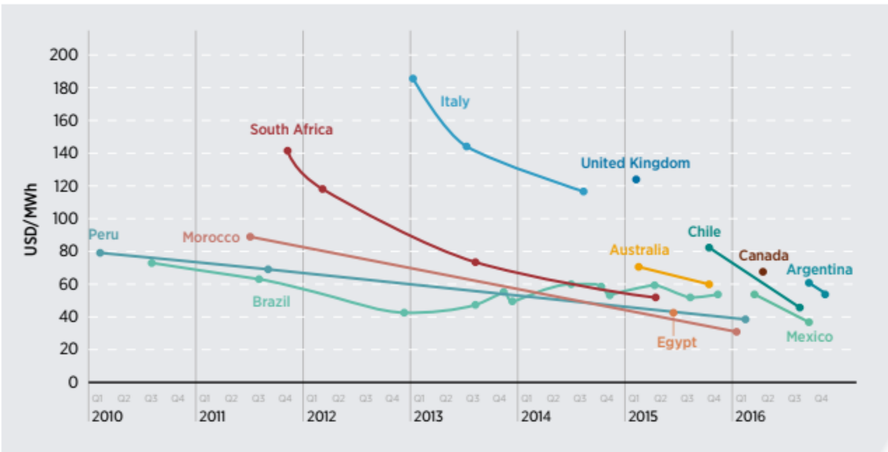


IRENA, 2017 (forthcoming).

Figure 5 – Average Solar Prices Auctions from 2010-2016

Source: Renewable Energy Agency (2016, p. 9)

Figure 8 Evolution of average auction prices for onshore wind energy, January 2010-July 2016



IRENA, 2017 (forthcoming).

Figure 6 – Average Wind Prices Auctions from 2010-2016

Source: Renewable Energy Agency (2016, p. 14)

it is interesting to buy the energy of a specific generator to meet a contract, or even to acquire power from a generator near a particular region, thus reducing transmission losses in the electrical network. Another variable that can be considered is the water balance since the Brazilian generation is predominantly hydroelectric. In water shortages times, it is necessary to obtain energy from other sources, such as thermoelectric plants. Thus, it is important for the distributor agent to auction off a few batches of alternative energy at auctions, even at prices higher than its hydroelectric supply, to ensure compliance with its distribution contracts and the continuity of power supply in the region.

There are several auction management topologies, such as: English auction (upward price); Dutch auction (descending price); discriminatory auction (first-price); second-price auction; among others. The lowest tariff criterion is more adopted in Brazil to define the event winners, aiming at the efficiency of contracting energy (TOZEI; VIEIRA; MATTOS, 2014). There are also private auctions, which are little explored in the national energy market, which can be an exciting tool for free consumers and independent producers to interact to obtain energy under more flexible and advantageous conditions than the public auctions of distributors. In private auctions, both consumer agents and generators are free to establish bilateral supply contracts under particular conditions that meet those involved. This is an important factor in favor of the private auction in the ACL. The freedom in negotiation allows the auction organizer to receive an additional benefit by defining the auction type, as it determines how the market competition will interact to maximize its goal (TOELCH et al., 2014). A way to plan bids for a private auction is through Nash equilibria, such as proposed in (ABAPOUR; MOHAMMADI-IVATLOO; HAGH, 2019). Private auctions can also take advantage of new methods of pricing, such as recommended in (MATHEWS; SCHWARTZ, 2017) for problems with a mixed-strategy solution.

The auctioning system involves a number of other important aspects that must be taken into account, such as: the principle of disclosure, which consists in finding that it is possible to define a set of rules that will lead agents to reveal their true perceptions about the value of product, even if the other participants profiles are not known; price discovery, which consists of the process of reviewing the evaluations of the proponents during a competition, a process that results from observing the behavior of other agents; competition between agents; and interdependence, which consists in the existence or not of interdependent relations between the values of the various products auctioned.

As can be seen, the procedures of energy trading by using auctions are complex, extensive, and involve different aspects. Private auctions improve consumer tactics to choose an adequate energy provider. However, there is a lack of methods to help the small consumer to deal with this buying process. And it represents in the buying process his own needs, and risks.

2.3 Brazilian Deregulated Market: Changes to Come

In 2004 was introduced the actual Brazilian energy market, aiming at solving the problem of long term investments necessary to afford the energy mix evolution and reducing the regulatory risk to the investor. With a very volatile economy, the Brazilian government decided to unbundle the utility industry and enrolls a long term contract auctioning policy. Such way contracts could protect the new agents from possible changes in law and ensure enough time to the investment maturing.

This policy is mainly represented for the following rules (MASTROPIETRO et al., 2016):

- the demand must be 100% covered by supply contracts and it owns to the demand side the responsibility for the energy forecasting (could be done by the distribution company in the regulated market and by the consumer in the deregulated). The amounts are audited monthly and the positive mismatching forecasts are settled by spot market price.
- the contracts are covered by "Firm Energy Certificates", that is an index, ensured by the Ministry of Energy, that represents the power plant max energy production in the worse conditions. The contracts are financial tools and not influence the energy dispatch.
- the long-term contracts that cover the captive demand should be assigned through public auctions. The free consumers don't need to buy energy by auctions but need to be fully covered by an energy contract.

This policy favored competition among agents, energy matrix diversification, and price reduction. But agents still get chained in some market regulations. Only consumers with demand above 3000kW are entirely free. The ones between 500kW e 3000kW are free only to buy from renewable sources and under 500kW are all captive buying energy from the distribution companies. In turn, the distribution companies do not choose the energy suppliers', it just informs to ANEEL the amount of energy needed. Afterward, ANEEL performs the auction in a centralized way sharing the energy contracts auctioned equally among the distribution companies.

Now, the law projects (CÂMARA, 2015) and (SENADO, 2016) aims at defining a new milestone in the Brazilian market. It is called portability for all and extends the benefits regarded to the free clients to all the consumers, even to the distribution companies. It allows the distribution companies to do auctions themselves requesting ANEEL authorization. Moreover, it implements a schedule of freeing consumers progressively, what reduces the demand restrictions as seen in Table 1. The law is not in force yet, but it is in the final round of approvals. It is expected to be in effect starting on January 2020.

This new law feature is a world trend. The UK and the USA markets implemented similar regulations. It allows an energy cost reduction for the final consumer while, at the same time, promoting a significant increase in competition and efficiency for the energy market (ABRACEEL, 2016). Although, now, in the Brazilian market, there is no tool suitable to afford this feature. It's imperative to develop a bespoke technology that could be used by the small consumer to have the benefits proposed by the laws indeed. Design this kind of methodology is one of the improvements proposed in this research.

Table 1 – Schedule of deregulation in the Brazilian Market.

Deregulation	Schedule in Brazilian market
thus far	above 3000 kW
18 months	above 2000 kW
30 months	above 1000 kW
42 months	above 500kW
54 months	plan for limits' extinction
66 months	above 300 kW
90 months	no restrictions

Source: (SENADO, 2016)

2.4 Summary

This chapter showed the energy market environment throughout the world, placing the Brazilian case. The new opportunities that are being created by the improvements in the Brazilian regulation are pointed out. The next chapter introduces ways of representing the market main uncertainties regarded with the amount of energy needed by the players (consumers and generators).

Chapter 3

Quantitative Risk

3.1 Risk

This section aims at describing how to deal with distinct kinds of risk and it's properties. It also represents the mathematical model and the proposed algorithm to solve problems involving risk management in energy trade.

Risk can be defined as the occurrence probability of an event as a function of an uncertain event. The author in (LINDAAS; PETTERSEN, 2016) establishes the difference between risk and uncertainty as:

a) Risk occurs where there are visible outcome generators, thin tails on the probability distributions, simple payoffs, and where sampling the past causes convergence to the real mean and real variance of the type of event in question;

b) Uncertainty occurs where we have invisible (and/or non-linear) outcome generators, complex payoffs, fat tails or non-scaleable probability distributions, and where sampling the past does not converge to a real mean and real variance, since no such mean and variance exist.

Risk management is a well-developed area in financial fields, that has many developments. Many of these approaches deal with quantitative risk such that (GIANNAKIS; PAPADOPOULOS, 2016), (CHEN; ZERILLI; BAUM, 2018), and (MAIER; STREET; MCKINNON, 2016). Some deals with the qualitative risk, or uncertainty (SAJID; KHAN; ZHANG, 2018). In turn, the literature lacks approaches do deal with risk and uncertainty at the same time (AVEN, 2016).

As pointed out in (AVEN, 2016) a key challenge of risk management is related to the development of the risk field, with a focus on knowledge and lack of knowledge characterizations, instead of accurate risk estimations and predictions. The author points out the following list as open issues to be handled:

i) how to describe and represent the outputs of risk assessment in a way it is useful to decision-makers, which clearly presents the assumptions made and their justification;

ii) how to precisely represent and account for uncertainties in a way that properly justifies the confidence in the risk results;

iii) how to state how good expert judgements are, and how to improve them.

This section addresses the risk concepts (quantitative risk) and Chapter 4 devises an approach to deal with uncertainty (qualitative risk), putting together both approaches and dealing with all the topics discussed above.

3.1.1 Quantitative Risk

A straightforward approach to evaluate the performance of a system is by pointing out, in the row of possible states for this system, the number of states that leads the system to a trouble condition times it occurrence distribution (ROSS, 2014). Thus, let π be a random variable, Γ the set of all possible states of π, and $p(.)$ a probability function. Then, if $\pi > 0$ is the undesirable values of π, the risk becomes $Risk = p(\pi > 0)$.

Now consider the step function $u(\pi)$ defined as:

$$u(\pi) = \begin{cases} 1, & \text{if } \pi > 0 \\ 0, & \text{otherwise.} \end{cases} \tag{1}$$

where $u(.)$ is the function of values of π.

Then, the risk expected value $E(\pi)$ is calculated as

$$E[\pi] = \sum_{s \in \Gamma} u(\pi)_s p_s. \tag{2}$$

Risk is a statistic associated with a quantile of a distribution function of a random variable. In an integer formulation, the risk represents the calculus of a distribution quantile of a random variable π in which the occurrence probability of π is greater than zero. This approach issue is that it compensates the risk. The mean softens extreme values not representing them adequately.

3.2 Value at Risk - VaR

VaR measures the expected loss in a given interval of time and a determined confidence level. It can be achieved by the probability distribution of a portfolio where VaR_α is the lowest value for a confidence level α (FÖLLMER; SCHIED, 2011).

$$VaR_\alpha = \int_{VaR_\alpha}^{\infty} f(\omega, \mathbf{y}) = p(f(\omega, \mathbf{y}) \geq \alpha), \tag{3}$$

$$VaR_{1-\alpha} = \int_{-\infty}^{VaR_{(1-\alpha)}} f(\omega, \mathbf{y}) = p(f(\omega, \mathbf{y}) \leq \alpha). \quad (4)$$

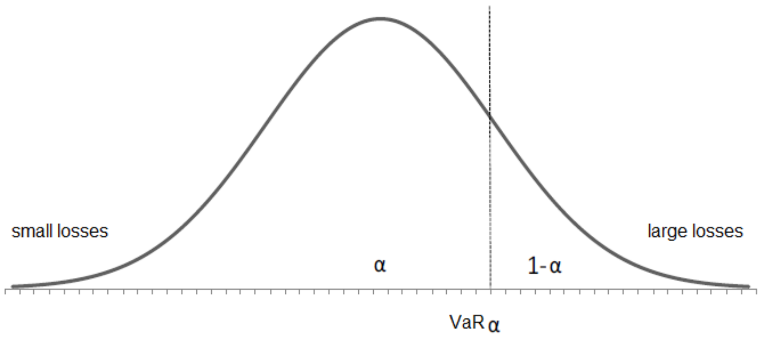


Figure 7 – VaR associated with losses distribution.

$f(\omega, \mathbf{y})$: loss function in Reais (R$)

ω: decision vector (a portfolio consisting of n instruments);

$\mathbf{y}$: random vector of price scenarios for the portfolio ω in Reais [R$];

α: confidence level of VaR;

VaR_α: a value of the losses in a confidence interval α;

$p(\mathbf{y})$: the probability density function of the price scenario $\mathbf{y}$.

VaR is localized in the right tail of a probability distribution when the losses are investigated, such as Figure 7. In that figure, the value VaR_α represents the lower loss value with a confidence level of α. If the problem considers the gains' distribution, then they are located in the left tail of a probability distribution.

A critical consideration about VaR as a risk index is that it does not attains subadditivity property. Thus, it is not considered as a coherent measurement of risk. Also, VaR does not show information about the level of losses that surpass its value, which makes it not suitable for tail risk representation.

3.3 Conditional Value at Risk - CVaR

The ANEEL and the Câmara de Comercialização de Energia Elétrica (CCEE) adopts CVaR as the risk measurement (CCEE, 2018). VaR represents the larger loss for a given period, within a chosen confidence level α. In turn, CVaR can be defined as the weighted average of losses strictly exceeding VaR. It can be depicted as (TESTURI; URYASEV, 2004):

$$\mathrm{CVaR}_\alpha = \phi_\alpha(\omega) = (1-\alpha)^{-1} \int_{f(\omega,\mathbf{y}) \geq \mathrm{VaR}_\alpha(\omega)} f(\omega,\mathbf{y}) p(\mathbf{y}) d\mathbf{y} = F_\alpha(\omega,\zeta_\alpha). \quad (5)$$

$f(\omega,\mathbf{y})$: loss function in Reais (R$)

ω: decision vector (a portfolio consisting of n instruments);

$\mathbf{y}$: random vector of price scenarios for the portfolio ω in Reais [R$];

α: confidence level of VaR;

VaR_α: a value of the losses in a confidence interval α;

$p(\mathbf{y})$: the probability density function of the price scenario $\mathbf{y}$

F_α is the objecive function.

where the probability that $f(\omega,\mathbf{y}) \geq \mathrm{VaR}_\alpha(\omega)$ is $(1-\alpha)$.

The CVaR, or Expected shortfall, is a convex and coherent measurement of risk. It differs from VaR once it considers the tail risk.

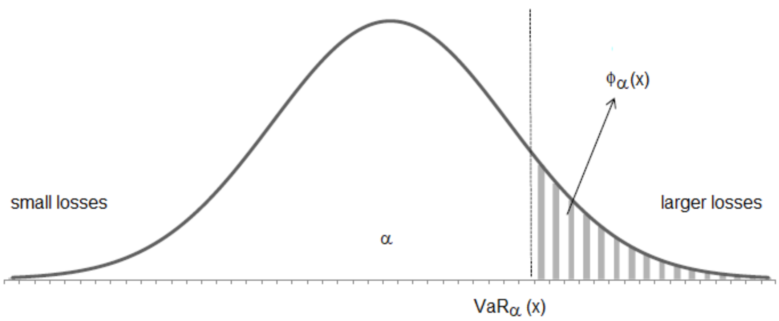


Figure 8 – CVaR associated with expected losses distribution.

The CVaR value is a quantile of a random variable that answer the question "which is the expected value conditioned to the α% worst scenarios". If random variable is the energy value than CVaR_α represents which is the expected value of the energy considering the α% worst scenarios.

Considering that $f(\omega,\mathbf{y}^j) = \omega^T(-\mathbf{y}^j)$ is the loss function for scenario j in a discret formulation, , the distribution of the vector $\mathbf{y} \in \mathbb{R}^m$ is modeled by s historical scenario returns, $\{\mathbf{y}^1, \ldots, \mathbf{y}^s\}$ than, CVaR can be addressed as an optimization problem where the objective function is defined as:

$$\begin{aligned} G_\zeta(\omega) &= \frac{1}{s}\sum_{j=1}^{s}\left[-\omega^T\mathbf{y}^j - \zeta\right]^+, \\ F_\alpha(\omega,\zeta) &= \zeta + (1-\alpha)^{-1}G_\zeta(\omega). \end{aligned} \tag{6}$$

where $[.]^+$ is the subset greater than 0.

Hence, to calculate CVaR is sufficient to minimize expression 6. The formulation to calculates CVaR is written as

$$\begin{aligned} \phi_\alpha = \underset{(\omega,\zeta)\in\Omega\times\mathbb{R}}{\text{Min}} & F_\alpha(\omega,\zeta), \\ & \text{subject to} \\ & \frac{1}{s}\sum_{j=1}^{s}\omega^T\mathbf{y}^j \geq \rho \text{ (lower bound on expected return)}, \\ & \sum_{k=1}^{n}\omega_k = 1 \text{ (normalization constraint)}, \\ & \Omega = \{\omega : \omega \in \mathbb{R}^n, \omega_k \geq 0, k = 1, 2, \ldots, n\}. \end{aligned} \tag{7}$$

where n is the number of energy sources, $(.)^T$ is the transposed of $(.)$, and ρ is the lower bound accepted.

In this work, CVaR is the risk measurement chosen to represent the unwanted events considering that a historical database is available. The decision regards that CVaR is adopted by Brazilian regulation as risk measurement. Besides, it is applied in many other markets.

The captive consumers do not need to deal with the risk; the distribution company do this risk management and share it proportionally among its clients by a price. The energy price perceived by the client already comprises the risk management cost in this case.

However, the client migrating to the free market has a trade-off decision to make. It trades a higher energy price and all-inclusive services done by the distribution company in the captive market for a lower energy price in the free market, where the client itself needs to manage its energy needs. This management includes, but it is not limited to, energy amount, seasonality, price, energy sources availability, uncertainties, and any other consumer particularity.

Some objectives are common to both markets, such that reducing the energy price and risk associated with energy providers. Distribution companies have recorded many years of data about its clients' consumption behavior. Thus, they have consistent information about the captive market. However, it is an one-sided viewpoint. The captive market regards just the distribution company perspective.

The clients sign an adhesion contract committing themselves to accept all the plan conditions. Thus, the consumer perception of risk is not well priced. It needs to accept the distribution company perspective. When this client is free-up, it needs to model its consumption preferences under much less information about the market, then the distribution company does. Buying energy is not usually the companies' core business. Thus, it is not possible to model the risk just by financial approaches as the distribution companies do. Even these companies should not do their risk analyses only under financial procedures. Once doing that, they felt by a risk of not representing rare events in their models. From (LINDAAS; PETTERSEN, 2016) definition of risk and uncertainty, the client in that situation has to deal with uncertainty instead of risk, given its non-representativeness in the financial approaches.

Here it is proposed to split the risk representation into two types: the quantitative and the qualitative ones. Quantitative risk uses financial approaches and numeric information about the energy market to proceed with the analysis. It follows a probabilistic approach mainly represented by CVaR. In turn, the qualitative one represents the intrinsic knowledge of a row of specialists about the client core business, its perception about the market and other information that could not be well represented by numbers. Whether by lack of knowledge, lack of data about the risk causes or even by the hardship of representing a specialist knowledge about the risk in a statistical way.

Three objectives are proposed to model the energy buying of a free market consumer.

- ❏ Reducing the buying price;
- ❏ reducing the quantitative risk measured as CVaR;
- ❏ reducing the qualitative risk (uncertainty) depicted by a payoff matrix representing the specialists' perception of risk to the energy buying strategy.

These three objectives should be minimized in order to design the best buying strategy for a free market energy consumer.

3.4 Formulation for quantitative risk

The Electric Energy Trading Chamber, CCEE, is a Brazilian organization that registers all the energy trades. It aims at keeping records of energy procurements by making the regulatory agencies aware of the ballast in the system. This organization states CVaR as risk index for energy trades. As proposed by (CCEE, 2019), the consumer usually has two objectives to deal with. The energy price and the risk. Aiming at handling these objectives it can be written:

a) a formulation to minimize the risks constrained by the energy price;

b) a formulation to maximize the profit constrained by the quantitative risk CVaR.

We proposed to improve that formulation also by inserting the qualitative risk, accounting for the specialists' knowledge about the uncertainties that represents a threat for the energy buying but, by lack of statistical information, are not captured by the quantitative risk formulation. There is no such formulation that deals with the qualitative and quantitative risks in a substantiated way. The three objectives problem can be written as:

$$
\begin{aligned}
&\underset{\omega\in\Omega}{\text{Min}} \\
&\quad f_1(\omega) = \sum_{k=1}^{n} \omega_k e_k && \text{Energy Price} \\
&\quad f_2(\omega) = \sum_{k=1}^{n} \omega_k \Psi_k && \text{Qualitative risk} \\
&\quad f_3(\omega) = \text{CVaR}_\alpha && \text{Quantitative Risk} \\
&\quad \text{subject to} \\
&\quad \sum_{k=1}^{n} \omega_k = 1 && \text{decision variables} \\
&\quad \sum_{k=1}^{n} \Psi_k = 1 && \text{qualitative risk} \\
&\quad \Omega = \{\omega : \omega \in \mathbb{R}^n, \omega_k \geq 0, k = 1, 2, \ldots, n\}
\end{aligned}
\tag{8}
$$

where ω is the vector of decision variables that represents the share of each energy provider in the portfolio, Ω feasible solution set, e_k is the energy price of the k^{th} energy provider, n is the number of energy sources, Ψ_k is the qualitative risk, and CVaR_α the quantitative risk.

In that formulation the three objectives are presented. Chapter 3 presented the quantitative risk, and Chapter 4 presents in details how to calculate the qualitative risk (uncertainty).

3.5 Concluding remarks

This chapter has presented some risk measurements by addressing the differences between risk and uncertainty. It states that new regulations will push different kinds of consumers to the market. Some of them lacking in a robust database to apply the standard formulations of risk, and others that could enrich their models representing risks of qualitative nature. Both need a suitable representation of qualitative and quantitative risk. In this chapter, it was chosen CVaR as the risk index for quantitative risk. The choice considers the Brazilian regulation selects it as risk measurement for the energy markets as well as other countries does. It was also proposed a formulation for minimizing the risks of qualitative nature, intrinsic in any portfolio set. Next chapter points out how to deal with qualitative risks (uncertainties), the one where the outcome generators are not fully understood or lack in databases also calculating the values of $\mathbf{\Psi}$ used in the present chapter.

Chapter 4

Qualitative Risk

Last section discussed the most relevant approaches to deal with risk. CVaR is a well understood risk measurement adopted in finances (YAN et al., 2017) (CHOI, 2015), engineering (KWON; ZENIOS, 2017), e-commerce (YANCHUN; QIUCEN, 2017), energy supply (SHI et al., 2017), climate policy (NAZARI et al., 2015), medicine (CHAN; MAHMOUDZADEH; PURDIE, 2014) and many other fields (YAN; WU; WANG, 2018) (URGO et al., 2018). But its use demands the knowledge of reliable historical data to work correctly. In cases where the outcome generator is not fully understood, or it is too complicated or even when there is no data available to represent the real situation, the CVaR approach is not applicable or does not behave well. For these cases, here it is proposed to include a qualitative risk, which is a function that represents the view of a row of specialists about the risks associated with a portfolio. It can be expressed under linguistic variables and can express other variables of qualitative nature as well.

The approach makes it possible to represent the experience of a specialist about a particular subject or strategy, addressing the risks according to the specialist expertise, knowledge, and intuition. The risks can be ordered, gathered, and prioritized according to the situation. It represents the uncertainty involved in specialists' advice in a justified way. The method presented also allows to evaluate the specialists, and it is suitable for group decisions.

This section proposes how to deal with the risk in the energy commercialization when a substantial historical database is not available, and it is necessary to evaluate the energy trade opportunities based on the knowledge of a row of specialists managing the qualitative risks.

The section defines the qualitative risk and then describes the process to represent the specialists' knowledge and take decisions that minimize the qualitative risk associated to the energy trade. In summary, the whole process follows the steps:

a) structuring the problem (defining qualitative risks);

b) building specialists preferences;

c) aggregating preferences;

d) solving problem analysis (prioritizing, ordering alternatives, decision making).

4.1 Qualitative Risk (or uncertainty)

In the field of energy commercialization, the consumer needs a long-term plan to join the core-business and energy market own characteristics, taking into account the uncertainties of different natures. They need to carry out strategic planning in a cooperative and multidisciplinary environment with the contribution of people who can occupy different hierarchical levels. Many works deal with decision-making problems associated with strategic planning of electricity sector companies. Strategic decisions in electricity companies impact thousands of companies and could not be a one-sided viewpoint (GONTIJO, 2011).

Strategic decisions, such that energy buying, by standard involves the evaluation, comparison, prioritization, and ordering of strategic initiatives according to criteria of different natures that can interrelate in different ways (with different levels of compensation) (LØKEN, 2007).

It is common to process information with a high degree of uncertainty during strategic planning. The uncertainties came from many sources such as the specialists' difficulty to drive a consensually strategic goal for the company; the hardness in formalizing some data and information of qualitative nature essential to make the decision; the impossibility of making accurate and reliable forecasts for the future; or also by lack of reliable information about the business environment behavior (PEDRYCZ; EKEL; PARREIRAS, 2011).

In Table 2 it is proposed the following actions to manage the uncertainty

Table 2 – Categories of Uncertainties and Uncertainty Management Options

Knowledge on the subject	Awareness of knowledge	
	Aware	Not Aware
A lot known	No uncertainty (deterministic representation)	Reduce uncertainty by knowledge management
A lot unknown	Reduce uncertainty by gathering more knowledge	Use conservative assumptions (e.g., defense-in-depth).

Source: (MODARRES, 2016)

The first quadrant can be dealt with approaches presented in Chapter 3. It regards there is available enough data to handle the problem. The other quadrants are the object of study in this chapter that presents ways to process and reduce the uncertainty.

The uncertainty in the decision-making process can be represented through Preference Relations. It is a method that aims at expressing the specialists' knowledge about the issue in analysis. Preference Relations can be used to state the specialist preference over a set of alternatives clarifying the understanding about it and solving the problem. There are many ways to express the preferences such that multiplicative preferences (SAATY, 1988), utility functions (HERRERA-VIEDMA; HERRERA; CHICLANA, 2002), preference orderings (LIU et al., 2017), or additive preference relations (XU; LIU; WANG, 2018). The Fuzzy preference relations are particularly useful in these situations, given its power to represent qualitative and imprecise characteristics. It is suitable to represent linguistic variables making it easier for the specialist to express his opinion.

A consensus level is a necessary point in the group decision-making process, even that the agreement of all involved is unrealistic for most real-life applications (XU; WU, 2018).

To deal with these problems here it is proposed a method based on Fuzzy Reciprocal Preference Relations (FRPR) to deal with the qualitative risk issues (uncertainty) in a free-market energy buying. The method comprises the risk ordination and then devises the risk perception of each option according to a row of specialists. This representation of qualitative risk is the third objective and should be minimized as well as the other two already disclosed. These three objectives encompass the larger areas of necessary knowledge to evaluate the energy commercialization: the price reduction, quantitative risk, and uncertainties in qualitative risk. Another critical issue related to energy buying is the amount of energy. This quantification can be handled with forecast techniques such as proposed in (BERNARDES et al., 2018).

4.2 Qualitative Risk Assessment

These concepts which were detailed in section 4.1 are extended to a general approach that includes a group of specialists to analyze the risk. Two approaches about managing the risks of qualitative and quantitative nature are presented at the end of this section.

4.2.1 Modeling the preferences

The specialists invited to analyze the risks manifest their comprehension about the risk trough preference relations. How to express it is a personal choice. It is a subjective decision that takes into account the intuition, aimed accuracy level, easiness of understanding, or clarity to evaluate the alternative. Therefore, it is expected that distinct specialists choose different templates of preference relations to express their judgment. It is natural to feel more pleasant with one model than the other, selecting the one that fits better the aim of expressing his opinion over the alternatives (PEDRYCZ; EKEL; PARREIRAS, 2011). The literature is fruitful in models to represent the preference relations, and they usually are interchangeable, that means one format is convertible in the others. The following are the most common (HERRERA-VIEDMA, et al., 2002) (ZHANGA, Q.; CHENA, J.C.H.; CHONG, 2004):

- Alternatives Ordination: ordination is the simplest way to perform classification. Its use is appropriate when the evaluator is insecure about its preferences level over the alternatives (CHICLANA; HERRERA; HERRERA-VIEDMA, 1998).

- Utility value sets $U_i(.)$: This kind of preference considers the difference between the preference levels. Thus, given $U_i\,(x_k)$ a utility function where x_k, x_l, x_m are solution alternatives to be evaluated, and i is a criteria of evaluation of alternatives. If $U_i(x_k) - U_i(x_m) \geq U_i(x_l) - U_i(x_k)$, then it means the difference between the preference levels $U_i(x_k)$ and $U_i(x_m)$ is greater than $U_i(x_l)$ and $U_i(x_k)$ (KEENEY, 1996).

- Multiplicative Preferences Relations $RM_i(.)$: The Multiplicative Preference Relations adopts the Analytic Hierarchy Processes (SAATY, 1988). It is represented in a $n \times n$ matrix, and the intensity ration of the preferences is given by a ratio of pair of alternatives. Hence, $RM_i(x_l, x_k) = 1/RM_i(x_k, x_l)$. The limitation is that approach demands at least a weak transitivity.

- Fuzzy Estimations $F_i(.)$: Fuzzy estimations such as $F_i(x_l), ..., F_i(x_n)$ can be applied to evaluate the alternatives in the set X. Hence, $\mu_{F_i}(x_k)$ is the pertinence function of the fuzzy estimation applied in the evaluation of the alternative x_k, considering the criteria c_i. The fuzzy estimation $\mu_{F_i}(x_k)$ is applied to a fuzzy number that could be addressed directly by the specialist or indirectly through a linguistic term (LT) of a set such that $LT(c_i) = small, medium, high$. In the indirect case, each of the linguistic terms is previously modeled as a fuzzy estimation (PEDRYCZ; EKEL; PARREIRAS, 2011).

Specialists often experience difficulties representing their opinion. The literature debates these issues of expressing the specialists' preferences pointing out as the main ones: discordant viewpoints and interests among specialist making it harder to reach a consensual agreement (ALONSO et al., 2010); hardness modeling the problem such way it represents the specialist's experience and its level of knowledge (ALONSO et al., 2009); multiple hierarchical topologies demanding to structure the problem in a hierarchical or democratic way (PEDRYCZ; EKEL; PARREIRAS, 2011); specialists handling difficulties to express their opinion for all the alternatives (HERRERA-VIEDMA et al., 2007); specialists, at times, failing to provide information with an adequate consistency level (ARNOTT, 1998).

Thus, choosing a proper model to represent the specialists' advice is determinant to reach a quality solution. A better way to constitute the specialist preference is by selecting a model of preference that he can easily understand, giving the specialist a better stand to express his knowledge. Linguistic variables and fuzzy models are approaches heading in that direction, making it easy for the specialist to express himself. These approaches are similar to the human language, and it is easy to be understood, resulting in better conditions to make decisions.

Hence, a convenient way to improve the mathematical models of risk such way they can represent the uncertainties and ambiguities of the specialists is through fuzzy sets (ZADEH, 1965). Many authors use these sets to represent the specialist preference. (YAN; MA, 2015) proposes a fuzzy preference relation approach to address two types of uncertainties in quality function deployment for customers preference evaluation; (LIU et al., 2016) developed a type of preference relations based on fuzzy preference relations to represent the specialist confidence; (EKEL, 1999) describe models $< X, R >$ to represent the preferences based on Orlovsky choice (ORLOVSKY, 1978), where X represents a finite and discrete set of alternatives, which are to be evaluated, compared, and/or ordered under the consideration of a set of fuzzy nonstrict preference relations R, reflecting the collective preferences for different criteria.

Another important aspect is how to present the alternatives to the specialist. It must be clear and not give rise to misunderstandings. As it is placed in (ARNEY, 2010) when a specialist has many alternatives to judge at the same time, the specialist is distracted, and its judgment is biased by the decoy effect that impairs the decision. It is avoided or at least minimized when the evaluation is given in pairs of alternatives. The assessment in pairs leads the specialist to focus on the attributes of one pair at a time, highlighting its particularities. The procedure should regard all the possible combination of alternatives, splitting a complex evaluation into many simple ones that are easier to be assessed. This comparison in pairs is called a binary relation, or fuzzy binary relation when it deploys fuzzy variables.

4.2.1.1 Fuzzy binary preference relation

A binary relation A defined in the universe X is a bi-dimensional fuzzy set witch pertinence function is given by $\mu_R : X \times X \to [0, 1]$. Given a relation R, the ordered pair of elements $(x_k, x_l) \in X \times X$. In a ordered pair (x_l, x_k) it is considered (x_k, x_l) and (x_l, x_k) as distinct elements. The author (FODOR; ROUBENS, 1994) describes as relations of an ordered pair the inverse relation $\mu_{R^{-1}}(x_k, x_l) = \mu_R(x_l, x_k)$; the dual $\mu_{R^d}(x_k, x_l) = 1 - \mu_R(x_l, x_k)$, and the complement $\mu_{R^C}(x_k, x_l) = 1 - \mu_R(x_k, x_l)$.

An example of this kind of representation is as follows:

$$R = \begin{array}{c} \\ x_1 \\ x_2 \\ x_3 \end{array} \begin{array}{c} \begin{array}{ccc} x_1 & x_2 & x_3 \end{array} \\ \begin{bmatrix} 1 & 1 & 1 \\ 0.3 & 1 & 0.8 \\ 0.4 & 0.8 & 1 \end{bmatrix} \end{array},$$

where R is a preference relation that represents the evaluation of three alternatives x_1, x_2, x_3.

Each ordered pair of elements is a fuzzy value that represents the specialist advice over the alternatives. Preference relations based on <X, R> models lead to a substantiated evaluation, being that the strong point of this approach (ORLOVSKY, 1978).

4.2.1.2 Evaluating the judgments' consistence

Once the judgments are formulated, it is also necessary to check it's consistency. Its consistency brings information both from the specialist's knowledge as much as from the problem itself.

The preference models based on paired evaluation of alternatives present the simplicity as a significant upside over other approaches. Fuzzy preference relations and multiplicative relations (MENG; TAN; CHEN, 2017) take advantage of this simplicity to make the problem modeling more suitable to the specialists. At each evaluation, the specialist just needs to evaluate which is the best among two alternatives. Thus, it is possible to break a complex problem in many paired assessment, that are clearly understandable by the evaluators. Hence, they could better represent their knowledge about the situation.

Consistency is associated with the ordinal coherence. As a result, in an evaluation process, let it be x_k, x_l, x_m a set of alternatives. A soft definition of consistency suitable to real applications could be exemplified as: if x_k is preferable to x_l and x_l is preferable to x_m then x_k must be preferable to x_m. It is also known as weak transitivity and could be represented in reciprocal fuzzy preference relations as (CHICLANA et al., 2008):

$$\begin{aligned}&\textbf{if}\quad \mu_{R_i}(x_k, x_l) \geq \mu_{Ri}(x_l, x_k) \quad \textbf{and} \quad \mu_{R_i}(x_l, x_m) \geq \mu_{Ri}(x_m, x_l)\\ &\textbf{then}\\ &\mu_{R_i}(x_k, x_m) \geq \mu_{Ri}(x_m, x_k) \quad \forall x_k, x_l, x_m \in X.\end{aligned} \tag{9}$$

Another approach takes into account the preference level associated with the judgments. This is known as cardinal consistency. It observes the preference ratio of one alternative over the other and can be represented as follows:

$$\mu_{R_i}(x_k, x_l) \geq \min(\mu_{R_i}(x_k, x_m), \mu_{R_i}(x_m, x_l)) \quad \forall x_k, x_l, x_m \in X. \tag{10}$$

4.2.2 Method for risk evaluation using <X,R> models

Once the preferences are built it is necessary to evaluate the judgments. The literature presents distinct approaches to model the recommendations in decision situations. $< X, R >$ models are base for many of them. Notwithstanding, it is fair to highlight that each procedure bases on distinct assumptions, has it owns justification, and it is natural to lead to different recommendations. Thus, it is up to the decision-maker the responsibility for selecting the procedures more suitable to generate recommendations according to its needs and expectations. A widely applied method for multicriteria decision is the Orlovsky procedure (ORLOVSKY, 1978). This method uses the fuzzy preference relations for the choice and ordination of alternatives and has been used in (EKEL et al., 1997), (EKEL et al., 1998) e (MACHARIS, et al., 2004). This procedure is based on the construction of the fuzzy strict preference relation and the designing of the fuzzy set of non dominated solutions:

Indifference

$$\mu_{I_i}(x_k, x_l) = \min\left\{\mu_{R_i}(x_k, x_l), \mu_{R_i}(x_l, x_k)\right\}, \tag{11}$$

Incomparability

$$\mu_{J_i}(x_k, x_l) = \min\left\{1 - \mu_{R_i}(x_k, x_l), 1 - \mu_{R_i}(x_l, x_k)\right\}, \tag{12}$$

Preference

$$\mu_{P_i}(x_k, x_l) = \max\left\{\mu_{R_i}(x_k, x_l) - \mu_{R_i}(x_l, x_k), 0\right\}. \tag{13}$$

This selections of operators 11, 12, 13 have been successfully applied to solve multicriteria decision problems (EKEL, et al., 1998), (EKEL, et al., 2009), (EKEL, et al., 2006), (PARREIRAS, et al., 2011), (PEDRYCZ; EKEL; PARREIRAS, 2011), (EKEL et al., 2019) and (MACHARIS, et al., 2004).

The Orlovsky procedure uses the fuzzy strict preference relation, given by 13, to choose the alternatives. $\mu_{P_i}(x_l, x_k)$ describes the set of all alternatives x_k that are strict dominated by x_l (considering only the i^{th} criteria). In turn, the complement $\mu_{P_i^c}(x_l, x_k)$ matches the set of alternatives non dominated by x_l. Thus, to find the set of non dominated alternatives, it is enough to calculate the intersection of the fuzzy sets $\mu_{P_i^c}(x_l, x_k)$ for each alternative x_k in X as described in equation 14. This equation represents the fuzzy set of non dominated solutions:

$$\mu_{ND_i}(x_k) = \min_{x_l \in X}\left\{1 - \mu_{P_i}(x_l, x_k)\right\} = 1 - \max_{x_l \in X} \mu_{P_i}(x_l, x_k). \tag{14}$$

A natural choice for a monocriteria problem based on this approach is the set of alternatives

$$XND_i = \left\{x_k^* \in X | \mu_{ND_i}(x_k^*) = \max_{x_k \in X} \mu_{ND_i}(x_k)\right\}. \tag{15}$$

The alternatives that fulfill $XND_i = \{x_k^* \in X | \mu_{ND_i}(x_k^*) = 1\}$ are the non-fuzzy solution for the decision problem. To ordinate all the alternatives in X, the sequence of non dominated solutions are built such way $XND^1 \succ XND^2 \succ \cdots \succ XND^i$ where $\succ$ means "better than". So, XND^1 is the non-dominated solution for the entire set X, then for XND^2 the problem is solved again withdrawing the non dominated element in XND^1 (withdrawing the column and the row in which was the XND^1 element). The procedure is repeated until the i^{th} element is withdrawn having he set of non dominated solutions (KULSHRESHTHA; SHEKAR, 2000).

The equations 13, 14, and 15 are suitable to solve either monocriteria as well as multicriteria problems (EKEL, et al., 2008). One way to solve a multicriteria problem is to gather the fuzzy relations matrix in a group matrix as proposed in (PEDRYCZ; EKEL; PARREIRAS, 2011), where it is proposed to build a global matrix of preference relations grouping the q individual preferences relations $R_1, R_2, \ldots, R_q$, where q is the number of matrix of preference relations to be evaluated. Many aggregation operators are available to do so, as proposed in section 4.2.3.1.

As an example, using the mean aggregation operator, the global matrix can be written as

$$\mu_G(x_k, x_l) = \sum_{i=1}^{q} w_i \mu_{R_i}(x_k, x_l), \forall\, x_k, x_l \in X, \tag{16}$$

where the weights $w_1, w_2, \ldots, w_q$ satisfy the condition $w_i \in [0, 1] \quad \sum_{i=1}^{q} w_i = 1$. Given an a nonstrict fuzzy preference relation R_G the equations 13, 14, and 15 can be used to reach a the set of non dominated alternatives, that is equivalent to the Pareto Optimal front.

E.g.: given an aggregated non-strict fuzzy preference relation

$$R_G = \begin{bmatrix} 1 & 0.2 & 0 \\ 1 & 1 & 0.3 \\ 0.9 & 1 & 1 \end{bmatrix}, \tag{17}$$

that represents the relations of alternatives x_1, x_2, and x_3. Using equations 13, and 14 we have the strict preference

$$P_G = \begin{bmatrix} 0 & 0 & 0 \\ 0.8 & 0 & 0 \\ 0.9 & 0.7 & 0 \end{bmatrix}, \tag{18}$$

and the fuzzy set of non-dominated solutions

$$\mu_{ND}(x_k) = [0.1 \quad 0.3 \quad 1]\,. \tag{19}$$

Then, from 19, the alternative x_3 is selected as the best alternative and also the non-fuzzy, non-dominated solution for the example given.

The second best alternative is obtained from 17, now extracting the first best solution, the alternative x_3. The reduced new aggregated non-strict fuzzy preference relation becomes

$$R_{G1} = \begin{bmatrix} 1 & 0.2 \\ 1 & 1 \end{bmatrix}. \tag{20}$$

Applying the equations 13 again we have

$$P_{G1} = \begin{bmatrix} 0 & 0 \\ 0.8 & 0 \end{bmatrix}, \tag{21}$$

as the reduced fuzzy strict preference relation. Then, applying 14 we have

$$\mu_{ND}(x_k) = [0.2 \quad 1]\,, \tag{22}$$

as the new set of non dominated solutions. From 22 it is identified the element x_2 as the second best alternative. The set of non dominated solutions XND for the problem become

$$\text{XND}_G = x_3 \succ x_2 \succ x_1. \tag{23}$$

The methods based on $< X, R >$ models present some characteristics that make them suitable to solve and analyze decision problems as the qualitative risk. Some of the desired features are: allowing to modeling and dealing with the uncertainties of different natures in a justified way; allowing the specialists to express their preference using different models of preference relations; allowing modeling the ties among the criteria by different aggregation operators.

The literature presents different ways to extend these methods to the group decision environment, allowing inviting specialist from different hierarchical levels and disciplines to contribute with their knowledge to make the best evaluation.

4.2.3 Risk management based on <X,R> models and group decision

It is natural to expect that the decision-making process in complex situations involves distinct specialists, subjects, and hierarchy levels to evaluate the alternatives and reach the final solution. Thus, it is necessary to develop methods suitable to deal with this challenge managing the risks. A way to extend the <X,R> models presented in subsection 4.2.2 to a group decision is trough preference aggregations. Also, it is proposed some quality index such as Comparability index, agreement and disagreement index, consensus index, to reduce the risk through the proper representation of the uncertainty bounded to human behavior and present in the specialists' advice.

4.2.3.1 Preferences aggregation

Preference aggregation aims at jointing the evaluations in a single preference relations matrix preserving the original characteristics of the individual matrix. A review of aggregation operators is given in (YU, 2015) highlighting the following aggregation operators:

a) Weighted Arithmetic Means operator (WAM): it is remarkable by compensatory behavior. A lower evaluation is compensated by a higher evaluation given by another specialist. We can address this operator as

$$\mu_{R_{i,G}}(x_k, x_l) = \sum_{y=1}^{v} w_y \mu_{R_{i,y}}(x_k, x_l), \tag{24}$$

where the weights represent the importance of each specialist advice and satisfy $0 \leq w_y \leq 1, y = 1, 2, \ldots, v$, $\sum_{y=1}^{v} w_y = 1$, and y, v are the the number of specialists. Each specialist fulfills one matrix of preference relations per i^{th} criteria. Thus, the number of matrix of preference relations is equal to the number of specialists.

b) Weighted Geometric Mean operator (WGM): WGM works as the WAM operator but displaying a weaker compensatory behavior. Weights balance the preference relations proportionally to the advice strength. The operator implementation is done as follows

$$\mu_{R_{i,G}}(x_k, x_l) = \prod_{y=1}^{v} \mu_{R_{i,y}}(x_k, x_l)^{w_y}, \tag{25}$$

where the weights represent the importance of each specialist advice and satisfy $0 \leq w_y \leq 1, y = 1, 2, \ldots, v$ and $\sum_{y=1}^{v} w_y = 1$.

c) Min operador (Min): its striking feature is to be conservative. It is not compensatory and it preserves the most pessimistic evaluation. Its implementation is given as follows:

$$\mu_{R_{i,G}}(x_k, x_l) = \min_{1 \leq y \leq v} \mu_{R_{i,y}}(x_k, x_l), \tag{26}$$

d) Ordinated Weighted Average operator (OWA): design by (YAGER, 1988) it has an intermediary behavior between the max and min operators:

$$\mu_{R_{i,G}}(x_k, x_l) = OWA(\mu_{R_{i,1}}(x_k, x_l), \ldots, \mu_{R_{i,v}}(x_k, x_l)) = \sum_{i=1}^{v} w_i b_i \quad \forall x_k, x_l \in X, \tag{27}$$

where b_i is the i^{th} greatest value in the set $\mu_{R_{i,1}}(x_k, x_l), \ldots, \mu_{R_{i,v}}(x_k, x_l)$ and satisfy the conditions $0 \leq w_y \leq 1, y = 1, 2, \ldots, v$ and $\sum_{y=1}^{v} w_y = 1$. As proposed in (QUEIROZ, 2009) the weights w_y can be devised with

$$w_y(i) = Q\left(\frac{i}{v}\right) - Q\left(\frac{i-1}{v}\right), \tag{28}$$

where Q_φ is an linguistic operator that assumes values such as: at least half, most, as much as possible. Those operators are defined by

$$Q_\varphi = \begin{cases} 0 & \text{if} \quad \varphi < d \\ \frac{\varphi - d}{\sigma - d} & \text{if} \quad a \leqslant \varphi \leqslant \sigma \quad \forall \quad d, \sigma, r \in [0,1] \\ 1 & \text{if} \quad \varphi > \sigma. \end{cases} \tag{29}$$

4.2.3.2 Comparability index

Individual preference relations should be reliable for getting in on the aggregated matrix. High levels of hesitation in the personal preference relations could point out specialists unprepared to deal with the subject and may negatively influence the conclusions reached by the collective matrix.

The author proposed a comparability index-based to evaluate the personal preference relation of the specialists. The index bases on the incompatibility relation, equation 12, related to the nonstrict preference relation. The following expression represents the comparability index

$$\mu_{J^c_{i,y}}(x_k, x_l) = 1 - \mu_{J_{i,y}}(x_k, x_l) = \max\left\{\mu_{R_{i,y}(x_k,x_l)}, \mu_{R_{i,y}(x_l,x_k)}\right\}. \tag{30}$$

From expression (30) we can devise a global comparability index for each pair of alternative. That is implemented with the min operator and it is pointed out in formula 31. The expression represents the intersection of all individual preference relations.

$$ICMP_i(x_k, x_l) = \min_{1 \le y \le v} \mu_{J^c_{i,y}}(x_k, x_l) \tag{31}$$

The proposed comparability index represents the specialist's evaluation reliability and has many useful applications. It allows identifying the hardest pair of alternatives to be evaluated and also allowing to point out the evaluations that had a low level of reliability. Also, it is possible to identify confident specialists and hesitating ones. These information are useful to guide the discussion flux.

4.2.3.3 Agreement and disagreement index

Agreement index and disagreement index measure the similarity and differences among the specialists' opinions. They can be used to identify the discordant specialists and the ones more inclined to reach the consensus. A way to find the discordance level between two specialists y and z for the i^{th} criteria expressed through no reciprocal fuzzy preference relations is through the expression

$$IDSC_i^{y,z}(x_k, x_l) = \frac{1}{2}\left(\begin{array}{c}\frac{|\mu_{P_{i,y}}(x_k,x_l)-\mu_{P_{i,z}}(x_k,x_l)|+|\mu_{P_{i,y}}(x_l,x_k)-\mu_{P_{i,z}}(x_l,x_k)|}{2}+\\ \frac{|\mu_{I_{i,y}}(x_k,x_l)-\mu_{I_{i,z}}(x_k,x_l)|+|\mu_{I_{i,y}}(x_l,x_k)-\mu_{I_{i,z}}(x_l,x_k)|}{2}\end{array}\right). \tag{32}$$

The agreement between the preferences of two specialists is then estimated for each pair of alternative using the following index

$$ICNC_i^{y,z}(x_k, x_l) = 1 - IDSC_i^{y,z}(x_k, x_l). \tag{33}$$

The mean concordance by criteria can be calculate as:

$$ICNCM_i^{y,z} = \frac{2}{n(n-1)} \sum_{k=1}^{n} \sum_{l=1 \wedge l>k}^{n} ICNC_i^{y,z}(x_k, x_l). \tag{34}$$

4.2.3.4 Consensus index

Consensus is a unanimous concordance among the members of a group involved in some discussion. However, this is an excessive strict. (Herrera et al. 2000) discussed the existence or not of an unanimous agreement and introduced for practical cases the concept of soft consensus, or level of consensus. The index of soft consensus is 1 when the consensus is maximum (unanimous concordance) and 0 when it is minimum (none concordance). The values in between mean a partial agreement among the specialists. Thus, it is possible to estimate the consensus level in a group by aggregating $ICNCM_i^{y,z}, y = 1, 2, \ldots, v$ with the mean operator:

$$ICNS_i = \frac{1}{v} \sum_{y=1}^{v} ICNCM_i^{y,z}, \tag{35}$$

where z is the matrix reference for the comparison; in this case, it is the group matrix.

4.2.4 Method for qualitative risk management

The author proposes two approaches for dealing with qualitative risk. The first considers a low corporate maturity level and few specialists to analyze the risk. The second proposes a solution for complex problems using all the index presented in this section. Both methods are divided into two parts: the first classifies the qualitative risks by its influence in the energy commercialization; the second evaluates the alternatives of energy providers considering the risks assessed in the first part. In the end, it is achieved a set of non dominated alternatives and its weights of influence.

4.2.4.1 Method 1 - qualitative risk for individual decisions

Its contribution is associated with the flexibilization of the process of information acquisition about the specialists' preferences and, thus, benefiting the risk management. It aims at filling a lack of solutions to solve both issues that have robust historical data and problems where there is no historical information.

It was chosen to express the risk judgments preferences modeling through fuzzy binary relations and linguistic variables. It allows specialists to express their judgments in a linguistic way, easy to be assimilated. This kind of preference can assume linguistic values such as preferable, not preferable, better, worse, or indifferent. For the sake of simplicity, the representation is based on a Mudge diagram (KEENEY; RAIFFA, 1993) (SCHUSTER; SCHUSTER; OLIVEIRA, 2015) where the specialist judges the pair (x_k, x_l) and its inverse relation (x_l, x_k) is automatically filled with the complement. It is a straightforward solution that avoids an inconsistent evaluation over alternatives but costs the analysis of reliability over the specialists. Thus, it is suitable for situations with one specialist or for a group that evaluates and fulfills only a single matrix of preference relations. It does not assess the specialists, just their advice about the alternatives.

The devised method proposes mainly to define the risks associated with the portfolio, ordering them by relevance, and then classify each asset by its susceptibility to the risk. These steps are described in Algorithms 1, and 2. Algorithm 1 defines the risks ordering them by relevance. Then, Algorithm 2 evaluates the susceptibility of the alternatives to the risk.

Algoritmo 1 Qualitative Risk prioritizating

Step 1: defining the qualitative risks associated with energy buying process;

Step 2: building specialists preferences through the binary comparison of the risks (x_l, x_r). It should be answered which risk of the pair impacts higher the energy commercialization;

Step 3: scoring each risk. The specialists' preferences are aggregated with operator mean (operator WAM with equal weights, expression 24) finding the risk total score. This is necessary to find which risk is the most important, and to evaluate its risk relevance against the others;

Step 4: norming the score of risks and finding a weight for each risk. It is calculated a weight Δ for the τ^{th} risk. The risks are ordered according to its relevance.

This procedure results in a set of risks and its respective weights of importance. The set of weights will take place in the evaluation of the alternatives in Algorithm 2 that manage the susceptibility of the energy providers to the qualitative risks evaluated.

Example of the risk prioritization process

Table 3 – Evaluating the importance of a set of 5 risks

τ^{th} risk	1	2	3	4	5	sum	%	Δ_τ
1		1B	1A	1A	1B	18	56	0.56
2			2D	2D	5C	4	13	0.13
3				4D	3C	3	9	0.09
4					5D	2	6	0.06
5						5	16	0.16
Total						32	100	1

Score (Δ)		
A	5	higher
B	4	
C	3	indifferent
D	2	
E	1	lower

Let Δ_τ be the weight of importance of the τ^{th} risk. Δ is obtained from Algorithm 1 (risk prioritization procedure) Step 4, and it evaluates the relative importance of the risks in the set of risks devised in Step 1. The sum of all risks weight is one, $\sum_{\tau=1}^{\tau} \Delta_\tau = 1$.

Now, let be r_τ considered as the impact of τ^{th} risk for the k^{th} asset (energy provider). Hence, the value of risk susceptibility Ψ_k for the k^{th} energy provider becomes

$$\Psi_k = \sum_{\tau=1}^{\tau} \Delta_{k\tau} r_{k\tau}. \tag{36}$$

Algorithm 2 evaluates the alternatives of energy providers considering the risks. Each of the options that could compound the portfolio is assessed according to the matrix of qualitative risks devised in Algorithm 1.

Algoritmo 2 Qualitative Risk - items evaluation

Step 1: defining the potential energy providers (setting the possible portfolio assets. It could be items, contracts, energy providers. It ought to be a list of objects that will have its susceptibility to qualitative risk evaluated.);

Step 2: building the table of qualitative risk susceptibility and resilience, e.g., Table 4. (susceptibility is an index for minimization problem and resilience for a maximization problem);

Step 3: building the qualitative risk evaluation r_τ for the k^{th} asset and τ^{th} risk using the values devised in the table of risk susceptibility. The specialists should evaluate each asset (energy provider x_k) considering their susceptibility to the qualitative risks listed in Algorithm 1. If the event that characterizes each qualitative risk occurs, the candidate of an energy provider will be profoundly or slightly affected? As higher the asset is affected by the risk occurrence higher is its susceptibility to the risk;

Step 4: calculating the susceptibility to risk for each asset (energy provider) using expression 36. The risk susceptibility Ψ_k of the k^{th} asset is the weighted sum of the evaluations r_τ, given by a specialist, weighted by the risk importance Δ_τ of the τ^{th} risk evaluated in Algorithm 1. It considers the operator WAM, but the specialists can choose any other aggregation operator depending on their compensatory preferences for the problem.

Step 5: finally, it is reached a distribution set of risk influence of each asset, and the influence level of the qualitative risk in the k^{th} asset.

Table 4 represents a possible set of risk resilience and susceptibility.

Table 4 – Qualitative Risk Susceptibility Table

Value	Resilience to risk	Risk Susceptibility
0-0.19	Very High	Very Low
0.2-0.39	High	Low
0.4-0.59	Medium	Medium
0.6-0.79	Low	High
0.8-1	Very Low	Very high

A set of k values of susceptibility to risk is reached from Algorithm 2. Higher values indicate the asset is highly susceptible to the group of risks evaluated, and a small value indicates the asset is slightly affected by the risks.

The outcome of Method 1 for qualitative risk evaluation is:

a) a set of weights Δ_τ with τ risks that indicates the relevance of each qualitative risk,

b) a index of susceptibility to risk Ψ_k calculated for each energy provider x_k.

The results represent the influence of the qualitative risks in the options of energy providers. The sets can be used to balance the influence of the assets in the portfolio by rewriting the CVaR objective with the specialists' view.

We proposed WAM as the aggregation operator in Algorithm 2, Step 4. However, any other operator can be applied. To choose the most suitable operator, we propose to analyze the weights of relevance (Δ) of each qualitative risk calculated in Algorithm 1. If the values of the weights are similar, it indicates that the risks have the same relative influence, meaning it is appropriated an aggregation operator with compensatory behavior. Weights with distant values suggest that it is not suitable to choose an aggregation operator with high compensatory response, given the distinct nature of the risks. The more distant is the value of the weights, the less compensatory should be the aggregation operator characteristic.

An example of Method 1 is given in section 5.1.1.

We defined the Susceptibility to Risk as the property of one asset of withstanding to a risk event. It is a value among [0,1] where 0 indicates the asset has no impact if the τ^{th} risk event occurs, and 1 indicates the highest degree of influence if it occurs. The opposite of Susceptibility is Resilience, and it is the complement relation of the risk Susceptibility. The difference regards the objective nature in an optimization problem. The susceptibility can be used in a minimization problem and the resilience in a maximization problem.

4.2.4.2 Method 2 - qualitative risk for group decisions

It adopts a $< X, R >$ model to express the preferences since they are flexible with non-reciprocal preference relations. Different from Method 1, they enable to identify and treat the uncertainties related to the specialists in a justified manner; Non-reciprocal fuzzy preference relations allows identifying the specialist reliability over its judgments. These characteristics cannot be evaluated in other approaches (PARREIRAS; EKEL; JR, 2012).

The method is described in Algorithms 3 (prioritization and ordination of the qualitative risk) and 4 (selection of energy providers). An example is given in section 5.1.2.

The great advantage of this procedure is to represent, through a justified way, the uncertainties regarded to the qualitative criteria (risks), the alternatives, and specialists involved. Also, the method allows reducing the uncertainty during the process until it reaches an acceptable level. It is done implementing rounds of debate. Thus, at each round, the specialists that did not achieve adequate standards in the set index could review their advice acquiring more information from the other specialists. In turn, a moderator could review the bounds established if it is excessive set and clarify the problem such a way the specialists can improve their judgments.

Algoritmo 3 Qualitative Risk - Risk prioritization

Step 1 elect the set of qualitative risks (or criterias c_i) that affect the alternatives of energy providers;

Step 2 build the non-reciprocal matrix of preference relations with the qualitative risks and answering in each pair of risks which one impacts higher for the energy buying if the risk event happens;

Step 3 use equations 13, 14, and 15 to find the level of non-dominance for the qualitative risks and the order relevance. The operator OWA is applied to calculate the weights of the relevance of the risks. These weights are used to aggregate the matrix of energy providers in Algorithm 4.

This first part of Method 2 leads to the classification and ordination of a set of qualitative risks that influence the energy commercialization. As an outcome, we have the risks ordination and the respective weight (Δ).

The second part of the Method focuses on the evaluation of the alternatives of energy providers. Differing from Method 1, this second part evaluates the quality of the answers given by the specialists and guides a debate to reach acceptable levels of agreement.

Algoritmo 4 Qualitative Risk - items evaluation

Step 1: setting the acceptable bounds for the quality index: incomparability level $\mu_{J_i}(x_k, x_l)$, concordance I_{CNC_i}, consensus I_{CNS_i}, maximum number of iterations;

Step 2: collect the fuzzy preference relations R of each y^{th} specialist and i^{th} criteria;

Step 3: value the level of incomparability for each specialist using 12 and the global comparability level through 31.

Step 4: obtain the temporary collective fuzzy preference relation using the chosen aggregation operator. ($R_{i,z}$,$R_{i,G}$)

Step 5: calculate the agreement index $I_{\text{CNC}_i^{y,z}}$ through expressions 33 and 34 ($I_{\text{CNCM}_i^{y,z}}$).

Step 6: calculate the consensus index given by 35 (I_{CNS_i})replacing z for G in such way the opinion deviation is calculated accounting for the temporary collective matrix. (the temporary matrix z becomes the final group matrix G)

Step 7: a) if the maximum number of interactions is reached finish the discussion process, or if the accepted levels for comparability and consensus are reached then, end the process. For that cases the output data becomes the matrix from Step 4.

b) If $I_{CNS} < mincons$ and $I_{CMP} < mincomp$ go to step 8 and promote debate among the specialists trying to achieve the expected levels of consensus and comparability

Step 8 If there is no specialist with an acceptable level of comparability (that means none of the specialists could compare x_k and x_l with an adequate level of reliability) check if the bound of comparability was set too high or if the alternative should be better explained.

Step 9 if there are specialists with an acceptable level of comparability than invite them to debate with the lowest levels of comparability such way they can explain their choices.

Step 10 invite the specialists to make their advice again and return to step 2.

The process of Algorithm 4 is repeated for each qualitative risk considered in Algorithm 3. So if 3 qualitative risks if were evaluated, now it is devised 3 matrix of preference relations for evaluate the alternatives of energy providers. At the end of the debate of the specialists, the matrix of alternatives are aggregated using the weights devised in Algorithm 3.

Then, it is applied the expressions 13, 14, and 15 to find the level of non-dominance for the alternatives. As an outcome, we have the ordination of energy providers ordinate by the risk resilience of susceptibility. By using the operator OWA, it is obtained the weights of importance of the k^{th} option of energy provider. The output of this procedure is the weights of importance, and it represents the risk susceptibility Ψ_k of the k^{th} alternative.

4.3 Concluding remarks

This chapter has presented the qualitative risks, uncertainties, and how to formalize then to reduce the risks of energy commercialization. Also, it was introduced some index to evaluate the specialists' advice. Two methods were proposed to deal with the qualitative risks of the energy trade: one method is designed for situations where there is no interest in evaluating the specialists involved; and and the other one can guide the group to reduce the uncertainty, improving the understanding of the specialists about the problem.

These methods contribute for loosening the process of information acquisition, in a justified way, when it needs to make decisions based on specialists' preferences and, thus, benefiting the risk management and the group decision-making.

The following chapter aims at presenting some experimental results and achievements of this work.

Chapter 5

Experimental Results

This section presents a case study by giving examples of how to work with the methods proposed. Three possible approaches are presented by using the two methods developed. Method 1 is implemented in two different strategies (i. and ii.) to deal with the lack of information. The strategies are presented: Method 1i, Method 1ii, and Method 2. The procedures are presented by considering the availability of a crescent level of information to the decision-maker. Hence, in the examples, Method 1 deals with low levels of information, and the process is stoped in the step where there is no more data to evaluate. In turn, Method 2 example considers that it is available enough specialists and data, and it is possible to manage the information to enrich the decision-making process reducing all the kinds of risk at the same time.

5.1 Results in energy commercialization

5.1.1 Method 1

This section devises a case study applying the Method 1 developed in section 4.2.4.1. As mentioned above, authors drive less effort to solve problems faced by energy consumers rather than to distribution company problems. The leading cause is that the ordinary consumer does not have the energy buying as the mainstream activity, devising little attention to it. The Brazilian energy market topology also plays a role on this point since it gave limited options to the consumers in the near past. This method contributes to fulfill this lack of knowledge presenting a case of study that devises an energy buying strategy for a regular consumer.

Suppose a consumer intending to buy energy for its needs in the next year. It has as reference the spot price of the last years, and it is evaluating four alternatives of energy providing:

(a) buy a photo-voltaic power plant;

(b) operate uncovered in the spot market;

(c) remain as a captive consumer;

(d) buy energy from a commercialization company.

Then, the primary stages for solving that problem are:

1. define and classify the qualitative risks Algorithm 1;
2. evaluate the alternatives according to the risk susceptibility - Algorithm 2;
3. calculate the quantitative risk with expression 36;
4. forecast the energy necessary.

Following the steps in Algorithm 1, first, it is necessary to define the qualitative risks associated with each option of energy providers available above. They are the base to build the preference relation matrix. This matrix is constructed to answer which risk is more relevant for energy buying.

Then specialists should evaluate the risks to identify the relevance of each one. The evaluation is given in pairs of alternatives. The specialist represents its preference by a linguistic variable (Higher, Lower, Indifferent). At each pair of risks combinations, the specialists evaluate which one impacts higher, lower, or if they are indifferent. The outcome is represented in Table 5.

Table 5 – Qualitative Risk Matrix Evaluation

	Law Changes	Default risk	New technologies	Short Term market risk	New pricing strategies	Hydrologic Risk	Physical Grant (GF)	Labor law penalties	Stimulus (interest rate GF)	Fuel risk (price)	Damage to property	Sum	%	Δ_τ
Law Changes		5	1	3	3	5	1	1	1	3	3	26	7,9	0,079
Default risk	1		5	1	1	1	1	5	1	3	3	22	6,7	0,067
New technologies	5	1		1	1	1	1	1	1	3	3	18	5,45	0,055
Short Term market risk	3	5	5		5	5	5	5	5	5	5	48	14,5	0,145
New pricing strategies	3	5	5	1		3	5	1	5	3	3	34	10,3	0,103
Hydrologic Risk	1	5	5	1	3		5	5	5	5	5	40	12,1	0,121
Physical Grant (GF)	5	5	5	1	1	1		1	1	5	3	28	8,5	0,085
Labor law penalties	5	1	5	1	5	1	5		1	1	1	26	7,9	0,079
Stimulus -interest rate	5	5	5	1	1	1	5	5		5	3	36	10,9	0,109
Fuel risk (price)	3	3	3	1	3	1	1	5	1		1	22	6,7	0,067
Damage to property	3	3	3	1	3	1	3	5	3	5		30	9,1	0,091

Table 6 – Score for Qualitative Risk evaluation

Score	
1	if the line is less important than the column
3	if the line is indifferent to the column
5	if the line is more important than the column

Therefore, the risk influence is normalized and ordered, resulting in Table 7. That table represents the order of importance and the degree of relevance for each risk evaluated.

As depicted from the table, hydrology risk is evaluated as the most relevant risk for the energy buying and tax stimulus the less relevant in the specialists' evaluation. The next step is to evaluate the risk influence in each asset (each option of energy provider or portfolio of energy providers) as proposed in Algorithm 2. The evaluation aims at determining the Risk Resilience of each option and is done by applying the linguistic variables very low, low, indifferent, high, very high as set in Table 8, column "Risk Resilience".

The Risk Resilience is the propriety that indicates how the alternative withstands if the risk event occurs. Is the alternative highly susceptible or not to this event? The highest value of resilience is 1, and it means the alternative is not sensible to the risk. The value zero means the alternative evaluated is greatly affected by the risk. The opposite of risk resilience is risk susceptibility. It represents the difference of value necessary to the risk resilience reach 1. Therefore, the risk resilience plus the risk susceptibility is always 1.

Table 7 – Qualitative Risk importance order

Group of parameters for selection	Relative importance of the group Δ_τ
Short Term market risk	0.145
Hydrologic Risk	0.121
Stimulus such that special interest rate for GD	0.109
New pricing strategies	0.103
Damage to property	0.091
Physical Grant (GF)	0.085
Law Changes	0.079
Labor law penalties	0.079
Default risk	0.067
Fuel risk (price)	0.067
New technologies	0.055

Table 8 – Qualitative Risk Resilience Table

Value	Resilience to risk	Risk Susceptibility
0-0.19	Very High	Very Low
0.2-0.39	High	Low
0.4-0.59	Medium	Medium
0.6-0.79	Low	High
0.8-1	Very Low	Very high

Table 9 – Qualitative Risk Evaluation Table

		Alternatives			
Risks	Relevance	(a)	(b)	(c)	(d)
Law changes risk	7.9%	medium	very high	medium	medium
Default Risk	6.7%	very low	very high	very low	medium
New Technologies	5.45%	very low	very high	high	medium
Short Term Market risk	14.5%	very low	very high	low	high
New pricing strategies	10.3%	medium	medium	high	very low
Hydrologic Risk	12.1%	very high	high	high	medium
Physical Grant (GF)	8.5%	high	high	high	very low
Labor law penalties	7.9%	medium	very low	very low	very low
Stimulus such - interest rate to GD	10.9%	low	very high	medium	very high
Fuel risk (price, and availability)	6.7%	very low	very high	very high	very high
Damage to Property	9.1%	very high	very low	low	low
Resilience to risk		0,71	0,35	0,51	0,43
Risk susceptibility		0,29-low	0,65-high	0,49-medium	0,57-medium

Table 9 presents the output of Algorithm 2. It shows the evaluation, provided by the specialists, of the influence of each risk to a given alternative or scenario. For example, in the column Risks, the first risk to be evaluated is "law changes.". In column Alternatives, alternative (a) represents the option of buying a Photo-voltaic plant. Thus, the specialist assesses the influence of law changes in alternative (a) as a medium influence, and very low the influence of the default risk in the same alternative. (What is the impact for the alternative (a) if it happens the risk "law changes"? It means the specialist evaluates that, in the occurrence of a law change, the alternative (a) is "mediumly" impacted). At the Table bottom, there is the overall risk influence for each alternative. It is represented by the resilience to risk and by the risk susceptibility. It is desirable to choose the alternative with the highest level of risk resilience to reduce the risk. Thus, the consumer that aims at avoiding risk should take the alternative (a), that is the most resilient to risk set under the specialists' evaluation.

Next step is to evaluate the quantitative risk. This is done with CVaR as described in section 3.2. When there is no complementary information or historical database from the consumer intending to buy energy, it is possible to use public data to improve the information weighted with the qualitative risk devised by the specialists. In Brazil, it is possible to use the energy spot price as a numerical reference to buy energy together with CVaR, as presented in Chapter 3.

Then, it is possible to evaluate the price and the quantitative risk. As the consumer do not have any other parameter it uses the spot market price to balanced with the Risk susceptibility calculated in Table 9.

We propose two ways of applying the CVaR to manage the quantitative risk:

i. Defining the ratio of each energy provider in the portfolio of energy providers. This approach requires that the consumer is allowed to have more than one energy provider at the same time. Thus, the values of Risk Resilience, calculated from the qualitative risk, are applied to weight the spot market prices. The CVaR defines the weight of each energy provider available in the portfolio such way the quantitative risk is as lower as possible;

ii. Defining the best moment to buy energy along the year and the share of energy to buy each month. This approach considers that the consumer is allowed to choose just one energy provider, and the qualitative risk approach has already defined this source. Then, the CVaR is used to determine the seasonalization, (when it is better to buy the energy and the share of power to buy each month).

Following strategy i. we have:

Figure 9 shows the price of each source weighted by the Risk Resilience calculated in Table 9 of qualitative risk.

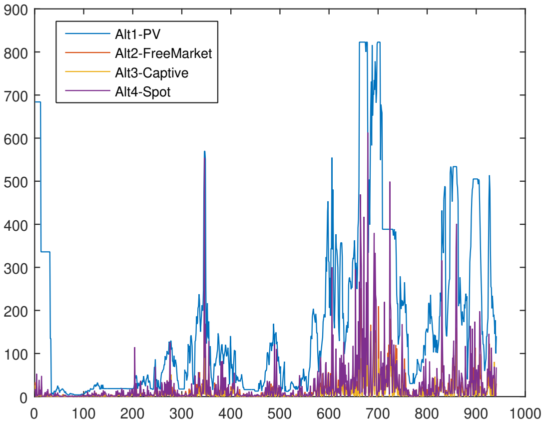


Figure 9 – Energy Values 4 alternatives

The Pareto combination of sources that reduce the risk and minimize the price is shown in Table 10 and in Figure 10.

Table 10 – Allocation of the Alternatives

Alt.1	Alt.2	Alt.3	Alt.4
0.458	0.019	0.249	0.274

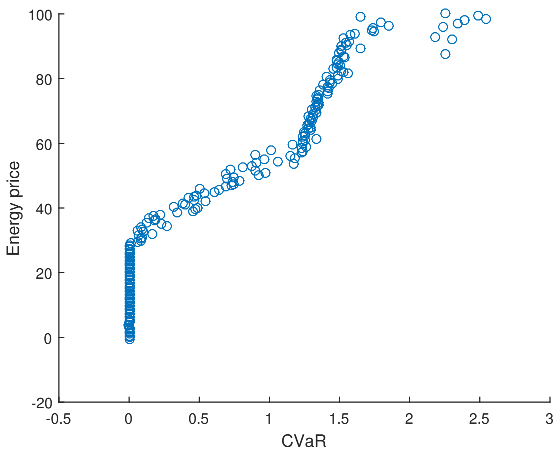


Figure 10 – Pareto 4 alternatives

The outcome of approach i. is a set of weights that determine the share of each energy provider in the consumer portfolio. This set minimizes the energy price and the risk of energy buying. In most of the cases, it is reached a Pareto front of portfolios, which leads the consumer to a trade-off decision. It should choose, from the Pareto front, the solution that best fits its energy buying objectives, considering its disposition to take risks.

Following strategy ii. we have:

This strategy considers that the qualitative risk procedure has already defined the energy provider. Then, CVaR is applied to find when it is better to buy the energy. It uses the spot market price as a measurement of seasonality.

Energy value along the years from 2001 to 2018.

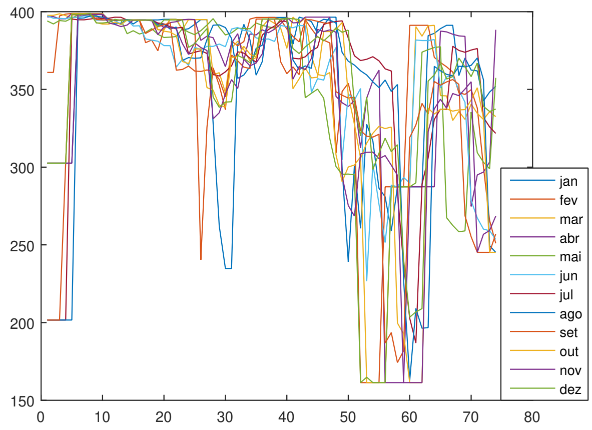


Figure 11 – Energy Value along the years

Then it is evaluated the buying seasonality.

Month	Weight
January	0,15257219
February	0,093518357
March	0,095366673
April	0,106982716
May	0,073814881
June	0,10216243
July	0,096112225
August	0,079634445
September	0,064345791
October	0,072761528
November	0,062728744
December	0

Table 11 – Distribution of energy buying along the year

The outcome of approach ii. is a set of weights that determine the share of energy to buy at each month. This approach considers each month as an option of energy provider in a portfolio, and the year is the whole portfolio. The price of each month is the respective set of variables from the spot market historical data. The set of weights reached from CVaR represents the ratio of energy to buy each month that minimizes the price and the risk of energy buying. Moreover, it reaches a Pareto front of portfolios, with each portfolio having a set of weights. It is up to the consumer to choose, from the Pareto front, the portfolio that suits best its needs.

Energy forecasting

At last, it is necessary to determine how much energy is necessary to buy. This procedure is done as proposed in (BERNARDES et al., 2018) using forecasting techniques. Applying the cluster forecasting method, and the client historical data of energy consumption it is obtained the following forecast

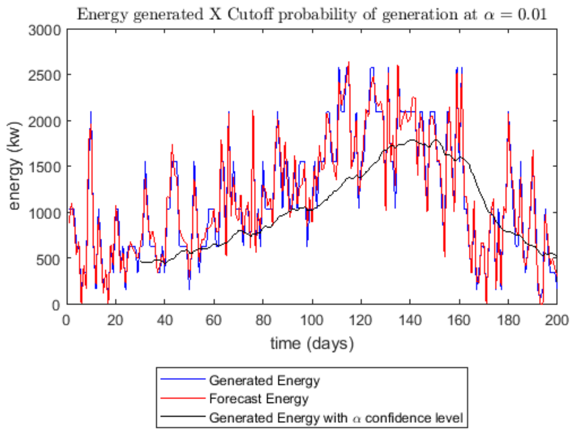


Figure 12 – Energy generated and forecast

which concludes the energy buying process. The consumer now has the necessary information to proceed the energy buying. He had minimized the risk, selected the share of buying in each source, selected the monthly ratio to buy, and has the forecasting of the energy needed to the next year.

The results were cross-checked, applying the calculated variables to advise the energy buying of a company that usually buys the energy yearly from a single contract. Then, the yearly buying was changed to a 12 installment energy purchase according to the proportion addressed by the quantitative risk calculation in Table 11. That procedure resulted in an economy of 18% for the company if compared with the way it is buying energy today that is only one contract of energy provide.

5.1.2 Method 2

Method 1 has focused on an energy buying strategy that does not evaluate the specialists; just their advice is assessed. It considers that the specialists can give coherent information and reach an agreement to express the preference relation matrix without conflicts. Method 2 focus on a group decision where it is necessary to tackle conflicts, dealing with specialists that have different levels of knowledge and interests. Such way, the matrix of preference relations of the group should be evaluated, and the group guided to reach an acceptable level of coherence and quality judgments. Method 2 represents the uncertainties regarded to the specialists' interests and knowledge. It also gives an index to evaluate the quality of the final matrix of preference relations. If an acceptable level is not reached, the matrix can be discarded or reviewed to achieve the standards set.

Thus, the same data of Method 1 is addressed. Method 2 is applied in reaching the qualitative risk, considering that it is necessary to achieve an acceptable level of consensus and coherence among the specialists.

Hence, the process of evaluating the qualitative risk of the alternatives addresses the relative importance of the risks and then evaluates the alternatives of energy providers. Method 2 is treated as follows:

a) Algorithm 3 Prioritizing the qualitative risks

b) Algorithm 4 Evaluating the alternatives of energy providers

Applying Algorithm 3 to priotization the risks we have:

(a) Step 1 The group of specialists selected as qualitative risks: damage to property, law changes, and hydrologic risk (respectively x_1, x_2, and x_3).

Table 12 – Set of risks evaluate for the energy buying with linguistic evaluations

	Damage to property	Law changes	Hydrologic risk
Damage to property	indifferent	low	very low
Law changes	very high	indifferent	very low
Hydrologic risk	high	very high	indifferent

(a) Step 2 The specialists' evaluations resulted in

$$R = \begin{bmatrix} 1 & 0.3 & 0 \\ 0.95 & 1 & 0 \\ 0.9 & 1 & 1 \end{bmatrix}, \qquad (37)$$

that is the matrix of non-reciprocal preference relations for Qualitative Risks.

(a) Step 3 Using equations 13 and 14 we have the strict preference

$$P = \begin{bmatrix} 0 & 0 & 0 \\ 0.65 & 0 & 0 \\ 0.9 & 1 & 0 \end{bmatrix}, \qquad (38)$$

and the fuzzy set of non-dominated solutions

$$\mu_{ND}(x_k) = \begin{bmatrix} 0.1 & 0 & 1 \end{bmatrix}. \qquad (39)$$

From the set 39 the alternative x_3 is selected as the most relevant qualitative risk in the specialists evaluation. To calculate the second most relevant risk it is sufficient to withdraw the element x_3 in expression 38, withdrawing the line 3 and column 3 and applying the expression 14. This procedure lead to

$$P = \begin{bmatrix} 0 & 0 & \cancel{0} \\ 0.65 & 0 & \cancel{0} \\ \cancel{0.9} & \cancel{1} & \cancel{0} \end{bmatrix}, \mu_{ND}(x_k) = [0.35 \quad 1]\,. \tag{40}$$

The set 40 defines the alternative x_2 as the second most relevant qualitative risk in the specialists evaluation. The importance order of qualitative risks becomes

$$x_3 \succ x_2 \succ x_1, \tag{41}$$

or hydrologic risk $\succ$ law changes $\succ$ damage to property. That means, if an event of hydrologic risk happens, the impact for the energy buying will be more significant than if happens a law change, and a law change impacts higher on the energy commercialization than an event of damage to property.

The expression 41 represents the non-fuzzy non-dominated solutions for the problem. It defines the order of relevance of the risks, ordering them by the most relevant to the fewer. That order is the reference to define the weights to aggregate the matrixes of energy providers and should be respected.

The weights to aggregate the matrix of energy providers are devised respecting the order in from expression 41. The weights represents the relative importance of qualitative risks according to specialist advice and the weights must satisfy $0 \leq w_y \leq 1$, y= 1,2,...,v and $\sum_{y=1}^{v} w_y = 1$ where y is the number of risks evaluated.

Considers OWA operator, expressions 27, 28, and 29. Now considers the linguistic quantifiers (QUEIROZ, 2009): at least half (0.3;0.8), the majority (0;0.5), as many as possible (0.5;1) where (d; e) are the respective index values for expression 29. Then, choosing the linguistic quantifier "the majority", (d;e)=(0;0.5) it is devised the weights

$$w = [0.66 \quad 0.33 \quad 0.0]\,, \tag{42}$$

that represents the relative relevance of the risks. The weights are employed in the aggregation of the alternatives. The most relevant risk receives a higher value in this first part of the method. In the second part, where the weights will take part in an optimization problem, the ordering of the weights depends on the objective of the problem. The values are in ascending order if it is a maximization problem (the most important receive the higher weight), and in descending order if it is a minimization problem (the most important receive the lower weight).

Next, the second part of the Method 2 is addressed (Algorithm 4). This part evaluate the alternatives under the qualitative risk view.

(b) Step 1 set the acceptable bounds for the quality index:

$\mu_{J_i}(x_k, x_l) \leq 0.15$ (incomparability level),
$I_{\mathrm{CNCM}_i} \geq 0.85$ (mean concordance),
$I_{\mathrm{CNS}_i} \geq 0.80$ (consensus).

The maximum number of interaction is setting as 5, and it was picked up three specialists $y = 3$ to evaluates the alternatives. The mean is chosen as the aggregation operator to reduce the specialists' advice to a global matrix per i^{th} criteria (qualitative risk). The weights calculated in expression 42 are used to aggregate the risks matrix in a single global matrix of risks. The global matrix of risks is used to calculate the set of risk susceptibility for the k^{th} alternative of energy provider.

(b) Step 2

From Table 12, in the risk prioritization algorithm, three risks were considered for this problem: hydrologic risk, law changes, and damage to property. Thereby, the specialists ought to evaluate the alternatives of energy providers considering these devised risks. Hence, each of the y^{th} specialists should evaluate the k^{th} alternative considering the i^{th} criteria (qualitative risk) building a preference relation $R_{i,y}$. In the current problem, each specialist will devise three matrix of preference relations, one per risk considered. The specialists should express their preference relations to answer which is the best alternative to resist the risks set in Table 12. For example, consider hydrological risk. In that case, the specialists will build a matrix of preference relations that evaluates which alternative of energy provider is less influenced when happens the hydrological risk. This process is repeated, creating one matrix per risk. The solution of the group matrix will be the alternative most resilient to the set of risks evaluated by the specialists. The matrices of each risk are devised in (43), (44), and (45).

Qualitative risk 1 preference relations for specialists 1, 2, and 3:

$$R_{1,1} = \begin{bmatrix} 1 & 1 & 0 & 0.5 \\ 0 & 1 & 0.99 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \end{bmatrix}, R_{1,2} = \begin{bmatrix} 1 & 1 & 0.3 & 0 \\ 0.5 & 1 & 1 & 0 \\ 1 & 0.6 & 1 & 0.8 \\ 0.95 & 0.8 & 0 & 1 \end{bmatrix}, R_{1,3} = \begin{bmatrix} 1 & 0.9 & 0.1 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 1.1 & 1 \end{bmatrix}, \quad (43)$$

Qualitative risk 2 preference relations for specialists 1, 2, and 3:

$$R_{2,1} = \begin{bmatrix} 1 & 0 & 1 & 0.85 \\ 0 & 1 & 0 & 0.2 \\ 1 & 1 & 1 & 0.29 \\ 0.45 & 1 & 1 & 1 \end{bmatrix}, R_{2,2} = \begin{bmatrix} 1 & 0.75 & 0.39 & 1 \\ 0.86 & 1 & 0 & 1 \\ 0.71 & 1 & 1 & 1 \\ 1 & 0.48 & 0.2 & 1 \end{bmatrix}, R_{2,3} = \begin{bmatrix} 1 & 1 & 1 & 0.85 \\ 0 & 1 & 1 & 0.2 \\ 0 & 1 & 1 & 0.29 \\ 0.45 & 1 & 1 & 1 \end{bmatrix}, \quad (44)$$

Qualitative risk 3 preference relations for specialists 1, 2, and 3:

$$R_{3,1} = \begin{bmatrix} 1 & 1 & 0.95 & 0.85 \\ 0 & 1 & 0.97 & 0.2 \\ 0.1 & 0.97 & 1 & 0.29 \\ 0.45 & 1 & 1 & 1 \end{bmatrix}, R_{3,2} = \begin{bmatrix} 1 & 0.75 & 0.39 & 1 \\ 0.86 & 1 & 1 & 1 \\ 0.71 & 1 & 1 & 1 \\ 1 & 0.48 & 0.2 & 1 \end{bmatrix}, R_{3,3} = \begin{bmatrix} 1 & 1 & 0.95 & 0.85 \\ 0 & 1 & 0.97 & 0.2 \\ 0.1 & 0.97 & 1 & 0.29 \\ 0.45 & 1 & 1 & 1 \end{bmatrix}. \tag{45}$$

For the sake of simplification, just the risk three is developed in details in next steps.
(b) Step 3 value the level of incomparability for each specialist using expression 12 and the global comparability level through expression 31.

$$J_{3,1} = \begin{bmatrix} 0 & 0 & 0.05 & 0.15 \\ 0 & 0 & 0.03 & 0 \\ 0.05 & 0.03 & 0 & 0 \\ 0.15 & 0 & 0 & 0 \end{bmatrix}, J_{3,2} = \begin{bmatrix} 0 & 0.14 & 0.29 & 0 \\ 0.14 & 0 & 0 & 0 \\ 0.29 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}, J_{3,3} = \begin{bmatrix} 0 & 0 & 0.05 & 0.15 \\ 0 & 0 & 0.03 & 0 \\ 0.05 & 0.03 & 0 & 0 \\ 0.15 & 0 & 0 & 0 \end{bmatrix}, \tag{46}$$

that are the incompatibility relations for the respective preference relation matrix of each specialist. The ratio at which the specialist could not evaluate the alternatives. Then, applying the expression 31 it is calculate the global index of comparability I_{CMP_3}.

$$I_{CPM_3} = \begin{bmatrix} 1 & 0.86 & 0.71 & 0.85 \\ 0.86 & 1 & 0.97 & 1 \\ 0.71 & 0.97 & 1 & 1 \\ 0.85 & 1 & 1 & 1 \end{bmatrix}. \tag{47}$$

Expression (47) is the measurement at which the alternatives are comparable. Low levels indicate a high degree of incomparability and can be caused by hesitant specialists, low level of knowledge about the subject, or an inadequate expression of the problem to the specialists.

As could be seen, some evaluations reached a comparability level bellow the set on step 1 assumptions.
(b) Step 4 obtain the temporary collective fuzzy preference relation using the chosen aggregation operator. ($R_{i,z}$,$R_{i,G}$) It was selected the WAM operator in step one considering that the specialists have the same importance in the decision process, and it is expected specialists with a similar level of knowledge about the subject.

$$R_{3,z} = \begin{bmatrix} 1 & 0.92 & 0.76 & 0.90 \\ 0.29 & 1 & 0.97 & 0.47 \\ 0.3 & 0.97 & 1 & 0.53 \\ 0.63 & 0.83 & 0.73 & 1 \end{bmatrix}. \tag{48}$$

Applying expressions (13), and (11) it is calculated the strict preference $P_{3,z}$ and the indifference $I_{3,z}$ of the temporary global matrix of the preference relations $R_{3,z}$ for the risk 1:

$$P_{3,z} = \begin{bmatrix} 0 & 0.63 & 0.46 & 0.27 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0.36 & 0.21 & 0 \end{bmatrix}, \quad (49)$$

$$I_{3,z} = \begin{bmatrix} 1 & 0.29 & 0.3 & 0.63 \\ 0.29 & 1 & 0.97 & 0.47 \\ 0.3 & 0.97 & 1 & 0.53 \\ 0.63 & 0.47 & 0.53 & 1 \end{bmatrix}. \quad (50)$$

These values are used to calculate the next index.

(b) Step 5 calculate the agreement index $I_{\mathrm{CNC}_i^{y,z}}$ through expressions (33) and (34) ($I_{\mathrm{CNCM}_i^{y,z}}$).

From disagreement index, expression 32, it is calculated

$$I_{\mathrm{DSC}_3} = \begin{bmatrix} - & 0.24 & 0.20 & 0.12 \\ - & - & 0 & 0.24 \\ - & - & - & 0.24 \\ - & - & - & - \end{bmatrix}, \quad (51)$$

for specialist y=1.

Disagreement index by each specialist considering the temporary global matrix z become:

Table 13 – Disagreement index by specialist

$I_{\mathrm{DSC}_3}(x_k, x_l)$	y=1	y=2	y=3
$I_{\mathrm{DSC}_3}(1,2)$	0.24	0.4	0.24
$I_{\mathrm{DSC}_3}(1,3)$	0.20	0.3	0.20
$I_{\mathrm{DSC}_3}(1,4)$	0.12	0.3	0.12
$I_{\mathrm{DSC}_3}(2,3)$	0	0	0
$I_{\mathrm{DSC}_3}(2,4)$	0.24	0.2	0.24
$I_{\mathrm{DSC}_3}(3,4)$	0.24	0.4	0.24

Thereby, using the expression 33, the concordance index $I_{\text{CNC}_i^{y,z}}$ and the mean concordance index ($I_{\text{CNCM}_i^{y,z}}$) for each specialist becomes:

Table 14 – Concordance index I_{CNC_3} and Mean concordance index $I_{\text{CNCM}_3^{y,z}}$ by specialist

$I_{\text{CNC}_3^{y,z}}(x_k, x_l)$	y=1	y=2	y=3
$I_{\text{CNC}_3}(1,2)$	0.76	0.6	.76
$I_{\text{CNC}_3}(1,3)$	0.80	0.7	0.80
$I_{\text{CNC}_3}(1,4)$	0.88	0.7	0.88
$I_{\text{CNC}_3}(2,3)$	1	1	1
$I_{\text{CNC}_3}(2,4)$	0.76	0.8	0.76
$I_{\text{CNC}_3}(3,4)$	0.76	0.6	0.76
I_{CNCM_3}	0.83	0.7	0.83

It can be noticed that specialists fully agree on the evaluations of the pair of alternatives (2,3) and have a significant discordance level on the pairs (1,2) and (3,4).

(b) Step 6 calculate the consensus index I_{CNS_i} given by expression 35. It is replaced z for G in such way the opinion deviation is calculated accounting for the temporary collective matrix. (the temporary matrix z becomes the final group matrix G)

The group consensus for risk 1 becomes $I_{\text{CNS}_3} = 0.78$. The consensus reached by the group in the first round of evaluations is below the acceptable level established in step 1.

(b) Step 7 That step evaluates the results of the steps above.

7.1 if the maximum number of interactions is reached, or if the accepted levels for comparability and consensus are reached then, the discussion process is finished. For those cases, the output data becomes the matrix from Step 4. While it is no exceded the maximum number of rounds and are not reached acceptable levels of comparability, and consensus then proceeds to option Step 7.2;

7.2 if $I_{\text{CNS}} <$ minimum consensus and $I_{\text{CMP}} <$ minimum comparability go to step 8 and promoting a debate among the specialists trying to achieve the expected levels of consensus and comparability.

(b) Step 8 if there is no specialist with an acceptable level of comparability (that means none of the specialists could compare x_k and x_l with an adequate level of reliability) check if the bound of comparability was set too high or if the alternative should be better explained.

(b) Step 9 if there are specialists with an acceptable level of comparability than invite them to debate with the lowest levels of comparability such way they can explain their choices. The specialists y=1 and y=3 had a acceptable level, and specialists y=2 performed bellow in the alternatives evaluation. Thus, these groups of specialists ought to be invited to debate the advice given. Also, it is possible to identify that was evaluations (1,2) an (3,4) received the lowest level of concordance. Thus, those are the starting point of the discussion, those evaluations should be debated aiming at clarifying what arguments justify the disagreement of the evaluations.

(b) Step 10 invite the specialists to make their advice again and return to step 2.

After the specialists' discussion, the second loop of evaluations is performed by having the following results.

Qualitative risk 3 preference relations for specialists 1, 2, and 3 second evaluation:

$$R_{3,1} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0.11 & 1 & 0.99 & 0.7 \\ 0.11 & 0.99 & 1 & 0.29 \\ 0.96 & 0.93 & 0.78 & 1 \end{bmatrix}, R_{3,2} = \begin{bmatrix} 1 & 0.29 & 0.90 & 0.7 \\ 0.99 & 1 & 1 & 0.70 \\ 0.70 & 0.8 & 1 & 0.69 \\ 0.95 & 0.80 & 0.4 & 1 \end{bmatrix}, R_{3,3} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0.11 & 1 & 0.99 & 0.7 \\ 0.11 & 0.99 & 1 & 0.29 \\ 0.96 & 0.93 & 0.78 & 1 \end{bmatrix}. \tag{52}$$

The new index of global comparability becomes

$$I_{\text{CPM}_3} = \begin{bmatrix} 1 & 0.99 & 0.9 & 0.95 \\ 0.99 & 1 & 0.99 & 0.8 \\ 0.90 & 0.99 & 1 & 0.69 \\ 0.95 & 0.8 & 0.69 & 1 \end{bmatrix}, \tag{53}$$

and the new concordance index I_{CNC} and I_{CNCM} by specialist becomes

Table 15 – Round 2 - Concordance index I_{CNC_3} and Mean concordance index $I_{\text{CNCM}_3^{y,z}}$ by specialist

$I_{\text{CNC}_3^{y,z}}(x_k, x_l)$	y=1	y=2	y=3
$I_{\text{CNC}_3}(1,2)$	0.72	0.68	0.72
$I_{\text{CNC}_3}(1,3)$	0.84	0.69	0.84
$I_{\text{CNC}_3}(1,4)$	0.95	0.85	0.95
$I_{\text{CNC}_3}(2,3)$	0.95	0.9	0.95
$I_{\text{CNC}_3}(2,4)$	0.99	0.98	0.99
$I_{\text{CNC}_3}(3,4)$	0.87	0.86	0.87
I_{CNCM_3}	0.89	0.83	0.89

Calculating the new consensus index for the risk three it is reached $I_{\text{CNS}_3} = 0.866$.

As could be seen now the index respects the bounds set.

The process is repeated until it is reached an acceptable level of consensus or entering the maximum number of rounds. With the new series of evaluations, it is reached the final answer with acceptable levels for the index. The process is repeated to all risks associated, reducing the uncertain regarded to specialists preference relations, leading to the following global matrix of the specialists

$$R_{1,G} = \begin{bmatrix} 1 & 0.97 & 0.13 & 0.17 \\ 0.17 & 1 & 1 & 0 \\ 1 & 0.2 & 1 & 0.93 \\ 0.98 & 0.93 & 0.03 & 1 \end{bmatrix}, R_{2,G} = \begin{bmatrix} 1 & 0.29 & 0.67 & 1 \\ 0.99 & 1 & 1 & 1 \\ 1 & 0.70 & 1 & 1 \\ 0.8 & 0.12 & 0.32 & 1 \end{bmatrix}, R_{3,G} = \begin{bmatrix} 1 & 1 & 1 & 1 \\ 0.11 & 1 & 0.99 & 0.24 \\ 0.11 & 0.99 & 1 & 0.3 \\ 0.96 & 0.93 & 0.78 & 1 \end{bmatrix}, \tag{54}$$

that are the group preference relations to the three risks evaluated.

These matrices are aggregated using the weights calculated in expression 42, that defines the importance of each risk, and the aggregated matrix of risks, expression 54. This process is calculated such as $G_G = 0R_{1,G} + 0.33R_{2,G} + 0.66R_{3,G}$ that results in

$$G_G = \begin{bmatrix} 1 & 0.76 & 0.97 & 0.9 \\ 0.40 & 1 & 0.99 & 0.70 \\ 0.31 & 0.93 & 1 & 0.42 \\ 0.96 & 0.89 & 0.65 & 1 \end{bmatrix}, \tag{55}$$

as the group matrix of risks.

Applying equations 13 to matrix 55 we have the group strict preference relation:

$$P_G = \begin{bmatrix} 0 & 0.36 & 0.66 & 0 \\ 0 & 0 & 0.07 & 0 \\ 0 & 0 & 0 & 0 \\ 0.06 & 0.19 & 0.23 & 0 \end{bmatrix}, \tag{56}$$

The expression 14 is applied to matrix 56 to obtain the fuzzy set of non-dominated solutions:

$$\mu_{ND} = [0.94 \quad 0.64 \quad 0.34 \quad 1]\,. \tag{57}$$

From this outcome, it is obtained the alternative $XND^1 = \{x_4\}$ as the best one. That means x_4 is the alternative with the highest resilience to risk. That can also be interpreted that alternative x_4 will be less affected in the occurrence of the events represented by the qualitative risk evaluated. Then, alternative x_4 is withdrawn from the matrix 56 and the process is repeated until reach the final solution: $x_4 \succ x_1 \succ x_2 \succ x_3$. Now, consider that the objective is to use this ordering in a minimization problem, then, this set can receive weights such that $\{0.1 \succ 0.25 \succ 0.3 \succ 0.35\}$ respectively devised by a chosen operator. These weights represent the risk susceptibility Ψ_k for the k^{th} asset.

From this point, the problem can be solved following Method 1 strategies, as described in items i. and ii.. It makes it possible to determine how much energy to buy and when.

Otherwise, if enough data is available, the three objective formulation in 8 can be implemented to minimize the quantitative and qualitative risk as well as the energy price.

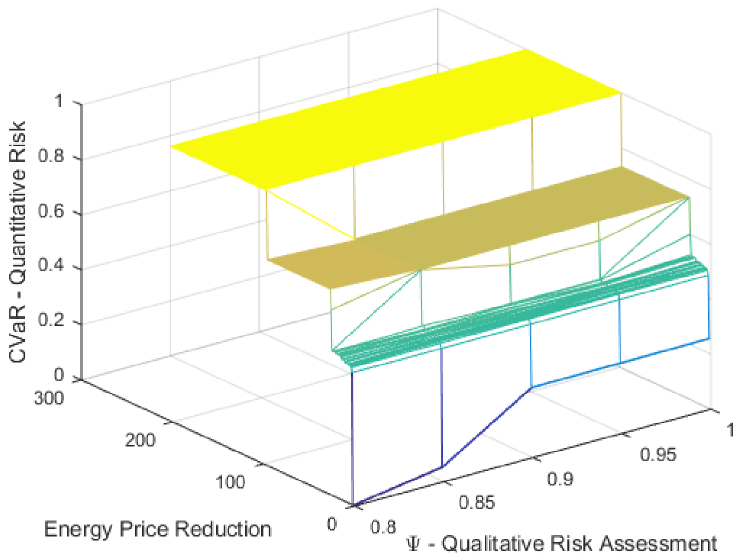


Figure 13 – Pareto front for three objective formulation

Figure 13 indicates the result from expression 8 minimization. The quantitative risk is minimized having the qualitative risk and the price reduction as constraints.

It represents the Pareto front of portfolios that minimize the objectives set. Any of the solutions on the surface are optimal solutions. It is up to the decision-maker to choose, in the set of solutions, which solution is the most appropriated according to the importance given to the qualitative risk, quantitative risk, and reduction in the energy price. In the example given, it is not possible to reduce the energy price, risk, and uncertainty at the same time. If the decision-maker aims at lowering in R$100,00 the energy price, it must take a qualitative and quantitative risk different than zero. If it aims at a risk-free buying, then it is not possible to reduce the energy price.

5.1.2.1 Summary

The Brazilian energy market unbundling has resulted in a competitive environment, generating new marketing relations. In the near future, these relations are to become even more dynamics. The agents must develop appropriate strategies to take full advantage of the opportunities generated.

This chapter has presented how to implement Method 1 and Method 2, developed in this work, to process an energy buying for end-users. Method 1 focused on a more accessible representation of uncertainties, considering a single decision-maker or a group that could perform an unique matrix of evaluation. Method 1 does not evaluate the specialists quality, or their ability to give good advice. Also, this method considers that the decision-maker does not have extense or reliable databases to perform the evaluations.

Method 2 considers a more complex problem where many specialists are invited to evaluate the alternatives. The method allows to identify the hesitant specialists, the key alternatives where there was not reached an agreement from the specialists' advice and promotes the debate such way it is possible to improve the problem understanding by the specialists. Besides, it is possible to advance the problem representation in the cases the specialists identify the problem is not clear enough to give adequate advice. It provides the decision-maker useful information about the uncertainty such way it can take better decisions with the information provided by the specialists. It can identify the hesitant specialists and neglect or highlight their influence on the evaluation of qualitative risk.

In the end, it was implemented a three objective formulation allowing the specialists to choose the optimal set of solutions that best represents their preferences and risk-taking behavior.

Next Chapter concludes the work.

Chapter 6

Conclusion

This work aimed at modeling, processing, and analyzing problems regarded to the energy trade, focusing on the difficulties of the small consumer. Specifically, it dealt with issues perceived in the representation of uncertainties, lack of robust historical data to process, information of qualitative nature, level of knowledge of the specialists, and forecasting. This work had handled these issues to make the risks of the energy trade as low as possible. Some of these issues are partially credited to the Brazilian energy market structure. The market changed, but most consumers don't. Historically, the energy generation and distribution companies hold the information and top-rated techniques to trade energy since energy commercialization is its core business. On the other hand, the final consumer does not dominate this discipline. It usually lacks robust data, and can't afford the research in most cases.

As the outcome, we designed two methodological procedures that are useful in facilitating the energy buying process. They aimed at representing the uncertainty and the risks (qualitative and numeric). That improves the energy trade heading the consumer to make a better decision.

6.1 Discussions and Achievements

The main activities tackled by the methods are:

a) addressing the numeric risks when there is available databases to calculate the CVaR;

b) calculating the expected energy consumption;

c) calculating the ratio of each energy providers such way it is possible to reduce the risk and the price;

d) calculating the schedule of energy buying (by calculating the share of energy to buy each month to reduce the risk);

e) extracting the relations of indifference, strict preference, and incomparability from the specialists preference;

f) aggregating the individual preferences to build the model of collective perception of risks;

g) identifying the most discordant specialist, the hesitant ones and the no hesitant;

h) ordinating the alternatives of energy providers by qualitative risk susceptibility;

i) calculating the qualitative risk;

j) calculating the index of uncertainty regarded to the qualitative risk;

k) providing a three objective formulation to construct the Pareto optimal front of qualitative risks, quantitative risks, and price. Helping the specialist to choose the safest solution for energy buying;

This work contribution is associated with the fact that, in many cases, it is not possible to collect robust historical data to reduce the risk in the energy commercialization. Also, many risks associated with the energy trade are from qualitative nature and not represented in the numerical data. The literature lacks a method that deals with qualitative and quantitative risks at the same time, in a substantiated way, and without restrictions. As addressed in section 4, the most relevant measurement of risk, CVaR, presents limitations if there is not enough data. The proposed method do not have this constraints. The lack of historical data is relieved by the knowledge of a group of specialists in a degree chosen by the decision maker. Also, the reliability of the group is measured by the index of indifference, incomparability and consensus that gives an numerical estimation of the group reliability.

The outcome allows loosening the collecting of information from the specialists' preference by combining the qualitative and quantitative risks assessment. Also, we highlight that, using the methods proposed, the specialists can represent their query, raise questions, and present their convictions. The issues are addressed such way it enriches the understanding of the risks associated with the energy buying and ensuring the validity of the findings in a numeric and qualitative ways.

This work has also contributed to the following topics:

Energy buying for CEFET-MG; the methods developed here had resulted in two concrete processes of energy buying for CEFET-MG. One regarded the migration to the free market and the other regarding the implementation of a photo-voltaic power plant with external resources. They have the potential of reducing energy price in 18% and 55% respectively. The process can be replicated in any other university. The method also improves the new regulation of public procurement introducing ways to manage the risk as defined by law. The public procurement instruction, (PLANEJAMENTO, 2017), determines that it is necessary to manage the risk, but it does not present a method to do so.

Improvements recommendation in Brazilian wind energy policy (BERNARDES et al., 2018): the research indicates that Brazil has a restrictive wind policy if comparing with other countries' regulation. That leads to losing attractiveness to international players. It is possible to reduce the implementation of wind energy farms in at least one year just changing the Brazilian regulation to an international standard. That change could contribute to save resources expended in energy fees, attract investments, and increase the reliability of energy matrix since hydric and wind energy have a complementary behavior in Brazil.

Distributed Generation (BERNARDES; CARVALHO; SALDANHA, 2017): demonstrated that the distributed generation and Nash equilibrium can improve the row of strategies to deal energy improving the revenue.

Seasonalization (BERNARDES; FERREIRA; SALDANHA, 2016): was showed that shorter-term contracts tend to reduce the risk and variance in a portfolio of energy providers.

Forecasting (BERNARDES; FERREIRA; SALDANHA, 2016) (BERNARDES et al., 2018): it was presented the fuzzy time series as an useful tool to forecast energy. It highlights the clustering fuzzy time series as a precise tool;

6.2 Future Works

This thesis points out the following topics related to this work that could be explored in future researches:

a) improving the energy consumption scheduling according to the hourly charging system.

b) the forecasting just dealt with the energy inputs to generate the energy outputs. But the forecasting process can be benefited from a exogenous variables connected with the core busyness of the energy buying. That can address even more significant information.

c) the qualitative risk had been addressed. But other information of qualitative nature can be easily represented. It is important to develop the strategic planning of the consumer and heading these objectives to energy buying.

d) development of a web app with a visual interface for the methods.The energy market expects the implementation of an hourly charging system, possibly in the next year. Together with the gradual reduction of contracted loads to joining the free market, it will deeply change the energy market structure. The market will become dynamic and competitive. Consumers with flexible production that can schedule its energy consumption in particular seasons, days, or hourly days, can make the energy an income rather than a primary input. If the hourly price becomes higher than the previously procured energy price, the consumer can decide to sell the energy instead of consuming it. This kind of consumer will be highly benefited from a web application that can help him to decide in real-time.

e) adapt the methods for smart grid situation. Markets as Chile and the USA already have similar devices such as hourly charging as it is proposed to the Brazilian market. In those markets, it is possible to configure the power meter to acquire the energy automatically buy from the cheapest energy provider available. Here, it can be included qualitative evaluations of risk to make this automatic buying.

f) include exogenous variables to improve the decision. The methods aimed at developing the risk understanding of energy buying. Notwithstanding, many others qualitative information can be addressed to improve the decision. e.g., the consumer can have an index that represents its expectation about costumers acquisition and retention, that indicates the necessity of increasing or reducing the energy contracts.

g) deepen the understanding of the energy providers strategies such a way to improve energy buying. That is important, given the intensity of the changes expected for the next year in terms of regulation. We have designed methods to deal with the final consumer issues, but it is still fuzzy how the energy providers will deal with the changes in the regulation. It is necessary to understand what kind of procurement they will realize it is profitable and, thus, make it market available.

h) OWA operator: the evaluation of the risk aimed at representing the uncertainty regarded to the specialists and the process, but the decision is taking over the strict preference. We can devise an approach based on the incomparability providing the levels of incomparability to each alternative. Thus, this information can bound the numeric decisions given a guess about the lack of knowledge about the problem.

The energy markets are in constant change. The energy matrix is improving to become more efficient and greener. But it is not enough to advance just the energy sources, to fully improve the energy matrix all the agents involved must improve their strategies, and develop new methods to take advantage of the current regulatory framework for energy commercialization in Brazil.

This research has shown that it is necessary to develop new methods to take advantage of the current regulatory framework for energy commercialization in Brazil. The regular consumer needs to improve its energy buying strategies aiming at exploiting the benefits offered by the current legislation and near-future changes.

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