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Investment Assessment in Co-generation with Biomass in the Presence of Uncertainty and Flexibility

Wadaed Uturbey and Luis Alberto Aguilar

Abstract— **This work deals with generation expansion from biomass co-generation. A methodology to assess investment decisions, based on cash flow analysis and financial tools, is presented. In order to incorporate the investor risk aversion criterion, a measure of risk given by the probability of obtaining negative cash flows net present values, is employed. Main uncertainties that influence cash flows are taken into account by Monte Carlo simulation and managerial flexibilities given by investment alternatives are compared employing a Real Options approach. Moreover, in order to illustrate the proposed methodology, the paper presents an analysis of the investments opportunities in the Brazilian power market for co-generation from sugar cane bagasse.**

***Index Terms*—Investment Assessment. Generation Expansion. Biomass Co-generation. Monte Carlo Simulation. Real Options.**

I. Introduction

ENERGY markets with competition in electrical energy generation offer a wide variety of investment opportunities and bring about the need of assessing investment decisions properly. Uncertainties associated with fuel availability, energy price, fuel price and taxes are usually present on investor decisions. Also, the flexibility of selecting a specific market for the activities (spot market, long term contract market, etc), the flexibility to choose among different kinds of energy contracts and to expand or contract activities are situations commonly faced by investors. The ability to make mid-course modifications in a project, like an additional expansion of generation capacity under future favorable market conditions, allows the investor to capture future opportunities.

Investment decisions should follow an economical and financial competitive analysis of alternative projects. Among the traditional financial tools used for investment evaluation, the discounted cash flow, the Net Present Value (NPV), the internal rate of return and the payback method are the most common deterministic methodologies [1]. These methods do not allow the representation of the important uncertainties above mentioned, which strongly influence cash flows [2,3,4]. Moreover, they do not consider the managerial flexibilities previously reported [5,6]. Tools that are currently being used to incorporate uncertainties and flexibility are Monte Carlo simulation and Real Options theory. Power systems applications of these methodologies focus on generation expansion planning [7,8,9] and short-term generation valuation for managing risk in operations decisions [10,11]. Applications in other segments, like transmission expansion are limited [12].

This work presents an analysis of the investments opportunities in the Brazilian power market for co-generation from sugar cane bagasse. The main uncertainties that influence cash flows are taken into account by Monte Carlo (MC) simulation. Investment alternatives are compared employing a Real Options (RO) approach.

The paper is organized in five more sections. Section II presents investment opportunities in the Brazilian energy market for co-generation from biomass. Section III describes the proposed methodology. The RO approach is presented in section IV. In section V, the proposed methodology is applied to an expansion co-generation project analysis. Finally, section VI concludes the paper.

II. Investment opportunities for co-generation in the Brazilian market

One of the main objectives of the current regulation model of the Brazilian Electrical Energy Sector is to encourage generation expansion. The market structure allows competition in the generation sector and establishes two environments for energy commercialization. In the regulated market, called Regulated Commercialization Market (ACR), distribution utilities buy energy through auction mechanisms. In the bilateral market, called Free Commercialization Market (ACL), large consumers and generators establish bilateral energy contracts freely. Also, in order to take differences between real consumption/generation and contracted amounts into consideration, a spot market of differences operates weekly. In this latter market, prices are based on operation marginal costs and are determined by an optimization model. This model is similar to the dispatch model used by the Brazilian Independent System Operator (ISO) to operate the

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W. Uturbey is an assistant professor at the Department of Electrical Engineering of the Federal University of Minas Gerais, Belo Horizonte-MG, Brazil (e-mail: wadaed@cpdee.ufmg.br).

L. A. Aguilar is a researcher at the Federal University of Minas Gerais, Belo Horizonte-MG (e-mail: aguilarbr@yahoo.com.br).

bulk power system [13].

The Brazilian electrical energy system has 100GW of installed capacity, is a predominantly hydroelectrical system, with almost 85% of hydro installed capacity [14]. Nowadays, due to the high demand grow and low level of investments in hydro plants, thermal participation is increasing. Also, as a consequence of environmental constraints, the new hydro plants are mainly run-of-river units. Under present circumstances, energy constraints become a serious concern.

It is well known that in hydrothermal systems, prices are highly volatile. One traditional form of hedging against price volatility, strongly encouraged by the Brazilian market regulation, is to establish medium and long term contracts. In order to guarantee generation expansion, auctions for "new energy", that is, energy from plants not yet constructed, are conducted in the ACR market. Long term contracts of 15 or 30 years are signed between generators and distribution utilities and energy delivery starts, respectively, three or five years later. Observe that a safe environment is created, in which the certainty offered by long term contracts with fixed prices guarantees financial support for investors. A second class of auction is intended for "old energy", from plants already constructed. In this case, energy delivery starts a year latter and contract durations are at maximum eight years. On the other hand, bilateral contracts, freely negotiated in the ACL market, may be short, medium or long term.

An important energy resource in Brazil is co-generation from biomass of sugar cane bagasse, which represents 3% of the electrical energy matrix [14]. Estimates indicate that it may represent more than 20% in 2020 [15]. Bagasse biomass production has the interesting characteristic of being complementary with hydro generation: the harvest time, from April to November, coincides with the dry period of the hydrological cycle.

In the Brazilian energy market, there are investment opportunities for co-generation plants in both the ACL and the ACR markets. An attractive opportunity was the Reserve Energy Auction (REA) that took place in August 2008, for buying biomass energy to be delivered from 2009 or 2010 on, during 15 years. As a result of the auction, long term contracts were signed between the generators and the market administrator. The energy costs are transferred to all consumers through special charges. The contracted energy is intended to operate in the base of the load curve, as if it came from an inflexible unit. Favorable financial conditions with low interest rates are offered by the National Development Bank (BNDES) [16] and, in general, this auction establishes very favorable conditions for generators.

Most Brazilian co-generation plants from sugar cane bagasse currently in operation are of low efficiency type, with a low pressure and low temperature steam cycle. In order to participate in the power market, it would be necessary to make high investments in technology upgrade. Nevertheless, as these plants are, in general, near the end of their life cycle, this is the right moment to undertake this analysis.

Options are created by above circumstances: investors have the option of upgrading the power plant in order to participate in the REA or, alternatively, upgrading the power plant to sell energy in the ACL market by bilateral contracts or, furthermore, not investing at all. Also, a strategy could be to bid part of the energy in the REA and sell the remaining energy in the ACL market. Therefore, the exceptional favorable financing conditions offered for energy contracted in the REA could be attained. In this work, a methodology is proposed in order to assess this late strategy.

III. The Proposed Methodology

In order to evaluate sugar cane biomass co-generation investment strategies, aiming at participating in the REA, a two-stage methodology is proposed. In the first stage, a relationship among the risk level, the amount of energy contracted in the REA and the energy price is established. The objective is to assess the convenience of the following strategy: submit only part of the available co-generated energy in the REA, sufficient to honor loan obligations. A certain amount of energy is left available to be contracted in the ACL market, in the hope of obtaining advantageous short-term and mid-term contracts. This has been a common strategy among investors, since ACL contract prices are freely negotiated among both parts and, in general, positively correlated with spot prices. One can observe that this strategy virtually divides the plant in both an inflexible plant and a flexible one. The flexible plant may allow obtaining great profits during high spot price periods.

In this first stage, a MC simulation is carried over the project cash flows and the probability distribution of the NPV is obtained. The risk measure adopted is the probability of obtaining a negative NPV. Uncertainties considered in the MC simulation are related to the co-generation process, basically, sugar cane bagasse availability and cost. Note that energy price should be fixed in these simulations, since the project considers that energy is sold by a constant price in a long term contract.

The second stage of the methodology aims at comparing alternatives for selling the flexible energy. The idea now is to appraise the flexibility given by the adopted strategy. Observe that, after defining the inflexible and corresponding flexible amounts of energy, in the future, the flexible energy could be contracted in the ACL or, alternatively, in the ACR, in "old energy" auctions which take place every year.

Therefore, selling the flexible energy can be viewed as two mutually exclusive projects: sell in the ACL with short/medium term contracts with prices correlated with the spot price or, alternatively, sell in the ACR with a fixed price in eight years duration contracts. A RO approach is adopted to appraise this point. Next section addresses RO basic concepts and describes the general procedure of RO application and implementation.

IV. Real Options Approach

Real options, akin to financial options, give the owner the right but not the obligation, to undertake an action. However, unlike financial options, they require ownership of real, tangible assets. In this work, the underlying asset on which the real option is acquired, are the future cash flows of the project. As described in [6], the simplest RO examples that can be applied to investment projects are the option to defer, abandon, expand/contract activities and, also, choose among alternative and mutually exclusive actions. Uncertainty conditions on the asset value originate managerial decisions throughout the project life, when the level of uncertainty decreases over time, which are intended to implement mid-course corrections and change business decisions and strategies. Real options provide a method of evaluating capital investment strategies by taking into account this strategic decision-making process.

The uncertainty in cash flow predictions can be easily captured and quantified with the use of MC simulation. On the other hand, if there are strategic options in these projects, there may be value in these flexibilities. These options can be better quantified using RO analysis.

In this work, the binomial option pricing model proposed in [17] is adopted. In this approach, the stochastic process, a Geometric Brownian Motion given by (1), which describes the time evolution of the asset value, is substituted by a discrete simulation process.

$$\frac{\delta S}{S} = \mu(\delta t) + \sigma\varepsilon\sqrt{\delta t} \qquad (1)$$

In (1), S represents the underlying asset value and the percentage change in the variable S combines a deterministic and a stochastic part. The deterministic component, given by $\mu(\delta t)$, represents a drift on variable S. In the stochastic component, σ is a volatility parameter and ε is usually a Wiener process.

The discrete simulation process generates a binomial lattice; see Fig. 1, called binomial event lattice, which summarizes asset value uncertainty. This approach was first proposed in [17]. A binomial lattice node has two bifurcations, one above and one below its current level and this spreads out to multiple time periods. Two time intervals are relevant, the investment time duration, during which managerial options are available, which is the longest interval and the model time steps, which represent decision points. In Fig.1, each node corresponds to a possible value of the asset, and the tree defines the time evolution of the asset value. The up and down factors which modify asset value, are defined in (2),

$$u = \exp(\sigma\sqrt{\Delta t})$$
$$d = \exp(-\sigma\sqrt{\Delta t}) \qquad (2)$$

where u and d are up and down factors, σ is the asset value volatility, and Δt is the time intervals duration, defined by the discretization process.

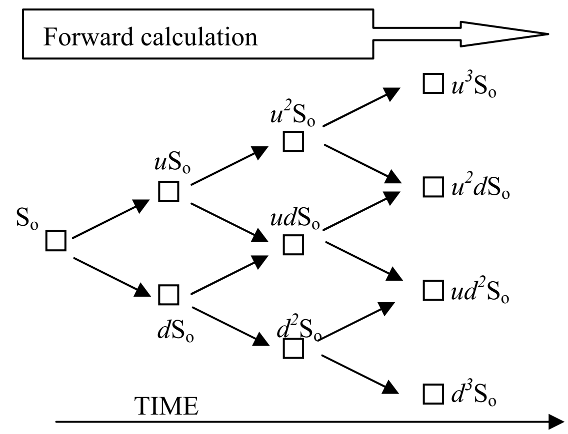


Fig. 1. Binomial event lattice. Three time steps.

Notice that the down factor is the reciprocal of the up factor. This fact ensures that the lattice is recombining: bifurcations must meet at places along the future path. Also, observe that the higher the volatility, the higher the up and down factors.

In order to appraise the option, a second lattice is generated, the binomial option valuation lattice. In the case of simple options, the RO approach involves two binomial lattices. For more complex options, like compound options, more lattices are needed [6,18].

Fig. 2 presents the binomial option valuation lattice. This lattice is evaluated by a backward process, terminal nodes are calculated first and then the intermediate nodes. The objective is to determine the option value at the first node. This backward process is necessary since option evaluation involves the following decision:

$$OV = \max(V\_exer\_option, E(V\_option\_open)) \qquad (3)$$

where OV is the option value, V_exer_option is the current value of exercising the option at a particular moment (node) and $E(V\_option\_open)$ is the expected value of leaving the option open.

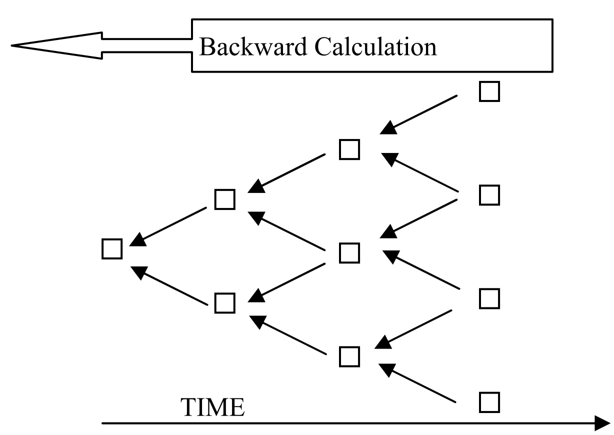


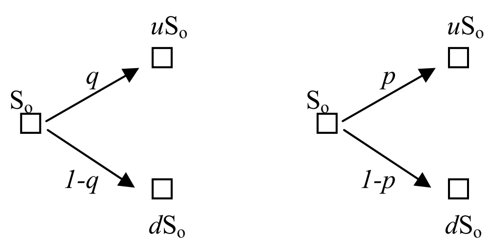
Fig. 2. Binomial option valuation lattice.

Terminal nodes evaluation is straightforward. At each intermediate node, the expected value of leaving the option open, $E(V\_option\_open)$, is determined as the expected value of next level nodes using the risk-neutral probability p given by (3), discounted at a risk-free rate rf.

$$p = \frac{e^{rf \cdot \Delta t} - d}{u - d} \quad (3)$$

Notice that risk-neutral probability p is just a mathematical convenience, which simplifies calculations and computational implementation. Risk-neutral probability p must not be interpreted as the probability of evolving from one node to the next. In the sequel, the intuition behind this point is explained [6,18,19].

In using risk-free discount rates, one must observe that risk-adjusting cash flows (discounting with risk-adjusted discount rates) provides the same results as risk-adjusting the probabilities leading to those cash flows and discounting with a risk-free discount rate. Fig. 3 illustrates this point. In Fig.3-a, present asset value So may evolve to uSo with probability q or to dSo with probability (1-q). Equation (4) indicates the relationship among present and future asset values considering the risk-adjusted discount rate r. Fig. 3-b represents an alternative cash flow in which a risk-free discount rate rf and a fictitious transition probability p are used. In order to both cash flows to be equivalent, (5) must verify. This is the concept of certainty-equivalence for discounting risky cash flows [6,18]. From (5), one can derive the expression of the risk-free probability given by (3).



(a) Risk-adjusted discount rate r. (b) Risk-free discount rate rf.

Fig. 3. Equivalent uncertain cash flows.

$$\left[q \cdot uS_o + (1-q) \cdot dS_o\right] e^{-r} = S_o \quad (4)$$

$$\left[p \cdot uS_o + (1-p) \cdot dS_o\right] e^{-rf} = S_o \quad (5)$$

In the NPV world, a single discount rate is usually used to acknowledge risk in discounting future cash flows. Thus, the NPV approach assumes that the risk is constant for the course of the project. This assumption is not justified in many real option projects, since when an option is exercised, market/project conditions change and, as a consequence, risk changes. Cash flows with discount rates that vary throughout project life should be used. The RO framework presented offers an appropriate way of dealing with changing risk, by allowing the cash flows to be discounted at the risk-free rate.

The value obtained for the first node of the binomial valuation lattice is the project present value with flexibility. If this value is greater that the present value of the project without flexibility, which is the initial node of the binomial event lattice, the exercise of the real options created by available managerial flexibilities will increase the value of the project.

A. Asset value volatility assessment

As mentioned previously, the underlying asset in the RO approach to investment evaluation is the present value of the project free operational cash flows. Usually, the volatility of the asset is measured as the standard deviation of the logarithmic relative returns on the free cash flows stream [6,18].

Volatility can be determined by a MC simulation in which all relevant uncertainties are considered. This approach is presented in [18], and is called consolidated approach to volatility estimation. Fig. 5 illustrates the idea.

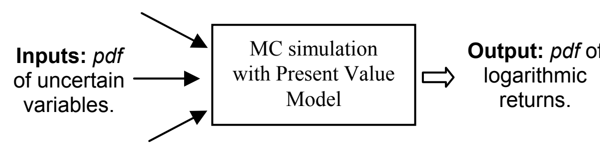


Fig. 4. Consolidated approach to volatility estimation.

The logarithmic present value approach collapses all future cash flow estimates into two values, one for the first time period and another for the present time. Equations (6) and (7) show project present value at present time and at first time. Logarithmic return is given by (8). In order to obtain the probability distribution of returns, the denominator in (8) remains constant. MC simulation is carried over the numerator.

$$PV_o = \sum_{t=1}^{T} \frac{CF_t}{(1+r)^t} \quad (6)$$

$$PV_1 = \sum_{t=2}^{T} \frac{CF_t}{(1+r)^{t-1}} \quad (7)$$

$$Re = ln\left(\frac{PV_1 + CF_1}{PV_o}\right) \quad (8)$$

where PV_0 and PV_1 are the project present values at present time and at first time respectively, CF_t is the cash flow at time t, Re is project return and r is the discount rate.

V. Co-generation Plant Investment Analysis

This section presents the application of the methodology to an expansion project of a typical co-generation plant of the Southeastern Brazilian region, in order to commercialize the co-generated energy in the REA. Project data, presented in Table I, are based on typical values obtained from a survey conducted by [20] and published in the auction rules documentation elaborated by the regulatory agency [16]. Table I also presents financial conditions available for investors participating in the REA. For comparison purposes, an exchange rate of 1.00 US$ = 2.35 R$ should be used.

TABLE I
Co-generation Plant Expansion Project Data and Investment Financing Conditions

Expanded capacity	27 MW
Investment costs	2042.59 R$/kW
Variable O&M costs	6.00 R$/MWh
Fixed O&M costs	25.00 R$/kW year
Bagasse price	0 to 30 R$/ton + Transport cost
Fiber content	25 to 28%
Transmission charges	5.00 R$/kW month
Sector taxes	1.52 R$/kW year (Regulatory agency) + 1% (R&D)
Income tax + Social contributions	35%
Discount rate (risk-adjusted)	15%
Risk-free discount rate	6.25%
Depreciation period	20 years
Project life	15 years
Debt	85 % of the total investment
Interest rate	5.5% + 3.5%
Amortization	14 years, constant
Grace period	3 years

In order to apply the first stage of the proposed methodology, a cash flow model that takes into account the main uncertainties was implemented. Various MC simulations were conducted for each specified amount of energy contracted in the REA and each energy price. For each simulation, the probability distribution of the NPV is obtained and the corresponding risk level, defined as the probability of a negative NPV, is determined. Notice that the energy price is a fixed value obtained from the REA. In the co-generation process, main uncertainties are related to sugar cane bagasse. The amount of bagasse needed to produce a certain amount of energy varies with the fiber content of sugar cane, and sometimes is necessary to buy bagasse. Uniform probability distributions are assumed to both the fiber content of sugar cane and the bagasse price.

In order to illustrate the concept of risk level, Fig. 5 presents the probability distribution of the NPV obtained with an energy price equal to 149.00R$/MWh, when 15 MW of inflexible energy are contracted in the REA. Observe that the mean NPV is positive and the risk level, given by the darker region, is equal to 6.36%.

Fig. 6 presents a graph of risk level as a function of energy price, for different levels of inflexible energy contracted in the REA. An investor can use this graph to determine the level of energy to be submitted in the REA. An acceptable risk level must be defined and a plausible energy price chosen. The graph gives the amount of energy to be submitted to the REA.

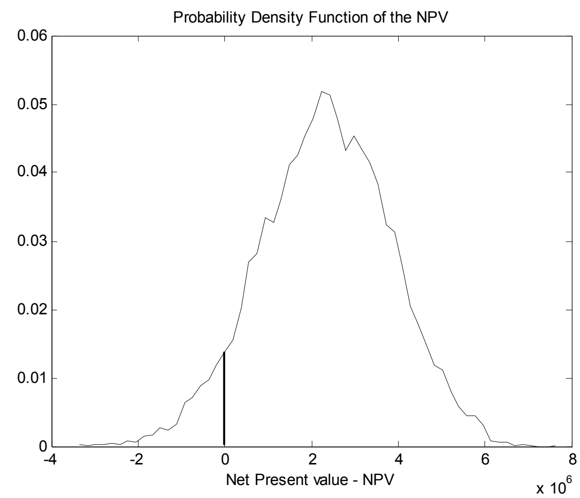


Fig. 5. NPV Probability density function, for 15 MW contracted in the REA at an energy price equal to 149.00 R$/MWh.

Observe that risk level choice depends on each investor's risk aversion characteristics. In this work, a 5% risk level is adopted. Energy price is unknown, since it will be the output of the REA. Auctions in the Brazilian market are reverse price type with an initial price established by the government. A plausible value for the final price discount must be estimated. Results of previous auctions designed for thermal energy are used to estimate the obtained price discount. An average 5% discount was estimated. Since the initial price in the auction is equal to 157.00R$/MWh, a final energy price equal to 149.00R$/MWh is adopted. Finally, the graph in Fig. 6 indicates that 16MW should be offered in the REA, which represents almost 60% of the total commercialized capacity.

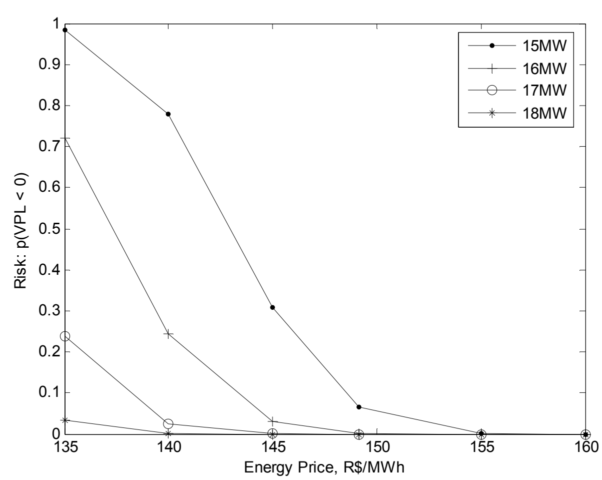


Fig. 6. Risk level as a function of energy price, for different contracting schemes.

At this point, an important matter should be addressed. Which is the correct discount rate to be used in this first stage of the methodology? As the objective is to guarantee loan obligations, and the REA offers a safe environment to commercialize energy, a risk-free discount rate should be used.

In the second stage of the proposed methodology, the RO analysis process described in section IV is applied to the remaining 11 MW. Should this 11MW be contracted in the ACL market or, alternatively, should be submitted to "old energy" auctions or should have been submitted to the REA?

Observe that, since an "old energy" auction takes place every year, there exists the managerial flexibility of moving from ACL market to ACR market each year. In order to model this movement, the simplest type of option that can be used is an abandon option which can be exercised once a year. The "salvage" value is the present value of long term contracts. This approach models the first switch between markets, future movements are not modeled. Therefore, through this simple analysis, the level (project value) at which movements between markets should occur is addressed.

In order to maintain coherence with REA conditions, a 15 years time horizon is considered for the RO analysis. Time steps are one year duration. The underlying asset to be appraised is an 11 MW plant which sells energy in the ACL market. Table II presents obtained parameters, needed in the calculation of binomial lattices: returns volatility, time step, up and down factors and risk free probability.

In order to determine project returns volatility, a MC simulation is carried, considering bagasse uncertainties and also price uncertainties. Notice that, in this case, energy prices are correlated with spot prices and also depend on market conditions. In this work is assumed that contracts indexed by the spot price are obtained, and that the mean price over the project life is 149.00 R$/MWh, which most of the time is higher that the mean spot price during the same period. Spot prices projections available in [20] were used.

Fig. 7 shows the binomial event lattice. The initial node value, which is an estimation of the project present value, is obtained by a deterministic cash flow with fixed energy price and discounted at a risk-adjusted discount rate equal to 15%. The energy price to be used is the expected value of the prices in the ACL market. Free negotiated ACL contracts prices are not registered, thereby, 149.00 R$/MWh is adopted.

Fig. 8 presents the binomial decision valuation lattice, formed by backward calculations. At terminal nodes, the option value can be calculated directly, taking the maximum value between the project value at the same node of the event lattice and the "salvage" value, R$ 15611126.47. In Fig. 7 and Fig. 8, values in binomial lattices are related to the time at which plant starts activities.

TABLE II
PARAMETERS FOR BINOMIAL LATTICES CALCULATIONS

Volatiliy σ	*Time step* Δt	*Up factor* u	*Down factor* d	*Risk-free probability* p
53.07%	1 year	1.7001	0.5882	0.42835

Intermediate nodes are calculated backward, by taking the maximum between the value of leaving the option open and the value of exercising the option. For instance, consider node (1,5). The value of leaving the option open is calculated as:

$$[p * 222106261.48 + (1-p) * 78163282.98] * exp(-rf)$$

The value of exercising the option is equal to the "salvage" value. Therefore, at this node, the decision is to leave the option open.

Fig. 9 shows the obtained optimal strategy. "Open" indicates that it is more valuable to maintain the option open, remaining in the ACL market. Notice that movement is indicated only when future project value are below a certain level equal to R$ 5400937.06, node (3,3) in Fig. 7.

The results obtained indicate that the value of the 11 MW project with flexibility, node (1,1) in Fig. 8, is 38 % higher than the project value without flexibility, node (1,1) in Fig. 7. The option value is obtained as the difference between project value with flexibility and project value without flexibility, given R$ 4479426.73 (project values must be discounted to present time, that is, two time steps, due to the plant construction time).

In order to complete the analysis, the proposed strategy must be compared with the alternative of bidding all the 27 MW in the REA. To address this point, the present value of the mentioned project is determined. A cash flow model in which energy price is constant and equal to 149.00R$/MWh, is implemented. MC simulation is used to represent bagasse variability, akin in previous analysis. In this case, a risk-adjusted discount rate should be used, since there is just one project to fulfill investors return expectancy. The expected NPV obtained is equal to R$ 8566204.05. This value should be compared against the sum of the expected NPV obtained by bidding 16 MW in the REA, equal to R$ 4891767.07, and the cash flows present value of the 11 MW left to the ACL, equal to R$ 11804254.42 (project value given in the event lattice, node (1,1), discounted two time steps). Clearly, the adopted strategy is preferable.

15611	26540	45123	76715	130426	221741	376989	640932	1089669	1852581	3149632	5354789	9103847	15477740	26314196
	9182	15611	26540	45123	76715	130426	221741	376989	640932	1089669	1852581	3149632	5354789	9103847
		5400	9182	15611	26540	45123	76715	130426	221741	376989	640932	1089669	1852581	3149632
			3176	5400	9182	15611	26540	45123	76715	130426	221741	376989	640932	1089669
				1868	3176	5400	9182	15611	26540	45123	76715	130426	221741	376989
					1099	1868	3176	5400	9182	15611	26540	45123	76715	130426
						646	1099	1868	3176	5400	9182	15611	26540	45123
							380	646	1099	1868	3176	5400	9182	15611
								223	380	646	1099	1868	3176	5400
									131	223	380	646	1099	1868
										77	131	223	380	646
											45	771	131	223
												26	45	77
													15	26
														9

Fig. 7. Binomial event lattice (values x 1000).

21535	30828	48030	78494	131350	222106	377072	640932	1089669	1852581	3149632	5354789	9103847	15477740	26314196
	17001	21415	30622	47743	78163	131043	221895	376989	640932	1089669	1852581	3149632	5354789	9103847
		15611	16933	21247	30335	47357	77748	130713	221741	376989	640932	1089669	1852581	3149632
			15611	15611	16835	21003	29926	46832	77249	130426	221741	376989	640932	1089669
				15611	15611	15611	16686	20634	29324	46118	76715	130426	221741	376989
					15611	15611	15611	15611	16450	20047	28394	45123	76715	130426
						15611	15611	15611	15611	15611	16054	19063	26540	45123
							15611	15611	15611	15611	15611	15611	15611	15611
								15611	15611	15611	15611	15611	15611	15611
									15611	15611	15611	15611	15611	15611
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											15611	15611	15611	15611
												15611	15611	15611
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														15611

Fig. 8. Binomial option valuation lattice (values x 1000).

open	open	open	open	open	open	open	open	open	open	open	open	open	open	open
	open	open	open	open	open	open	open	open	open	open	open	open	open	open
		move	open	open	open	open	open	open	open	open	open	open	open	open
			move	move	open	open	open	open	open	open	open	open	open	open
				move	move	move	open	open	open	open	open	open	open	open
					move	move	move	move	open	open	open	open	open	open
						move	move	move	move	move	open	open	open	open
							move	move	move	move	move	move	move	move
								move	move	move	move	move	move	move
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Fig. 9. Project decision lattice.

VI. CONCLUSIONS

In this work, a methodology to assess investment opportunities has been presented. Uncertainties and managerial flexibilities were addressed by Monte Carlo simulation and real options method. Choosing between free market and regulated market has been modeled by one of the simplest types of real options: the option to abandon.

The binomial approach used to appraise the option of moving from the free market to the regulated market is very simple, both from the computational and the conceptual points of view. In general, binomial lattices give a convenient way to combine managerial flexibilities with project value, since decisions are often taken in discrete time points.

The analysis presented in the paper shows that the proposed methodology is a useful tool which enhances the investment evaluation process, when compared to deterministic financial methods that do not consider the conjoint effect of uncertainty sources or consider a limited set of scenarios.

The explicit characterization of uncertainty sources and managerial flexibilities and their inclusion on the evaluation criteria, add value to the decision making process and allow maximum project financial returns.

VII. References

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VIII. Biographies

Wadaed Uturbey received her degree in Electrical Engineering from UDELAR, Uruguay, in 1991, the M.Sc. and Dr. Eng. degree from Federal University of Santa Catarina, Brazil, in 1995 and 2002, respectively. She is currently an assistant professor at the Department of Electrical Engineering of the Federal University of Minas Gerais, Brazil. Her research interests include probabilistic methods for power systems operation and energy markets.

Luis Alberto Aguilar received his M.Sc. and Dr. Eng. degree in Production Engineering from Federal University of Santa Catarina, Brazil, in 1994 and 2002 respectively. His research interests include probabilistic methods in management and marketing research.