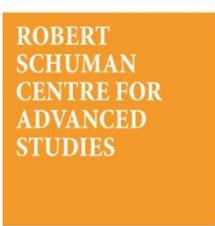




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Enhancing flexibility and ensuring efficiency and security: Improving the electricity market in Brazil via a virtual reservoir model

Felipe A. Calabria, J. Tomé Saraiva and Jean-Michel Glachant

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Abstract

The Brazilian electricity market has certain particularities that contribute to considerably distinguish it from other markets. With a continental interconnected transmission system in which around 70% of the total installed capacity comes from hydropower plants, this electricity market recently passed through two large institutional reforms and it currently contains a number of special features together with other usual market instruments. Nevertheless, the conciliation between the commercial commitments of the market participants and the physical dispatch is not smooth. Moreover, the Brazilian short-term market is a mechanism to settle differences rather than a market, and the electricity short-term market price and the schedule dispatch are not determined through the interaction between market participants. This paper focuses on these problems, discusses some dilemmas that have to be faced if a more conventional market oriented approach is to be adopted, and proposes a solution in order to address these issues. Pointing towards the enhancing of the flexibility for market participants to bear their contracts, while still ensuring the efficient use of the energy resources and maintaining the current level of the security of supply, this new framework was designed based on a virtual reservoir model.

Keywords

Brazilian electricity market, market design, virtual reservoir model

1. Introduction

The electricity industry has changed over the years from vertically integrated utilities to more decentralized structures and competitive electricity markets. Ever since, several electricity market structures are being designed and tested to ensure free access, fair competition, higher efficiency, while maintain or improving reliability and security of operation.

The Brazilian electricity market has certain particularities that contribute to considerably distinguish it from other markets. With a continental interconnected transmission system, a large and growing demand, a total generation installed capacity around 135 GW, from which around 70% comes from hydropower plants, this electricity market passed through two large institutional and regulatory reforms in the last 20 years and it currently contains special instruments such as the Mechanism for Reallocation of Energy and the Seasonalization process.

The first reform promoted a transition from the vertical integrated utility structure to a market where agents could freely negotiate contracts. Besides that, the quantities that were traded by contracts have been reduced whereas more trading in the short-term market was encouraged (Arango *et. al.*, 2006). During this time, Brazil had a decentralized energy planning, but with an indicative energy planning conducted by the National Council for Energy Policy (CNPE). Then, in 2001 Brazil experienced a major supply crisis, which led to an aggressive energy rationing from June 2001 to February 2002. The 2001/2002 energy rationing had major economic and political impacts and encompassed about 80% of population, GDP and electricity consumption (Maurer *et. al.*, 2005). Driven by the mentioned rationing, the second reform took place as an electoral commitment of the opposition party, who won the Presidential election in 2002. This reform basically pushed Brazil to a structure corresponding to the single buyer model, but preserving some competition features in the retail market. In practice, a new regulatory framework (introduced by Law 10848/2004) was implemented in 2004 bringing back some old fundamentals and adding new guidelines:

- A. Reintroduction of the long-term centralized planning conducted by the federal government to address the security of supply. Thus, the expansion of the system doesn't rely on a market-based economy;
- B. Competition through public auctions according to the single buyer model. The main target of this scheme is to provide affordable tariffs to the growing economy;
- C. Implementation of long-term contracts (PPAs) with availability of payment. The goal was to foster the installation of thermal power plants;
- D. Requirement that consumers must be fully supplied by energy and power purchase contracts, and all contracts must be registered in the Brazilian market operator (CCEE);
- E. Requirement that sellers must have enough capacity when selling energy and power to entirely ensure their contracts; and
- F. Restructuring of the commercialization processes by creation of two contracting environments: the *ACR* - Regulated Contracting Environment and the *ACL* - Free Contracting Environment.

Both the implementation of PPAs with availability of payment (item C) and a mandatory bilateral contracting scheme (item D) with physical backing (item E) were adopted to guarantee the return of investments and address the security of supply, since this was appointed as one of the reasons of the above mentioned rationing.

Regarding item D, it is relevant to reinforce that the electricity demand of both distribution utilities (on behalf of captive consumers) and free consumers must ensure the compliance of 100% of their consumptions by energy and power purchase bilateral contracts (Decree 5163/2004, art 2º, items II and III). Otherwise, specified penalties will be applied to them. As a result, this legal provision definitely imposes a bottleneck on the trading of electricity into the short-term market.

Concerning item E, it means that all electricity sold by sellers should be 100% physically backed (Decree 5163/2004, art 2º, item I). This “physical coverage for sale” consists of what is known as “physical guarantee” of the power plants. The physical guarantee corresponds to the maximum amounts of energy associated with each power plant project. Relating to hydros, physical guarantee corresponds to the maximum energy production that can be maintained almost continuously over the years, simulating the occurrence of thousands of inflow sequences created statistically, and assuming a certain risk of not feeding the load (ANEEL, 2013). To sum up, the physical guarantee, which is defined by the Ministry of Mines and Energy (MME), has the value of a certificate that determines the amount of energy that each power plant can trade.

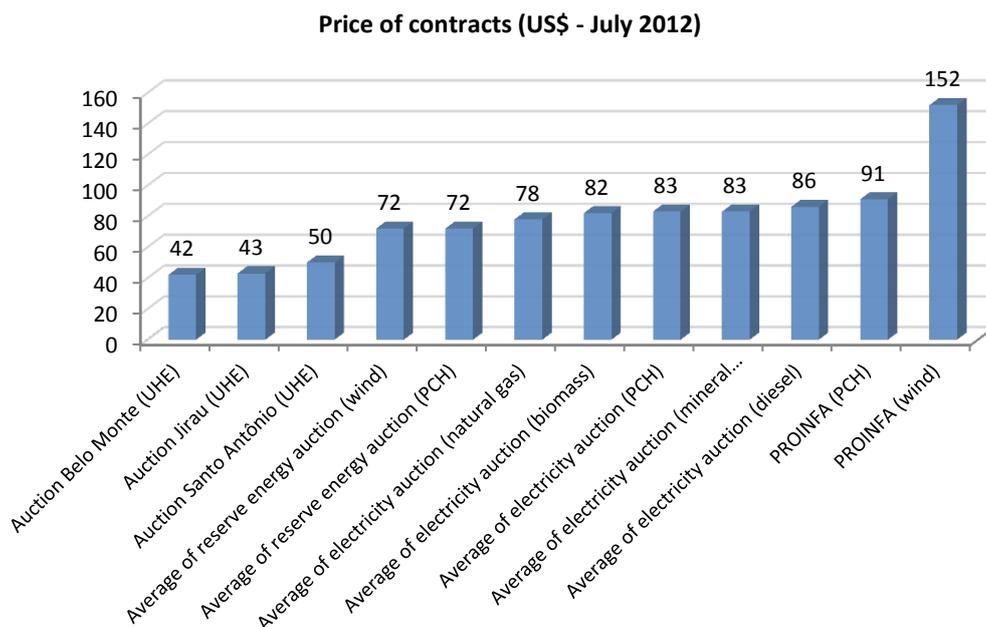
2. From Market Results to Physical Operation of the Power System

For end consumers, the Brazilian electricity market operates in two ways. It operates under competition in the retail market, named *ACL*, for those eligible consumers that fit in the characteristic of free consumers or special consumers, and it works according to the single buyer model structure, entitled *ACR*, for the final consumers that are not free to choose their supplier.

In the *ACR*, prices are determined by national public auctions. Differently, in the *ACL* prices are freely negotiated between buyers and sellers through a non-organized market like *OTC*, where a lot of traders can mediate the deal between consumers and producers, or through emerging private power exchanges. Additionally, there is also the short-term market, in Brazil known as *MCP*, which is designed to account for and settle the differences between the contracted energy amounts and the generated/consumed energy.

There are several kinds of national public auctions. Some of them are implemented to buy “new energy”, i.e. electricity that will be produced by power plants that still have to be built, while others aim at buying electricity from power plants already under operation. Moreover, there are also specific auctions designed to buy electricity only from renewable energy sources (such as wind, PV, biomass and small hydros), to raise the level of security of supply (reserve energy auction), and to promote the feasibility of relevant and structuring projects. Figure 1 shows average prices of *ACR* auctions carried out between 2004 and 2012 by energy source.

Figure 1 – Average prices by types of auctions in Brazil (Rosa et. al., 2013)



Then, all contracts must be registered at the market operator (CCEE) in order to be considered in the settlement process of the *MCP*. Additionally, when a power plant becomes available for operation, the CCEE considers the associated physical guarantee available to be also settled. Then, regularly in December of every year, market participants can perform a seasonal adjustment of the contracted energy and of the physical guarantee to be applied for the entire next year (CCEE, 2012). This process is called “seasonalization” and, in other words, it allows distributing the total annual amount in monthly MWh packages. Besides the seasonalization, the MWh are also allocated in three load steps, in a process known as “modulation”.

The power plants are then dispatched by the system operator (ONS) in order to optimize the hydrothermal system and to efficiently use energy resources. The dispatch is performed without considering the amount of the contracted energy and physical guarantee. Instead of a market-based approach, the dispatch is defined based on the solution of a minimum operational cost problem that seeks for a trade-off between saving water now and using thermal fuel (if the expectation of inflows is low) or using water now and saving thermal fuel (if the expectation of inflows is favourable). Furthermore, concerning the coordination of the operation, since there are a lot of cascades of hydro stations with different owners, it is also important to consider the use of the potential energy stored in the reservoirs installed in the same water basin.

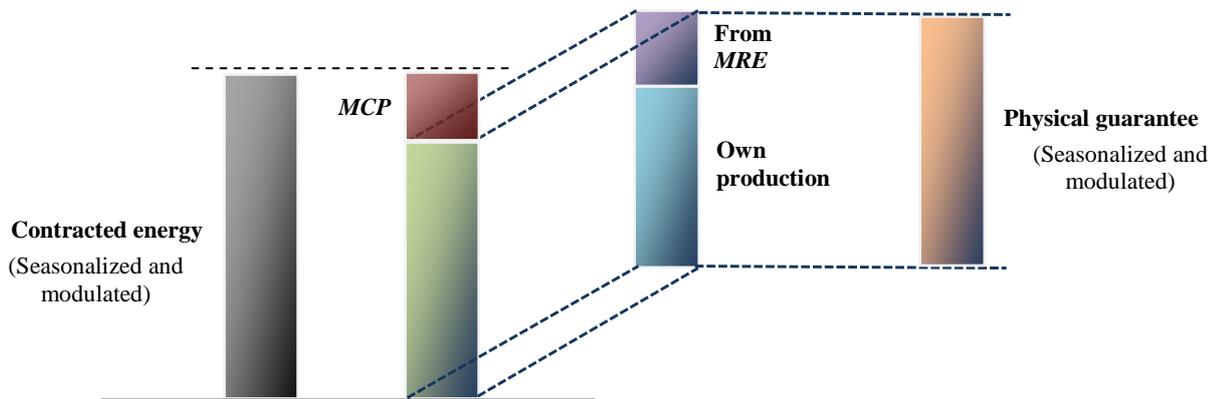
As a consequence, the dispatch is centralized and the optimal dispatch problem is currently solved basically through a stochastic dynamic programming software package called NEWAVE together with a linear programming software called DECOMP. The two main outputs of these two packages are as follows: the dispatch schedule of the power plants under operation and connected to the National Interconnected System; and the Brazilian short-term market prices, well-known as *PLD* (Price of the Differences Settlement). Both of them are weekly established for each load step of the day.

Because the dispatch is performed by the ISO in a centralized way and it decides the market participants’ outputs without considering their contracted energy, and once generators need to bear their contracts by delivering the electricity committed through contracts, there is in Brazil a mechanism called Mechanism for Reallocation of Energy (*MRE*). The *MRE* is applied to hydros, that usually close contracts following the modality for quantity, i.e., they are committed to deliver a certain amount of electricity (MWh) during a specific period at a pre-defined price. The goal of this mechanism is to cover the risk of generators having to buy electricity in the short-term market at *PLD* to fill in the amount of energy committed in their contracts.

All generators receive their contractual payment because they sell the “physical guarantee assigned to them”, and not because they sell the “actual electricity produced by them”. Then, in each accounting period, the *MRE* reallocates energy, transferring the surplus generated from those that produce beyond their physical guarantee to those that produce below. So, if the own production of a hydro station is less than its physical guarantee (which is calculated in long term to represent the amount of electricity that can be continuously produced), this station will receive energy from stations that produced more.

The own production plus the energy allocated from the *MRE* is equal to the verified energy, which is then compared with the contracted energy, and the resulting difference is settled in the short-term market (*MCP*) at the short-term market price (*PLD*). This settlement is performed for each agent and it is illustrated in Figure 2.

Figure 2 – Traded energy in MCP: negative exposition



To bring this section to a close, Table 1 shows a number of types of contracts from both the *ACR* and the *ACL*, and briefly explains how the dispatch procedure is carry out by the system operator (ONS) and the settlement of exposed positions performed by the market operator (CCEE).

Table 1 – The ACR and ACL markets, the dispatch procedure and the MCP

ACR - Regulated Contracting Environment	ACL - Free Contracting Environment	ISO dispatch procedure	Brazilian short-term market (MCP)
Types of contracts involved:		How generators are dispatched by ONS?	How exposed positions are settled by CCEE?
<ul style="list-style-type: none"> • <i>CCEAR</i> (Contract for Electricity Trading in the Regulated Environment) 	<ul style="list-style-type: none"> • <i>CCEAL</i> (Contract for Electricity Trading in the Free Environment) 	<ul style="list-style-type: none"> • ISO knows the installed capacity, availability, and fuel cost of generators. • ISO also knows the predicted consumption due distribution companies' monthly declarations. • ISO forecasts the weather to stipulate rivers inflows. • It is run software based on stochastic dynamic and linear programming to establish the dispatch schedule and the <i>PLD</i>. 	<ul style="list-style-type: none"> • All closed contracts (in both <i>ACR</i> and <i>ACL</i>) have to be recorded in CCEE. • CCEE performs measurements of the amounts actually produced / consumed by each agent. • <i>MRE</i> is applied for participants of this mechanism. • Differences between contracted energy and the verified energy are accounted. • Exposed positions are valued by <i>PLD</i>.
<ul style="list-style-type: none"> • <i>CER</i> (Contract for Reserve Energy), signed between CCEE and sellers agents 			
<ul style="list-style-type: none"> • <i>CONUER</i> (Contract for Use Reserve Energy), signed between CCEE and consumption agents 			
<ul style="list-style-type: none"> • Contracts for Distributed Generation 	<ul style="list-style-type: none"> • <i>CCEI</i> (Contract for Purchase Encouraged Electricity) 		
<ul style="list-style-type: none"> • Contracts of Adjustments 			
<ul style="list-style-type: none"> • Contracts of <i>PROINFA</i> (Program of Incentives for Alternative Electricity Sources) 			
<ul style="list-style-type: none"> • Contracts of Itaipu Hydropower Plant 			

3. Problems

Notwithstanding, there are some problems that arise from this market design, which are discussed below.

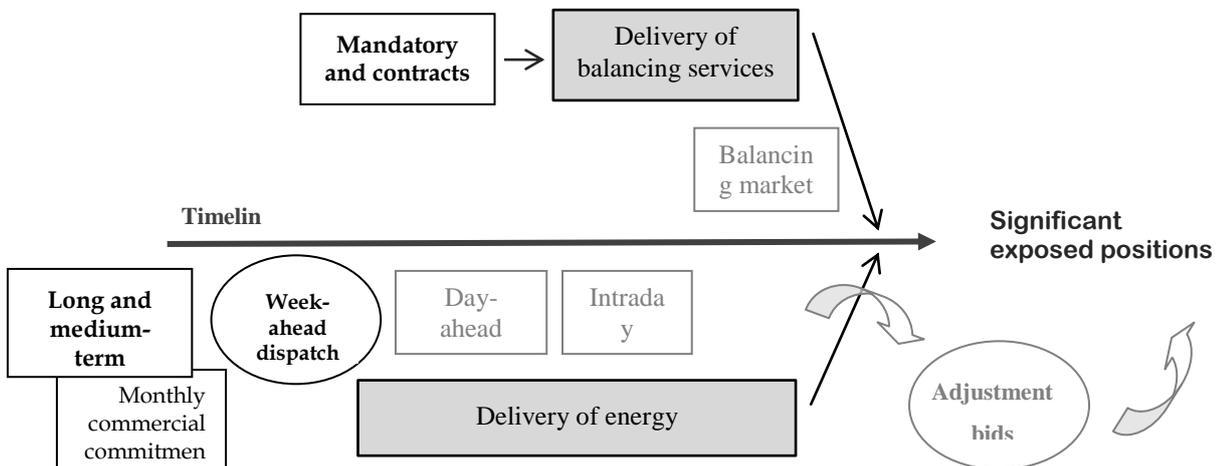
3.1 Problem 1: The conciliation between the commercial commitments of the market participants and the physical dispatch is not smooth

In order to trade both energy and power, several markets have emerged with the market liberalization: day-ahead, intraday, balancing, forward, future and options markets. However, when all these markets are operating together it should have a concern related with the coordination conditions between them. For instance, it is possible that weak links exist between forward and short-term markets, as well as between the distinct markets for electricity and reserves.

(Wilson, 1999) addresses this concern bringing the idea of the “sequence of markets”, which means that a rich sequence of forward markets (e.g. long-forward, day-ahead, hour-ahead, spot) approximates a single complete market. Thus, the “incompleteness of the market” can be addressed by repeated trading of a few simple contracts in order to allow contingent contracts to come close to a complete market. As a result, frequent trading opportunities enhance the completeness of the entire market.

In the Brazilian case, there is no balancing market, neither an intraday, day-ahead, options nor future markets. Instead of that, there is an annual “window” to monthly distribute the physical guarantee and the contracted energy (via the seasonalization process already described) and, once the centralized dispatch is carried out by the ISO (not considering the signed contracts), generators are not allowed to, in the medium and the short-term, decide their own generation in order to bear their contracts. As shown in Figure 3, this can significantly expose them to the risk of having to buy electricity in the MCP at the high volatile PLD in order to deliver the energy committed in their contracts.

Figure 3 – Traded energy in MCP: negative exposition



The issue regarding the conciliation between the commercial commitments of the market participants and the physical dispatch of the power system becomes more evident when the Brazilian electricity market is compared to other electricity markets around the world. Thus, to bring a broader outlook to this problem, Table 2 presents a helpful comparison.

On balance, in markets as day-ahead, intraday and balancing markets, players are more active in the definition of the merit order on a day-by-day basis and so they have more opportunities to cover

their positions engaged by bilateral contracts. This fact can be viewed as a higher completeness of the market when compared with a market where participants close their positions by long-term contracts.

Table 2 – Conciliation between physical dispatch and commercial commitments

Electricity industry structures	Contracts between market participants	System operator dispatch	Conciliation between dispatch schedule and contracted positions	Costs/prices passed on to tariff of final consumers
Vertically integrated utility	Without contracts (command and control management)	System operator dispatches considering the minimal operational cost, since it a priori knows each marginal cost.	There aren't electricity market and contracts involved, so there isn't need for conciliation.	Consumers pay for the cost of each MWh produced based on cost of service regulation.
Single buyer model (Brazilian case)	<ul style="list-style-type: none"> • Long-term contracts (PPA) via public auctions in the <i>ACR</i> • Ancillary services are provided by grid codes and by contracting for reactive energy • Medium-term contracts in the <i>ACL</i> 	<ul style="list-style-type: none"> • Minimization of the operation cost through the tight pool approach. <p>ISO doesn't consider the amount of electricity sold or bought through contracts (it just uses the price from the public auction to perform the merit order). Generators are not active in this central-dispatch procedure.</p>	It is expected that participants bear their closed contracts by their own production. However, it is the ISO who decides their outputs without considering their contracted amounts. So, it is needed a mechanism (the <i>MRE</i>) to share the associated risk.	<ul style="list-style-type: none"> • Prices of the PPAs, which have two components: energy payment and availability payment; <p>PS: Participants settle imbalances.</p>
Wholesale and retail competition (like Texas in 2000)	<ul style="list-style-type: none"> • Bilateral physical contracts • Balancing market • Financial forward contracts 	<ul style="list-style-type: none"> • Minimization of the difference between the closed contract and the real production. <p>In short-term, generators submit notifications to the ISO/TSO, which are expected to be equal to contracted positions. ISO/TSO dispatches considering these notifications. Generators are active through a self-dispatch procedure.</p>	ISO/TSO tries to dispatch the exact amount of the physical notifications, i.e. his goal is to minimize the suppliers' exposed position.	<ul style="list-style-type: none"> • Prices coming from the bilateral contracts and balancing market; <p>PS: Participants settle financial contracts and imbalances.</p>
Wholesale and retail competition (like some USA states, and European countries)	<ul style="list-style-type: none"> • Short-term markets, as day-ahead and intraday • Balancing market • Financial and physical forward contracts 	<ul style="list-style-type: none"> • Minimization of the operation cost through the loose pool approach. <p>Sellers and buyers submit their bids. Power Exchange dispatches considering the successful bids. Generators influence, through their bids, the dispatch schedule.</p>	ISO/TSO implements technical adjustments to enforce violated constraints.	<ul style="list-style-type: none"> • Price of the short-term markets and balancing market; <p>PS: Participants settle financial contracts and imbalances.</p>

3.2 Problem 2: The Brazilian short-term market is a mechanism to settle differences rather than a market

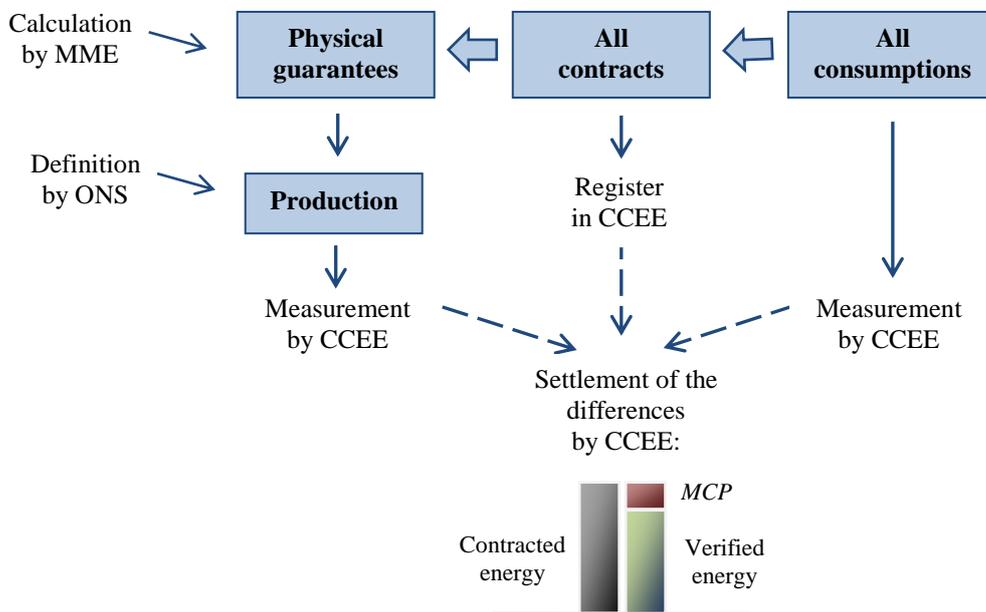
The *MCP* takes place after the dispatch of the ISO. Unlike other market designs addressed in Table 2, the Brazilian short-term market is not the marketplace where generators are active through a self-dispatch procedure, or generators influence, through their bids, the dispatch. Ultimately, the Brazilian short-term market is not an environment where market participants meet in order to perform short-term trades on behalf of their own account.

Neither party arrives at some point to make any declaration of intent in the short-term. Moreover, the price that values these transactions (*PLD*) does not result from the interaction of market participants, but comes from the application of a chain of software packages, which is run by a third party entity. In summary, it would be a short-term market if, in this environment, market participants meet with each other in order to negotiate electricity and close agreements in the short-term according to their own will.

So, contrasting with other short-term markets, the *MCP* is a mechanism to settle differences between the amounts of electricity committed by contracts and those amounts of electricity that each agent ends up providing / receiving. These differences, illustrated in the Figure 2, must be automatically purchased or sold in the *MCP*.

Figure 4 synthesizes relevant points related with this issue. Once all consumption has to be contracted ex-ante and contracts have to be physically backed, structurally the Brazilian market was designed to have no mismatches between the “computed long-term production (physical guarantee) and the foreseen consumption”. As a consequence, it is the responsibility of the *MCP* to deal with the differences that may occur due to the mismatch between the monthly verified energy and the contracted energy.

Figure 4 – An overview of the commercialization processes



3.3 Problem 3: The codes associated to the chain of software used to run the centralized dispatch are under intellectual property rights

As previously indicated, it is not the market through the interaction between its participants that determines the electricity short-term market price and the dispatch schedule. Basically, since around

80% of the electricity produced in Brazil comes from hydropower plants, this is performed by two computational programs (NEWAVE and DECOMP) that value the present electricity cost considering, among other variables, future scenarios of water inflows.

Therefore, inconsistencies in these algorithms have a huge impact within the entire sector, and the confidence of the market can be affected. Unfortunately, during 2007 and 2011, relevant problems related with inconsistencies in these models were detected. These problems caused a large impact on the electricity sector, not to mention transparency problems since the software codes have intellectual property rights and, therefore, they are unknown by the market participants and the authorities, inducing some instability in the Brazilian electricity sector.

4. Dilemmas

A solution typically adopted in other markets is the employment of a more market oriented approach. This market approach could enable all generators to offer, in short-term, quantity and price bids, which would be used to set the market positions and, consequently, substitute the seasonalization process and the MRE. As a result, the short-term market price would be based on the interaction between market participants. Nevertheless, particularly focusing on a power system with large share of hydros, there are some dilemmas that must to be faced.

4.1 Efficiency of energy resources

The Brazilian and the New Zealand power systems are quite similar in terms of the importance of hydro generation. Both recently had around 60% of the electricity produced coming from hydropower plants (New Zealand System Operator, 2014) (ONS 2014a). However, in New Zealand generators make offers and are dispatched each half hour in a compulsory market pool. Thus, the offer stacks they submit are the only mechanism that they have to sculpt a varying generation plan to comply with their own constraints over the day.

Additionally, in New Zealand the vast majority of the hydros in the same river are operated by a single generation company, and there is a block dispatch scheme that allows generators to rearrange the dispatch amongst their stations on the river-chain, as long the total energy delivered is the same as the required stations are geographically close. Nonetheless, an empirical study performed by Philpott et. al., 2010 quantified some production efficiency losses of this market.

These authors developed a centrally-planned model in order to compare New Zealand market outcomes with a counterfactual central plan. The results show that the yearly centrally-planned policy incurs less fuel cost than the market approach. For 2005, 2006 and 2007, the saved fuel costs are, respectively, 16.0%, 13.4%, and 14.6% of the total generation cost. In conclusion, the main source of the inefficiency pointed out by these authors relies on the fact that the New Zealand decentralized dispatch is essentially an instantaneous process and the inter-temporal features of river chain operations are not represented in the single-period market clearing mechanism.

Putting into perspective the dichotomy between a centralized dispatch (based on hierarchy) and a decentralized one (based on a market solution), it becomes clear the importance of the coordination of the use of the water stored in the reservoirs in order to safeguard the efficiency of using the energy resources. Moreover, the presence of several owners in the hydro cascades, which is the case of Brazil, endorses a market design based on a centralized dispatch.

4.2 Security of supply

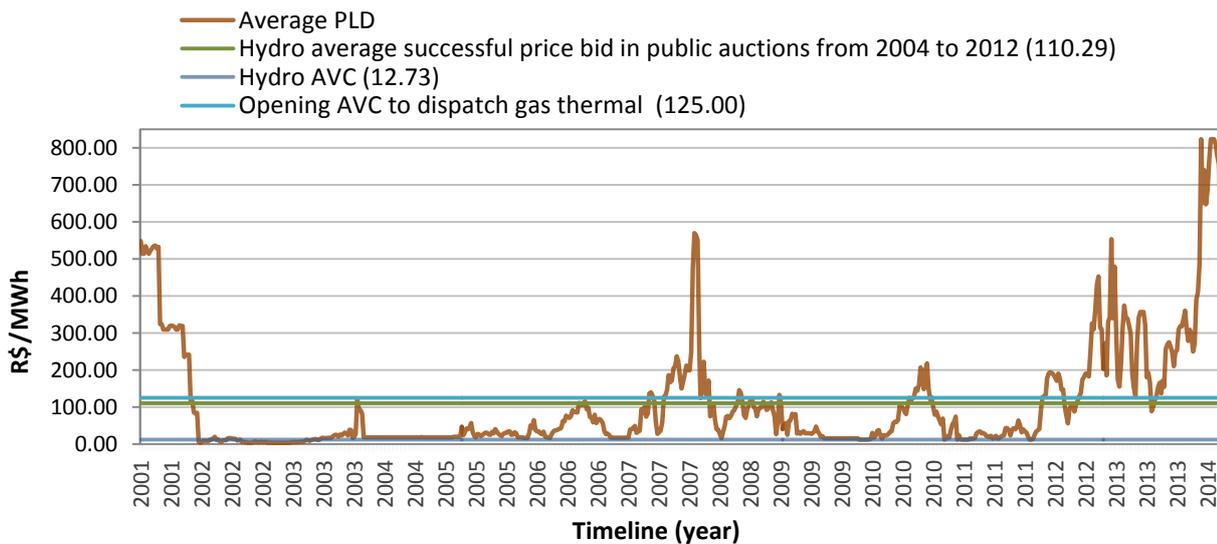
Concerning the ability of the market to ensure sufficient capacity to meet the demand in the future, it must be kept in mind that generation companies will only invest in new power plants if they expect that their total costs (both variable and fixed costs) will be totally recovered in the end. Then,

considering the hypotheses that Brazilian electricity market will be operated entirely based on a short-term market, the following question arises: Will the response of generators regarding the short-term market prices come in the form of new installed capacity?

The Brazilian short-term market price, *PLD* is calculated for four submarkets (South, Southeast/Midwest, Northeast and North) and is set on a weekly basis for three load steps (heavy, medium and light). Regarding this issue, Figure 5 presents: the *PLD* curve¹ (CCEE, 2014a); the hydro average successful price bid that came from public auctions (110.29 R\$/MWh) (CCEE, 2014b); the hydro Average Variable Cost - AVC (12.73 R\$/MWh)²; and the AVC starting point to dispatch the gas thermal power plants (125 R\$/MWh)³ (ONS, 2014b). It is worth mentioning that the price bid in public auctions is the PPA contract price. Thus, the value 110.29 R\$/MWh can be perceived as the hydro Average Total Cost (ATC), once at this level it is expected to recover both the Variable Cost (VC) and the Fixed Cost (FC).

The Brazilian short-term market has about 15 years of existence. For the time being, the *PLD* has an average value of 109 R\$/MWh. Therefore, it is close to the aforementioned 110.29. Nevertheless, it should be noted that, since the beginning of the *PLD* historical data, Brazil has passed through two large energy crises (in 2001-2002 and in 2013-2014) that made the *PLD* to remain in extreme levels for long periods. Besides, these so high price levels were not expected in a country that traditionally has an electricity matrix based on one of the lowest electricity production AVC technologies, hydro power.

Figure 5 – PLD historic data: from 2001 to 2014



Anyway, supposing that from now on there will be more thermal stations in the dispatch and, thus, the *PLD* will be frequently higher, the question is if the shape of the *PLD* curve will not be a barrier for the investment that intend to recover their FC and VC through the short-term market. At that point, the analysis rests on the *PLD* volatility. The *PLD* standard deviation of the entire set of data is around 160 R\$/MWh. With an average of 109 R\$/MWh, a standard deviation equal to 160 imposes a big risk to the health of the business, especially regarding the stability of the cash flow.

¹ *PLD* shown in this figure is merged considering the four submarkets and the three load steps.

² 12.73 R\$/MWh was achieved by computing regarding hydros in Brazil with installed capacity higher than 100 MW (ANEEL, 2012).

³ 125 R\$/MWh is equivalent to the percentile 20, i.e., 80% of the gas thermal power plants have a AVC higher than 125 R\$/MWh.

Finally, it is recognized the need to have a capacity mechanism in order to provide enough incentives to ensure the security of supply. Nowadays, this concern is addressed both via the contracting scheme where loads must to be fully ex-ante contracted and contracts physically backed, and via the dispatch of the ISO (either through the mechanism of risk aversion implement into the NEWAVE and DECOMP or through a dispatch out of the merit order authorized by a the CMSE - Electricity Sector Monitoring Committee⁴).

4.3 Flexibility to bear contracts

Notwithstanding the general opinions favor maintaining the current centralized dispatch in order to ensure the efficiency in the use of the energy resources and the security of supply, it is missing in the electricity market design some flexibility for hydros to better address their risk of exposition in the short-term market according to their own risk perception and strategy.

There is one unique “window” (in December) to define the (monthly) amount of the physical guarantee that will bear the contracts. Taking into account the market completeness analysis, there is a lack of “trading opportunities”. Moreover, generators operate their power plants just following the amount of production defined by the ISO, and the MRE is automatically performed, which imposes a kind of strait jacket to the market participants. Taking a closer look at the seasonalization process and at MRE, the following situation brings to light a weakness of this market design.

Every time that *PLD* is high, there are more dispatched thermal stations and less hydro dispatched units. Thermal power plants are typically contracted in the “modality for availability”, so they receive an availability payment and an additional remuneration for each MWh produced. Nevertheless, hydros are normally contracted in the “modality for quantity”, i.e. they are committed to deliver a certain amount of electricity (MWh) at a pre-defined price, and the difference between the contracted energy and the verified energy must be automatically bought or sold in the *MCP* at the *PLD*.

Depending on the amount of thermal dispatch, hydros can be displaced in such a way that the total production in the *MRE* will not be larger or equal than the total physical guarantee of the *MRE*'s hydros. As a result, *MRE* will not have the extra energy to be shared among its participants. Unlike, an adjustment factor will be applied to withdraw a fraction from the seasonalized physical guarantee. Extending this reasoning to occasions of water scarcity, a large decrease in the seasonalized physical guarantee of all hydros participants of the *MRE* (current there are 528 hydros in the *MRE*) represents a widespread negative exposed position for these hydros.

In order to illustrate this situation, Table 3 presents the allocation procedure considering four power stations having a total of generation of 80,000 MWh. The total verified energy to be allocated to each hydro is given by the multiplying of their own production by the adjustment factor (eq. 1). The adjustment factor is computed as the ratio between the total production and total seasonalized physical guarantee into the *MRE* (eq. 2).

$$\mathbf{Verified\ energy} = (\mathit{adjustment\ factor}) \times (\mathit{Own\ production}) \quad (1)$$

$$\mathbf{Adjustment\ factor} = (\mathit{total\ MRE\ production}) \div (\mathit{total\ MRE\ physical\ guarantee}) \quad (2)$$

⁴ The CMSE is an authority established to mainly assess the conditions of supply adequacy of the country.

Table 3 – Into MRE: when things go really bad

Hydro	Own production (MWh x 1,000)	Physical guarantee (MWh x 1,000)	Adjustment factor	Verified energy (MWh x 1,000)	TEO (R\$/MWh)	PLD (R\$/MWh)	Contracted energy (MWh x 1,000)	Financial Settlement (R\$)
Hydro A	37	50	0.571	28.57	10.54	700.00	50	-14,911,163
Hydro B	12	40		22.86			40	-12,114,434
Hydro C	7	20		11.43			20	-6,046,677
Hydro D	24	30		17.14			30	-8,927,726
Total =	80	140	-	80.00	-	-	140	-42,000,000

Since the total production (80,000 MWh) is less than the total allocated physical guarantee (140,000 MWh), the adjustment factor (0.571) will be lower than one, and the verified energy will not fill the level of the physical guarantee. Considering the *TEO* (Energy Optimization Tariff)⁵ established for 2014 (10.54 R\$/MWh) (Approving Resolution ANEEL 1658/2013) and a *PLD* consistent with a situation of energy shortage (700 R\$/MWh), the total financial settlement associated to the operation for these hydro stations is equal to a loss of R\$ 42 million (or about US\$ 18 million). Accordingly, all hydro stations must make substantial payments. Admitting that this situation will last for some months and that a plenty of hydro stations have to buy energy in the *MCP* at a very high *PLD*, this can seriously affect their cash flow.

In short, in situations like the one illustrated above, the *MRE* is not able to cover the risk of generators that have to buy electricity in the short-term market to complete the energy committed in their contracts. This risk is called “hydrological risk” once hydro stations are being dispatched at lower levels because there is not enough water in their reservoirs. Unluckily, nowadays Brazil is facing a situation like this. Due to an unusual rainfall cycle that has lasted since 2012, the power system has a widespread water shortage, a large thermal dispatch and sky-rocketing short-term market prices. For this reason, hydro stations appealed to the Federal Government for financial support as reported in a Brazilian newspaper:

“Hydro generators prepared a request for help to the Federal Government in order to equalize the negative financial impact on the revenues of hydro power plants participating in the Mechanism for Reallocation of Energy (MRE). Consultants estimate that the exposure of the generators to the short-term market can cause a loss of over R\$ 20 billion in 2014.” (Jornal da Energia, 2014b)

The Federal Government has been arguing that this is a business risk of hydro stations, and that it does not intend to relieve them. Hydro stations argue that the growing *PLD* curve was not taken into account by generators at the moment that they signed the long-term contracts. At the long term, this arm wrestling suggests that there will be a point in which the economic and financial balance of the projects can be severely affected. Pragmatically speaking, within this conjuncture the question to be answered is as follows: for how long this negative exposition can be supported by hydro companies?

If each hydro station would decide its own production, the management of their reservoir would be on their own. However, in the Brazilian case, the decisions regarding each production level, and consequently the amount of energy to be stored in the reservoirs, is made by a third party, the ISO. Nonetheless, hydrological risk is assumed by hydro stations, once the *MRE* doesn't cover this risk. As pointed out by (IEA, 2005), the framework of incentives should be structured such that risks are allocated to those who make decisions and who hold responsibility for taking them into account. Lastly, this unsuitability emphasizes that it is missing in the market design some flexibility so that hydro companies can manage this risk in a more adequate way.

⁵ The *TEO*, expressed in R\$/MWh, is established by ANEEL and aims to financially compensate hydro stations that provide energy to the *MRE*.

5. A New Market Design

Focusing on the enhancement of the flexibility for market participants to bear their contracts, while still ensuring the efficient use of the energy resources and maintaining the current level of the security of supply, and bearing in mind some proposals of interventions in the Brazilian electricity market (Revitalization Committee of the Electricity Sector, 2002) (Simba, 2005), a new market design was developed to be applied to hydrothermal systems. This market design is supported by the following proposed virtual reservoir model:

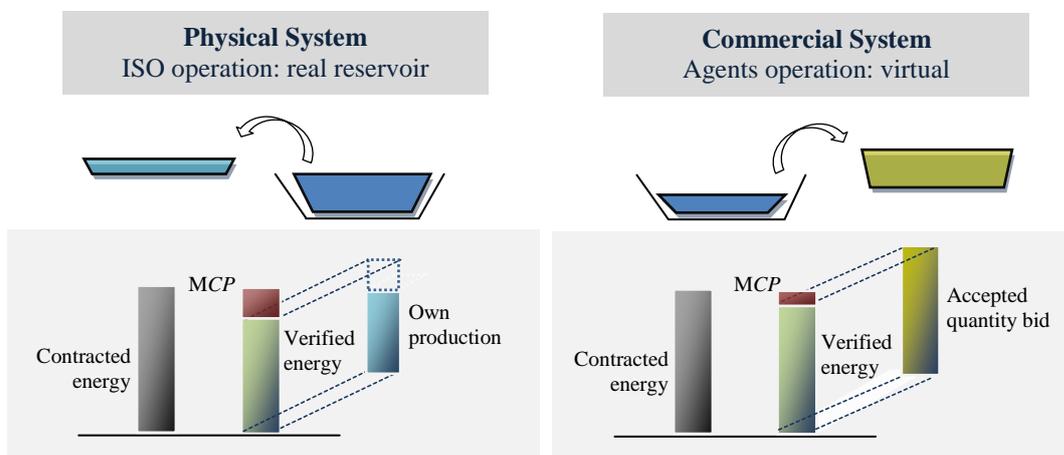
- Each cascade of hydro stations operates as an equivalent reservoir;
- Each agent has a virtual account that represents how much energy is virtually stored in his hydropower plant;
- For each accounting period, each account is fed by the fraction of the total affluent energy of the equivalent reservoir proportional to the hydro's physical guarantee.

Then, the ensuing sequence of events should be followed:

- 1° The system operator does his work as it currently does (running NEWAVE, DECOMP as well as other software, procedures and schemes), and defines the amount of generation for each power plant. So, the efficiency of the use of the energy resources and the security of supply are maintained at the current levels;
- 2° It is calculated the “remaining demand”, which is equal to the total demand minus the total dispatch of the thermal power plants;
- 3° It is established a liberalized hydro short-term market for this remaining demand:
 - a. Regarding the price bid: hydros can bid a price between zero and the cost of the cheaper thermal power plant dispatched in this period;
 - b. Regarding the quantity bid: each agent can offer any value within the balance of his account;
- 4° The final short-term market price is calculated as a weighted average considering the hydro short-term market price that comes from the hydro virtual short-term market and the variable cost of the dispatched thermal power plants and other energy sources.

Thus, as can be observed in Figure 6, two worlds would coexist: the real one, associated with the power system considering physical effects; and the virtual one, related with the settlement system and with commercial effects.

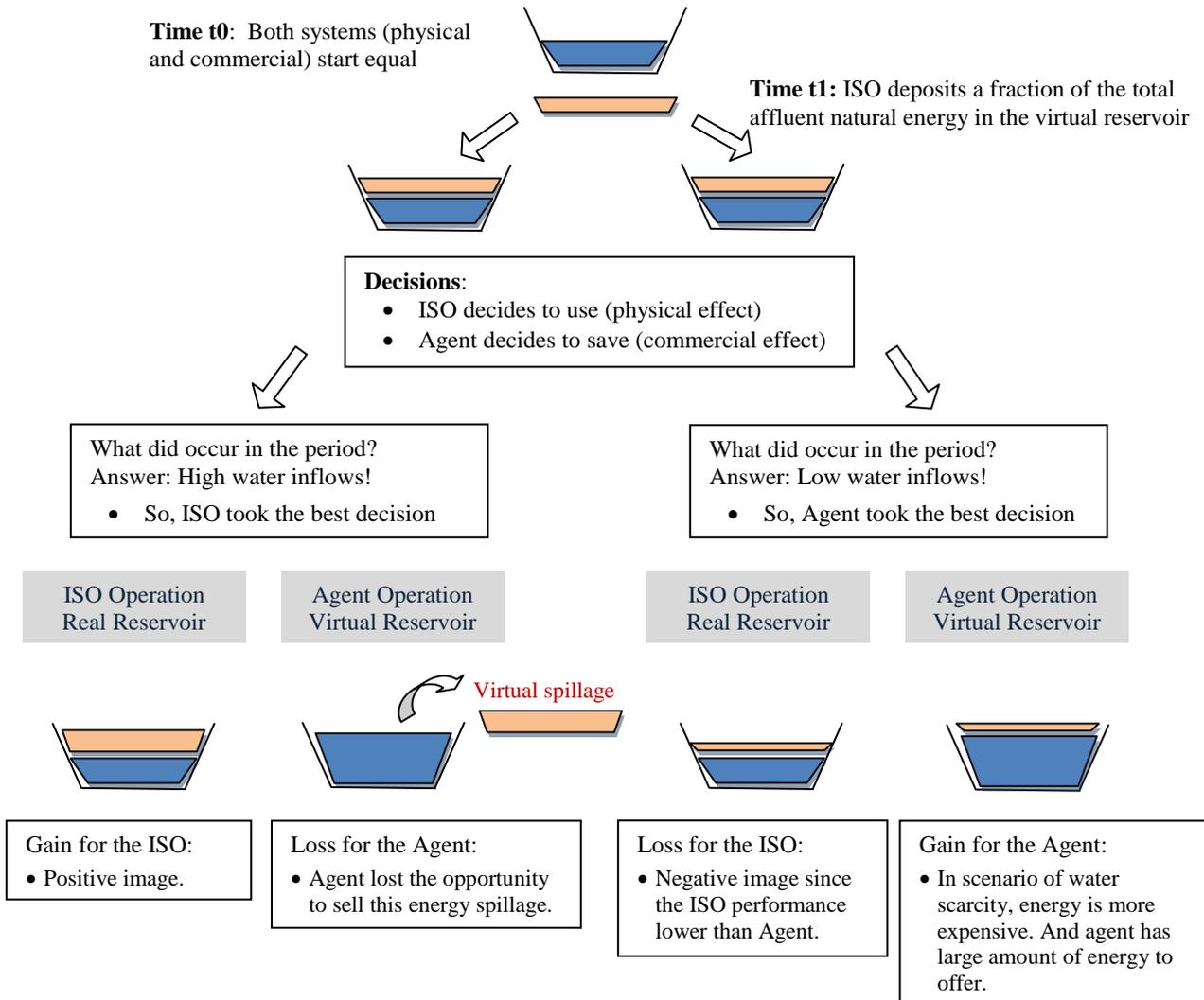
Figure 6 – Physical system (ISO operation) versus Commercial system (agents operation)



Through this market design, agents would be responsible for deciding, in commercial terms, how much they want to withdraw from their virtual reservoirs to meet their contracts. To do that, their bids have to be accepted in an auction that will be performed as a day-ahead market. In doing so, each generator has the opportunity to manage his contracts more efficiently, without affecting the real operation of the physical system.

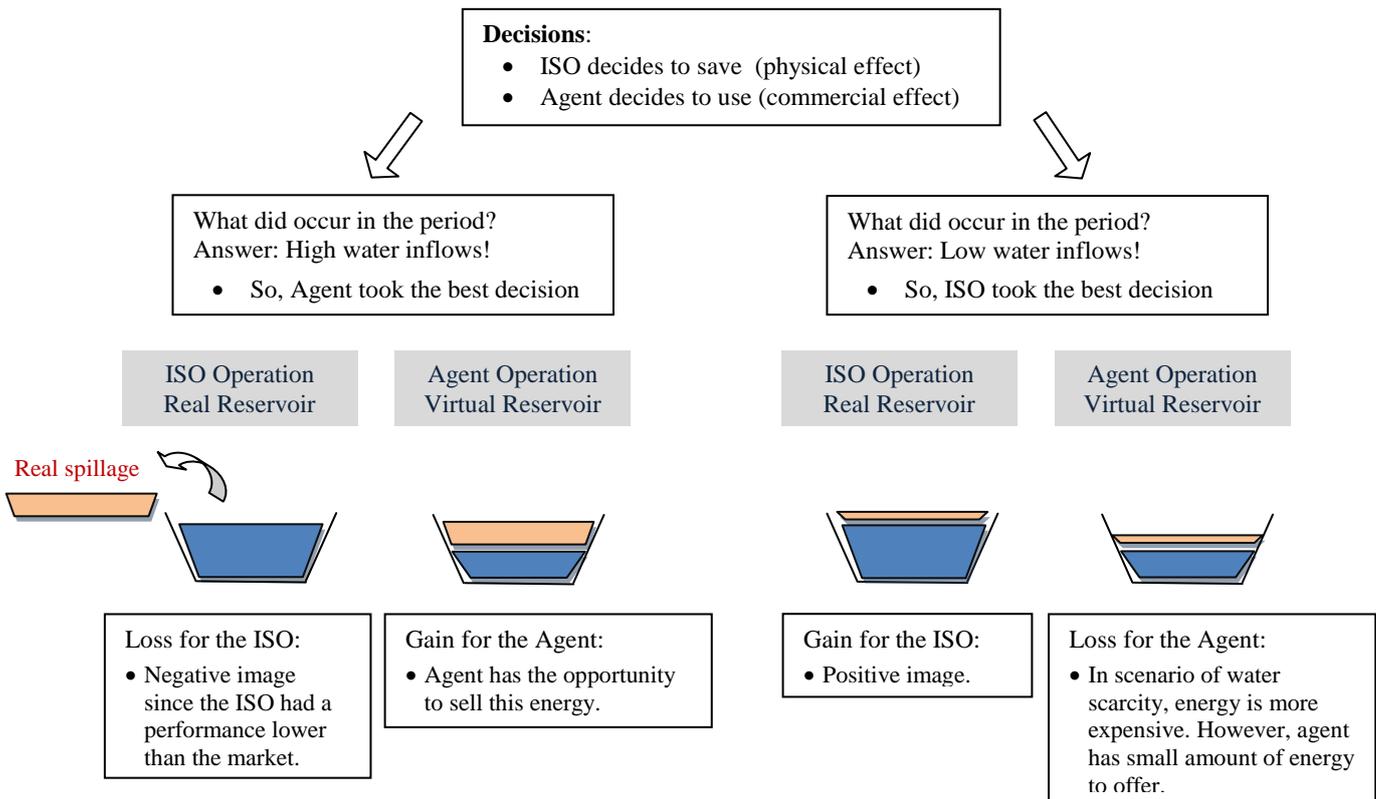
Furthermore, this model promotes a monitoring of the ISO performance based on comparisons between his decisions (the physical world) and the market participants decisions (virtual world). To address this issue, Figure 7 presents a scheme illustrating the decision making process in this new market design.

Figure 7 – Decision making process: ISO decides to use water; agent decides to save water



In Figure 7 the ISO decided to use water, while the generation agent decided to save it. When these decisions are reversed (ISO decided to save and the agent to use), instead of having a virtual spillage, as shown in Figure 8, it can happen a physical spillage.

Figure 8 – Decision making process: ISO decides to save water; agent decides to use water



At the end of this process, the prices no longer result primarily from a chain of computational models that may eventually present problems related with inconsistencies and transparency, but they can be obtained through the combination of thermal costs originated from the ISO dispatch and the short-term market price arising from the liberalized hydro short-term market.

Thereby, this market design maintains the same levels of the previously mentioned efficiency and security, while increases the level of flexibility of the agents' commercial aspects. This flexibility can be achieved by replacing the *MRE* and the seasonalization process by a virtual reservoir model. As a result, the management of (virtual) reservoirs is the responsibility of each hydro, which could save (virtual) water according to their own risk perceptions and in doing so the operation of the physical system is not affected at all.

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