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Learning from Developing Country Power Market Experiences

The Case of Colombia

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Abstract

The Colombian power market was established in 1995, driven primarily by concerns about the reliability of supply in the largely hydro-based domestic power system. The power sector reform was expected to help avoid blackouts by attracting private investment and increasing the efficiency of existing capacity. However, two decades after its inception, the market has not been successful in providing reliable supply along competitive outcomes. This paper analyzes the experience of Colombia with power markets, including market design, implementation, and outcomes. A single-node, bid-based market was established overnight, with bilateral contracts among market participants (mostly short-to-medium term). The original regulated capacity payment was replaced in 2004 by a reliability market intended to ensure supply during tight hydrological conditions (mainly due to El Niño phenomena). However, the Colombian power sector is currently showing signs of structural weakness: the reliability market has shown dysfunctionalities, the government has intervened the market during critical situations, and concerns persist regarding market power exercise. The experience of Colombia is important for other developing countries, since it highlights the challenges of designing and implementing a power market that successfully provides reliability, competitive outcomes, and sustainability. Although key local hydrological conditions were considered in the design of Colombia's capacity market, the market had difficulties delivering intended outcomes due to design and institutional issues, particularly the lack of a comprehensive approach to gas supply and transport.

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Learning from Developing Country Power Market Experiences: The Case of Colombia[1]

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Acronyms and Abbreviations

ASIC	Trading System Administrator (pool market operator)
BCOP	Billion Colombian Pesos
CND	National Dispatch Center (system operator)
COP	Colombian Pesos (nominal values unless otherwise stated)
CREG	Commission for the Regulation of Energy and Gas
CSMEM	Committee for Monitoring the Wholesale Energy Market
LTSO	Legally unbundled Transmission System Operator
MEM	Wholesale Energy Market
OEF	Firm Energy Obligation
PLF	Plant Load Factor
PPA	Power Purchase Agreement
SSPD	Superintendence of Public and Domiciliary (household) Services
XM	System and market operation company (a subsidiary of Interconexión Eléctrica SA or ISA)

1 Introduction

The World Bank is seeking to update its understanding of power sector reforms in developing countries, accounting for emerging challenges and new reform directions over the past decades. Implementation of power sector reforms in developing countries has been varied, especially when it comes to power markets, with widely different outcomes. This work forms a part of the World Bank's project "Rethinking Power Sector Reform", which was commissioned to analyze the recent experience of developing countries, including a series of case studies on wholesale power markets. These case studies, including the incumbent one for Colombia, were developed based on both qualitative and quantitative inputs from experienced consultants of each studied country.

The objective of this paper is to document and analyze the experience of Colombia with power markets, regarding design, implementation and outcomes of the market. Ultimately, the analysis in this paper is expected to be useful for developing countries which are currently developing or considering the development of a power market. However, the paper does not aim at providing policy or market recommendations for improving the performance of the Colombian market. Furthermore, the scope of this paper is limited to assessing competitive power markets, with an emphasis on the generation and supply segment. Hence, retail competition, as well as the transmission and distribution segments, are not the primary focus of this paper. Moreover, the paper does not directly address several power sector reform issues, such as regulation, privatization, and political economy. These and other subjects are addressed elsewhere for each country, as part of the wider project.

The evolution process of the Colombian market is described next (section 1.1), followed by an overview of the market structure and some salient features of the Colombian power market in section 1.2. Section 2 describes the basic pre-conditions for power markets in Colombia, referring to both power system infrastructure and ownership (section 2.1), and to fuel supply (section 2.2). Section 3 describes the design of Colombia's power market. Section 4 details the reliability mechanism of the Colombian power market, followed by governance and institutional mechanisms in section 5. Section 6 assesses the performance of the power market, from the perspective of prices and efficiency (section 6.1), investment and security of supply (section 6.2), and sustainability (section 6.3). Section 7 concludes this case study.

1.1 Evolution process of the Colombian power market

The origins of the Colombian Wholesale Energy Market (MEM) can be found in the restructuring of the electric sector developed through the application of Laws 142 and 143 in 1994. In MEM, generators, transmitters, distributors, traders and unregulated users participate; the market's purpose is the exchange of large blocks of electric energy through the National Interconnected System (SIN) at efficient prices, reflecting the marginal costs incurred for its generation.

The Electric Law 143 explicitly established the basis for power sector reform including vertical unbundling, regulation and competitive regimes. The law established the following provisions related to power markets (ECSIM, 2013):

- Separation of monopolistic activities (transmission and distribution) from the ones where competition was feasible and desirable (generation and supply / retail, called commercialization in Colombia). Surveillance authorities were created to prevent anticompetitive behavior;
- Suppression of regional electricity supply monopolies seeking free access to transmission and distribution networks;

- Freedom of investment in generation assets. Mandatory planning for the transmission activity, and indicative planning of generation expansion;
- Creation of a wholesale electricity market both for short- and long-term, with the participation of generators, traders and large electricity consumers; and
- Contractual freedom for consumers whose consumption levels exceed the thresholds established by the regulator.

Law 142 of 1994, or public services law, created a system operator exclusive for the purpose of setting short-term prices, ancillary services and electricity dispatch. The new legislation also required administrative and budgetary autonomy, as well as political independence, to all entities that provide the public services of electricity supply.

Subsequent resolutions established the operation norms for the wholesale energy market, which became operational in the mid-1995; and created a regulated capacity payment for the generation activity. This capacity mechanism established an annual fixed income per MW installed, at a regulated price defined by CREG. It is worth noting that no specific obligation was imposed to generators associated with this remuneration.

In 1996, CREG issued Resolutions 020 and 128, seeking to ensure free competition in the purchases of electricity made in the newly constituted wholesale market, regulate the market share in the different segments of energy sector and setting limits to shareholding between companies with complementary activities. Resolution 128, particularly, stipulates that:

- No company may have more than 25% of the effective installed capacity in electricity generation;
- No company may have more than 25% of total retailing (in terms of energy sold to final customers);
- No company may have more than 25% of distribution activity; and
- No generation company may have shares, quotas or parts on social interest that exceed 25% of a distribution company's social capital.

These regulatory constraints on the ownership structure of the market were later modified in 2007 (CREG Resolution No. 060), which required special surveillance for Gencos with a market share between 25% and 30% (in terms of firm energy) and if the Herfindahl-Hirschman index (HHI) of the generation segment (in terms of firm energy) is at or above 1800; and a regulated offer mechanism for Gencos with 30% of total firm energy market share, if the HHI is at or above 1800.

Two important regulatory events took place soon after the turn of the century: the creation of XM in 2004, the company in charge of the operation of the energy market; and the adoption of the reliability charge by the CREG resolution 071 of 2006, which replaced the regulated capacity charge mechanism. This new mechanism, further described in section 4, created the Firm Energy Obligations (OEF for their Spanish acronym), which imposed commitments to electricity generation companies during critical conditions (droughts). The first firm energy auction took place in 2008.

In the last 10 years, the main regulatory milestones related to wholesale power markets included:

a) the decision to centralize the functions of monitoring and control under the competence of the Superintendence of Industry and Commerce in 2009;

b) the enactment of Law 1715 of 2014, which established the legal and instrumental framework for the promotion and use of non-conventional energy sources (FNCE).

It is also noteworthy that in 2006 the Committee for Monitoring the Wholesale Energy Market – CSMEM was formed with two fundamental objectives: to monitor the Colombian electricity market in order to provide timely signals to the regulator, control entities and market agents, and contribute to global efficiency.

Today, the Wholesale Energy Market (MEM for its Spanish acronym), administered by the system operator XM, aims at facilitating its participants to agree on short- and long-term energy transactions. In this market, the energy required by end users is negotiated by traders and generators. Transactions are carried out under the terms of the bilateral contracts (long term) and in the energy pool (short-term energy exchange).

A summary of the evolution of the wholesale power market is shown in Table 1-1.

Table 1-1 Milestones and other relevant events of Colombian power market evolution.

Year	Milestone (or major event related to power markets)
1991 - 1992	Rationing due to El Niño phenomenon
1994	Enactment of Laws 142 and 143
1995	CREG resolutions 025 (grid code) and 024 (commercial code). Establishment of the scheme of Energy Market Wholesaler.
1996	CREG resolutions 020 and 128 to limit market share in different power segments and extent of vertical integration.
1997 - 1998	El Niño phenomenon, without rationing.
1998	Competitive auctions are established for awarding new transmission expansion projects to either existing of new Transcos (CREG Resolution 051, 1998)[3]
1999 - 2002	Attacks on the National Transmission System (STN). These attacks on national infrastructure by illegal actors caused increasing restrictions and increased costs for the system as a whole.
2003	Entry of International Energy Transactions (TIE).
2004	System and market operation functions transferred from ISA to its newly created subsidiary XM.
2006	Market monitoring entity created (CSMEM).

[3] Available online at http://apolo.creg.gov.co/PUBLICAC.NSF/2b8fb06f012cc9c245256b7b00789b0c/0c6c108919cdaf530525785a007a60f0/$FILE/Cr051-98.pdf [accessed December 21, 2017]

Year	Milestone (or major event related to power markets)
2006	CREG resolution 071: regulated capacity mechanism is replaced by the Firm Energy Market.
2008	First Firm Energy Auction is conducted.
2009	Monitoring and control of competition in the power sector is centralized in the Superintendence of Industry and Commerce.
2009	CREG resolution 051: Market rules are modified to allow bidding of startup / shutdown prices to thermal power plants.
2009	CREG resolution 138: Constraints imposed to reduce mobility of customers between regulated and liberalized regimes.
2014	Enactment of Law 1715, which established the legal and instrumental framework for the promotion and use of non-conventional energy sources (FNCE).

1.2 Architecture and structure of the Colombian power market

The wholesale power market in Colombia can be divided into three main markets (further described in sections 3 and 4):

- Market of bilateral contracts or long-term market.
- Pool market or "stock" market ("Bolsa" in Spanish): it is a market for the next day, with mandatory participation for all generators registered in the market.
- Reliability auctions: it is a form of capacity market based on auctions.

An organized futures market for energy commodities has been recently developed by the Colombian company Derivex. However, participation in Derivex's futures market remains very limited. Furthermore, the Colombian regulator has been trying to develop an organized futures market for the regulated power market for over a decade (the *"Mercado Organizado Regulado"*, or MOR), without success.

Market participants and their roles in the Colombian power market are the following:

- **Gencos**: own and operate power plants, and compete in both the day-ahead market and the market for long-term contracts (either with suppliers or directly with large customers).
- **Distcos**: own and operate distribution networks as a regulated natural monopoly. Open access to the distribution network is established.
- **Suppliers / traders** ("comercializadores" in Spanish): engage with Gencos for long-term contracting, and with final customers to supply their demand; or perform wholesale trading. Both Gencos and Distcos can also (and often do) perform supply functions in the Colombian power market.
- **Transcos**: own and operate transmission networks as a regulated natural monopoly. Multiple Transcos exist (although the biggest one is government-owned ISA), and both incumbent and new entrants to the transmission segment can participate in auctions for new transmission projects

since 1999. On the other hand, remuneration of transmission facilities existing before 2001 is regulated. Open access to the transmission network is established.

- **System and market operator:** ISA, a major government-owned Transco (which owns about 70% of the National Transmission System), is also the system and market operator through a subsidiary company named XM.
- **Final customers**:
    - **Regulated**, mostly households and small businesses connected to distribution networks, with regulated tariffs.
    - **Non-regulated or liberalized** (large customers can opt for the liberalized supply regime): engage directly with suppliers for long-term contracting in order to cover their demand. Currently, customers with a peak consumption over 100 kW can opt for the liberalized supply regime.

Significant degrees of vertical and horizontal integration throughout the Colombian electricity supply industry prevail to date. This has raised concerns regarding the competitiveness of the market, despite limits to integration established at the outset of the market reform (i.e. Resolution 128 described in the previous section). The following table summarizes market shares of major Gencos / retailers. Empresas Públicas de Medellín (EPM) has a generation market share of 24%, and a retail market share of 21% (including both retailers owned by EPM, namely EPM and ESSA - Santander). Endesa has a generation market share of 24% (through Emgesa) and retail market share of 16% (through Codensa). Finally, Isagen has a generation market share of 19% and a retail market share of 6% (concentrated in the non-regulated customers segment).

Table 1-2 Firm-level generation and retail demand in GWh and Market Shares in 2008.

Table 2.1: Firm-Level Generation and Retail Demand in Gigawatt-hours (GWh) and Market Shares in 2008

Suppliers	*Production in 2008 in (GWh)*	*Market Share (%)*
EEPPM	13,104.8	24.09
EMGESA	12,979.9	23.86
ISAGEN	10,105.1	18.58
GECELCA	4,462.0	8.20
EPSA	4,205.6	7.73
CHIVOR	3,760.2	6.91
GESTIÓN ENERGÉTICA	1,323.0	2.43
Retailers	*Demand in 2008 (GWh)*	*Market Share (%)*
EEPPM	796.8	17.50
CODENSA	735.3	16.15
ELECTRICARIBE	611.6	13.43
EMCALI	284.8	6.25
ISAGEN	252.7	5.55
EMGESA	186.3	4.09
ESSA (SANTANDER)	149.3	3.28

Source: "Colombian Electricity Market," Presentation by XM, Bogota, April 14, 2009.

Source: (Wolak, 2009)

It is worth noting that the major Genco / Supplier ISAGEN -which is also a natural gas retailer- was originally a government-owned company integrated with the major Transco ISA. At the outset of the reform, generation assets were divested from the Transco ISA, thus establishing the independent government-owned Genco ISAGEN (Arango, Dyner, & Larsen, 2004). The Colombian government sold its stakes in ISAGEN in 2016, effectively completing ISAGEN's privatization.[4]

2 Preconditions for power markets

2.1 Power System

Domestic consumption of electricity in Colombia reached 66 TWh in 2016, growing at a CAGR of 3% from 2010 (see Figure 2-1). Colombia's electricity demand is dominated by regulated users (i.e. mostly small households and businesses) which account for 67% of total consumption, followed by manufacturing and mining industries and other liberalized customers (i.e. those which can choose their supplier, see Figure 2-2). Industrial consumption is dispersed among 3,000+ customers in Colombia (mining, food, clothes manufacturing, iron and steel industries). Exports of electricity from Colombia to Ecuador and the República Bolivariana de Venezuela reached 457 GWh in 2015, less than 1% of total demand.

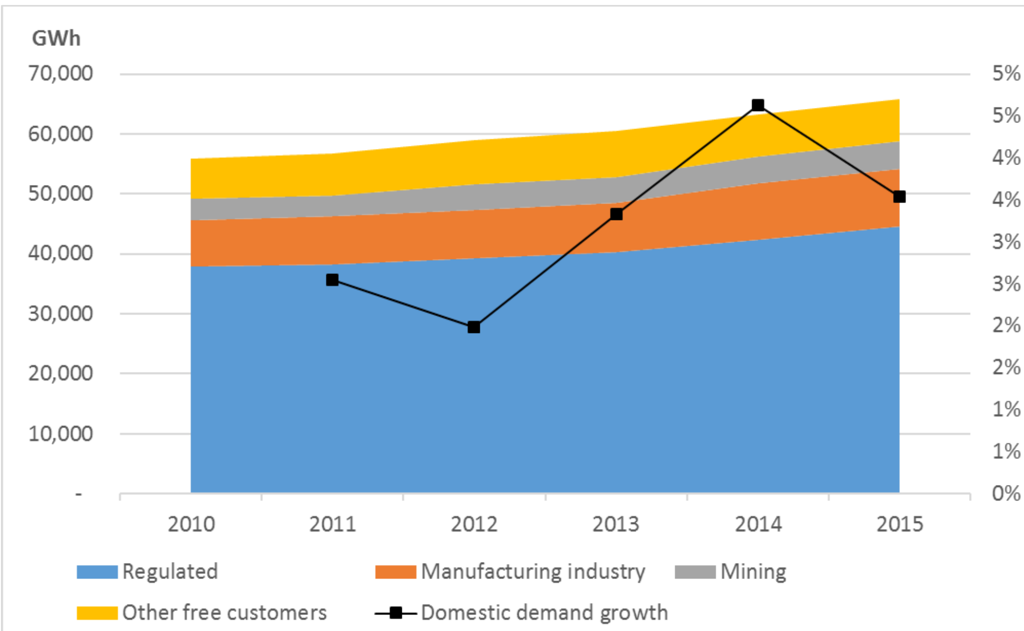

Figure 2-1 Evolution of Colombia's domestic electricity demand.

Source: Own elaboration based on data collected by the World Bank.

[4] ISAGEN, Online: https://www.isagen.com.co/SitioWeb/es/nosotros/quienes-somos/nuestra-historia [accessed December 26, 2017]

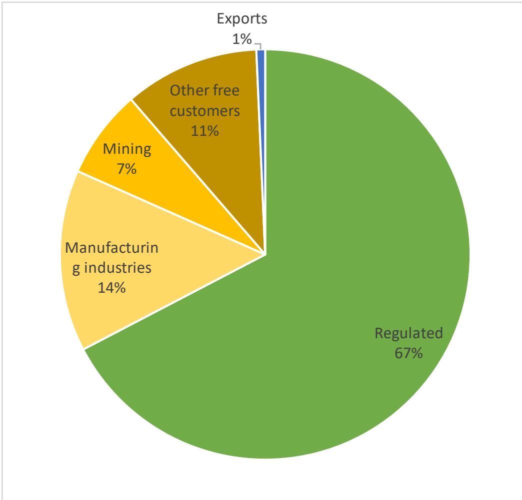

Figure 2-2 Structure of Colombia's electricity demand during 2015.

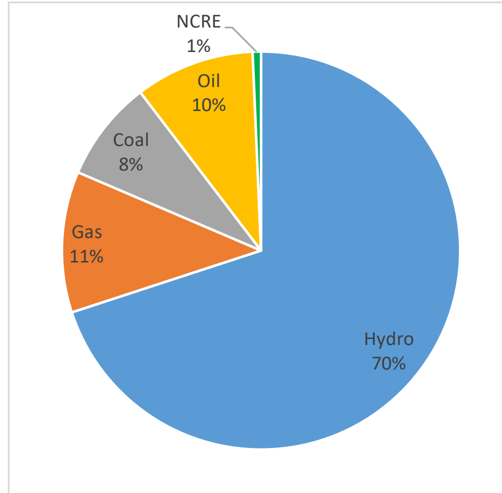

Figure 2-3 Share of installed capacity (in MW) per technology in Colombia, 2015.

Source: Own elaboration based on data collected by the World Bank.

The power generation fleet is largely hydro-based generation (70% of national installed capacity in 2015 with 11.5 GW), followed by gas, oil and coal-fired power plants with 11%, 10% and 8% of total installed capacity, respectively (see Figure 2-3). However, most of the oil-fired installed capacity adding to the 10% is dual gas power plants which have been increasingly declaring oil as their primary fuel due to the lack of gas supply contracts, as well as the regulatory measures that incentivized installation of liquids as primary fuels to guarantee security of supply (e.g. the Firm Energy Obligations, further discussed in section 4). Those "oil-fired" power plants are therefore not necessarily producing power fueled by diesel (UPME, 2016c). A very small amount of renewable generation is installed in Colombia.

The Colombian power market experiences some degree of market decoupling (or separation) due to transmission constraints, mostly driven by hydrological conditions. However, major problems concentrate in the transmission and distribution facilities of Distco Electricaribe (at or below 110 kV), which serves about 25% of Colombian electricity demand. Transmission congestion also exists between the center and north regions of the country.

Interconnectors exist with Ecuador and the República Bolivariana de Venezuela, totaling 600 MW in imports and 871 MW in exports. Two interconnection transmission lines with Ecuador sum up to 395 MW of import capacity, and 535 MW of export capacity. Three interconnectors with the República Bolivariana de Venezuela sum up to 205 MW of import capacity and 336 MW of export capacity.

2.2 Hydro Availability and Fuel Supply

The Colombian power system is highly dependent on hydro availability due to the composition of the generation fleet and the limited water storage capacity (only 6% of total capacity in reservoirs can store water for more than six months (Keay et al., 2018)). Hydro availability is volatile and largely unpredictable a year in the future, translating into highly volatile spot price outcomes. Moreover, climatic phenomena such as El Niño or La Niña can heavily impact the availability of hydro resources. As further discussed later in this case study, serious El Niño events caused major power shortages in 1992 and have recently contributed to price spikes in the short-term electricity market (in 2009-2010, and then in 2015-2016). Colombia's dependence on hydro availability directly impacts power supply security (Maurer & Barroso, 2011) and wholesale electricity prices. Supply security issues related to hydro availability have been one of the major drivers for several market reforms, such as the reliability mechanisms discussed further in section 4.

Colombia is self-sufficient in natural gas supply and began exporting gas to neighboring República Bolivariana de Venezuela in 2007 (EIA, 2016). About 30% of domestically produced natural gas is used for power generation, to ensure supply security during tight hydrological conditions which constrain hydro-power generation (such as El Niño events, with a remuneration mechanism further described in section 4). Domestic gas production is liberalized but intrinsically retains an oligopoly structure with public and private participation, and market-based prices; while natural gas transportation is activity regulated by CREG (SSPD, 2014).

Colombia's natural gas production is dominated by three companies, the largest of which in terms of market share is government-owned company Ecopetrol (EIA, 2016). Production occurs at a number of gas fields, the two largest being Guajira and Cusiana, with 48% and 31% of the total country production during 2013, respectively (SSPD, 2014). The price of natural gas from the Cusiana field is freely set by market forces, while the price at the Guajira field was regulated until 2013.[5] The price at Guajira field was previously regulated by CREG, which updates the price twice a year (every February and August) according to an indexation formula to the price of fuel oil. The average price for natural gas in Colombia for the last five years was 5.61 USD/MMBtu (15,376 COP/MMBtu).

Colombia has experienced difficulties regarding the flexibility and security of natural gas supply, and the coordination of gas and electricity supply. Gas demand for power generation increases sharply during tight hydrological conditions (e.g. during El Niño events). Meanwhile, both reserves and production have decreased since 2013. Gas-fired power generators have had trouble signing natural gas supply contracts. The sporadic use of natural gas for power generation (i.e. only during dry periods) does not support exploration and expansion of natural gas production and transportation, activities which require significant capital investment and may be difficult to finance with an uncertain demand profile. Instead, natural gas producers may prefer to target the residential and industrial market, with a more stable consumption profile.

Moreover, natural gas security of supply remains sensitive to disruptions in the natural gas transport network, due to both the radial nature of the network and the regional sparsity of production fields. Concerns with natural gas security of supply have promoted some regulations aimed at improving Colombia's energy security, most notably Decree 2100 from 2011, which forces agents who supply "essential demand" (including residential customers and others alike, but not power plants) to contract upstream supply and transportation services (UPME, 2016a). A new regasification terminal commissioned in 2017 could contribute to security of supply by providing natural gas for backup power generation. However, the lack of a robust natural gas transport network is still a reason for concern, particularly

[5] According to CREG resolution 088-2013, available online: [accessed December 22, 2017]. According to regulations in force, the price of natural gas remains regulated at Opón field.

considering that three major thermal power plants are located in the interior of the country, far from the regasification terminal.

Colombia is South America's largest coal producer, and it was the world's fifth-largest coal exporter in 2015 (EIA, 2016). Although Colombia exports most of the coal it produces, domestic consumption for coal-fired power generation has increased in recent years, especially during El Niño events (see section 6). Nevertheless, there has been no investment in new coal-fired power generation capacity recently, and investment is not expected in the future either. Coal-fired generation is more capital intensive compared to natural gas generation. Considering the uncertainty on the Colombian market for coal-fired generation (for example, wholesale prices driven by hydrology, and lack of political support due to environmental concerns), investment has not followed.

3 Market design

This section describes the power market design adopted in Colombia, focusing on the technical and economic dimensions of the reform. The sub-sections cover the following elements of the market: generation scheduling and dispatch (section 3.1); price formation (section 3.2); demand participation (section 3.3); contracts and bilateral markets (section 3.4); and market settlement (section 3.5). The Colombian capacity market is addressed in section 4.

3.1 Generation scheduling and dispatch

Colombia's short-term market for electric energy is organized as a single-node, bid-based, day-ahead power pool, often referred to as the energy stock market (or *"bolsa"* in Spanish). In the pool, which has been in operation since 1995, a sealed bid auction is held daily to determine the so-called *"ideal generation schedule"* for each hour of the next day (see section 3.2 also). Generators offer each plant a unique price for the next 24 hours and declare their hourly availability and inflexibilities. There are also ancillary services (frequency regulation), offered at the same price.

The system operator organizes auctions in order of merit to cover the estimated hourly commercial demand. Demand is passive and total supply is valued at the price offered by the last "elastic" plant required to meet demand (System Marginal Price, not considering prices offered by plants with dispatch constrained by technical constraints). Hourly transactions are settled assuming a single-node network and no transmission restrictions or security constraints. This process is known as *"ideal dispatch"*. Here the price to remunerate scheduled plants is formed, as well as the reference value to settle prices for long-term contracts.

There are two additional types of energy dispatch:

1. Economic or programmed dispatch: carried out a day before operation, considering the state of the network. In this case system restrictions lead to the integration of "out of merit" plants to the generation schedule (i.e. out of the merit dispatch resulting from the single node market).
2. Real dispatch: which refers to effective system operation to meet demand. The main differences with programmed dispatch are unforeseen events (e.g. plant or network failures).

It is also worth noting that regulations provide a general framework for market intervention by changing the economic dispatch (see section 5.1.2).

Since 2009, the programmed dispatch considers both energy and start / stop prices offered by Gencos, and is determined by the system / market operator by solving an optimization problem which minimizes the costs of supplying forecasted demand. An uplift payment for covering start-up costs is provided to thermal power plants (CREG Resolution No. 051, 2009). A similar optimization problem is solved to assign Automatic Generation Control (AGC) services among generators, based on the same offered prices by Gencos for the energy pool.

Regarding the contracts market, suppliers and large customers freely agree on prices and traded quantities (see section 3.4 also). Contracts must have hourly resolution to settle them against effective generation. Prices must be equal to the lower value obtained in the sealed-bid auctions if contracted energy is used to supply regulated customers. Although specific terms of contracts are confidential, every contract must be registered with the Trading System Administrator (ASIC).

All power plants with installed capacity above 20 MW must participate in the power pool. Power plants with installed capacity between 20 MW and 10 MW can voluntarily participate in the pool, while smaller power plants are not centrally dispatched. Self-dispatch by smaller power plants has been a characteristic of the Colombian pool since its inception.

Regarding maintenance and availability, companies that own or operate centrally dispatched generation plants have their own maintenance and/or disconnections programs with time horizons between 12 and 24 months. These programs are collected by the system operator, who ensures necessary power reserve for the reliable and safe operation of the system. Companies will be able to access an information system to modify, if possible, the maintenance schedule of their generating units.

The operator performs weekly coordination of equipment maintenance and/or discontinuation using models of Energy and Electrical Operative Planning. The operator also verifies if the maintenance programs recorded in the information system are preserving the safety and reliability of National Interconnected System. If not, the system operator will inform the agents in order to reschedule maintenance of their plants.

In addition, maintenance of transmission equipment is considered, which is reported to the system operator at least one week prior to the maintenance start date. Scheduled maintenance must have previous system operator approval, in accordance to a weekly coordination of equipment maintenance plan. Agents may introduce changes to said schedule, but in that case, penalties will be applied by the regulator.

3.2 Price formation

Short-term energy price formation in Colombia is based on a single-node, bid-based, day-ahead power pool; and a cost-based power pool for out-of-merit settlement; as further explained below.

According to CREG: "*One of the principles behind the price system that was designed for the Colombian MEM is to guarantee long term economic signals to encourage the expansion of the installed capacity of generation plants to meet the country's development needs. By encouraging investments in power projects and guaranteeing supply reliability of firm energy in the long-run, price volatilities should be mitigated and the evolution of prices should reflect the end-users' level of confidence on supply reliability and their willingness to pay for this firm energy.*"

Hourly energy prices are cleared in the day-ahead market through a uniform-price auction based on offers and availability declared by generators. Gencos bid a single offered price for power generation during all hours of the next day. Prices offered to the market must reflect expected costs for thermal plants (including variable fuel and Operation & Maintenance costs, and start-up / stop costs), and the opportunity cost of water for hydro plants (CREG Resolution 055, 1994). Since 2009, Gencos also bid a price for start and stop of thermal power plants (CREG Resolution No. 051, 2009).

Originally, Gencos were allowed to bid an hourly price for the next day (CREG, 1995, para. 3.1). However, the offer scheme was modified by the regulator in 2001 by allowing a single price bid for each of the 24-hours of the next day, and by establishing a maximum limit on price offers (CREG Resolutions 026 and 034, 2001). Such modifications of the offer scheme were conducted by CREG in an attempt to reduce the cost of constraints, which the regulator said were being determined by market power exercise, facilitated in turn by market segmentation following terrorist attacks on transmission facilities (Millán et al., 2003). However, there is currently no maximum limit on price offers in force, and spot prices spiked up to 822 USD/MWh during the 2015-2016 El Niño event (further discussed later).

Demand, i.e., end-use customers, do not directly participate in this market (see section 3.3), and suppliers / retailers do not bid but provide inelastic consumption schedules (forecasting the demand of their customers). In turn, Gencos declare hourly availability besides the offered price. Based on this input, a single energy price is cleared by economic dispatch, for each hour of the following day and for every location in the national transmission system. The cleared energy price is the offered price by the last committed power plant.

Hourly national prices and generation schedules cleared in the pool disregard the transmission grid and its constraints. Therefore, charges due to transmission losses, and derived from transmission congestion and other system constraints, are settled in a different basis, and in particular, these extra costs are added to the energy price paid by final customers (see also section 3.5).

As explained in section 3.1, a day-ahead security-constrained "programmed" schedule is developed along the "ideal" schedule. The ideal schedule differs from the programmed schedule since this programmed schedule considers technical constraints in the transmission grid, which are ignored in the ideal dispatch. Furthermore, the realized real-time dispatch differs from the programmed schedule due to unforeseen events such as forced facilities outages.

The difference between ideal and programmed schedules results in power plants scheduled to operate despite not being part of the cleared market schedule (so called "out-of-merit" plants); and also in differences between ideal and scheduled quantities for each power plant. A reconciliation amount is then defined as the difference between programmed ("actual dispatch") and ideal generation.

Power plants scheduled to generate in excess of the ideal schedule (i.e. with "positive" reconciliation) are remunerated based on a technology differentiated reconciliation price; while power plants scheduled to generate less than the ideal schedule (i.e. with "negative" reconciliation) pay a technology differentiated reconciliation price. Positive and negative reconciliation prices are defined according to formulas established in the regulation (CREG Resolution 034, 2001). For thermal power plants, reconciliation prices are based on daily offered prices; variable generation costs (fuel and transport) declared weekly by the Genco; and other parameters set by the regulator or the system operator. For hydro power plants, reconciliation prices are based on offered prices; stored water and spillage risks; and other parameters set by the regulator or the operator (CREG regulation 036, 2010).

Automatic Generation Control services are payed in the pool at a price equal to the offered price bid by each power plant in the day-ahead energy pool (Wolak, 2009). Moreover, the reconciliation price is different depending on whether the power plant provides Automatic Generation Control services. Also, deviations of power injection in excess of 5% with respect to the schedule is levied a penalty equal to the absolute value of the difference between the offered price and pool price. These deviation penalties have been reduced in practice (see section 6.1).

3.3 Demand participation in the wholesale market

The demand side in Colombia does not participate directly in the wholesale market but rather through retailers / suppliers. In turn, retailers engage in contracting with Gencos for the provision of electricity. Imbalances between the retailer’s contracted quantities and actual demand are settled in the pool. It is worth noting that both Gencos and Distcos can (and do) perform retail functions.

In Colombia, the provision of electricity service is divided into two customer types:

- Non-regulated or liberalized customers (with large power consumption) which engage directly with retailers in order to contract the supply of electricity.
- Regulated customers (primarily households and small businesses), with tariffs regulated by CREG.

Customers whose average monthly power demand over six months is over 0.1 MW in terms of capacity, or over 55 MWh in terms of energy, engage directly with retailers (regulation CREG 131, 1998). Liberalized customers also need measurement equipment capable of remote metering with hourly resolution. It is noteworthy that the demand threshold for eligible customers was lowered from its initial level of 2 MW in 1996, to its current level of 0.1 MW in 2000. Telemetering equipment with hourly resolution is required for demand.

There is no demand-response program currently in place in Colombia, although a temporary program was established during 2016 to avoid rationing (see section 4.2).

3.4 Contracts and bilateral trading

In the regulated market, users cannot directly acquire energy supply. Instead they are “represented” by a retailer in the energy market, who contracts energy supply with generators. This agent can arrange two types of bilateral negotiations to meet demand: long- and short-term contracts. The contract transactions are made between generators and retailers (which can be integrated in the same company), or among retailers. The purpose of these contracts is to reduce risk and volatilities that can be present in market prices. The support of these contracts is based on the necessary acquisitions that are made in the energy market, or is covered by other agents of the Wholesale Energy Market (MEM for its Spanish acronym).

The terms of the contracts have no restriction of quantities or prices, which are determined by the parties involved in these contracts through bilateral negotiation. However, supply for regulated customers must be procured by retailers (whether or not these retailers also perform generation and distribution activities) through competitive mechanisms. Gencos-retailers can supply regulated customers with their own generation only after conducting a public auction. Furthermore, supply with generation by the same firm can cover a maximum of 60% of regulated demand, if the respective retailer serves 5% or more of total system demand (CREG Resolution 020, 1996).

For the unregulated / liberalized customers market, agents can contract freely with a supplier without intermediaries, and no prior authorization is required from the regulator (CREG Resolution 020, 1996). There are contracts between final customers and suppliers, establishing prices and quantities for specific periods of time.

It is now important to mention that, among the main forms of bilateral contracting, the following cases may occur:

1. **Take-or-pay supply contract**: the retailer must pay for a fixed amount of energy, regardless of whether it makes full use of it or not. If consumption exceeds agreed quantities, energy must be purchased in the wholesale market at the energy price. On the other hand, the retailer sells excess energy in the stock market in case the contracted quantities exceed the supplier's commercial commitments.
2. **Pay-as-demanded supply contract** (i.e. depending on the amount consumed): the retailer will pay a fixed price, previously agreed by the parties, for all consumed energy. Hence, the risk of demand variations is borne by the seller Genco.

Although contracts are not standardized, in general most of the contracts in the Colombian power market adopt a structure similar to a take-or-pay contract, and are between 1 and 2 years of duration.

Retailers who serve regulated users (residential) should cover a percentage of their demand with long term contracts. Contracting is also mandatory for all generators that produce 20 MW or more. By design, these contracts are intended to facilitate financing of new investments and support renewable energy.

3.5 Market settlement

Settlement in the day-ahead market is administered by the system operator based on market-clearing prices, market schedules (i.e. scheduled output disregarding transmission constraints as cleared in the day-ahead market), and registered bilateral contracts.[6] Although bilateral contracts are confidential, the quantities and types of contracts (pay-as-demanded, or take-or-pay) must be informed to the system operator for the purpose of pool settlement for the amounts not covered in the contracts.

Contracts are settled by the agents with transactions valued at the agreed price. Differences between the market schedule (or ideal dispatch) and contracted quantities are sold or bought from the pool at the spot price. In the contract settlement process, take-or-pay contracts are assigned first, while pay-as-demanded contracts are liquidated in merit order (ascending price order).

Transactions in the pool market are settled in three stages (Harbord, 2016). Gencos submit three-part bids to the pool a day before operation (t - 1), consisting of a single offered energy price for all daily and hourly availability, and startup / shutdown offered prices in the case of thermal plants (see section 3.2). The market operator uses these offers, together with projections of demand and grid restrictions, to

[6] Settlement of international transactions is performed by the market operator but under a different regime from the national market.

schedule generation dispatch for the following day. The day before operations, XM also publishes the ideal pre-dispatch *bolsa* price, which shows the price of the marginal plant for each hour of the following day. Such preliminary price serves to activate imports or exports to Ecuador, the demand response program and the purchase options in the gas market.

On the day of operation (t), if a plant that entered the scheduled dispatch becomes unavailable, the market operator replaces it by calculating a new dispatch schedule based on the price offers made by generators the previous day. A generating company which declares a plant or unit unavailable does not incur any penalty, provided that advance notice is given.

The day after operation (t + 1), the market operator calculates an "ideal dispatch" using the day-ahead price offers (t - 1), the plants actually dispatched and actual demand on the operation day (t). These single-node pool prices are used to settle transactions in long-term contracts and in the spot market for each generator. Generators who have plants that are either "constrained on" or "constrained off" due to transmission constraints are paid (or pay) "reconciliation" payments.

Reconciliations and deviations with respect to the market day-ahead schedule are settled by the system operator. Since the day-ahead market disregards transmission constraints, the market schedule (called the ideal dispatch) may be different from the realized real-time dispatch. Reconciliations are then settled among generators, by making surplus generators (i.e. those that produced more than the scheduled quantity) pay shortage generators (i.e., those that produced less than the scheduled quantity); but at a regulated reconciliation price differentiated for technology and Automatic Generation Control service provision (see section 3.2). Furthermore, deviations exceeding 5% of the real dispatch schedule developed by the system operator are levied with a penalty equal to the absolute difference between the offered price and the market energy price.

For pool trades, the system operator collects and allocates funds from / to market participants. Furthermore, various mechanisms are available in Colombia to enforce payments through the electricity supply chain, such as suspension of particular participants from the market in extreme cases.

In summary, the following are the income sources for Gencos in the short-term market (Mcrae & Wolak, 2016):

- Pool (bolsa) price generation revenue: for the hours when the pool price is less than the scarcity price, this is equal to the pool price multiplied by the ideal generation. When the pool price is greater than the scarcity price, this is equal to the scarcity price multiplied by ideal generation.
- Automatic Generation Control Services Payments: daily payments for providing Automatic Generation Control Services (paid-as-bid in the energy day-ahead pool, see section 3.2).
- Net Payments for Reconciliations: daily net payments for positive and negative reconciliations. Negative reconciliation payments are the foregone Ideal Generation Revenue for units that produce less than their Ideal Generation (i.e. according to the ideal dispatch, which disregards transmission and system security constraints). Positive Reconciliation payments are the additional revenue that the generation owner receives for providing additional energy from a generation unit beyond its Ideal Generation.
- Start-Up / stop Payments: daily payments to generation units to recover their start-up costs.
- Payments related to the reliability mechanism (further described in section 4):

- Firm Energy Payments (reliability charge): daily payments for Firm Energy Obligations, according to quantities and prices cleared through periodic reliability auctions. These payments are provided whether or not tight supply conditions have occurred, and are passed-through to final customers.
- Net Firm Energy Refunds: it is a refund / penalty for generation above / below the Firm Energy Obligation during tight supply hours.

3.6 Overview of Market Design

A broad overview of the power market in Colombia is summarized in Table 3-1.

Table 3-1 Power market design overview, Colombia.

Power Market Element	Design Choice
Overall Market Organization	Ideal dispatch and spot price result from single node, day-ahead, bid-based mandatory gross pool. Cost-based power pool for settling differences between real and ideal dispatch.
Demand Participation	Eligible customers (i.e. with consumption over 0.1 MW or 55 MWh over 6 months) engage directly with retailers, while regulated customers are served by the distribution company. No demand response program is currently in place.
Coordination of Operations	Centralized pool to enable multiple-buyer / multiple-sellers trading: optimization undertaken by the system operator based on bids by generators. Regulation reserves scheduled centrally by the operator before the energy schedule, but based on the same bids for the energy market.
Congestion management	Transmission and other technical constraints omitted from the bid-based pool; a different technically feasible schedule is developed based on the same bids, but settled at a reconciliation price (different from the pool spot price). Congestion charges are directly passed-trough to end customers.
Contracts and Bilateral Markets	All liberalized customers are required to sign a financial contract with a supplier / retailer.
Price Formation	Single-node hourly energy spot price cleared ex-post in the bid-based pool. An uplift is added to the pool price to compensate for startup / shutdown costs. Supply contracts for regulated customers are priced by sealed supply auctions, whereas bilateral contracts are priced through confidential bilateral negotiations.
Capacity Markets	Firm Energy Auctions are conducted to ensure reliability during dry hydrological conditions. Spot transactions are hedged by a reliability option during tight supply conditions.
Settlement	Energy quantities agreed through financial bilateral contracts are settled on bilateral basis. Differences between contracted and effectively traded energy are settled by the system operator,

	valued at the market price and adding charges for transmission congestion, Automatic Generation Control, and reliability.
Non-conventional Renewable Generation	No special treatment of NCRE in the market, and minor integration of NCRE to this date. Slow practical implementation of a related law.

4 Capacity markets: Reliability Auctions and Reliability Options

The 1991 Political Constitution of Colombia states that electricity supply is an essential service and that the State is responsible for establishing mechanisms that guarantee secure access and electricity provision with quality to final users.

As noted before, in 1992, electricity supply was about 80% hydroelectric, making it vulnerable to the droughts that may result from El Niño phenomenon, which indeed occurred that year, prompting energy rationing by the end of 1992. This was the catalyst of laws 142 and 143, that initiated the transformation of the electricity sector in 1994, and that created a capacity charge mechanism in 1996. Indeed, the CREG introduced capacity payments based on an indicative expansion plan of the power system to determine the annual optimal capacity payment (Arango et al., 2004).

The intention of the capacity payment was to promote new power capacity in order to guarantee security of supply. These new instruments were also seeking the establishment of payments for generation capacity. This was an administrative capacity payment rather than an auction-based market mechanism.[7] As is typical with administrative capacity charges, capacity payments can be set conservatively, making generators heavily reliant on energy prices. No clear commitment was made to generators. Investment in gas-fired power plants such as CCGT was subject to uncertain revenues, given abundant hydro-powered generation capacity which can drive energy prices to very low levels during wet periods. For example, spot prices plunged following heavy rainfalls caused by La Niña phenomena in 1998-1999. Abundant hydro inflows pushed CCGT power plants out of the market during these years. Thus, investment in CCGT and other thermal power plants diminished subsequently (Arango et al., 2004).

Ten years later, as progress was poor, the regulated capacity mechanism was changed, and the so-called reliability charged was created. This new market-based mechanism was largely dependent on auctions for new capacity and was designed to guarantee payments to generators for being available when needed. The new regulation also included a scarcity price for electricity supply in times of critical hydrology.

The design of the reliability mechanism is further described next in section 4.1, and the outcomes of the mechanism are discussed in section 4.2.

4.1 Design of the Reliability Mechanism in Colombia

The reliability mechanism comprises the following main elements, further described next (CREG, 2007):

1. **Firm Energy Obligations auctions** (see section 4.1.1) for procuring enough generation capacity is available to supply demand, even under dry hydrological conditions. Firm Energy Obligations are allocated and priced in these auctions. Winning Gencos receive a stable and continuous reliability revenue.
2. **A call option on the wholesale spot price** (see section 4.1.2) at a regulated strike price, called the "scarcity price", was established. The call option allows load to hedge price spikes, and the system operator to identify hours of tight supply. Gencos with Firm Energy Obligations must provide the energy committed by their Firm Energy Obligations in these hours of tight supply.

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[7] P. Cramton and S. Stoft, Columbia Firm Energy Market, Department of Economics, University of Maryland, 2007. (Cramton & Stoft, 2007)

3. **A safety net** (see section 4.1.3) designed to further ensure Gencos can supply the committed Firm Energy Obligation during hours of tight supply. Moreover, adjustment mechanisms in the safety net allow market participants and the regulator to update their positions regarding Firm Energy Obligations.
4. **Guarantees** (see section 4.1.4) to ensure compliance with the reliability mechanism.

During the initial transition period, Firm Energy Obligations were not awarded through auctions, but rather on a prorated basis according to the firm energy declared by existing Gencos (the Firm Energy for the Reliability Charge).

4.1.1 Firm Energy Obligation Auctions

The capacity market in Colombia is based on auctions for procuring enough generation capacity to be available to meet demand even under dry hydrological conditions (Cramton, Ockenfels, & Stoft, 2013). Firm Energy Obligations (OEF for their Spanish acronym) are awarded to Gencos through these auctions. Demand pays Gencos with Firm Energy Obligations a monthly reliability charge depending on the "firm" energy awarded to each Genco, and the respective auction clearing price. In exchange, Gencos commit to provide a given amount of energy (the firm energy), at a fixed price during tight supply conditions, as further described in the following section. Firm Energy Obligations are thus commitments from Gencos, backed by a physical resource capable of producing firm energy during scarcity periods. Moreover, Gencos must maintain active fuel supply and natural gas transport contracts required to fulfill their firm energy commitments.

At the discretion of CREG, Firm Energy Obligations needed to cover expected demand are auctioned among existing generators and investors that have or are planning to own generation resources. Firm Energy Obligations auctions are organized at least three years before the delivery period. A special treatment was designed for projects that may take longer than three years to commission, enabling investors to sell a portion of their future firm energy up to seven years before delivery.

A descending clock auction design was adopted for awarding Firm Energy Obligation. Gencos and investors actively participate in the auction, while demand is represented by a price-quantity curve established by CREG. For each round of the auction, the auctioneer sets both an opening and a lower price. Participants adjust their firm energy supply curves between these two prices. In each round, both the closing price (which is the opening price for the next round) and excess supply are calculated by the auctioneer based on updated firm energy supply curves. The closing price is thus lowered in each round until excess supply is minimal.

The clearing price resulting from this iterative process will be paid uniformly for all Firm Energy Obligations allocated to winning Gencos. The auction procedure is illustrated in Figure 4-1, and described in more detail in (Cramton & Stoft, 2007; CREG, 2007).

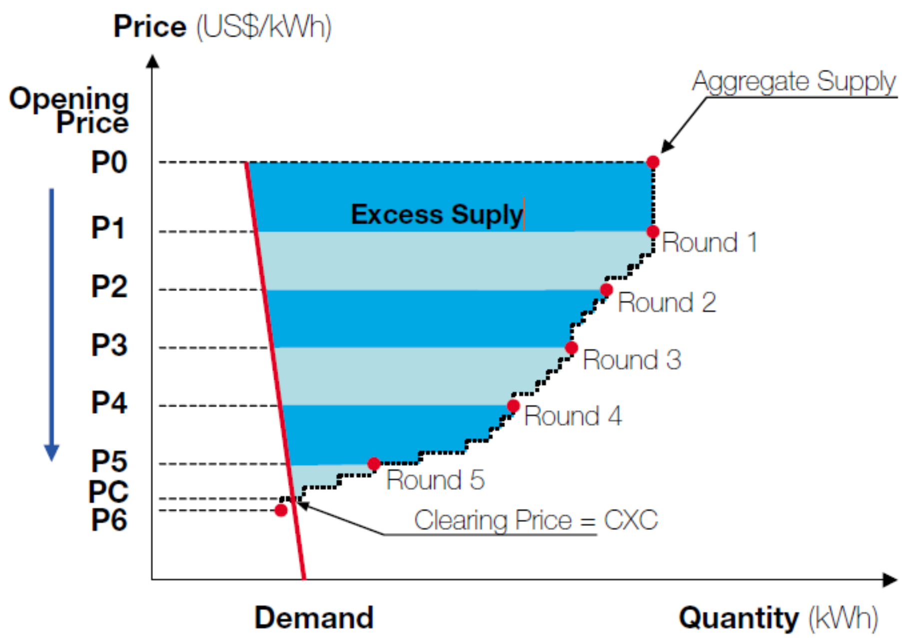

Figure 4-1 Descending clock auctions for Firm Energy Obligations.

Source:(CREG, 2007)

Real performance of power plants in operation is considered in the auctions since the quantity offered by a Genco cannot exceed the Firm Energy for the Reliability Charge (ENFICC, for its Spanish acronym). Such upper limit represents the energy that all power plants in the Genco's portfolio can provide continually during a dry year. The Firm Energy for the Reliability Charge declared by each Genco considers technical parameters of the power plants, hydrological uncertainty in the case of hydro power plants, and historic performance, such as forced outage rates, fuel availability, and natural gas transport availability. The system operator must coordinate the audits of declared parameters, and verify the calculation of the Firm Energy for the Reliability Charge.

The generator who wins a Firm Energy Obligation receives a transparent and stable compensation during a specific time period, depending on the type of power plant which backs the obligation (see Table 4-1). Such reliability payments are received by generators whether the fulfillment of its firm energy obligation has been required or not. Reliability incomes are particularly important for thermal power generation (see section 6). The reliability charge is settled and collected by the system / market operator and is paid by all the end-users of the SIN, through the fees charged by suppliers.

Table 4-1 Commitment period of Firm Energy Obligation for different types of power plants.

Type of power plant	Firm Energy Obligation time period
Existing power plants: those operating when the auction is held	One-year
New power plants: those for which construction has not started when the auction is held	Between one and twenty years

Special resource: those in the process of construction or installation when the auction is held	Between one and ten years

Source: (CREG, 2007)

4.1.2 Call option and the Scarcity Price

As previously described, Gencos with Firm Energy Obligations receive a stable reliability payment. In exchange, Gencos commit to provide a given amount of energy (the "firm" energy allocated in the auction), at a fixed price during tight supply conditions (i.e. dry hydrology). Such tight conditions are defined as the hours when the spot price exceeds a pre-defined strike price, called *"scarcity price"*.

The scarcity price is calculated and updated by the regulator (CREG), and its initial value was set so that 5% of the historic spot prices were above this scarcity price. The selected value was equal to the variable cost of the most inefficient operating power plant, which was therefore selected as a reference for the initial calculation. The scarcity price is therefore composed of three parts: fuel, variable O&M, and other variable costs of the National Transmission System. The fuel component of the scarcity price was originally set to 101.6 USD/MWh (in June 2006), and is updated monthly according to an international fuel price index (the New York Harbour Residual Fuel Oil 1% Sulphur LP Spot Price) (CREG, 2007). The variable O&M cost was set to 10.667 COP/kWh (in June 2006), and is updated monthly according to the Colombian Consumer Price Index. Other costs are calculated on a monthly basis depending on operating conditions, including the costs of Automatic Generation Control (AGC, see section 3.1) (CREG, 2006a).

The Firm Energy Obligation resembles a call option on electricity during tight supply conditions, with a strike price equal to the regulated *"scarcity price"*. Whenever the spot price surpasses the scarcity price, energy generated over the day in the ideal dispatch (see section 3) by Gencos who have Firm Energy Obligations must cover their firm energy commitments. Energy required in every hour of the daily ideal dispatch, by every power plant of a given Genco, is added to the complimentary energy that the Genco acquires through the available contingency mechanisms (see section 4.1.3). This total energy should cover the Genco's daily Firm Energy Obligation. Thus, the Firm Energy Obligation requires that Gencos produce a determined quantity of firm energy on a daily basis, without imposing the time this energy should be generated (CREG, 2007).

During scarcity hours, the Genco receives the scarcity price for each unit of power produced associated with its Firm Energy Obligation. If the total energy (generated and acquired through contingency mechanisms) does not cover the Firm Energy Obligation, the Genco must purchase the difference in the spot market. On the other hand, if energy generated in the ideal dispatch exceeds the Firm Energy Obligation, the excess energy is paid for at the spot price (CREG, 2007).

In theory, the design of the reliability mechanism does not distort the spot market since the call option works as a hedge against the spot price, just like a conditional contract for differences. Thus, incentives in the spot market remain based on the spot energy price. Moreover, the call option on the spot price reduces the incentives of generators to exercise market power in the spot market during times of scarcity (Cramton & Stoft, 2007).

4.1.3 Safety net for the reliability mechanism

The reliability mechanism comprises a safety net which helps Gencos fulfill their Firm Energy Obligation commitments, and allows Gencos and the CREG to adjust their respective positions. The following mechanisms comprise the safety net (CREG, 2007):

- A secondary market of bilateral contracts to allow trading of Firm Energy Obligations among Gencos
- Voluntarily interruptible demand
- Generation assets purely and exclusively used to fulfill Firm Energy Obligations
- Reconfiguration auctions in the case of excess or default of firm energy is foreseen by CREG

4.1.4 Guarantees of the reliability mechanism

The Colombian reliability mechanism establishes guarantees to ensure compliance with the commitments acquired by Gencos. These guarantees should be liquid, easy to execute immediately by the system operator, and cover all concepts arising from the Firm Energy Obligation market that are required to Gencos. Among others, guarantees to ensure the compliance of the following are required (CREG, 2007):

- Starting operation of a new or a special generation plant or unit.
- Contracting fuel supply and natural gas transportation required to back-up the OEF.
- Continuous fuel availability during the commitment period of the OEF for thermal generation plants and units.

4.2 Outcomes of the reliability payments and firm energy auctions

Following regulatory reform of the reliability payment markets in 2006, two Firm Energy Obligation auctions were held in 2008. The first auction, held in May 2008, was mostly awarded to existing plants, and three of the ten new power plants participating in the auction. The second auction, held in June 2008, ended early at the first point at which a large bidder could see that it had become pivotal and able to withdraw one of its offers to set a high capacity price. Indeed, the reserve price of this auction was set as the market clearing price due to insufficient supply to cover demand. Overall, in 2008, 63 TWh were allocated to existing resources, and 9 TWh were allocated to new resources, at a cleared price of 14 USD/MWh (in May 2008 USD) (Maurer & Barroso, 2011).

To avoid a recurrence of high cleared capacity prices due to insufficient offers, at the subsequent auction held in December 2011, the CREG reduced the amount of information on demand and supply revealed to bidders during the auction. This was not sufficient, however, and the auctioneers abandoned the auction after the initial two rounds and effectively held a sealed-bid auction in its place (Harbord & Pagnozzi, 2014).

Discussions have taken place about the complexity of the regulation of reliability payments (more than 170 resolutions that condition and shape implementation) and the effectiveness of the mechanism in practice.

Between 2009 and 2010, the threat of rationing led the CREG and the Ministry of Mines and Energy to intervene in the market. The reliability mechanism, which was specifically designed as part of solvency in periods of critical hydrology to operate, could not be activated. The regulator temporarily intervened the offered prices and declared availability of thermal and hydro power plants (CREG Resolution 137, 2009), and the commercial operation of hydro power plants (CREG Resolution 010, 2010), to reduce the possibility of demand rationing.

More recently, the threat of rationing in 2016 put again into question the operation and effectiveness of the reliability mechanism as hydroelectricity reservoirs attained very low levels because of droughts caused by El Niño. Several unforeseen events further stressed system operation. The forced outage of Guatapé hydro power plant (560 MW) in February due to a fire further reduced hydro availability from 47% to 34% of total system storage capacity. Low gas and diesel availability also contributed to the risk of rationing (XM, 2017a).

In a context of uncertainty, seeking to avoid at all costs a general "blackout", the government approved a series of tariff increases and issued Resolution CREG 029 of 2016 that established "*the costs of provision of electricity to regulated users in the National Interconnected System to promote voluntary energy savings*". This regulation also included costs for those Colombians who did not meet reductions in electricity consumption according to the imposed targets. The two month demand program (called *"It Pays to Shutdown"*) penalized electricity consumption above historical means, and rewarded customers in the opposite case (UPME, 2016d). The target of reducing 400 GWh of electricity consumption was largely surpassed with estimated reductions of 1,179 GWh.[8]

The determination of the scarcity price has proven difficult in practice. The scarcity price plunged during 2014-15 following the monthly indexation to the price of Fuel Oil No. 6 (US Gulf Coast) (see Figure 4-2). Such decline of scarcity prices occurred precisely in the midst of the stressful system situation during 2014-15 due to El Niño, increased demand and fuel supply shortages.[9] In response to this situation, the CREG intervened the scarcity price by establishing a floor of 302.43 COP/kWh (equal to the scarcity price in October 2015). Furthermore, the CREG established a new scarcity price of 470.66 COP/kWh for thermal generators operating with liquid fuels, to reduce the operating losses these generators incurred to fulfill their Firm Energy Obligations (since the variable cost of these thermal generators was higher than the scarcity price at that time). The CREG passed-through to final customers the costs of this intervention to the scarcity price.[10]

The flaws of the reliability mechanism were evidenced during El Niño 2015-2016, as not all generators were ready to supply electricity, and some were only willing to do so at a price much higher than the one established in the corresponding auctions. The regulator modified the existing rules favoring thermal generators during the 2015-2016 El Niño event. Some companies confronted financial complications, causing increases in tariffs to consumers. Users had to pay for these regulatory inefficiencies, as it was documented by The General Comptroller of the Nation in July 2016 (Contraloría General de la República, 2016).

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[8] http://www.elcolombiano.com/colombia/apagar-paga-la-campana-de-ahorro-de-energia-llego-a-su-fin-GC4040558

[9] An unexpected gas supply shortfall, the closure of the border with the República Bolivariana de Venezuela, and interruptions in oil supplies from refineries within Colombia all contributed to fuel supply shortages (Harbord, 2016).

[10] CREG Resolution No. 178, 2015. Available online at: http://apolo.creg.gov.co/Publicac.nsf/1c09d18d2d5ffb5b05256eee00709c02/76a145fdb83f6f7e05257eec0077bdc2/$FILE/Creg178-2015.pdf

Regarding availability, CREG dictates that quarterly availability tests must be made to 5 randomly selected plants from those that have Firm Energy Allocation and in the previous quarter did not meet a certain observed generation level. Such tests may also be performed by order of the CREG on a discretionary basis. Furthermore, for firm energy obligations, ENFICC and related parameters should be audited by the system and market operator (CREG resolution 071, 2006, article 38). However, it has been determined by the Comptroller of the Republic that XM did not comprehensively fulfill its responsibilities regarding the said audits (Contraloría General de la República, 2016).

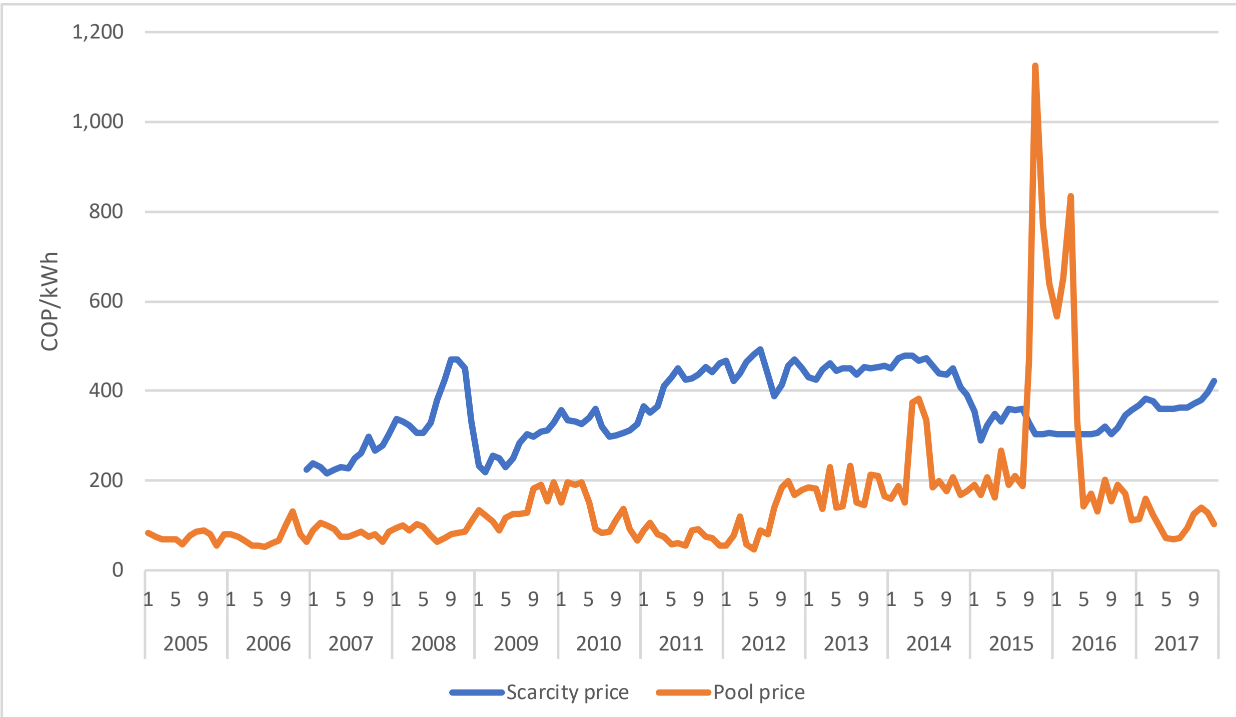

Figure 4-2 Monthly mean pool and scarcity price in Colombia.

Source: Own elaboration based on data collected by the World Bank.

The reliability charge mechanism thus reveals three main problems:

(i) the agreed pricing mechanism does not work correctly since not all Gencos were ready or willing to supply the firm energy commitments they had been continually paid for, and the scarcity price was temporarily intervened to partially allow recovery of very high variable costs,

(ii) guarantees were not met since Gencos with Firm Energy Obligations collected the Firm Energy Payments over the years, but their generation was not made available to supply firm energy when required during scarcity conditions,[11] and

(iii) the allocation of remunerations to generators was not fully transparent. Flaws are to do with plant availability (when required), fuel availability (when required) and the intensity of the phenomena (intensity of droughts).

5 Power market implementation

This section describes the implementation of the power market design. Governance of the power market is described in section 5.1. Then, institutional indicators developed for the Colombian power market are described in section 5.2.

5.1 Market governance

Entities governing the Colombian power market are the following:

- Ministry of Energy and Mines (MME) at the policy level.
  - UPME is the planning branch of the Ministry, in charge of mandatory transmission planning and also indicative plans for power generation expansion. UPME also plans projects for mining development.
- Superintendence of Domestic Public Services (SSPD) is the entity in charge of enforcing and supervising regulations. SSPD oversees and monitors the Colombian power market.
- CREG regulates the market. Among key function CREG's functions are the following:
  - CREG establishes requirements for entry of new competitors to both the wholesale and the retail market, in resolutions 054/1994 and 024/1995, respectively.
- XM, a company fully controlled by the major Transco ISA which, in turn, is mostly government-owned (further details in subsection 5.1.1).
  - Performs the functions of system operation (called in market regulations the National Dispatch Center, CND), wholesale market operation (called in market regulations the Trading System Administrator, ASIC), and collects transmission tolls (called in market regulations LAC).
  - In addition to UPME's planning work, XM performs electric and energy analyses on expected system behavior and provides information on the main variables of the power market.
- CNO: technical system operation committee formed by market participants. The council is formed by representatives of the generation, transmission, and distribution segment (Distcos with no generation businesses).

[11] In fact, based on explicit enabling law provisions, the Superintendence of Domestic Public Services (SSPD) took control of plant Termocandelaria in November 2016 to ensure supply reliability, after the said plant was declared unavailable by the Genco for financial reasons, despite having collected reliability payments. http://www.eltiempo.com/archivo/documento/CMS-16436994

- CAC: market operation committee which assists CREG in overseeing functioning and performance of both the market and its operator (XM) by developing reports and economic / technical studies; and proposes market rule changes to CREG.

Regulated **open access** to transmission and distribution networks is established in Colombia. Separate contracting for energy and network services is allowed, with transmission revenues separated from energy and other revenues. In the distribution network, network operators are obliged to offer users a feasible connection point to its system when these agents request it and will guarantee free access to the distribution network (according to distribution codes and regulations). It is noteworthy that integrated companies existing before the enactment of Laws 142 and 143 in 1994 could continue to be integrated, with some restrictions on market share (Distcos cannot attend more than 25% of demand), and limits on trading between related generation and distribution subsidiaries (Arango et al., 2004).

Specific regulations from the CREG are normally complied with and the entity is recognized as the regulator of the energy market. Other legislation applicable is also enforced and complied with; for example, public procurement laws are taken into account and into practice both by private entities participating in the energy market and the Superintendence and the CREG.

Both the governance of the operator (XM) and market oversight are further described below. The governance and ownership structure of the system and market operator XM is further described in section 5.1.1. Market oversight, rules enforcement and intervention are further described in section 5.1.2.

5.1.1 System and market operator (XM)

XM is in charge of operating the Colombian National Interconnected System -through the National Dispatch Center, CND-, and managing the Wholesale Energy Market -MEM. The institution manages International Short-Term Electricity Transactions -TIE- with Ecuador and coordinates interconnected operation with the Venezuelan Electricity System. XM is also in charge of planning, coordinating, supervising and controlling integrated operation of the National Interconnected System's generation and transmission resources. Additionally, XM performs analysis on expected system behavior in order to achieve quality, reliability and security in accordance with the current regulatory framework.

As a market operator, XM schedules generation resources to meet demand with criteria of economy, quality, safety and reliability. It offers information on daily offers, updated generation programs and marginal operation cost. XM manages commercial energy and transportation transactions in the Wholesale Energy Market, optimizing services exchange between agents. As Commercial Exchange System Administrator, XM is responsible for the registration of commercial frontiers, long-term energy contracts, liquidation, billing, collection and payment of financial obligations related to energy exchange, firm energy auctions and information systems maintenance.

As system operator, XM schedules plant dispatch to meet demand subject to observing economic, security and reliability criteria. More precisely, XM has the following functions as system operator (CND, Law 142 of 1994, art. 171):

- Operation planning (generation, transmission and international interconnectors).
- Coordinate, oversee, control and analyze system operations.
- Coordinate and plan maintenance schedules for generation and transmission infrastructure.

- Report regularly to the operation committee (CNO) regarding planned and actual system operation and the risks involved in supplying demand.
- Report violation of operation procedures.

XM also performs the following functions as wholesale market operator (ASIC):

- Keep an updated registry of long-term energy contracts in force.
- To calculate settlement, bill, collect and pay transactions among Gencos and suppliers in the wholesale market (the pool, with respect to energy and Automatic Generation Control transactions); and perform other related tasks such as developing and maintaining the required information systems.
- To organize and hold auctions for the supply of firm energy, whenever it is deemed necessary by XM with the objective of ensuring supply reliability.
- Report to the SSPD and the regulator (CREG) any improper conduct or violation of the procedures and regulations.

As market operator, XM collects and issues payments arising from the pool, and is forbidden of profiting from these funds. Instead, XM's services as system and market operator are levied to market participants (Gencos, Transcos, Distcos and suppliers) based on the regulated tariff determined by the CREG. Nevertheless, XM is allowed to pursue other non-regulated businesses.

The operator makes publicly available through its website relevant information such as system and market operation procedures and market prices. However, scheduled and dispatched quantities and settlements are only available to selected market participants. Timely and public dissemination of market data (provided that this does not violate confidentiality of commercially sensitive information) has evolved in Colombia from a rather opaque process a decade ago (Wolak, 2009).

The operator is a Legally-unbundled TSO (LTSO) controlled by the major government Transco ISA, and independent from other market participants (Gencos, suppliers and Distcos).[12] System and market operation functions were transferred from ISA to its subsidiary XM in 2005 by CREG's decree 848. XM's corporate governance is based on a board of five members elected by the shareholders. Three of the five board members must be independent from XM and other companies to which XM serves. The board of XM has real decision-making authority.

Decisions by the operator cannot be appealed. Operational rule changes must be approved by the regulator. However, the regulator is not allowed to revoke or modify decisions by the board of the operator.

5.1.2 Market oversight, rules enforcement and intervention

Colombian regulations provide a general framework for **market intervention** (changes to economic dispatch), when offered prices by hydro plants with reservoirs cause stored energy to fall below a safety level known as Upper Operative Minimum; or when offered prices are inferior to the lower bound set by

[12] ISA owns 99% of XM's shares, and in turn the state owns 62% of ISA's stakes. In turn, ISA owns and operates a large portion of the Colombian National Transmission System.

the energy-equivalent to the reliability charge (CERE) and a relatively small subsidy for isolated zones (FAZNI). There is also scope for changes in the economic dispatch in order to address the most recent changes in system operation, such as entry and / or exit of generation units, unscheduled maintenance or line shots.

The regulator has intervened in the power market based on legal powers and market rules, arguing that increased price volatility and deteriorating reliability required such intervention. In particular, SSPD took control during 2015 of thermal plant Termocandelaria to ensure supply reliability. However, dispatch has not been distorted by purely political pressures or other criteria unrelated to reliability or efficiency.

5.2 Summary and Institutional indicators for the Colombian Power Market

Colombia has adopted an advanced power market design with a relatively weaker governance, according to the institutional indicators developed and calculated in this study. Colombia ranks second on market design with a scores 59%, but it ranks fourth on market governance with a score of 59%. The high score on power market design reflects the bid-based market design with retail competition, while the lower rank on governance is related to a relative lack of independence of the TSO from other market players, and a few problems of transparency, which contrasts with relatively strong accountability and monitoring in the sector. It is worth noting that the aforementioned institutional indicators do not capture particularities of the Colombian case. For example, the market design indicator does not capture the market design for reliability (based on reliability auctions).

Table 5-1 Institutional indicators for Colombia's power market, per level

	Level	Colombia score
1	**Wholesale Market Design**	**59%**
1.1	Market Architecture	38%
1.2	Market Rules	80%
2	**Market Governance**	**59%**
2.1	Decision Making Autonomy	44%
2.2	Transparency	63%
2.3	Accountability and Monitoring	71%

Table 5-2 summarizes key dimensions of the governance of the Colombian Power Market.

Table 5-2 Overview of power market implementation across studied countries.

Power Market Implementation Element	Colombia
Key wholesale market participants and actors	• Gencos (some integrated with Distcos) • Retailers / Suppliers • Open access customers • Distcos • System and (pool) market operator • Regulator (CREG) • Committees on Operation (CNO) and Market (CAC)
Governance of system and market operation	**LTSO**

Power Market Implementation Element	Colombia
	System and short-term market operation by XM, a subsidiary of major government-owned Transco ISA.
Investment responsibility and risk allocation	Gencos borne risks and responsibility of investment, incentivized by short-term power market and capacity auctions. However, fuel price risk in the reliability options was exceptionally passed-through directly to final customers in 2015 due to falling oil prices and increasing stress of system reliability.
Barriers to investment and entry	• Regulatory uncertainty (lack of confidence on political commitment to reforms) • Lack of upstream infrastructure • Complicated and lengthy processes for permits and licenses • Public opposition to new generation projects • Limits have been imposed to vertical and horizontal integration
Open access in practice	Regulated open access to the transmission grid. Access tariffs set by CREG.
Market transparency	Market and system operation data and procedures are publicly disclosed. Bilateral contract details are confidential.
Approach to market monitoring and oversight	The Superintendence of Domestic Public Services (SSPD) oversees and monitors the Colombian power market.
Provisions for market intervention and related events	• 2009-10: threat of rationing led the CREG to intervene in the market by disallowing the reliability mechanism specifically designed as part of solvency in periods of critical hydrology to operate. • 2015, October: Government enables CREG to intervene the Reliability Charge by placing a temporary lower bound on the Scarcity Price, and a new (higher) temporary Scarcity Price for Thermal Generators operating with Liquid Fuels. The costs of this intervention were passed-through to final customers. • 2015, November: Government intervenes through SSPD by taking control of thermal power plant Termocandelaria to ensure supply reliability, after the said plant was declared unavailable by the Genco (for financial reasons) during El Niño event, despite having collected reliability payments.[13] In this case, intervention is allowed explicitly by Law 142, 1994.[14] • 2016: to ensure supply reliability, the Ministry sets forth a two-month demand program which penalizes electricity consumption above historical means, and rewards customers in the opposite case; with the target of reducing 400 GWh of electricity consumption. • 2016: Government intervenes Distco Electricaribe due to its deteriorated financial position.[15]

[13] http://www.eltiempo.com/archivo/documento/CMS-16436994

[14] http://www.contraloria.gov.co/documents/20181/467249/INFORME+ACTUACION+ESPECIAL+DE+FISCALIZACION+DEL+CARGO+POR+CONFIABILIDAD.PDF.pdf/8fd5cc08-809f-4351-9602-9d898eb6e38f?version=1.0

[15] http://www.eltiempo.com/economia/empresas/debate-a-electricaribe-41967

Power Market Implementation Element	Colombia
Year the market was introduced	1994 (enactment of Laws 143 and 142) 2006 (reliability mechanism introduced by CREG Resolution 071-2006)
Major reform adaptations and milestones	• 2004: System and market operation functions transferred from ISA to its newly created subsidiary XM. • 2006: Market monitoring entity created (CSMEM). • 2006: regulated capacity mechanism is replaced by the Firm Energy Market. • 2008: First Firm Energy Auction is conducted. • 2009: market rules are modified to allow bidding of startup / shutdown prices to thermal power plants. • 2014-15: severe El Niño event produces pool price spikes but no black outs, albeit with regulatory and government intervention.

6 Power market performance

6.1 Wholesale and Retail Prices and Market Efficiency

The most relevant power submarkets in Colombia are the following (see Figure 6-1 also):

1. Financial Bilateral Contracts (mostly long-term supply contracts), with 67 TWh (78%) and $11,305 BCOP during 2017.
2. Spot market (pool), with 19 TWh (22%) and $ 2,032 BCOP during 2017.
3. Capacity market: reliability payments and firm energy auctions.

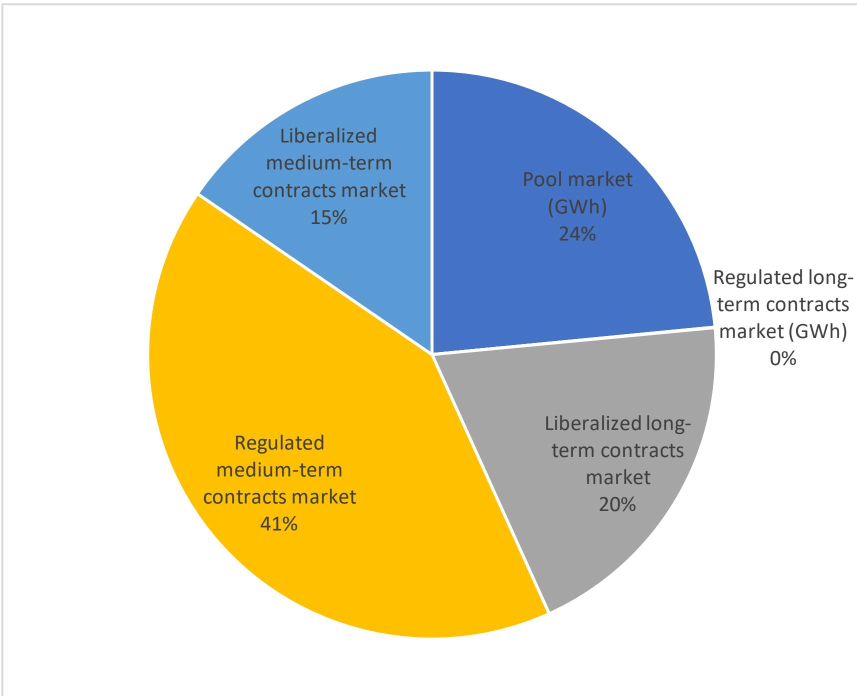

Figure 6-1 Relative size of power submarkets in Colombia during 2016, as percentage of total traded energy.

Source: Own elaboration based on data collected by the World Bank.

Incomes for Colombian Gencos include supply contracts, the spot market (including transactions at the spot price, reconciliations due to system constraints and Automatic Generation Control services), and the firm energy market (reliability market). The revenue structure varies across power plants (see next table). For example, firm energy payments account for about 15% of total revenues for major Gencos. However, firm energy payments account for up to 50% of revenues of fully thermal Gencos such as Termocandelaria and Termovalle (see Table 6-1).

Table 6-1 Revenues for major Colombian power plants (without supply contracts, assuming energy sold at spot price), 2006-2016.

Trillion COP	Bolsa Energy	Reconc.	FE Payments	Net FE Refund	Net Start-up	AGC Services	Total	FE % of Total
Large hydro and thermal generation firms								
EPM	20.37	-1.88	3.56	-0.58	-0.17	1.71	23.00	15.48
Emgesa	17.53	-1.45	3.25	0.12	0.06	2.04	21.56	15.08
Isagen	14.92	-1.25	2.29	0.15	-0.13	1.19	17.16	13.32
Celsia	7.05	0.56	1.78	0.06	0.07	0.42	9.93	17.90
Other thermal generators								
Gecelca / TEBSA	7.35	3.39	2.50	-0.23	0.22	0.00	13.23	18.88
Paipa	2.81	0.01	0.64	0.05	-0.01	0.00	3.51	18.28
Termotasajero	1.32	0.25	0.37	-0.08	0.00	0.00	1.87	19.68
Termoyopal	1.03	-0.01	0.05	0.13	-0.01	0.00	1.19	4.42
Termovalle	0.62	0.06	0.20	-0.00	0.03	0.00	0.91	22.01
Termoemcali	0.35	0.18	0.46	0.04	0.02	0.00	1.04	43.85
Termocandelaria	0.34	0.23	0.58	-0.03	0.01	0.00	1.13	51.44
Proelectrica	0.27	0.47	0.18	0.01	0.01	0.00	0.93	19.45
All others	11.41	-1.06	1.68	0.26	-0.09	1.26	13.46	12.47
Total	**85.37**	**-0.51**	**17.53**	**-0.10**	**0.00**	**6.62**	**108.92**	**16.10**

Source: (Mcrae & Wolak, 2016)

6.1.1 Contracts market

As previously stated, medium- and long-term supply contracts are currently the biggest energy submarket in Colombia, in terms of traded quantities (see Figure 6-2).

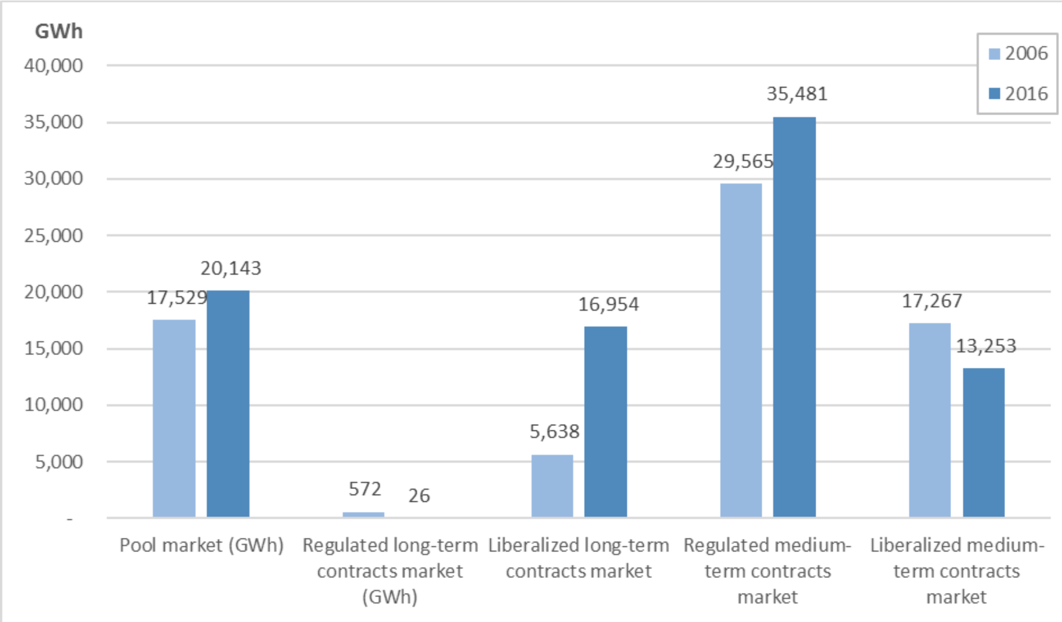

Figure 6-2 Evolution of traded quantities in each energy power submarket, from 2006 to 2016.

Source: Analysis based on data collected by the World Bank.

Over the past decade, prices in the contracts market increased by 38% in real terms (from 37 USD/MWh in 2005 to 50 USD/MWh in 2016, expressed in 2015 USD). Prices in the regulated and the liberalized contracts market have increased by 38% and 44% in real terms, respectively (see Table 6-2). In 2015 COP/kWh, average regulated contracts price grew from 113 COP/kWh in 2005 to 156 COP/kWh in 2016, while average liberalized contracts price grew from 92 COP/kWh in 2005 to 132 COP/kWh in 2016.

Table 6-2 Summary of yearly average contracts prices and the premium of regulated over liberalized contracts.

Year	Average regulated contracts price (COP/kWh)	Average liberalized contracts price (COP/kWh)	Price premium of regulated over liberalized contracts	Average regulated contracts price (USD/MWh)	Pool price (USD/MWh)
2005	77	62	23%	33	32
2006	77	65	17%	32	31
2007	82	71	15%	39	40
2008	93	83	13%	48	45
2009	114	96	19%	53	64
2010	121	99	22%	64	68
2011	132	102	30%	72	41
2012	134	107	25%	74	64
2013	140	113	24%	75	95
2014	144	118	22%	72	112
2015	156	129	21%	57	137

2016	167	142	18%	55	100
2017	174	155	12%	59	37

Source: Analysis based on data collected by the World Bank.

Contract prices in the regulated market have consistently been priced at a premium of about 20% higher with respect to the liberalized market, reaching a 30% premium during 2011 (see Figure 6-3). Price differences in the regulated and liberalized contracts market have raised persisting concerns regarding the possibility of price discrimination by dominant Gencos / Suppliers (CREG, 2006b; SIC, 2016). However, no formal prosecution of market power abuse nor regulatory reform has been held to this date to address price discrimination in the wholesale contracts market. It is worth noting that, partly to address these concerns, the regulator (CREG) has intended to develop an organized futures market for supplying regulated customers since 2006. Such efforts have faced the opposition of existing Gencos, and to this date the organized future market for regulated customers has not been established.

Contract prices are far less volatile than pool prices (see Figure 6-4). Furthermore, pool prices have increased by 158% over the past decade (2005 to 2016) in real terms, that is, pool prices have increased at much faster rates than contract prices, in particular over years 2012-2015, driven mainly by low hydro inflows. Prices fell significantly during 2017 given normal hydro inflows and slow demand growth (see section 6.1.2).

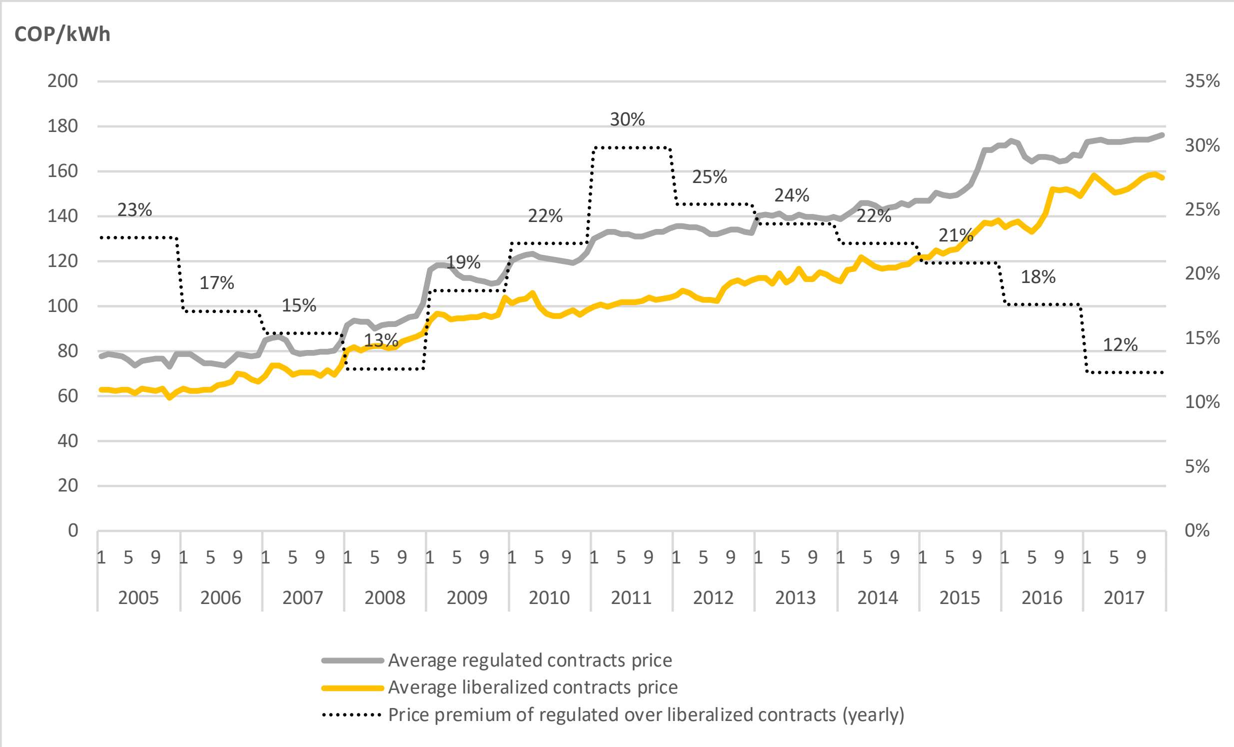

Figure 6-3 Average price of contracts in the regulated and liberalized markets.

Source: Own elaboration based on data collected by the World Bank.

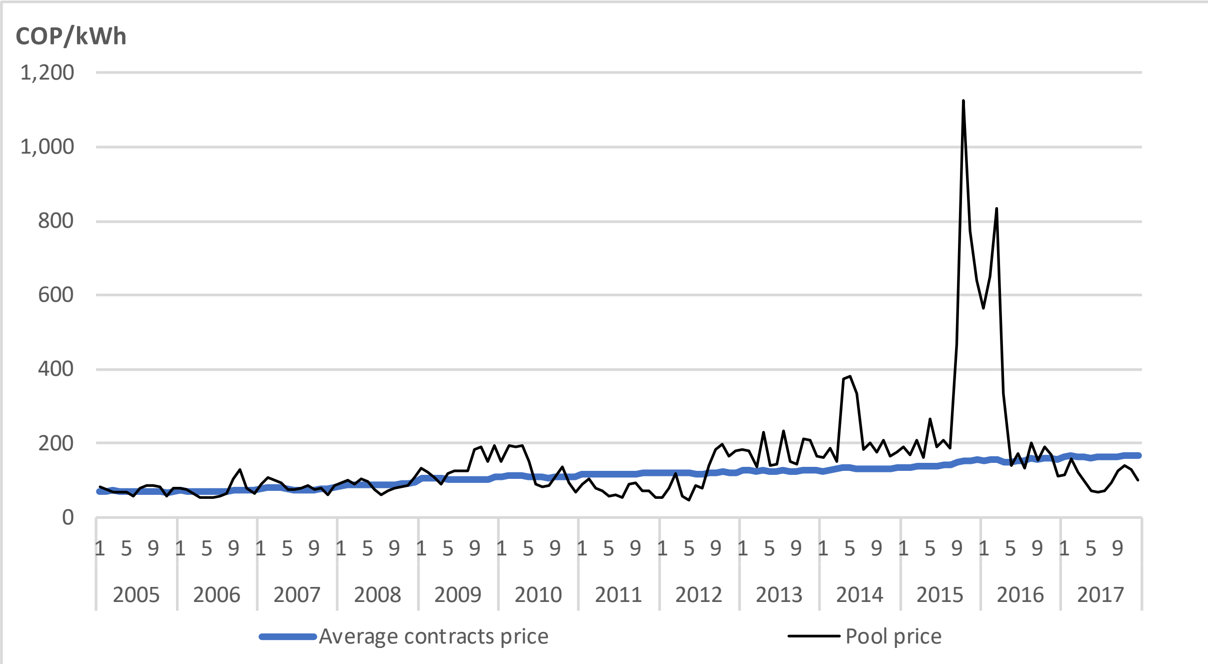

Figure 6-4 Comparison of the evolution of contracts and pool price.

Source: Own elaboration based on data collected by the World Bank.

6.1.2 Short-term wholesale prices

Short-term wholesale energy prices in Colombia increased by 158% in real terms from 2005 to 2016. Prices rose from 32 USD/MWh in 2005 to 100 USD/MWh in 2016, but then fell to 37 USD/MWh in 2017 (in nominal USD). The evolution of prices (see Table 6-3) highlights an upward trend of pool prices since 2011 due to low hydro inflows (XM, 2013, 2014, 2015); and price spikes that occurred during 2009-10 and 2015-16 due to El Niño phenomena. The monthly pool price is depicted in Figure 6-5. It is worth noting that prices fell in 2017 due to normal hydrological inflows (compared to the very low inflows seen during 2016), and also slow demand growth (XM, 2017b).

Pool price spikes occurred during 2009-10, and even more severe price spikes during 2015-2016, primarily due to reduced hydro availability because of El Niño climatic phenomena (see Table 6-3 and Figure 6-5, in nominal COP/kWh). It has been argued that pool price spikes in 2015-16 were more severe than price spikes during 2009-10, despite similarly low water availability, due to the increased incentives and ability of Gencos to exercise unilateral market power under the Reliability Payment Mechanism (Mcrae & Wolak, 2016). However, exercise of market power has not been proven nor prosecuted in the Colombian power market following the recent pool price spikes.

Table 6-3 Evolution of Colombian pool price and its volatility, and energy traded in the pool.

Year	Minimum pool price (COP/kWh)	Average pool price (COP/kWh)	Maximum pool price (COP/kWh)	Energy traded in the pool (GWh)	Average pool price (USD/MWh)
2005	28	74	187	17,747	32
2006	27	74	281	17,529	31
2007	30	84	155	16,692	40
2008	29	88	439	16,469	45
2009	33	139	321	17,934	64
2010	32	129	361	18,247	68
2011	33	75	404	16,786	41
2012	35	116	308	17,017	64
2013	40	177	451	14,949	95
2014	39	225	481	15,507	112
2015	47	377	2,822	16,905	137
2016	61	301	885	20,143	100
2017	60	108	383	19,254	37

Source: Own elaboration based on data collected by the World Bank.

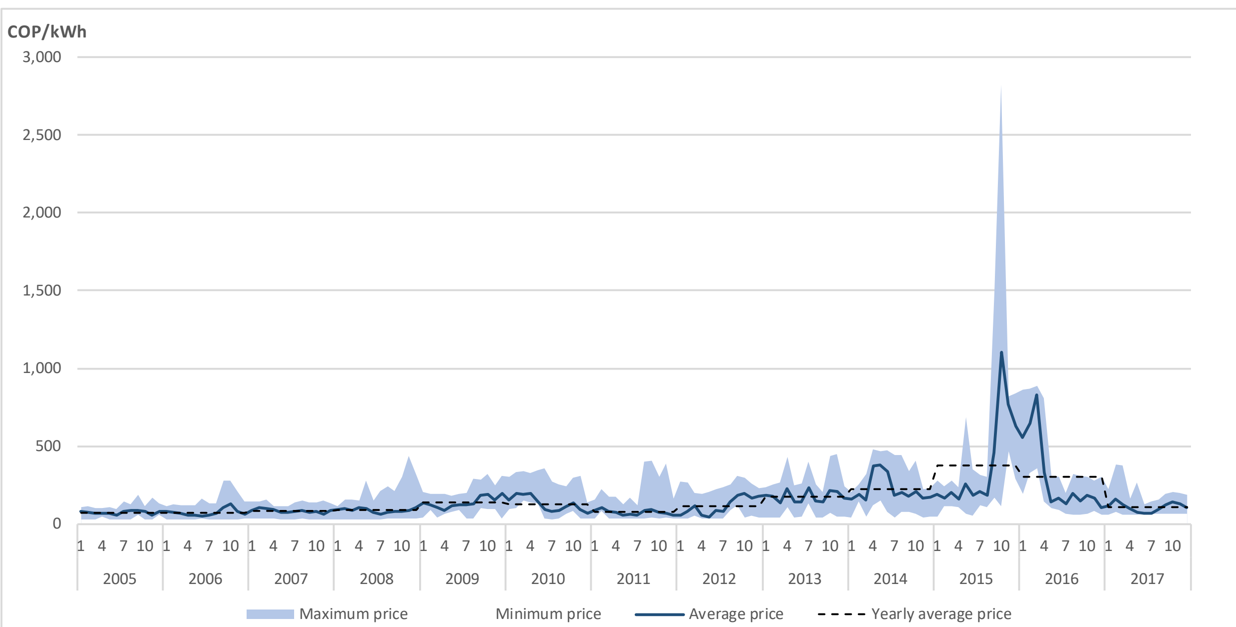

Figure 6-5 Evolution of monthly pool price (hourly minimum, average and maximum) in Colombia.

Source: Analysis based on data collected by the World Bank.

The spot price spike during the El Niño event of 2015-2016 was distorted by a regulatory intervention which capped Gencos' bids between November 2015 and May 2016.[16] Figure 6-6 depicts monthly spot price and generation per technology in 2015 and 2016. The sharp price spike in September and October of 2015 coincides with lower hydro generation and higher thermal generation, including generation from liquid-fuel with very high variable costs. However, prices decreased between November 2015 and May 2016 due to the regulatory intervention which capped the maximum offer price in the spot market to 75% of the Cost of the First Demand Rationing Step (UPME, 2016b).

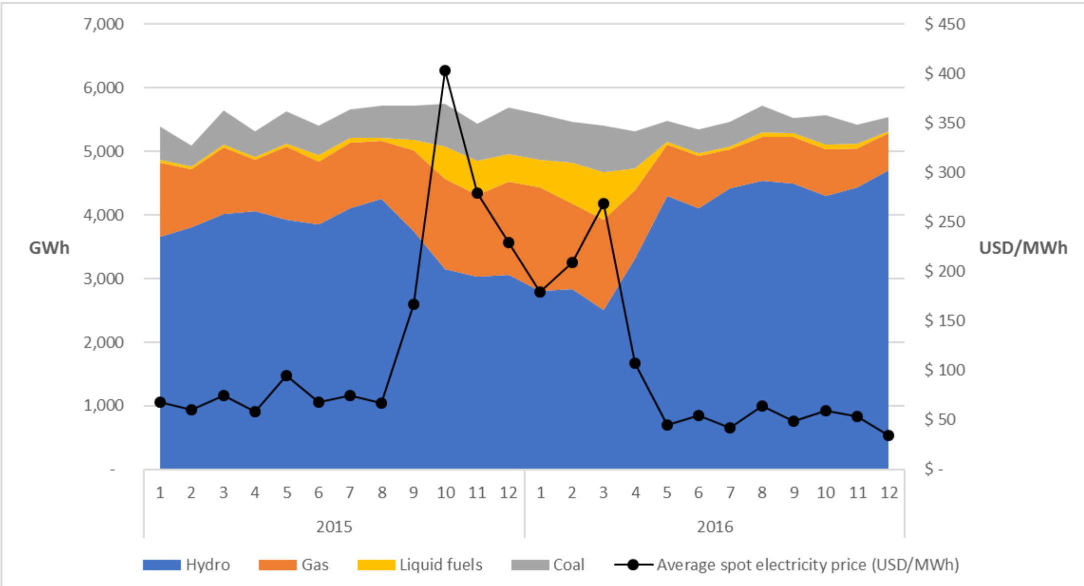

Figure 6-6 Monthly generation per technology and average spot price during 2015-16.

Source: Own elaboration based on UPME statistics.[17]

Although energy trading in the pool is the most relevant portion of the short-term Colombian power market, commercial Automatic Generation Control responsibilities (reserves) account for about 10% of that energy trading (in monetary terms, see Figure 6-7). The subsidy to support zones without connections to the National Interconnected System (FAZNI) has remained below 2% of pool prices, moving between 1.3 and 1.0 COP/kWh over the past decade.

[16] CREG Resolution No. 172 of 2015.

[17] Monthly generation per technology available online at: http://www.upme.gov.co/Reports/Default.aspx?ReportPath=%2fSIEL+UPME%2fGeneraci%c3%b3n%2fGeneraci%c3%b3n+(Gerencial) [accessed December 12, 2017].

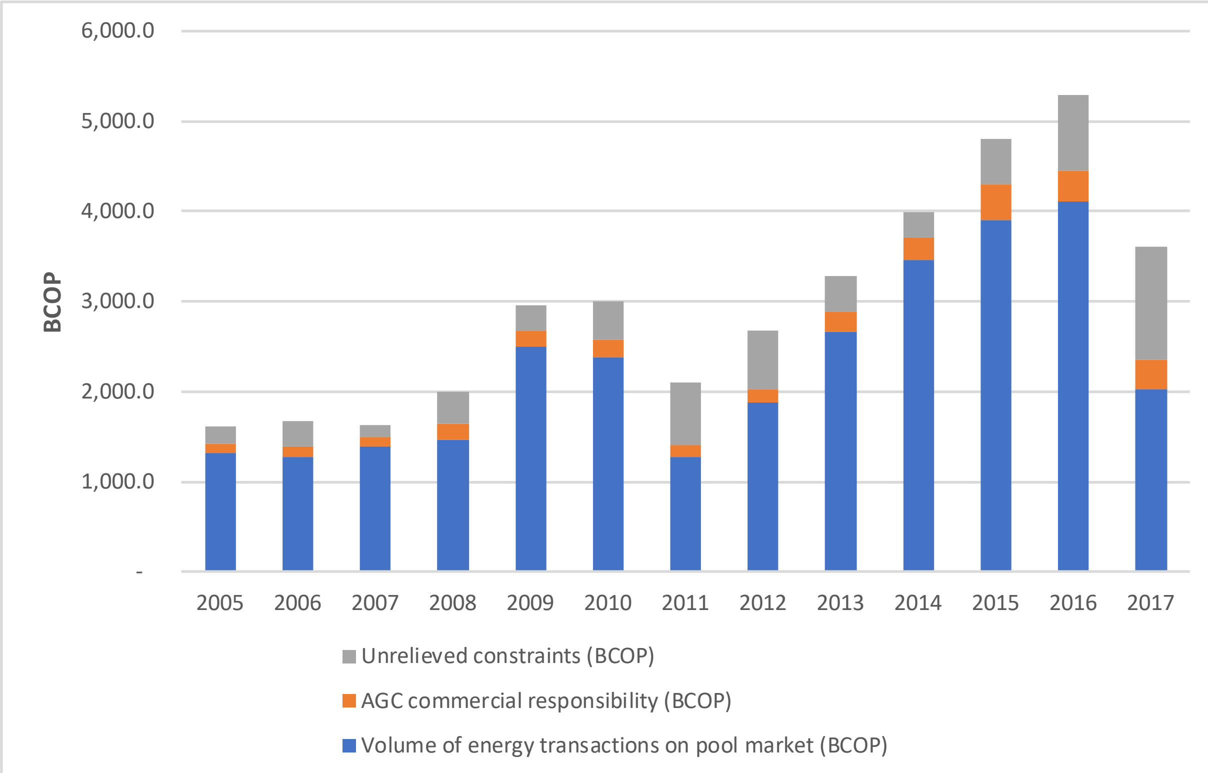

Figure 6-7 Evolution of total volume of transactions in the Colombian pool, considering energy, reserves (Automatic Generation Control) and transmission constraints.

Source: Own elaboration based on data collected by the World Bank.

As described previously (see section 3.2), the day-ahead pool in Colombia is a single-node market which disregards transmission congestions and any other system constraints. Although these costs are not reflected directly in spot prices (*"Bolsa"* prices), these constraint costs do pass-through to final retail tariffs (as described in section 3.2). Constraint costs are highly dependent on hydrology and particular operating conditions. Yearly unrelieved constraint costs in the day-ahead pool increased by 71% in real terms over the past decade, from 285 BCOP in 2005 (expressed in 2015 COP) to 487 BCOP in 2015. As a share of total pool trades, constraint costs have varied from 8% to its highest level of 54% in 2011. Considering the importance of these constraint costs, it has been argued that significant operating cost savings could be achieved by implementing a more efficient congestion management mechanism in Colombia, based on a market clearing more reflective of the physical realities of the transmission grid, and based on Locational Marginal Prices instead of a single-node price (Mcrae & Wolak, 2016). It is worth noting that the rules for transmission grid expansion and management have proved ineffectual to reduce congestion in the main electric link between the center (mostly hydro) and the north (mostly thermal) regions of the country, which translates into gas pipeline congestion.

6.1.3 Market concentration and efficiency

The Colombian power market is generally not highly concentrated as measured by the Herfindahl-Hirschman Index (HHI),[18] but has become slightly more concentrated from 2010 to 2015. The HHI for both energy and capacity shows a minor increase in concentration in terms of energy and capacity in the overall market (see Figure 6-8 and Figure 6-9). However, energy and capacity HHI are much higher for hydro power generating resources relative to thermal resources.

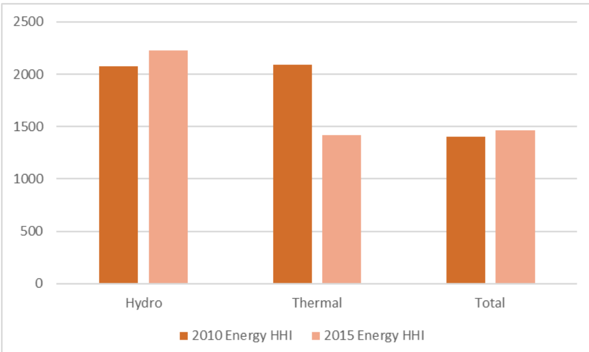

Figure 6-8 Concentration in the Colombian power market, measured by energy HHI.

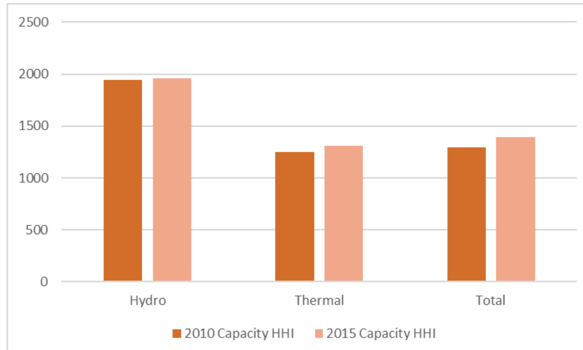

Figure 6-9 Concentration in the Colombian power market, measured by capacity HHI.

Source: Own elaboration based on data collected by the World Bank.

Energy and capacity HHI in Colombian power markets are above 2000 in some cases, hence signaling a relatively concentrated market particularly during tight supply conditions when HHI increases (see Table 6-4). Indeed, the three largest generation firms currently hold about 60% of power generation assets (see Figure 6-10). Although the high concentration of the Colombian wholesale power market raises concerns regarding market power abuse (in the spot, contracts / supply, and reliability markets), exercise of market power has not been prosecuted. The market monitoring committee (CSMEM) regularly analyzes the extent of market power in the Colombian power market, based on structural indicators (e.g. HHI, Lerner) and to a lesser extent by directly analyzing the agent behavior. However, proving sustained exercise of market power which is significantly detrimental to system reliability or efficiency is particularly difficult in practice (Wolak, 2005).

Unilateral market power can be exercised in the Colombian spot market by economic withholding of generation resources, particularly during tight supply conditions when HHI increases (Stoft, 2002). For example, the spot price increased 72% between March 4 and 5, 2014, from 149 COP/kWh to 257 COP/kWh (at 19:00). Demand increased modestly between these two days (see Figure 6-11). However, supply was also constrained primarily by two agents who drove their marginal resources out-of-merit, by increasing the price offered for these marginal resources (by a factor of 7 and 1.7 between the first and the second day). These agents had incentives to increase the spot price since they had other generating resources in-merit during March 5 (CSMEM, 2014). Despite this evidence, it is in general difficult to prove that observed

[18] HHI is a measure of market concentration defined as the sum of the squares of firm-level market share. Market share is calculated with respect to both energy output (in GWh) and installed capacity (in MW).

economic withholding was the result of market power exercise, and it is also difficult to identify sustained market power abuse (since isolated events are harder to track and may not be worth prosecuting).

Table 6-4 Concentration in the Colombian power market, measured by both energy and capacity HHI.

Technology	2010 Energy HHI	2015 Energy HHI	2010 Capacity HHI	2015 Capacity HHI
Hydro	2074	2228	1943	1956
Thermal	2087	1419	1250	1313
Total	**1402**	**1464**	**1296**	**1393**

Source: Own elaboration based on data collected by the World Bank.

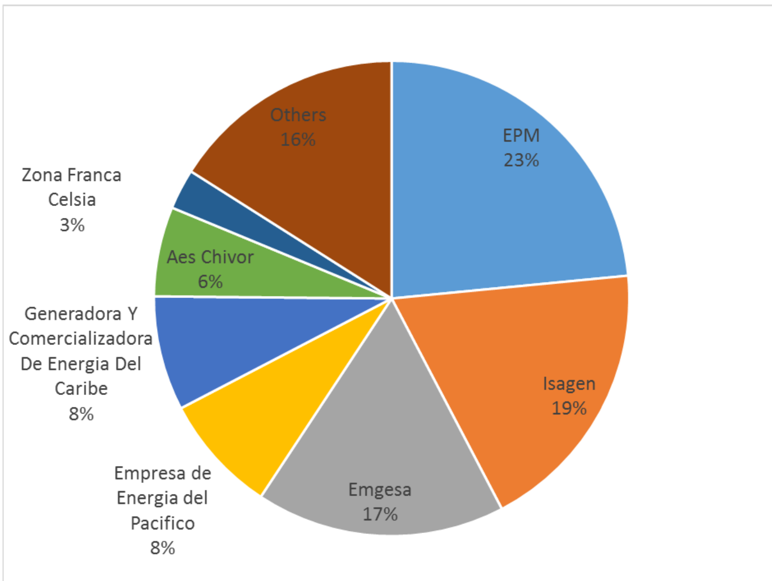

Figure 6-10 Concentration of power generating assets in Colombia (in terms of installed capacity), 2015.

Source: Own elaboration based on data collected by the World Bank.

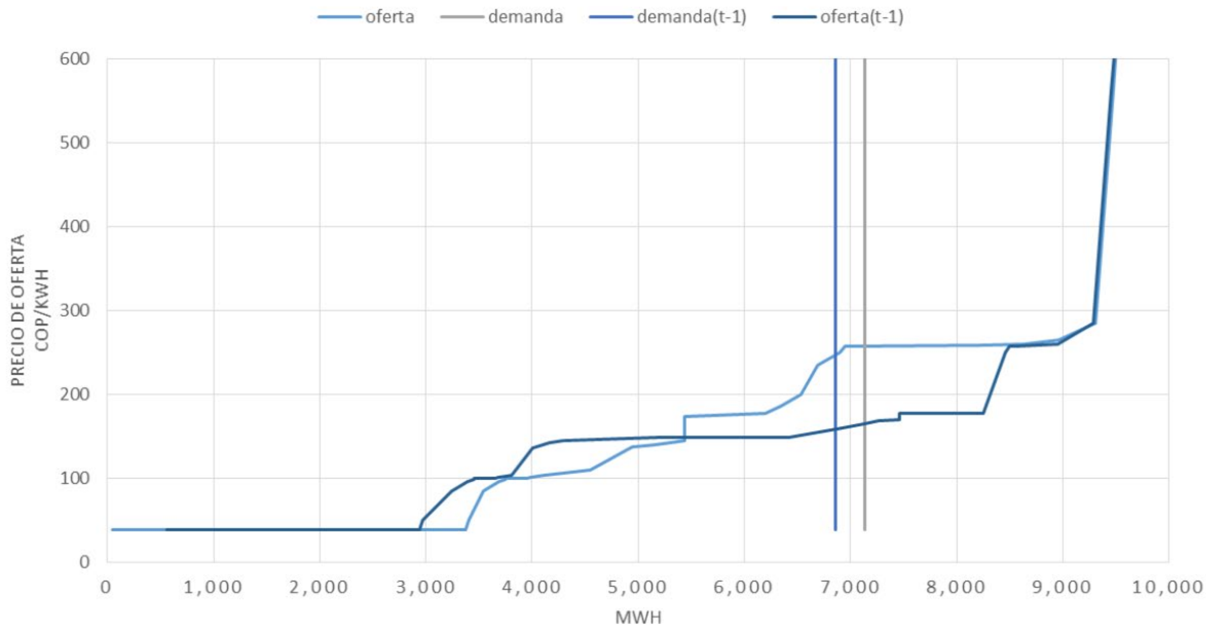

Figure 6-11 Example of price increase due to economic withholding in the Colombian power market.

Source: (CSMEM, 2014)

At the plant level, average Plant Load Factors (PLFs) in the generation segment have varied slightly between 55% and 60%. However, technology-wise PLFs have evolved diversely driven by volatile hydro inflows (see Figure 6-12). Average PLF of hydro power plants decreased from 55% in 2010 to 50% in 2015, while thermal PLF increased from 56% to 66% over the same period. Indeed, thermal-based output has replaced hydro generation due to lower hydro availability over the past years, especially during 2014-15 due to the impact of El Niño. On the other hand, average PLF of wind farms increased from 24% in 2010 to 42% in 2015, while PLF of cogeneration decreased from 62% in 2010 to 47% in 2015.

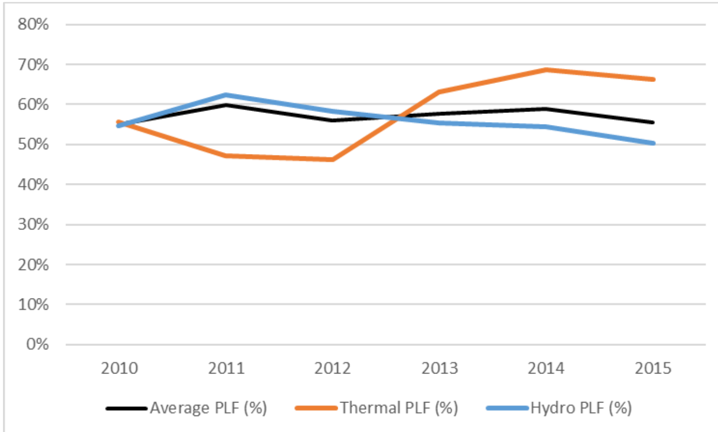

Figure 6-12 Evolution of average Plant Load Factor in Colombia, for hydro, thermal and all resources.

Source: Own elaboration based on data collected by the World Bank.

One study found that productive efficiency in the Colombian spot market increased after 2009, when CREG modified the pool by including a startup / shutdown bid for thermal plants. However, such reductions in total supply costs came about at the cost of higher price-cost markup, thus signaling market power exercise by Gencos. Therefore, productive efficiencies might have been appropriated by energy producers rather than being transferred to final customers (Castro, Oren, & Riascos, 2013).

6.2 Investment and Security of Supply

Security of supply has historically been an issue in Colombia. The rationing that occurred during 1992 El Niño event was one of the drivers for power sector reform. The Colombian power sector subsequently withstood another El Niño event in 1998 without rationing. Terrorist attacks to transmission facilities in the early 2000s again raised supply security concerns. Recently, the Colombian power sector had troubles withstanding a severe El Niño event during 2015 (along with facilities outages and fuel shortage), with government intervention to avoid rationing (see section 4).

Generation capacity growth has outpaced demand growth in Colombia over the last years (see Table 6-5). Demand for electricity has grown at a CAGR of 2% from 2010 to 2017 in Colombia (from 57 TWh in 2010 to 67 TWh in 2017), while system demand for peak power has grown at a CAGR of 1% from 2010 to 2017 (from 9.1 GW in 2010 to 10.0 GW in 2017). On the other hand, generation capacity has grown at a CAGR of 3% from 2010 to 2017 (from 13.3 GW in 2010 to 16.8 GW in 2017). Installed capacity remained almost unchanged from 2011 to 2013. Given growing generation capacity, Colombia's system reserve margin grew from 46% in 2010 to 68% in 2017.

Table 6-5 Evolution of energy demand, peak power demand and generation capacity in Colombia.

Year	System peak demand (MW)	Generation capacity (MW)	System reserve margin (%)	Peak demand growth (%)	Generation capacity growth (%)	Electricity demand (GWh)	Electricity demand growth (%)
2010	9,100	13,290	46%			56,621	

2011	9,295	14,420	55%	2%	9%	58,062	3%
2012	9,504	14,361	51%	2%	0%	59,211	2%
2013	9,383	14,559	55%	-1%	1%	61,182	3%
2014	9,551	15,489	62%	2%	6%	64,014	5%
2015	10,095	16,420	63%	6%	6%	66,275	4%
2016	9,904	16,595	68%	-2%	1%	66,318	0%
2017	9,996	16,779	68%	1%	1%	66,893	1%
CAGR 2010-17	**1.4%**	**3.4%**				**2.4%**	

*Net effective generation capacity in the National Interconnected System by December 31st.

Source: Own elaboration based on data collected by the World Bank.

Despite very high and rising reserve margin, supply reliability in Colombia must be assessed considering its dependence on hydro power plants with little multi-year storage capacity. Power generation from thermal power plants increased sharply during 2015, providing 32% of total generation (see Figure 6-13). Average PLFs increased for thermal power plants while PLFs decreased for hydro power plants, mostly due to the 2015-16 El Niño phenomena (see section 6.1.3). Such trend reversed during 2017 due to normal hydro inflows, highlighting the dependence of Colombia's generation mix on the prevailing hydrological conditions.

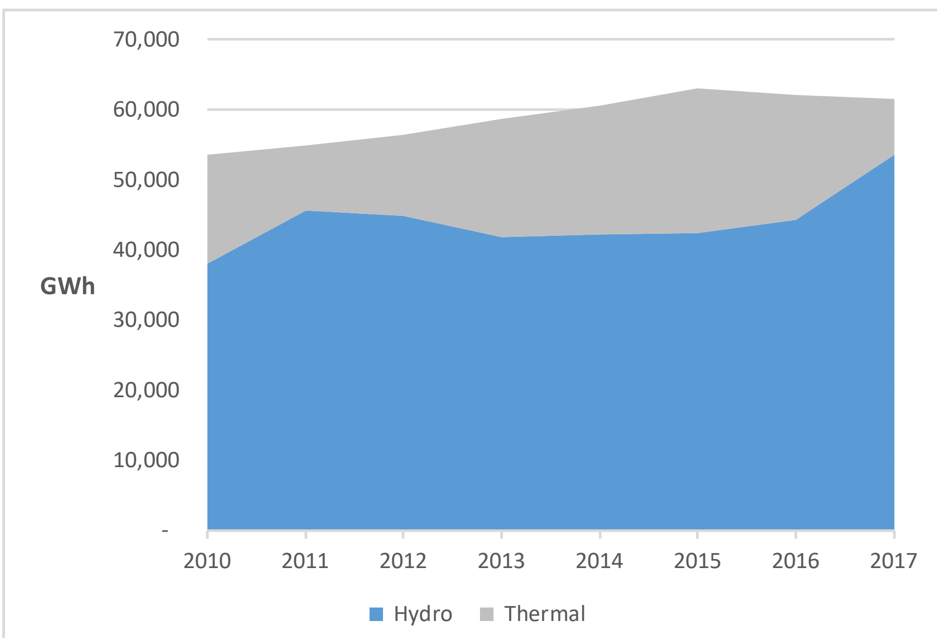

Figure 6-13 Evolution of power generation by technology in Colombia.

Source: Own elaboration based on data collected by the World Bank.

Nevertheless, capacity expansion of generation has been driven by hydro power plants over the past decade (see Figure 6-14). Indeed, hydro installed capacity grew by 28% (from 8.5 GW in 2005 to 10.9 GW in 2015), while thermal generation capacity grew by 9% (from 4.4 GW in 2005 to 4.7 GW in 2015).

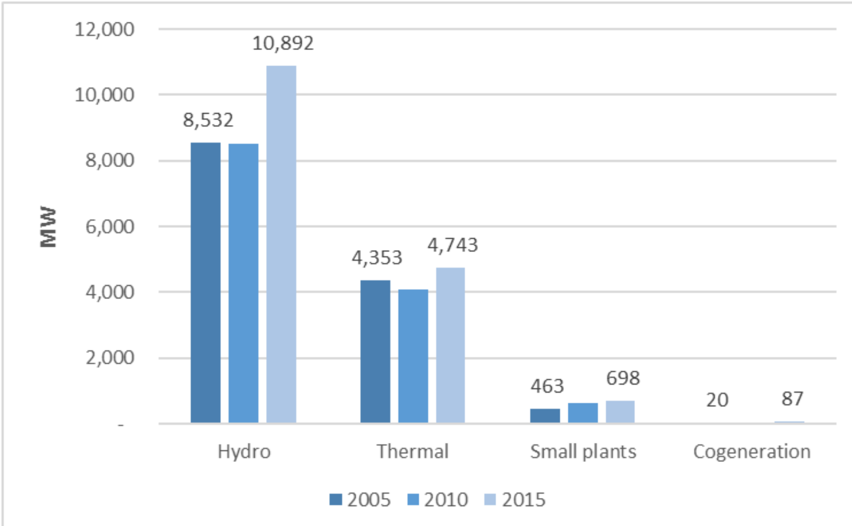

Figure 6-14 Evolution of technology-wise generation investment in Colombia.

Source: Own elaboration based on data collected by the World Bank.

The Colombian power sector has therefore improved its ability to withstand stressful system situations (e.g. severe El Niño phenomena combined with facilities outages and fuel shortage) without incurring politically, economic and socially costly rationing of electricity. Colombian power supply continues to rely on hydroelectricity backed by thermal (mostly gas and oil-fired) generation, with increasing but still minor contributions from other generating technologies (e.g. wind).

The main obstacles for generation investment and market entry in Colombia are regulatory uncertainty (in particular with respect to the stability and duration of the capacity market), gas supply scarcity and the lack of a robust gas transport network (see section 2.2), complicated and lengthy processes for permits and licenses, and public opposition to new generation projects.

Although there have been social and political issues that have caused delays in generation and transmission projects entry, it is also fair to say that clear signals have been provided to meet demand expansion and energetic needs. Generation planning in Colombia, however, is not exempt from criticism. While it is clear that generation planning is indicative, some agents affirm much remains to be integrated to the planning agenda, regarding the mix of generation technologies and the use of alternative resources (e.g. gas and renewables).

Imports and exports of electricity between Colombia and its neighbors have evolved unequally over recent years (see Figure 6-15). Exports from Colombia to Ecuador reached 1,295 GWh in 2011 and 457 GWh in 2015, with an uneven evolution. Very modest amounts are imported from Ecuador, peaking at 47 GWh in 2014. On the other hand, exports to the República Bolivariana de Venezuela grew from 249 GWh in 2011 to 715 GWh in 2013, and have since reduced to barely 3 GWh in 2015.

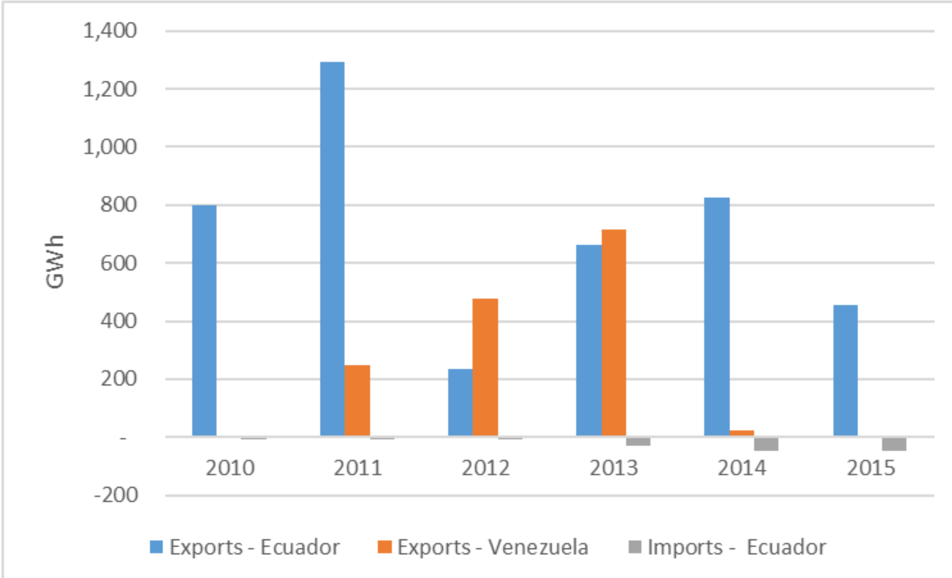

Figure 6-15 Imports and exports of electricity in Colombia.

Source: Own elaboration based on data collected by the World Bank.

Despite potential benefits from increased international trading between Colombia and its neighbors (Raineri et al., 2013), imports and exports remain limited and make up for less than 1% of total energy production in Colombia (see section 2.1).

6.3 Sustainability

Colombia's generation fleet primarily consists of hydro and thermal (mostly gas and oil-fueled) power plants, as described in section 2.1. Thermal-fired generation has increased over the last five years primarily due to low hydro availability. As a result, fossil fuel consumption for power generation increased from 45 TBtu in 2005 to 409 TBtu in 2015. The CO_2 emissions factor reached 0.23 tCO_2/MWh, particularly due to the El Niño events and very low hydro inflows during 2015-16. Emissions in the Colombian power sector can thus vary drastically across different hydrological conditions, with near-zero emissions during wet seasons. It is worth noting that normal hydrological inflows during 2017 result in lower thermal generation and thus lower CO_2 emissions equal to 0.08 tCO_2/MWh.

Non-conventional renewable energy has not developed substantially in Colombia. A public policy guideline for developing the power generation sector (and particularly renewables) through long-term contracting was issued in March 2018.[19] However, secondary regulation, implementation and the outcomes of this policy guideline remain to be seen. Furthermore, Colombia is yet to develop sophisticated ancillary services markets and demand response, among other market elements which could facilitate the integration of renewables in the Colombian power market. In particular, the firm-energy market has been criticized since it may not appropriately reflect the value of renewables as

[19] https://www.minminas.gov.co/documents/10180/23517/47726-dec_0570_230318.pdf

complementary sources to hydro generation, since firm-energy of each power plant is calculated on a stand-alone basis (Keay et al., 2018).

6.4 Summary

Table 6-6 summarizes previously described outcomes of the Colombian power market.

Table 6-6 Overview of power market outcomes in Colombia.

Power Market Outcome Element	Colombia outcome
Most relevant markets	1. Financial Bilateral Contracts (mostly long-term supply contracts), with 67 TWh (78%) and $11,305 BCOP during 2017. 2. Spot market (pool), with 19 TWh (22%) and $ 2,032 BCOP during 2017. 3. Capacity market: sporadic firm energy auctions and monthly reliability payments.
Evolution of prices and competition	• Contracts prices increased by 38% in real terms (from 37 USD/MWh in 2005 to 50 USD/MWh in 2016, expressed in 2015 USD). • Regulated contracts have consistently been priced about 20% higher than liberalized contracts. • Pool energy prices rose by 158% in real terms (from 39 USD/MWh in 2005, to 99 USD/MWh in 2016, expressed in 2015 USD). • Pool price spikes occurred during El Niño 2015 event. Although customers are hedged of the pool price through the capacity market up to the regulated scarcity price, CREG froze the scarcity price to protect Gencos from the plunge of oil prices. • Market can be concentrated during tight demand-supply conditions and prone to market power abuse specially under hydro scarcity conditions. Productive efficiency increased after allowing bidding of startup / shutdown prices in the pool (2009), but energy producers appropriated most of the efficiency gains. Firm energy auctions have lacked competition.
Stressful events for power markets	• 1992: rationing due to El Niño event is major driver for power sector reform. • 1998: no rationing despite El Niño event. • 2009: no rationing despite El Niño event. • 2015: no rationing despite intense El Niño event, proving success of the capacity market (although not exempt of flaws).
Evolution of investment and supply reliability	• System reserve margin grew from 46% in 2010 to 68% in 2017. Peak power demand grew at a CAGR of 2% from 2010 to 2017 (from 9.1 GW to 10.0 GW). Generation capacity grew at a CAGR of 4% from 2010 to 2017 (from 13.3 GW to 16.8 GW). • Power supply has become less dependent on hydro availability by increased investment in thermal power plants. Investment in generation to meet demand occurred despite social and political issues.
Evolution of sustainability	Increased fossil fuel use, no noticeable NCRE evolution. Carbon emissions factor of 0.23 tCO_2/MWh during 2015 (due primarily to El Niño event), down to 0.08 tCO_2/MWh during 2017 (given normal hydro inflows).

7 Conclusions on Colombia's Experience with Power Market Reforms

Competition: Most of electricity supply in Colombia is traded in medium- to long-term contracts between Gencos and suppliers on one hand, and on the other hand between suppliers and final customers. Two types of customers were separated: customers with regulated retail tariffs (mostly households and small businesses); and large customers with bilaterally agreed contract prices. Contract prices rose by 38% from 37 USD/MWh in 2005, to 50 USD/MWh in 2016 (expressed in 2015 USD). However, regulated contracts have been consistently priced about 20% higher than liberalized contracts.

Pool prices surged over the past decade, and especially until 2016 due to low hydro availability, up to 137 USD/MWh in 2015. Many diagnoses reveal that there are flaws that make the Colombian power market vulnerable to the exercise of market power. Market power derives from the concentration of generation resources, vertical integration of some agents which allow possibilities for pass-through implicit in market regulations (resolution 119); as well as shortcomings in the overall operation of the contracts market. In addition, tariffs, spot- and contract- prices have been rising, on average, at significant rates over the last ten years, raising concerns regarding the extent of market power abuse by dominant Gencos / suppliers. However, no formal investigation nor prosecution has proven sustained exercise of market power detrimental to either system reliability or efficiency. Moreover, obstacles remain for generation investment and market entry, including regulatory uncertainty, gas supply scarcity, weakness of power and gas transport networks, complicated and lengthy processes for permits and licenses, and public opposition to new generation projects.

Reliability of supply: There is sufficient evidence of the effects that the 1992 blackout had on electricity policy and regulation. The political, social and economic consequences of this event were such that it has had a major influence on the development of the sector since then. This event and the current structure of the Colombian electricity sector have explained why the expansion of the power sectors has been mainly based on hydroelectric and fossil-fuel technologies. Nevertheless, this path has not contributed to electricity-cost-reductions, technological diversification and long-run security of supply. As there is market concentration under hydro scarcity situations, companies and associations have not contributed to the required changes of the Colombian power sector, including to the diversification of the electricity matrix in the country.

While the promotion of savings is crucial to the system, the functioning of the regulatory mechanism designed to ensure reliability is called into question. By way of that charge Colombian users have paid more than 18 billion COP (approximately US$6 billion) in the last decade; there are, however, other mechanisms and interventions that have been implemented in episodes like "El Niño" 2010 and 2016. For example, the scarcity price was intervened by the regulator to protect Gencos from the plunge of oil prices, and excess costs were passed-through directly to final customers. Customers had to bear excess costs despite having continually paid for the reliability of service which, when needed, was provided with difficulties and regulatory interventions. Also, the first capacity auction held in 2008 was not very competitive.

Even though the Colombian regulator has set a mechanism that pursues security of supply, this has not operated adequately since:

a) there has been insufficient competition in auctions,
b) the clearing price reached at Firm Energy Obligation auctions has been increasing,
c) this has been the main driver for capacity expansion,
d) there has been need for reconfiguration auctions (to decrease capacity that has been previously auctioned), and finally
e) in critical times, the government has been forced to intervene prices and the power market as a whole, and excess costs arising from these interventions have been passed-through to final customers.

As politicians, scholars and consultants are demanding reforms to the reliability charge; some agents are proposing rises in the scarcity price, while others state that the mechanism has worked properly. There are also other political economy issues involved as politicians are deciding on very specialized technological-based issues, introducing uncertainty regarding the adequacy of the signals for coordinated future expansion of the power system.

In summary, the Colombian power market is currently showing some signs of structural weaknesses that include the following:

- Average generation and contract prices have been steadily increasing;
- The reliability charge shows dysfunctionalities;
- The Colombian electricity and natural gas markets lack integration necessary for ensuring reliable and efficient supply;
- Demand participation has been very limited in the power market; and
- Full implementation of Law 1715 (on incentivizing non-conventional renewable generation) is required.

8 References

Arango, S., Dyner, I., & Larsen, E. R. (2004). Lessons from deregulation in Colombia: successes, failures and the way ahead. *Utilities Policy*, *32*(15), 1767–1780.

Castro, L. De, Oren, S., & Riascos, A. J. (2013). *An Evaluation of CREG 051 – 2009 Regulatory Intervention in Colombian Electricity Mark*.

Contraloría General de la República. (2016). *Informe de resultados de la actuacion especial de fiscalización sobre el manejo de recursos del cargo por confiabilidad*.

Cramton, P., Ockenfels, A., & Stoft, S. (2013). *Capacity Market Fundamentals*. Retrieved from http://stoft.com/wp-content/uploads/2013-05_Cramton-Ockenfels-Stoft_Capacity-market-fundamentals.pdf

Cramton, P., & Stoft, S. (2007). Colombia firm energy market. In *Proceedings of the Annual Hawaii International Conference on System Sciences* (pp. 1–11). https://doi.org/10.1109/HICSS.2007.133

CREG. (1995). Código de redes. Retrieved from http://apolo.creg.gov.co/Publicac.nsf/Indice01/Codigos-1995-RES.025-1995.COD..REDES.-.COD..OPERACION?OpenDocument

CREG. (2006a). Resolución 071-2006.

CREG. (2006b). Resolution 065-2006. Retrieved from http://apolo.creg.gov.co/Publicac.nsf/1c09d18d2d5ffb5b05256eee00709c02/68320ef6fdb033c30525785a007a6d65?OpenDocument

CREG. (2007). *Reliability Charge: Regulatory Scheme to Guarantee the Reliability in the Supply of Electric Energy in Colombia, A Long-Term Vision*. Retrieved from http://www.creg.gov.co/cxc/download/documentos/ReliabilityCharge.pdf

CSMEM. (2014). *Informe No 94 – 2014*.

EIA. (2016). Colombia Country Analysis Brief. Retrieved December 22, 2017, from https://www.eia.gov/beta/international/analysis.cfm?iso=COL

Harbord, D. (2016). *CREG Expert Panel on Colombian Energy Market Reform*.

Harbord, D., & Pagnozzi, M. (2014). Britain's Electricity Capacity Auctions: Lessons from Colombia and New England. *The Electricity Journal*, *27*(5), 54–62. https://doi.org/10.1016/j.tej.2014.05.004

Keay, M., Letova, K., Yao, R., Davidson, M., Bialek, J., Robinson, D., … Godinho, C. (2018). June 2018: ISSUE 114, (114), 1–58. Retrieved from https://www.oxfordenergy.org/wpcms/wp-content/uploads/2018/06/OEF-114.pdf

Maurer, L., & Barroso, L. (2011). *Electricity Auctions : An Overview of Efficient Practices*. The World Bank. https://doi.org/10.1596/978-0-8213-8822-8

Mcrae, S. D., & Wolak, F. A. (2016). *Diagnosing the Causes of the Recent El Niño Event and Recommendations for Reform*. Retrieved from https://web.stanford.edu/group/fwolak/cgi-bin/sites/default/files/diagnosing-el-nino_mcrae_wolak.pdf

Millán, J., von der Fehr, N.-H. M., Ayala, U., Walker, I., Benavides, J., Rufín, C., & Brown, A. (2003). Keeping the Lights On: Power Sector Reform in Latin America. Retrieved from http://publications.iadb.org/handle/11319/311

Raineri, R., Dyner, I., Goñi, J., Castro, N., Olaya, Y., & Franco, C. (2013). *Chapter 14 – Latin America Energy Integration: An Outstanding Dilemma*. *Evolution of Global Electricity Markets*. Elsevier. https://doi.org/10.1016/B978-0-12-397891-2.00014-6

SIC. (2016). *Herramienta para el monitoreo del mercado eléctrico*. Retrieved from http://www.sic.gov.co/sites/default/files/files/monitoreoMEM_documentodiscusion.pdf

SSPD. (2014). *Informe sectorial Energía Eléctrica, Gas natural y Gas licuado de petróleo*. Retrieved from http://www.superservicios.gov.co/content/download/8267/70214

Stoft, S. (2002). *Power System Economics: Designing Markets for Electricity*. Piscataway, NJ: Wiley-IEEE Press.

UPME. (2016a). *Indicative Plan of Natural Gas Supply - 2016*. Retrieved from http://www1.upme.gov.co/Hidrocarburos/Estudios 2014-2016/Plan_Transitorio_Absatecimiento_Gas_Natural_Abril_2016.pdf

UPME. (2016b). *Informe Mensual de Variables de Generación y del Mercado Eléctrico Colombiano - Diciembre de 2016*. Retrieved from http://www.siel.gov.co/portals/0/generacion/2016/Segui_variables_dic_2016.pdf

UPME. (2016c). *Plan de Expansión de Referencia Generación-Transmisión 2015-2029*. *Ministerio de Minas y Energía*. Retrieved from http://www.upme.gov.co/Docs/Plan_Expansion/2016/Plan_Expansion_GT_2015-2029/Plan_GT_2015-2029_VF_22-12-2015.pdf

UPME. (2016d). *Plan De Expansión De Referencia Generación – Transmisión 2016-2030*. Retrieved from http://www.upme.gov.co/Docs/Plan_Expansion/2016/Plan_GT_2016_2030/Plan_GT_2016_2030_Final_V1_12-12-2016.pdf

Wolak, F. A. (2005). *Managing unilateral market power in electricity* (Policy Research Working Paper No. 3691). Washington, DC. Retrieved from http://documents.worldbank.org/curated/en/2005/09/6246687/managing-unilateral-market-power-electricity

Wolak, F. A. (2009). *Report on Market Performance and Market Monitoring in the Colombian Electricity Supply Industry*.

XM. (2013). *Informe de Operación del SIN y Administración del Mercado 2012*.

XM. (2014). *Informe de Operación del SIN y Administración del Mercado 2013*. Retrieved from http://informesanuales.xm.com.co/2015/SitePages/operacion/1-5-Lineas-de-transmisi?n-del-SIN.aspx

XM. (2015). *Informe de Operación del SIN y Administración del Mercado 2014*.

XM. (2017a). *Informe de Operación del SIN y Administración del Mercado 2016*. Retrieved from http://informesanuales.xm.com.co/2016/SitePages/operacion/Default.aspx

XM. (2017b). *Informe de Operación del SIN y Administración del Mercado 2017*. Retrieved from http://informesanuales.xm.com.co/2017/SitePages/operacion/7-1-Precios.aspx