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The Effect of Spot Price Control on the Future Electricity Supply

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ABSTRACT

This paper examines the effects of regulating spot price (energy generation prices) in the Colombian electricity market on the future supply and the expansion of the energy matrix. The analysis is conducted considering the recent draft resolutions from the energy and gas regulatory commission (CREG), which aim to intervene in the spot price given the increase in generation prices attributed to persistent extreme weather events such as the El Niño or La Niña Phenomenon, as well as the ongoing complaints from end users, particularly in the regulated market. The study employs econometric methods (autoregressive distributed lag models -ARDL-) and the construction of an investment function based on the concept of levelized cost of generation (LCOE). The findings suggest that a price restriction (either through regulation or presidential decree) would imply an excess of demand over supply and a reduction in investment in new projects. This would inevitably lead to the deterioration of the National Interconnected System (SIN), thereby compromising the country's energy self-sufficiency and sovereignty.

Keywords: Stochastic Process, Autoregressive Distributed Lag Models, Spot Price, Electricity Demand, Leverage Cost of Energy
JEL Classifications: C01, C12, C22, C45, C53, L11, L94

1. INTRODUCTION

During the mid-1990s, a significant number of countries began deregulating their electricity industries and restructuring their energy markets. The motivations were diverse, including addressing inefficiencies in price formation, improving quality and expanding service coverage, diversifying the energy matrix, and ensuring energy security (Stoft, 2002; Sioshansi and Pfaffenberger, 2006; Harris, 2006; Sioshansi, 2013). Energy security has been undermined by labor strikes at thermoelectric plants and severe weather events such as El Niño in several countries. In Colombia, this prompted the government to impose an 11-month period of strict energy consumption rationing in 1992.

With the enactment of Law 142 of 1994, the Colombian State granted the energy and gas regulatory commission (CREG) the authority to regulate the provision of public utilities, including energy services. The goal was to foster competition among public service providers to ensure that monopolistic or competitive operations are economically efficient, do not constitute an abuse of dominant position, and deliver high-quality services (Congreso de Colombia b., 1994). The wholesale energy market (MEM) was established in Colombia on July 20, 199 (Moreno, 2012). Since then, a significant regulatory dynamic has persistently aimed to adapt and modify the market structure to ensure sound operational and commercial practices. An annual average of 224 resolutions were issued between 2014 and 2017 (CREG a., 2018) to adapt both the energy and gas markets.

With the issuance of Law 143 of 1994 (Colombian Electricity Law), Colombia's vertically integrated companies were forced to separate their operations from the electricity production chain to promote competition and foster greater participation of the private sector. The Colombian State endeavored to meet the demand for electricity within the legal framework by ensuring efficiency and financial and economic sufficiency (Congreso de Colombia a., 1994, (Moreno, 2012).

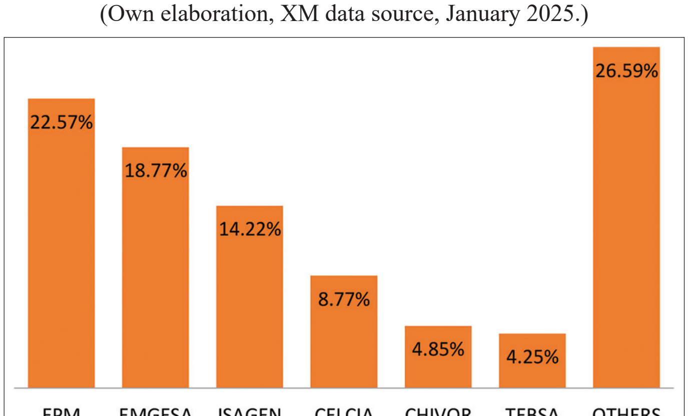
The wholesale energy market (MEM) presently exhibits an oligopolistic competition structure. The installed generation capacity in Colombia is approximately 21,452 MW, with 69% of it concentrated in four companies, as illustrated in Figure 1. Renewable energy accounts for 72% of the capacity, while non-renewable energy share is 22%. From a theoretical point of view, the energy generation price in the electricity market is not a perfect competition price; however, it primarily results from the competition between thermal and hydroelectric plants. This price is more reasonable than any control that could significantly distort agents' incentives in the market, as will be demonstrated in this paper.

The importance of this market is because electricity is a good that, unlike other goods, can only be produced in a power plant if there is an effective demand almost at the same time. This characteristic of energy production makes it different in the process of commercialization and exchange compared to other services or goods of public utility. Furthermore, this implies that neither temporal nor spatial arbitration can be made to take advantage of the competitiveness in its production and that there is no international price per kWh as there is for oil, gas or gold.

This paper examines the effects of controlling the spot price of energy generation in the Colombian electricity market on the future supply and the expansion of the energy matrix. This analysis is conducted in the context of the recent draft resolutions of the energy and gas regulatory commission (CREG) that seek to intervene in the spot price in response to rising generation prices attributed to persistent extreme weather events such as the El Niño or La Niña Phenomenon, as well as the ongoing complaints of end users, particularly in the regulated market. This intention was manifested through draft resolutions CREG 701 28 of 2023, "*whereby transitory rules are adopted on the spot price in the Wholesale Energy Market during the El Niño Phenomenon*," and CREG 701 49 of 2024, "*whereby rules are adopted on the spot price in the Wholesale Energy Market*."

The contribution of this papers can be summarized as follow: first, it is the first paper into analysis the effect of a deliberate (or artificial) intervention on the electricity market by performing a kind of price cap; second, we perform a dynamic multiplier in order to simulate effect of a positive shock on the electricity demand in the domestic interconnected system (SIN by its Spanish name); thirth, we show how the expected (future) spot price in the electricity market could affect the capacity installation, which depends of the evolution of the expected value of the spot price respect of the LCOE; finally, we are the first in introduce (and pointed out the relevance) of the concept of activation function as equivalent to an investment function.

Figure 1: Concentration of installed capacity by firm in Colombia. (Own elaboration, XM data source, January 2025.)



The analysis is conducted in two phases. First, the effects of price fluctuations on energy demand are modeled, considering the characteristics of the National Interconnected System (SIN) (e.g., a minimum-cost hydrothermal dispatch system), which would occur without an appropriate supply expansion. For this purpose, econometric methods (autoregressive distributed lag models -ARDL-) are employed, considering the historical data of the variables. Notably, generation prices in the electricity market have remained stable over time, with only minor fluctuations; they are generally weakly stationary in covariance (Barrientos et al., 2018 and Weron, 2014).

Second, the impact of price control on investment in new energy generation projects in the SIN is examined. To this end, an investment function is constructed based on the concept of levelized costs of generation (LCOE). The Levelized Cost of Energy (LCOE) is a long-term value that allows for an economic comparison of different energy generation technologies. It is a consequence of the different elements involved in construction, operation and financing, as well as the electricity market to which it will belong. The Energy International Association defines the LCOE as the cost per unit of energy in constant dollars of building and generating energy with a plant during the technical and financial life cycle. It is very important to keep in mind that LCOE concept and calculations are based on a levelized average lifetime cost approach, using the discounted cash flow (DCF) method. They are calculated at the plant level and therefore do not include transmission and distribution costs (IEA, 2020).

This analysis is conducted under the following assumptions: (i) All generation is sold in the short-term market (the electricity market); (ii) The remuneration mechanism of the generator is based on the spot price in the electricity market; (iii) The Colombian LCOE by technology is similar to the international LCOE by technology for a weighted average cost of capital rate defined as $WACC = 10\%$; (iv) Investors decide to invest in the Colombian electricity market when the spot price in the electricity market exceeds its LCOE.

This paper is divided into five sections: the introduction, the related literature, the statistical and econometric analysis, the examination of the proposed investment function, the conclusions, and the references.

2. LITERATURE REIEW

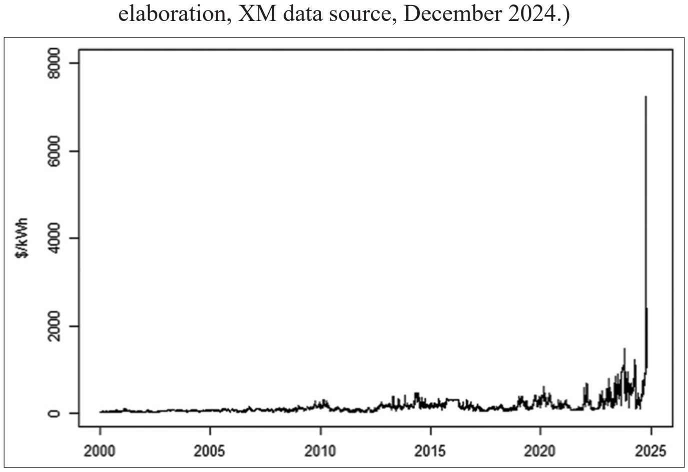
Papers related to ours are Gomez and Barrientos (2023), in this paper the authors carried out an impact evaluation of the reliability charge (Resolution CREG 071-2006) by performing discontinuity regression in time series (RDDiTS), they found that this resolution CREG significantly affected the formation of the spot market price. The results suggest that the resolution under study increased the bid of generators in the short and long term, which was accompanied by an average increase of approximately 12% in the spot price of electricity in Colombia. Figure 2 shows us the evolution of Colombian spot price, in which we can observe how in recently years it displays peaks and volatility and increasing trend. Which makes the regulatory authorities consider establishing spot price cap by introducing artificial controls.

It is worth noting that price cap regulations (PCR) involve a kind of paradox, as Sappington and Weisman (2016) show in their paper; they evaluate how PCR works in the electricity sector compared to telecommunications one, concluding that PCR has been seen it as an appropriate regulation in telecommunication but not in electricity markets because the institutional differences between the two sector matters (at least in U.S), it is due to the specific way in which PCR has been implemented in the U.S., this features may help to explain this outcome. Changes to the standard implementation of PCR might promote its adoption in the electricity sector.

The most common methods for determining transaction quantities and prices between buyers and sellers include the spot market, forward contracts, and futures contracts (Knaut and Paschmann, 2019). In a 2023 study, Trespalacios et al. analyzed the impact of El Niño on electricity prices in Colombia. Their findings indicate that the semi-nonparametric -SNP- representation of the stochastic process's random components performs better than the normal distribution. Additionally, they concluded that predicting significant weather changes can enhance risk management and decision-making in electricity systems. And the other hand, Velasquez et al in 2020 made a Comparison of the risk quantification on conventional and renewable (non-conventional) energy markets, they founded those actions of non-conventforecional market has more risk than conventional energy market.

Girish et al. (2018), investigates the spot electricity price discovery that exists among the five regions of Indian electricity market using

Figure 2: Evolution of Colombia electricity spot price. (Own elaboration, XM data source, December 2024.)



hourly spot electricity. By using Augmented Dickey and Fuller (1981) unit root tests, they find that the spot electricity prices for both peak and off-peak hours across all the regions are stationary at level, as in Barrientos et al. (2018), their study suggests that though India as a nation has all the regions inter-connected with single frequency of Power grid operation since 2008, however, these markets are not highly integrated in comparison to electricity markets of developed nations around the world.

Recently, empirical evidence suggested increasing price volatility and price spikes in electricity markets because of variable renewable energy generation, extreme weather events, and other factors. Clearly, it is the case in the Colombian electricity market because ENSO at the beginning of 2024. The fixed costs of power plants should be covered by incomes coming from competitive spot prices. Nevertheless, regulatory authorities have intended imposed market price caps to protect consumers and prevent abusive supplier behavior. But in the Colombia case, as we expressed above, these caps may be driven by political motives rather than economic logic in weak institutional settings. In this sense Murat-Sirin and Erten (2022), evaluates the welfare effect of the temporary price cap implemented in 2017 on the Turkish electricity market. By performing matching and panel data methods, they show that the temporary price cap reduced the total welfare but did not affect market clearing price and projected supply. Moreover, they show that this decision was driven by non-economic motives and identifies several fundamental problems in the Turkish market that limit the effective functioning of the market.

3. ANALYSIS OF THE EFFECT OF PRICE CONTROL ON DEMAND

While basic microeconomic theory posits that price control is detrimental by creating black markets (black economy) or shortages and undermining incentives for private (and even public) agents, our findings provide quantifiable evidence about the effects of such control, concluding definitively that a price restriction would lead to an excess of demand over supply and a decrease in investment in new projects. This, in turn, would cause the physical deterioration of the SIN and a drastic reduction in new MW of installed capacity, posing a financial risk for marketers regarding their collection process, with consequent impacts on the sector chain and the inevitable future electricity rationing.

The statistical information employed in this document consists of monthly data on the following variables: PN_t: National electricity generation spot price ($/kWh), AP_t: Water supply (kWh), DP_t: Availability (kW), D_t: Demand (kW), C_t^*: Fuel cost ($/kWh), $ECON_t$: Economic variables (CPI_t e PPI_t) for the period: 01/2021-06/2023. The estimation of the ARDL models, a short-term price and demand forecast, and a dynamic multiplier (Impulse Response Function -IRF-) simulation were conducted to assess the effect of a generation price shock on energy demand and its impact on the SIN in the absence of an increase in energy supply.

Figure 3 illustrates the evolution of the spot price in relation to hydrology (water inputs), confirming the counter-cyclical and instantaneous movement of both variables. In contrast, Figure 4 demonstrates that the evolution of the spot price and availability follows the same counter-cyclical pattern but with a delay of at least one quarter, as expected in an electricity system heavily reliant on hydrology.

3.1. Base Estimation Models

The models that will be applied belong to the autoregressive distributed lag family of order p and q with exogenous variables $x_t^{'}$, $ARDL$(p, q, q, q…):

$$y_t = c_0 + c_1 t + \sum_{j=1}^{p} \phi_j y_{t-j} + \sum_{j=1}^{q} \psi_j^{'} z_{t-j} + x_t^{'}\beta + \varepsilon_t \quad (1)$$

This model can be combined with variables in differences and lagged differences. Dynamic multipliers (impulse response function) and exchange rates of the following type can be calculated:

$$\frac{\partial y_{t+s}}{\partial y_t} = \phi_s \text{ and } \frac{\partial y_{t+s}}{\partial z_t} = \psi_s^{'} \text{ with } s = 1,2,\ldots; \frac{\partial y_{t+s}}{\partial x_{lt}} = \beta_l l = 1,2,\ldots,L \quad (2)$$

The estimated empirical models based on the general specification (1) are given by the following equations:

$$\begin{aligned}
&\ln(PN_t) = c + \alpha_1 \ln(PN_{t-1}) + \gamma_0 \\
&\ln(AP_t) + \gamma_1 \ln(AP_{t-1}) + \gamma_2 \ln(AP_{t-2}) \\
&+\theta_0 \ln(DP_t) + \theta_1 \ln(DP_{t-1}) + \theta_2 \ln(DP_{t-2}) \\
&+\beta_0 \ln(DM_t) + \beta_1 \ln(DM_{t-1}) + \beta_2 \\
&\ln(DP_{t-2}) + \delta_0 PPI_t + \delta_1 PPI_{t-1} + \varepsilon_t
\end{aligned} \quad (3)$$

$$\begin{aligned}
&\ln(DM_t) = c + \theta_1 \ln(DM_{t-1}) + \theta_2 \ln(DM_{t-2}) + \gamma_0 \\
&\ln(PN_t) + \gamma_1 \ln(PN_{t-1}) + \gamma_2 \ln(PN_{t-2}) + \gamma_3 \\
&\ln(PN_{t-3}) + +\theta_0 CPI_t + \theta_1 CPI_{t-1} + \theta_2 CPI_{t-2} \\
&+\theta_3 CPI_{t-3} + \theta_4 CPI_{t-4} + \beta \ln AP_t + \varepsilon_t
\end{aligned} \quad (4)$$

3.2. Estimation Results

The results of estimations (2) and (3) are presented in Tables 1 and 2. All the variables are expressed in logarithms; hence, the estimated parameters represent elasticities.

The forecast and the impulse response function of demand are displayed below, reflecting the changes in demand due to a negative (downward price) shock of 2 standard deviations in the generation price. This is based on the estimation of equation (3) and the results in Table 2 (Figures 5 and 6, respectively).

To interpret these results, the following factors must be considered: (i) The electric system in Colombia is hydrothermal, and dispatch is done at minimum cost; (ii) The energy balance of the system must be maintained (energy input must be equal to energy output); that is: $GH + GT = D$, in addition: Economic dispatch, by definition, implies the distribution of the total demand among each of the generating units to minimize the cost; (iii) The anticipated outcome is that an intervention/control of the spot price (which already has a ceiling and represents the scarcity price) would send a wrong signal regarding the system's expansion; (iv) It seems implausible for the national government to control, at least for now, the unit cost (UC) of energy without regulating the generation price in the electricity market, which would imply drastic modifications in contract prices resulting in catastrophic consequences for the entire sector's value chain and for potential investors.

Figure 3: Electricity generation spot prices and hydrology

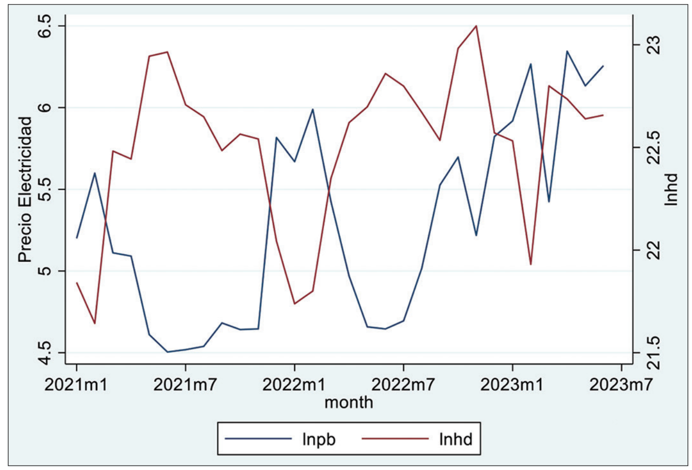


Figure 4: Electricity generation prices and availability

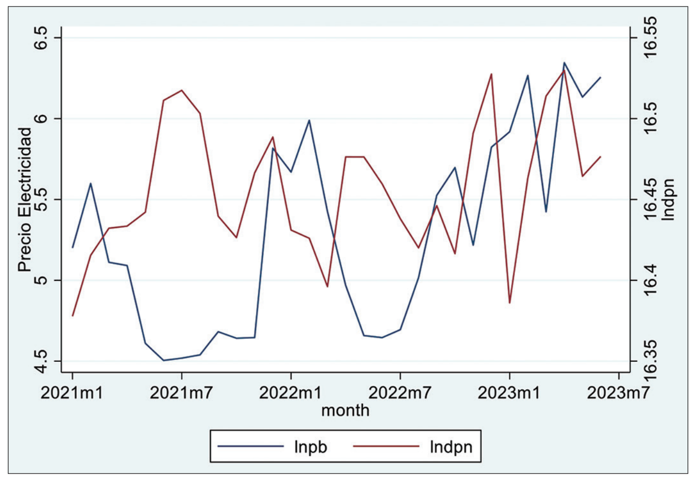


Figure 5: Short-term demand forecast

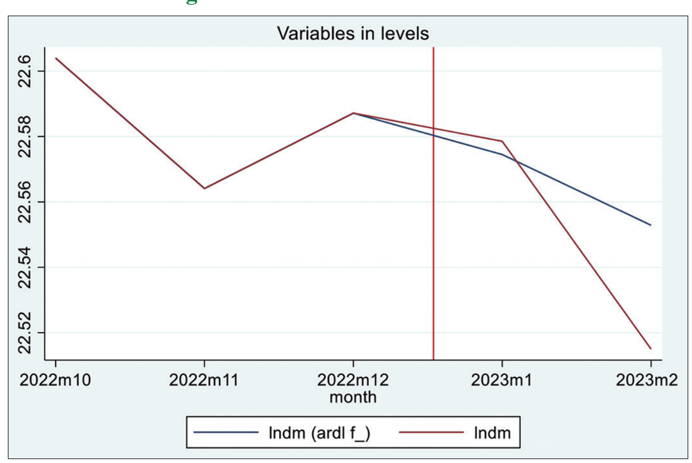


Table 1: Equation (2) Dependent variable ln (spot price)

Dependent variable ln (spot price)				
Covariates	Estimated coefficient	Standard Erres	t-value	P-value
$ln(PN_{t-1})$	0.626	0.173	3.62	0.003
$ln(AP_t)$	−0.9680	0.244	−3.96	0.001
$ln(AP_{t-1})$	0.526	0.321	1.64	0.12
$ln(AP_{t-2})$	−0.278	0.247	−1.12	0.281
$ln(DP_t)$	−2.14	2.05	−1.04	0.313
$ln(DP_{t-1})$	2.24	1.94	1.15	0.267
$ln(DP_{t-2})$	−2.65	2.02	−1.31	0.210
$ln(DM_t)$	−3.28	2.42	−1.36	0.195
$ln(DM_{t-1})$	1.33	2.21	0.60	0.55
$ln(DM_{t-2})$	3.48	2.42	1.43	0.172
PPI_t	−0.108	0.044	2.46	0.026
PPI_{t-1}	0.114	0.043	2.65	0.018
constant	25.16	101.16	0.25	0.807

Source: Own calculations. (+) Statistically significant

Table 2: Equation (3). Dependent variable ln (of demand)

Dependent variable ln (of demand)				
Covariates	Estimated coefficient	Standard erres	t-value	P-value
$ln(DM_{t-1})$	−0.198	0.265	−0.76	0.46
$ln(DM_{t-2})$	0.148	0.23	0.63	0.53
$ln(PN_t)$	−0.0060	0.024	−0.25	0.807
$ln(PN_{t-1})$	0.0195	0.0193	1.01	0.331
$ln(PN_{t-2})$	−0.0439	0.021	−2.09	0.057
$ln(PN_{t-3})$	0.00240	0.0219	0.11	0.915
CPI_t	−0.015	0.01	−1.5	0.036
CPI_{t-1}	−0.0018	0.0291	0.006	0.91
CPI_{t-2}	0.026	0.031	0.84	0.46
CPI_{t-3}	0.0209	0.030	0.69	0.503
CPI_{t-4}	−0.027	0.02	1.33	0.205
$ln(AP_t)$*	−0.021	0.031	−0.67	0.513
Constant	23.98	8.99	2.67	0.019

Source: Own calculations. (+) Statistically significant, (*) Hydrology is considered an exogenous variable

The regressions denoted by equations (2) and (3) are estimated using OLS, as all variables are stationary with level changes, and their seasonal components (especially of energy demand and hydrology. The results indicate that the signs are as expected in the estimations. Table 1 suggests there is price inertia since its historical trend keeps the price high, reflecting the agents' expectations. In the estimation, the price decreases almost instantly with a 1% increase in water inputs, while availability exerts an identical effect but with a more delayed response. The price requires time to adjust to increases in demand, although its significance is debatable; this may be attributable to the fact that a large portion of the demand is outsourced.

The spot price reacts to increases in the PPI with a one-period lag, albeit significantly. The estimation in Table 2 shows that a 1% price rise in subsequent periods, at least after the second, results in a statistically significant decline in demand. Demand responds gradually, but it does so within a daily framework at an hourly resolution; a duration of two or more periods is considered medium-term (although this is debatable). A similar behavior is observed with the CPI; demand responds to increases in this variable, although to a considerable extent. The forecasts confirm the already stated results: the price is expected to rise, and the demand is predicted to fall.

Figure 6: Demand response to a spot price shock

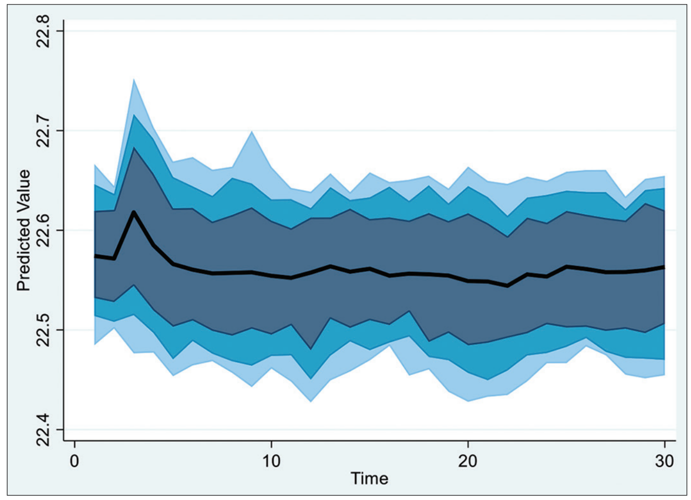
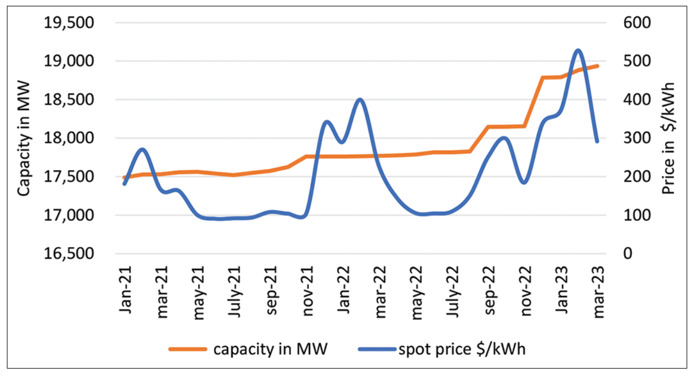


Figure 7: Spot price and effective capacity of the SIN



The simulated IRF indicates that a restriction in the downward spot price by only two standard deviations results in an approximate 2.1% jump in total demand. Given that the system's energy balance must always be maintained (term) and the economic dispatch must satisfy the power equals production conditions, more drastic price restrictions imply larger jumps in demand. There is a very high risk of discouraging system expansion (installing more MW), perhaps resulting in the deterioration of the existing installed capacity and subsequent rationing.

4. ANALYSIS OF THE EFFECT OF PRICE CONTROL ON INVESTMENT

4.1. Cost of Capital

The following assumptions are essential in understanding the conclusions derived from the activation function constructed: (i) All generation is transacted in the short-term market (the electricity market); (ii) The remuneration mechanism of the generator is based on the spot price in the electricity market; (iii) The Colombian LCOE by technology is similar to the international LCOE by technology for a $WACC = 10\%$; (iv) investors opt to invest in the Colombian electricity market when the spot price exceeds its LCOE; (v) the time in years for large-scale construction, including documentation and permits, is as follows: Solar: 4; wind: 5; large hydro ($x > 100\ MW$): 10; medium hydro ($x > 20\ MW$): 6; thermal: 4.

It is crucial to recognize that the decision to install capacity in the SIN depends on several factors, including the reserve margin (difference between supply and demand), the price in various markets, the electricity market, contracts, reliability, complementary services, expected profitability, macroeconomic variables, and regulatory stability. However, the spot price (electricity market) is a fundamental determinant as it contains a significant amount of information about these variables.

Figure 6 illustrates the monthly capacity growth in the SIN (supply) compared to the monthly behavior of the average spot price in the electricity market. It can be observed between years 22 and 23 that the capacity increases when the price is high and remains steady when the price is low. Between years 21 and 22, the exact relationship is observed, albeit with a delay of approximately 1 year. Thus, it is concluded that the entry of capacity into the SIN is based on the expected value of the spot price in the electricity market, consistent with the generation plants' construction periods.

Figure 7 illustrates capacity in the SIN will increase as long as the expected (future) spot price in the electricity market increases and surpasses the LCOE. Conversely, if the expected spot price decreases, capacity installation in the SIN will remain constant, provided that the future price is lower than the LCOE of energy generation. Therefore, the investment function for an investor in energy generation projects is an activation function, and the decision whether to invest or not depends on the behavior of the expected value of the spot price in the electricity market. The mathematical expression in equation (4) is an investment-activation function defined as:

$$I_t = \begin{cases} 1 : Pb_{t+\Delta t} > LCOE \\ 0 : Pb_{t+\Delta t} < LCOE \end{cases} \tag{5}$$

Where $pb_{t+\Delta t}$: Future spot price in the electricity market and *LCOE*: Levelized cost of energy.

5. CONCLUSION

This paper assesses the effect of controlling the generation price in the electricity market on generation expansion (new energy supply). The following conclusions are drawn. First, expansion is deteriorated by the negative effect of an increase in demand over supply, which, in the long run, results in higher prices, a greater risk of market concentration (Gómez and Barrientos, 2022), and adverse effects on the welfare of consumers in the regulated market. Second, in terms of investment in the sector, as long as the expected spot price in the electricity market does not exceed the levelized cost of energy production, investment in new generation plants stagnates, or operating capacity could be reduced as it becomes financially unviable and unsustainable. In the absence of generation expansion or with a generation contraction, the country's energy autonomy and sovereignty are at risk, as shortage is imminent.

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