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Financial Viability of Thermal Power Generation Plants in the Transition to Renewable Energy

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ABSTRACT

The energy transition will occur due to the natural decline in profitability of thermal power generation assets, and their place in the energy matrix will be taken over by renewable energies. Ensuring electric supply security, a cornerstone of the energy trilemma, is a priority for both developed and developing countries. Nations heavily reliant on hydrological resources employ thermal energy as a backup, making the exploration of financial feasibility for such projects pertinent. This study introduces an economic valuation model for a dispatchable thermal power generation plant in the Colombian market. Associated uncertainty is assessed based on revenue from market sales, bilateral contracts, and firm power remuneration – elements constituting the cash flow and converging into profitability and risk analysis. These are calculated through the Monte Carlo simulation methodology. Additionally, a sensitivity analysis is conducted, accounting for variables such as the "Reliability Payment" settlement price, capacity factor, and costs linked to coal supply. The results emphasize the need for firm power remuneration as a crucial incentive for the success of such projects. Furthermore, the criticality of dispatch level in relation to profitability is verified. Finally, the impact of coal taxes and supply negotiations on financial feasibility is assessed.

Keywords: Economic Valuation, Conventional Energies, Uncertainty
JEL Classifications: Q3, Q40

1. INTRODUCTION

The current energy demand needs environmentally friendly approaches. Global objectives extend beyond mere electricity generation and distribution, emphasizing sustainability and heightened efficiency. This leads to the rise of new technologies and policies promoting renewable or "clean" energies. However, new incentives directly affect conventional generation methods. Specially, considering that clean energies aim to replace fossil fuels.

According to BP's "Statistical Review of World Energy 2021," the regions of South and Central America possess significant hydropower potential. While Asian regions primarily rely on coal for power generation. In contrast, Europe leads with the highest proportion of renewable sources in the total energy generation. In comparison to the electricity generation matrix of other countries, Colombia's generation mix is similar to that of nations like Brazil (64% hydropower, 9% natural gas, 4% coal) and Canada (60% hydropower, 11% natural gas, 6% coal) (Grupo Energético Británico BP, 2021). With Canada as an example, the country aims to halt thermal coal exports before 2030. This complements the goal of phasing out coal-fired power by the same year, while providing financial assistance to coal industry workers and communities as they transition to more sustainable energy sources (Adebayo, 2022).

In the case of Colombia, the country has large coal reserves with an expected life of more than 90 years (UPME, 2020), with substantial annual royalties. The coal stands out for its high calorific value, promoting cleaner combustion with lower CO_2 emissions. This abundance raises questions about investing in conventional energy generation projects, which involve significant risks, uncertainties, and irreversible investments.

Colombia has maintained energy security since the 1992 blackout, an event that exposed the vulnerability of a hydro-dependent electrical system with an aging thermal power plant infrastructure. In general, such an incident represents an ongoing risk for countries that heavily rely on hydroelectric generation. Therefore, dry seasons pose a threat to the system. Colombia, in response, has implemented mechanisms such as the Reliability Payment (RP) through entities like the Energy and Gas Regulation Commission (Comisión de Regulación de Energía y Gas, CREG). Resolution CREG 071-2006 outlines the methodology and provisions for this payment in the Wholesale Energy Market (MEM, for its acronym in Spanish) (CREG, 2006), ensuring resource availability during scarcity periods. It introduces the concept of the "scarcity price." In MEM auctions, agents commit to generating when the spot price exceeds this scarcity price, which serves as both an activation and upper limit. Following observed impacts during the 2016 "El Niño" event, CREG adjusted the calculation, resulting in the Marginal Scarcity Price (CREG, 2017).

The RP serves a dual purpose in Colombia: it regulates prices during scarcity and incentivizes investment in thermal power plants. This encourages the growth of thermal power generation, offering energy security not dependent on weather conditions. In Colombia, most electricity comes from hydropower under normal conditions, but during dry periods, thermal plants and backup sources step in to ensure a continuous power supply. This highlights the importance of the discussed concepts.

Currently, not only have incentives for clean energies intensified, but also penalties have been established for the use of fossil fuels. The latest tax reform approved in December 2022 includes new taxes on coal usage (Congreso de la República de Colombia. (2022), Ley 2277, 2022), which directly impacts the financial projections of power generation plants utilizing this mineral.

In 2021, Colombia's electricity generation matrix was predominantly hydropower-based (67.3%), with a significant contribution from thermal power generation (30.7%) (XM, 2021b). However, the RP and Long-Term Contracts auctions for 2022 projected substantial changes: only 8% from coal-fired plants, 12% from gas-fired plants, and 6% from other liquid fuels, resulting in a total of 26% thermal generation. Unconventional Renewable Energy Sources (FNCER) accounted for 14% of the total, showcasing their impact (Ministerio de Minas y Energía de Colombia, 2021).

In nations with abundant water resources, heavy reliance on hydroelectric power generation is common, which is environmentally beneficial. However, water scarcity during droughts can deplete reservoir levels, exposing electricity systems dependent on hydropower generation. This requires contingency plans that often involve backup energy sources, such as fossil fuels. This study assesses the effectiveness of a well-known measure, capacity payments, in sustaining thermal power plants. Despite legal regulations that have driven investment in Unconventional Energy Sources (FNCE), transforming the energy sector, conventional sources like gas and coal remain pivotal for energy security.

This study aims to assess the financial value of conventional power generation assets, such as coal-fired plants, amidst a growing trend favoring unconventional and sustainable energy sources. The net present value (NPV) was employed as the decision criterion, accounting for uncertainty and risk through Monte Carlo simulation. Additionally, criteria such as value at risk (VaR) and conditional value at risk (CVaR) were utilized to quantify less optimistic scenarios. In the literature review (Section 2), prominent approaches for valuing assets and companies in the energy industry are analyzed. Subsequently, in Section 3, the methodology employed in our study is detailed, highlighting the specific methods that were applied. The main results are presented in Section 4, unveiling the conclusions and key findings that emerged from the study. Finally, in Section 5, the most relevant conclusions are drawn from our results.

2. LITERATURE REVIEW

Financial valuation models for assets in the electricity sector commonly rely on the use of NPV as the primary applied methodology. This is how several authors, such as Wu et al. (2019), assess the cost-benefit of various pollution reduction technologies in coal-fired power plants. Yang et al. (2021) evaluate the performance of a non-fiscal incentive policy for carbon reduction, and Kumar et al. (2021) estimate indicators like NPV and the capital recovery factor to gauge the financial viability of solar energy technologies. The internal rate of return (IRR) is also widely used. Li et al. (2021) in their valuation model for a coal plant with carbon capture and storage (CCS) technology, taking into account the sensitivity of IRR to variations in coal prices and electricity prices.

One of the applications of NPV in the electricity sector is the levelized cost of energy (LCOE). For instance, Abdelhady (2021) uses LCOE to evaluate a solar energy project's performance and efficiency in Egypt. Fan et al. (2019) employ LCOE to compare coal-fired plants with CCS technology in China to other low-carbon emission options, finding a significant relationship between coal supply distances, coal prices, and LCOE values. Fan et al. (2018) also employ LCOE to measure the competitiveness of CCS implementation for coal-fired plants compared to gas-fired plants. However, it is worth noting that LCOE has limitations, particularly in capturing risks, as it assumes static cost flows in a changing environment, potentially leading to less accurate results when evaluating alternatives exposed to various scenarios.

To effectively value power generation assets, it is essential to directly examine their operating costs. For instance, authors like Fleten et al. (2020) analyze the costs associated with startup, shutdown, or abandon certain power plants during peak hours in the United States. Notably, their study reveals that end consumers are shouldering higher costs for system reliability than necessary. Uncertainty plays a pivotal role in risk analysis, often taking precedence over profitability in decision-making for projects. In the U.S. electricity sector, Fleten et al. (2017) delve into how regulatory uncertainty and cash flow uncertainty impact decisions to startup, shutdown, or abandon power plants. Their findings suggest that regulatory uncertainty decreases both the probability of shutdown and startup, while cash flow uncertainty increases the probability of startup.

Complexity, substantial capital requirements, volatile electricity prices, and uncertainty regarding variables affecting project feasibility drive decision-makers in the electricity sector to explore a wider range of assessment methods. Given the significance of uncertainty in financial valuation, static scenarios may not adequately address risks. Therefore, utilizing supplementary tools like the Monte Carlo simulation method is essential for gaining a more comprehensive understanding of the landscape.

The Monte Carlo method, widely applied in various fields, involves the stochastic simulation of variables to approximate their probabilistic distribution closely. Harris (2017) demonstrates one application by examining the potential impacts of fiscal policies on the profitability of solar generation projects, incorporating risk through Monte Carlo simulation to calculate the probability of unfavorable outcomes. Martínez-Ruiz et al. (2021) use Monte Carlo simulation to evaluate the financial viability of a geothermal energy project in Colombia and apply real options theory to uncover strategic value in abandonment options during the investment phase. Most recently, Erfani and Tavakolan (2023) employ Monte Carlo simulation to assess the financial risk associated with wind energy investment projects, quantifying variability and uncertainty in financial outcomes.

In the current context of thermal power plants, recent studies have emerged. Rokhmawati et al. (2023) evaluated a coal-fired thermal plant using criteria like LCOE, NPV, and IRR, while also quantifying potential social costs associated with this technology. On the other hand, Zhang et al. (2023) utilized LCOE to assess the benefits of implementing CCS technology in a coal-fired thermal power plant, comparing its performance to similar CCS technologies and calculating carbon emission savings.

Financial valuation of electricity sector assets continually evolves, with NPV, IRR, and LCOE serving as robust tools for economic project assessments. However, the complexity and uncertainty inherent in this sector demand more comprehensive approaches, such as Monte Carlo simulation, to address dynamic risks. Balancing financial, technical, and environmental factors is essential for informed decision-making and sustainability in electricity generation.

3. METHODOLOGY

This work was based on a case study in Colombia, for a pulverized coal thermal power plant with an installed capacity of 350 MW. The financial valuation of the thermal plant is proposed by applying NPV and LCOE criteria through Monte Carlo simulation. First, the regulatory framework was reviewed, and the project's free cash flow was constructed, encompassing cost and revenue functions, investments, depreciations, and working capital. Then, 10,000 scenarios were simulated, considering the input arguments of the main variables of the financial model. Figure 1 presents the followed methodology for this study.

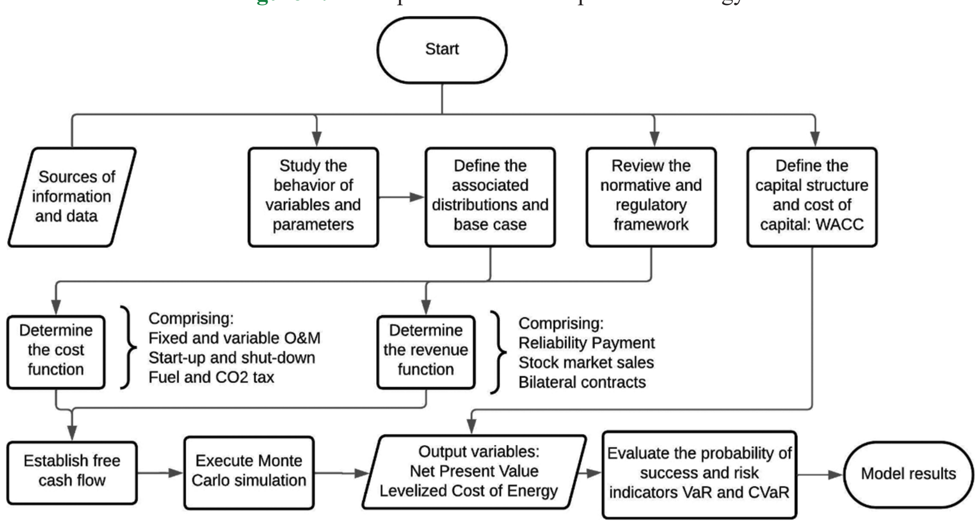
3.1. Variables and Input Parameters: Assumptions and Distributions

Among the established arguments for the configuration of the base case are a 24-year evaluation period, where the construction phase spans 4 years and the production phase spans 20 years, with a tax rate of 35%. The analyzed project entails an investment of 1500 USD$/kW, primarily composed of main equipment, civil, mechanical, and electrical works, and other mixed engineering, procurement, and construction (EPC) costs. Table 1 details the categories constituting the investment in capital expenditures (CAPEX).

A policy of 2 months of fuel costs was established for the working capital. The input variables and their distributions are provided in Table 2.

The parameters used are listed in Table 3.

Figure 1: Description of the developed methodology



Source: Own elaboration

3.2. Capital Structure

The project's cost of capital was estimated using the weighted average cost of capital (WACC), which was calculated based on a 30% equity (*E*) and 70% debt (*D*) structure. Such a capital structure with high levels of debt relative to assets (*A*) is well-known in the electricity sector, particularly recognized for maintaining a higher leverage level compared to other sectors. This is caused by the significant capital requirements and the high cost that private equity (K_e) could have in comparison to the cost of debt (K_d).

We used a private cost of capital, K_{e1}, as the base case, calculated based on IBR+Spread (IBR= Colombian Reference Banking Rate) (Banco de la República de Colombia, 2022a). Additionally, we calculated an alternative cost of capital, K_{e2}, for comparison, using the capital asset pricing model (CAPM) as shown in expression (1).

$$K_{e2}=(1+R_f+\beta_{l*}M_{rp})*(1+Dev)-1 \quad (1)$$

R_f=Risk-free rate = U.S. Treasury bonds (Damodaran, 2023b)
β_l=Leveraged beta based on the Debt/Equity ratio. Calculated using Damodaran (2023a)
M_{rp}=Risk premium (Damodaran, 2023b)
Dev=Implicit devaluation COP$/USD$ (%) (Banco de la República de Colombia, 2022b)

Table 1: Capital expenditures detail

Concept	(MM USD$)
Main equipment	293.48
Balance of plant	35.18
Civil engineering works	23.63
Mechanical engineering works	54.60
Electrical engineering works	5.25
Buildings	4.73
Plant startup costs	34.13
Mixed costs under EPC	51.98
Miscellaneous others	22.05
Total CAPEX (MM$)	525.00

Sources: Data adjusted based on the case study. CAPEX: Capital expenditures, EPC: Engineering, procurement, and construction

3.3. Revenues

In the Colombian electricity market, three main revenue sources exist for coal-fired power plants: RP, spot price sales, and bilateral contracts.

3.3.1. Payments for firm capacity (RP)

The RP is an agreed-upon income for a certain period, during which generation commitments are made at a "Activation Scarcity Price" in the event that the spot price exceeds it. The commitments made are linked to the firm capacity of the plant during periods of low hydrology (ENFICC by its acronym in Spanish) as stipulated by Colombian regulations (CREG, 2006). It is allocated through an auction process, and in the case of new plants, it is possible to secure a 20-year RP, as is the case in the base scenario. The ENFICC (MWh) of the plant in year *n*, denoted as $ENFICC_n$

Then, *RP* (USD$) is defined as follows (2):

$$RP_n=CENFICC*ENFICC_{n*}Prp_n \quad (2)$$

Therefore, Prp_n (USD$/MWh) is the price used to pay for RP in year *n*, and *CENFICC* represents the percentage of committed ENFICC for firm capacity. Prp_n is annually updated using the North American PPI and is settled based on the prevailing exchange rate.

3.3.2. Bilateral contracts

According to Colombian regulations, it is only possible to have bilateral contracts with a maximum value of *(1-CENFICC)*ENFICC* (MWh). In this way, the amount of energy sold in bilateral contracts is equivalent to $Bc_n*NEC*h$, which is less than or equal to *(1-CENFICC)*ENFICC*, where Bc_n is the percentage of energy desired to be sold at the price of bilateral contracts (Bp_n) in year *n*, relative to the maximum possible generation. The base case begins with a 1.21% value for *Bc*, where $Bc_n=Bcf_n*CF_n$, with Bcf_n denoting a portion of the total Capacity Factor utilized.

Table 2: Input variables and distributions

V	Description	Unity	DT	Minimum	Most likely	Maximum	TM	Ty.de	Base case
Bp	Bilateral contracts price	USD$/MWh	Normal	0	-	INF	77.33	4.46	77.33
Spa	Adjusted spot price	USD$/MWh	Normal	0	--	INF	73.25	2.89	73.25
Vom	Variable O&M costs	USD$/MWh	Normal	0		INF	20.19	3.82	20.25
Bcf	CF ratio used in B. Contracts	%	Uniform	5.00%	-	10.00%	7.50%	1.44%	5.00%
PP1 USA	U.S. producer price index	%	GM	-INF	-	INF	1.70%	0.90%	1.85%
IPC	Colombian consumer price index	%	Gamma	-INF	-	INF	4.20%	1.80%	4.25%
CF	Capacity factor	%	Triangular	18.62%	24.20%	33.19%	25.34%	0.03%	24.20%
CENFICC	Committed ENFICC	%	Triangular	92.50%	95.00%	97.50%	95.00%	1.02%	95.00%
HR	Heat rate	Btu/kWh	Triangular	8874.88	9244.67	9614.46	9244.67	150.96	9244.67
Dr	Annual heat rate degradation	%	Triangular	0.30%	0.50%	0.70%	0.50%	0.08%	0.50%
hm	Length of maintenance outage	Hours	Triangular	280	390	500	390	44.9	390
Fom	Fixed O&M costs	%	Triangular	2.00%	3.00%	4.00%	3.00%	0.41%	3.00%
DSS	Startup and shutdown costs	USD$/MW	Triangular	50.00	74.1	87.62	70.57	7.78	74.1
Vfp	Fuel price variation	%	Triangular	−3.00%	−1.50%	0.00%	−1.50%	6.10%	−1.50%

Sources: Calculations based on XM (2022f), XM (2022g), XM (2022e), UPME (2023), U.S. Bureau of Labor Statistics (2023), Departamento Administrativo Nacional de Estadística DANE (2022), XM (2022a), XM (2022b), XM (2022c), XM (2019), Consorcio Sergeing - Sisocoal - RMR (2016), IEA (2020), XM (2022d), Martínez Ortiz (2022). V: Variable, Ty.de: Typical deviation, TM: Theoretical mean, DT: Distribution type, GM: Gumbel maximum, O&M: Operation and maintenance. PPI USA has Alpha=0.013 and Beta=0.007. IPC has Alpha=5.538 and Beta=0.008

Table 3: Parameters

Parameter	Description	Unity	Value
Ifp	Initial fuel price (Coal)	USD$/t	57.18
CCV	Coal calorific value	Btu/lb	11,370
TP	Take or pay	%	70.00%
Prp	Reliability payment price	USD$/MWh	18.05
CAPEX	Capital expenditures (without IDC)	USD$/kW	1500
WC	Working capital	Months over fuel expense	2
SCp	Coal supply contract	%	60.00%
Dev	Implicit devaluation	%	4.42%
TR	Tax rate	%	35.00%
CSP	Credit spread	%	5.00%
ER	Exchange rate	COP$/USD$	4400

Sources: Calculations based on UPME (2023), XM (2021a), Banco de la República de Colombia (2022b), Banco de la República de Colombia (2022c). Coal Supply Contract is a percentage relative to maximum generation

According to Derivex (energy commodities derivatives market), prices per kWh beyond 2024 are not expected to exceed 334 COP$/kWh or 68.16 USD$/MWh at the exchange rate on the day of publication (DERIVEX, 2022). These prices may not adequately cover the costs of a thermal plant in the current context. In situations where spot prices fall below production costs, advantages can be gained by relying on spot market purchases. However, within the context of valuation, it is vital to consider the projections' sensitivity concerning bilateral contracts and direct plant production. Price updates are based on Colombia's Consumer Price Index (IPC).

3.3.3. Sales at the market price

The Colombian electricity market is highly influenced by the country's hydrological behavior, and thermal power plants do not operate continuously. The series of adjusted spot prices facilitated the determination of the distribution associated with the Adjusted Spot Price (Spa_n), given in USD$/MWh. In this way, a minimum operating price was set, and a stochastic distribution defined the price range within which the plant is willing to operate.

Hence, Es_n represents the percentage of energy sold at the price Spa_n in year *n*. Es_n will take a value of either zero or another value, depending on the condition stated in (3):

$$Es_n = \begin{cases} 0, \left| Spa_n - Vom_n - HR_n * FP_n / CCV < 0 \right. \\ CF - \left| Bc_n,\ Spa_n - Vom_n - HR_n * FP_n / CCV \geq 0 \right. \end{cases} \quad (3)$$

Vom_n (USD$/MWh) represents the variable operation and maintenance costs, *HR* stands for Heat Rate (MMBtu/MWh), *FP* is the fuel cost (USD$/t), while the coal calorific value (*CCV*) is given in (MMBtu/t). The capacity factor (*CF*) is estimated based on the actual generation dispatched by XM (the Colombian electric system operator) through SINERGOX, taking into account the data series of centrally dispatched coal generation plants.

The equation (3) works well within the proposed modeling without affecting the logic of the RP. In a general sense, the flexibility introduced by equation (3) should work as long as the spot price does not exceed the so-called "Activation Scarcity Price." However, this restrictive condition, not explicitly stated, is implicitly present in the original data series.

The revenues from sales in the spot market and bilateral contracts arise from the total Energy Generation (*EG*) in year *n*, given in MWh (4).

$$EG_n = NEC_n * (BC_n + ES_n) * h \quad (4)$$

Where *NEC* is the Net Effective Capacity in MW. The total revenue function for year *n* (R_n) (USD$) is expressed as follows (5):

$$R_n = RP_n + EG_n * \frac{\left(Bc_n * Bp_n + Es_n * Spa_n\right)}{\left(Bc_n + Es_n\right)} \quad (5)$$

Price updates for *Bp* and *Spa* are carried out based on the Colombian Consumer Price Index (IPC).

3.4. Operating Costs

This section presents the main operating costs considered for the case study.

3.4.1. Fixed and variable operation and maintenance costs

Operation and maintenance (O&M) costs are typically divided into two types. On one hand, there are variable costs that naturally depend on energy production levels, and on the other hand, there are fixed costs that remain independent of annual production. Fixed O&M costs are often associated with a percentage of the investment, depending on the fuel and technology that the power plant will use. According to data analyzed by the International Energy Agency (IEA) in their report "Projected Costs of Generating Electricity 2020," these costs had a median value close to $50 USD per installed kW (IEA, 2020). Therefore, we assumed fixed O&M costs (*Fom*) ranging from 2% to 4% of the initial investment, with 3% in the base case. In addition to the above, the costs (in USD$) of backup contracts (*Pb*) are added. So, the total value (in USD$) due to fixed O&M costs (*TFom*) for year *n* is defined as (6).

$$TFom_n = Fom_n + Pb_n \quad (6)$$

Variable O&M costs typically cover mainly periodic maintenance, fuel, replacement, and repair of parts (Schröder et al., 2013). However, the analysis will consider fuel separately in another section. For the estimation of variable costs, we utilized the daily price series of coal generator bids in the Colombian electric system, reported by XM (XM, 2022e). These offers are assumed as approximation of the variable costs, including the fuel component. Therefore, we subtracted the fuel component from the data, which was calculated as explained in the "Fuel Costs" section. This provides an estimator for the distribution of variable operation and maintenance costs (*Vom*) (USD/MWh). The total costs assigned (in USD$) under this classification are detailed in (7).

$$TVom_n = Vom_n * EG_n \quad (7)$$

3.4.2. Startup and shutdown costs

Startup and shutdown costs (SS) are considered within the O&M costs. Being essential in dispatch scheduling, these costs are broken down from the thermal offer price and reported quarterly (CREG, 2009), justifying their separate treatment in this study. Startup and shutdown costs include fuels, chemicals, labor, component depreciation, and shortening of lifespan (Schröder et al., 2013). The SS costs also vary based on the time since the last shutdown, affecting temperature and resource consumption to reach the power level (Glensk and Madlener, 2018). Thus, the total cost (USD$) of SS in year *n* will be equivalent to TSS.

3.4.3. Fuel costs

The cost of fuel is vital for the operational decisions of a thermal plant. UPME publishes quarterly the average cost of thermal coal in Colombia in its resolutions to define the base prices for royalty charges. These values are calculated from data provided by around 15 companies, which consider raw material costs, transportation, and handling before submitting their information. The annual costs of coal due to consumption for electricity generation, Cgc_n (USD$), are defined for each operating year *m* according to the following expression (8).

$$Cgc_n = EG_n * HR_{m-1}(1+Dr)^{m-1} * (FP_n / CCV) \quad (8)$$

EG_n=Energy Generation in year *n* (MWh)
HR=Heat Rate (MBtu/MWh)
Dr=Heat Rate Degradation Rate (%)
FP_n=Fuel Price in Year *n* (USD$/t)
CCV=Coal Calorific Value (MBtu/t)

Companies that require commodities such as gas or coal often use "Take or Pay" contracts. These contracts protect the interests of both parties: the customer ensures a supply, and the supplier receives a payment regardless of consumption. High coal demand can lead to "Take or Pay" contracts with high committed percentages, which affects the costs of the involved companies. The costs associated with this type of contract are represented in equation (9), where TP is the agreed minimum payment percentage and SC_n (coal supply contracts in year *n*) is measured in MBtu.

$$Ctp_n = TP * (SC_n / CCV) * FP_n \quad (9)$$

Therefore, the overall costs (USD$) generated from the need for firm supply contracts or direct coal consumption as fuel will be modeled using the expression (10)

$$CC_n = MAX\{Cgc_n ; Ctp_n\} \quad (10)$$

3.5. CO_2 Tax

The Colombian government implements a tax on the carbon content in fossil fuels, resulting in an additional charge on coal purchases. The cost associated with the "CO_2 tax" is reflected in the variable $TCO2_n$.

The total costs, including fixed and variable O&M costs, startup and shutdown costs, overall fuel costs, and costs due to the CO_2 tax payment, can be seen in the equation below (11):

$$TC_n = TFom_n + TVom_n + TSS_n + CC_n + TCO2_n \quad (11)$$

3.6. Free Cash Flow

Finally, the free cash flow is consolidated using equation (12), which takes into account the after-tax operating income, added to the depreciation and amortization in the valuation year *n* ($D\&A_n$), minus the capital expenditures (*CAPEX*) in that year, and the changes generated in working capital (*VWC*).

$$FCF_n = (R_n - TC_n) * (1 - TR) + D\&A_n - CAPEX_n - VWC_n \quad (12)$$

The O&M costs were updated according to the Colombian IPC. As for fuel, startup and shutdown costs, these were indexed to the "Fuel Price Variation" (*vfp*) variable, which aims to simulate the behavior of coal prices over the projected time, starting from an initial value (*1fp*) for the 1st year. Variables such as IPC and PPI USA were projected for the first 5 years of the relevant period using data from the "Guía Bancolombia 2023: La economía" (Equipo editorial Capital Inteligente. Grupo Bancolombia, 2022) report for IPC and our own projections using a linear regression model for PPI USA. After the 5th year, these variables were simulated based on Table 2, considering the existing correlation between both variables.

3.7. LCOE

As part of the valuation exercise, Table 4 presents the aspects considered for the calculated LCOE:

Where the total LCOE value is the sum of the present value of the mentioned *x* costs (*PVtc*) divided by the present value of the energy produced (PV_{EP}) (13).

$$\sum_{1}^{x} \frac{PVtc_i}{PV_{EP}} = \sum_{1}^{x} LCOE_i = LCOE_{Total} \quad (13)$$

4. RESULTS

4.1. Economic Evaluation of the Project

After simulating scenarios with distributions and a private cost of capital K_{e1} = 19.79%, the project's success probability is calculated, indicating the likelihood of NPV being greater than or equal to zero. For the valuation period, this stands at 37.52%, as depicted in Figure 2. The average NPV is −12.69 MM USD$.

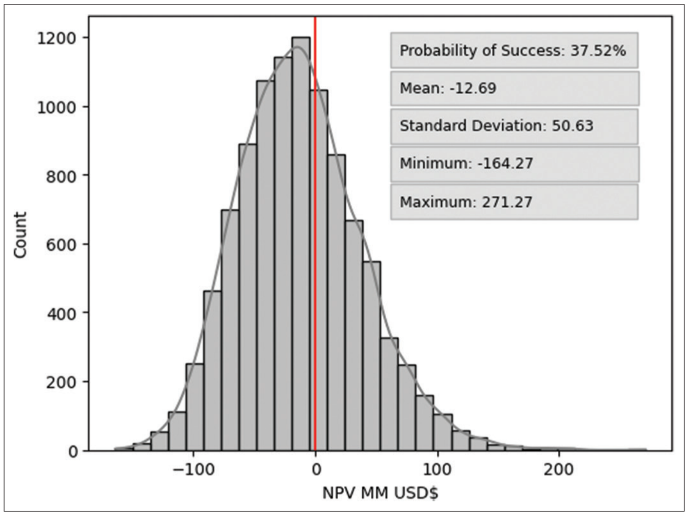
When quantifying the financial risk exposure of the project, the VaR and CVaR methods are used on the results of the 10,000 simulations performed. With a 90% confidence level, values

Table 4: Levelized cost of energy

Description	Variable
Variable O&M costs (USD$/MWh)	$LCOE_{VOM}$
Startup and shutdown costs (USD$/MWh)	$LCOE_{SS}$
Fuel costs (USD$/MWh)	$LCOE_{CC}$
CO_2 tax (USD$/MWh)	$LCOE_{CO2}$
Fixed O&M costs (USD$/MWh)	$LCOE_{FOM}$
Capital investments (USD$/MWh)	$LCOE_{CAPEX}$
Total LCOE (USD$/MWh)	$LCOE_{Total}$

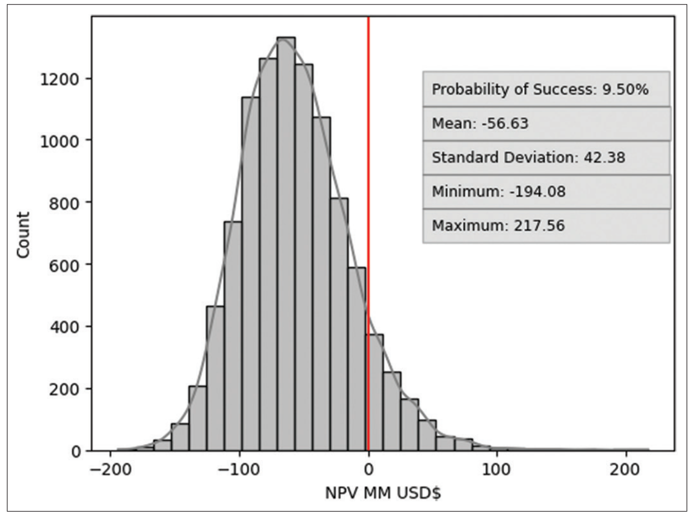
LCOE: Levelized cost of energy, O&M: Operation and maintenance

Figure 2: NPV histogram



Source: The authors

Figure 3: NPV histogram using CAPM



Source: The authors

exceeding −77.58 MM USD$ are expected, as illustrated in Table 5.

Conducting a comparative analysis using the CAPM model for estimating the private cost of capital K_{e2} = 30.14%, derived from an implied devaluation rate of 7.17% found in forward contracts traded in Colombia (Banco de la República de Colombia, 2022b), yields different results. Figure 3 illustrates a lower probability of success, with only 9.50% of favorable scenarios and an average NPV of −56.63 MM USD$.

The results regarding the VaR and CVaR criteria of the exercise using the CAPM model are shown in Table 6, indicating that at a 90% confidence level, values higher than −110.94 MM USD$ are expected.

Table 5: Value at risk and conditional value at risk of the project

Confidence level (%)	VaR (MM USD$)	CVaR (MM USD$)
90	−77.58	−101.55
95	−95.97	−117.13
99	−130.48	−147.64

VaR: Value at risk, CVaR: Conditional VaR

Table 6: Value at risk y conditional value at risk of the project using capital asset pricing model

Confidence level (%)	VaR (MM USD$)	CVaR (MM USD$)
90	−110.94	−131.00
95	−126.33	−144.04
99	−155.21	−169.57

VaR: Value at risk, CVaR: Conditional VaR

4.2. LCOE

Starting from the static base case, which is based on average and most probable values as applicable, the allocation of each component within the total LCOE is determined (Table 7).

Table 7: Levelized cost of energy composition

Variable	Result
$LCOE_{VOM}$	14.05%
$LCOE_{SS}$	1.78%
$LCOE_{CC}$	21.05%
$LCOE_{CO2}$	3.87%
$LCOE_{FOM}$	17.50%
$LCOE_{CAPEX}$	41.75%
$LCOE_{Total}$	100.00%

Source: The authors

Table 7 reveals that CAPEX costs are the most substantial component, followed by coal usage expenses. Additionally, it is evident that "CO_2 tax" costs account for a significant 3.87%. The introduction of new taxes on fossil fuels, particularly coal, has an immediate impact on the feasibility of generation projects utilizing these fuels. This includes a decrease in the competitiveness of pricing and, as a result, a reduction in central dispatch frequency. In conclusion, this trend diminishes the attractiveness of such investments.

The scenario simulation provides a 95% confidence interval with prices ranging from 181.95 to 290.65 USD$/MWh (Figure 4).

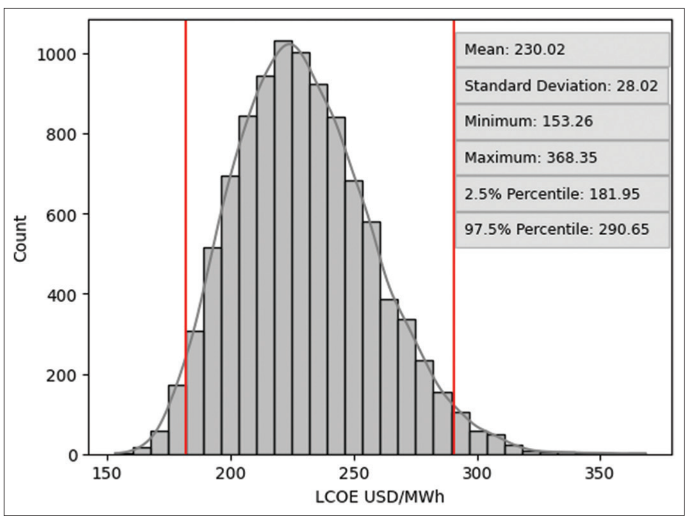
While initial LCOE impressions in this research warrant caution, it is essential to refrain from hasty judgments. The IEA's "Projected Costs of Generating Electricity 2020" report provides LCOE estimates for coal plants with specific parameters. Their findings suggest a median of 97 USD$/MWh, based on an 85% capacity factor, a 10% discount rate, and a 40-year lifecycle. However, sensitivity to capacity factor and discount rate must be considered. By adjusting these factors in our model, the LCOE converges to approximately 115 USD$/MWh.

4.3. Sensitivity Analysis

The impact of input variables' uncertainty is evaluated through a correlation analysis, as illustrated in Figure 5. The variables with the most significant influence on increasing project value are the capacity factor and PPI USA. PPI USA indexes the RP, which depends on the dollar price. Hence, it is essential to consider variations in the projected annual peso/dollar devaluation and its interaction with the committed firm power level for the RP. Other parameters under evaluation include fixed costs, initial coal cost, and initial electricity market price. The static base case was utilized to construct two-way tables, enabling the observation of the effects of varying two factors while keeping other components constant.

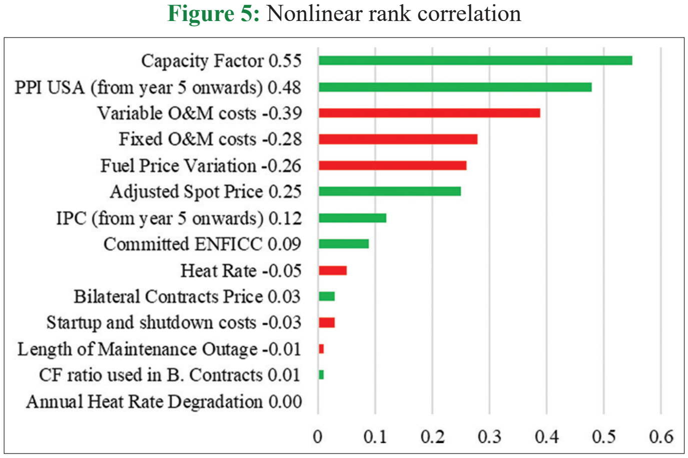
Table 8 results underscore the significance of revenue from installed capacity and reveal the project's sensitivity to exchange rate fluctuations. Scenarios with substantial devaluation and high Committed ENFICC levels yield more favorable NPV outcomes. Given that a significant portion of the project's revenue depends on exchange rate fluctuations, and costs do not rise proportionally, higher devaluation of the local currency (COP$) against the dollar is expected to enhance the overall project value. Conversely, Table 9 illustrates how the potential for larger-scale generation can lead to cost savings, even in the face of potential variations in fixed costs (USD$/kW-year). The color codes in Tables 8 - 11 represent scenarios in which the NPV is less than or greater than zero. Red color is expressed for a negative NPV, while positive NPV scenarios are represented with green color as their value is higher.

Figure 4: Total LCOE histogram



Source: The authors

Figure 5: Nonlinear rank correlation



Source: The authors

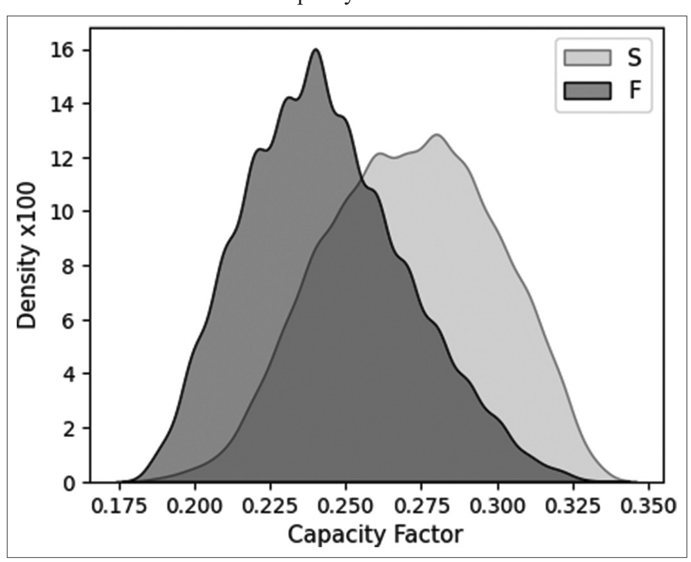
Clearly, coal prices play a pivotal role in the profitability of the power generation plant. Table 10 underscores that prices equal to or exceeding 130 USD$/t are prohibitively expensive, rendering the project's NPV unviable, even when the plant operates at capacities exceeding 80%. In conclusion, Table 11 suggests a requirement for short-term electricity prices higher than 68 USD$/MWh (300 COP$/kWh) to achieve a positive NPV when combined with an annual capacity factor of approximately 30% or higher.

As can be observed in the previous tables, the capacity factor is the most determining variable in supporting the project's profitability. Hence, the effects on economic viability were assessed. Figure 6 presents the results of simulating scenarios, categorizing the distribution of success (S) or failure (F) probability within each capacity factor range.

The capacity factor varies with meteorological conditions. During high hydrology periods, hydroelectric plants take precedence, reducing dispatch levels of thermal plants in Colombia. In such scenarios, RP revenues are crucial, unaffected by dispatch levels. Additionally, supply contracts and their terms gain importance, especially clauses that involve charges exceeding consumption, impacting financial outcomes. Thus, these values were assessed for their influence on average NPV and project success probability in the simulations. Figure 7 illustrates the significance of the RP for the project's profitability. Prices near or above 19 SD$/MWh provide a probability exceeding 50% of achieving scenarios with a positive NPV. However, values below 18.05 USD$/MWh (base case) exert pressure on this probability, reducing it below 38%.

Figure 8 presents the impact of varying the Take or Pay percentage on NPV. It demonstrates that as negotiated minimum consumption percentages in supply contracts increase, the project's financial viability declines. Such agreements often result from the direct relationship between supply and demand, implying higher

Figure 6: Probability distribution of success or failure based on the capacity factor



Source: The authors

Table 8: Devaluation COP$ versus USD$ and committed ENFICC

NPV (MM USD$)	Implicit devaluation									
	0%	1%	2%	3%	4%	5%	6%	7%	8%	9%
CENFICC (%)										
75.00	−178.79	−166.79	−153.00	−137.14	−118.86	−97.78	−73.44	−45.32	−12.81	24.83
77.50	−172.10	−159.31	−144.62	−127.73	−108.28	−85.86	−59.99	−30.11	4.42	44.37
80.00	−165.41	−151.83	−136.24	−118.32	−97.70	−73.94	−46.53	−14.90	21.65	63.91
82.50	−158.73	−144.35	−127.86	−108.91	−87.12	−62.02	−33.08	0.31	38.88	83.45
85.00	−152.04	−136.87	−119.48	−99.50	−76.54	−50.09	−19.62	15.52	56.11	103.00
90.00	−138.67	−121.92	−102.72	−80.69	−55.37	−26.25	7.29	45.95	90.56	142.08
92.50	−131.98	−114.44	−94.34	−71.28	−44.79	−14.33	20.74	61.16	107.79	161.62
95.00	−125.30	−106.96	−85.96	−61.87	−34.21	−2.41	34.20	76.37	125.02	181.16
97.50	−118.61	−99.48	−77.58	−52.46	−23.63	9.51	47.65	91.59	142.24	200.71

NPV: Net present value

Table 9: Capacity factor and fixed Operation and maintenance costs

NPV (MM USD$)	Capacity factor									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Fixed O&M costs (USD$/kW-year)										
15	−81.97	9.78	101.54	192.24	249.94	304.77	359.61	413.81	467.62	514.58
20	−93.59	−1.84	89.91	180.62	238.32	293.15	347.99	402.19	456.00	502.96
25	−105.21	−13.46	78.29	169.00	226.70	281.53	336.37	390.57	444.38	491.34
30	−116.83	−25.08	66.67	157.38	215.07	269.91	324.75	378.95	432.75	479.72
35	−128.45	−36.70	55.05	145.76	203.45	258.29	313.13	367.33	421.13	468.10
40	−140.07	−48.32	43.43	134.14	191.83	246.67	301.51	355.71	409.51	456.48
45	−151.69	−59.94	31.81	122.52	180.21	235.05	289.89	344.09	397.89	444.86
50	−163.31	−71.56	20.19	110.90	168.59	223.43	278.27	332.47	386.27	433.24
55	−174.93	−83.18	8.57	99.28	156.97	211.81	266.65	320.85	374.65	421.62

NPV: Net present value

Table 10: Capacity factor and coal price

NPV (MM USD$)	Capacity factor									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Coal price (USD$/t)										
50	−131.27	−39.51	52.24	143.08	205.05	264.52	323.99	382.83	441.27	492.87
70	−188.17	−96.41	−4.66	85.81	135.87	182.43	228.99	274.92	320.44	359.13
90	−245.07	−153.32	−61.56	28.54	66.69	100.34	133.99	167.00	199.62	225.40
110	−301.97	−210.22	−118.47	−28.72	−2.49	18.25	38.99	59.09	78.79	91.66
130	−358.87	−267.12	−175.37	−85.99	−71.67	−63.84	−56.01	−48.83	−42.03	−42.08
150	−415.77	−324.02	−232.27	−143.26	−140.85	−145.93	−151.02	−156.74	−162.86	−175.82
170	−528.20	−491.98	−455.75	−422.64	−424.17	−425.71	−427.24	−429.42	−431.98	−441.39
190	−616.34	−611.36	−606.38	−601.40	−596.41	−591.43	−586.45	−582.10	−578.15	−581.04
200	−644.79	−639.81	−634.83	−629.85	−624.86	−619.88	−614.90	−610.55	−606.60	−609.49

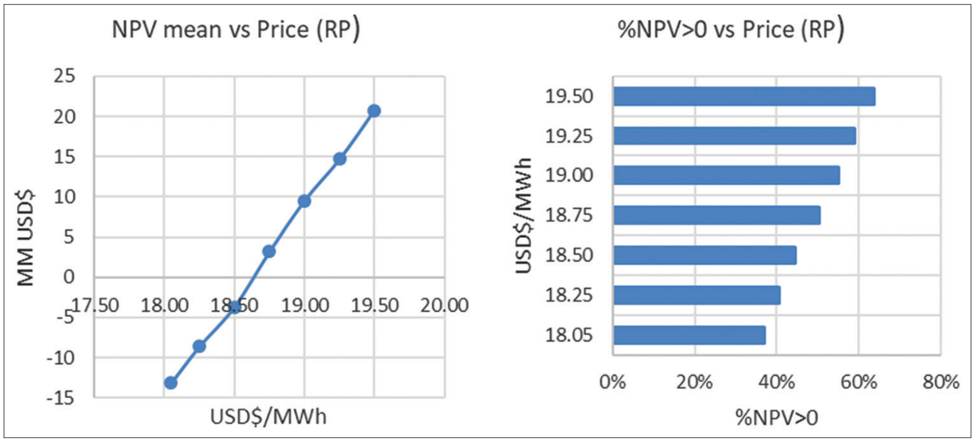
NPV: Net present value

Table 11: Capacity factor and spot price

NPV (MM USD$)	Capacity factor									
	10%	20%	30%	40%	50%	60%	70%	80%	90%	100%
Adjusted spot price (USD$/MWh)										
52.27	−192.27	−141.09	−89.91	−39.78	−22.65	−8.39	5.87	19.50	32.73	39.12
56.82	−183.47	−123.50	−63.53	−4.61	21.30	44.36	67.41	89.83	111.86	127.04
68.18	−161.50	−79.55	2.40	83.31	131.20	176.23	221.27	265.67	309.67	346.83
79.55	−139.52	−35.59	68.34	171.22	241.09	308.11	375.12	441.50	507.48	566.62
90.91	−117.54	8.37	134.28	259.14	350.99	439.98	528.98	617.33	705.29	786.41
102.27	−95.56	52.33	200.21	347.06	460.89	571.86	682.83	793.16	903.10	1006.20
113.64	−73.58	96.29	266.15	434.97	570.78	703.73	836.68	969.00	1100.92	1225.99
125.00	−51.60	140.24	332.09	522.89	680.68	835.61	990.54	1144.83	1298.73	1445.78
136.36	−29.62	184.20	398.03	610.80	790.57	967.48	1144.39	1320.66	1496.54	1665.58

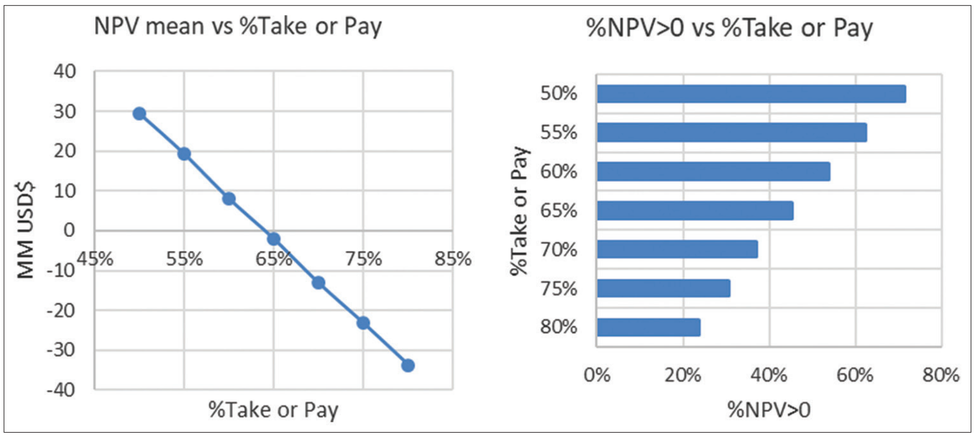
NPV: Net present value

Figure 7: NPV according to reliability payment price



Source: The authors

Figure 8: NPV according to take or pay percentage



Source: The authors

demands on clients during periods of increased coal demand. The inclusion of secondary "Make-up" clauses can enhance buyer flexibility by allowing recovery rights for unconsumed, paid-for product (Araya Maggi, 2017).

In addition to the previously conducted analyses, the potential impact of CAPEX on project viability was explored by assessing the variability in investment magnitudes. In this context, it is observed that an approximate investment of 1700 USD$/kW dramatically reduces the probability of success to just 2.24%. This underscores the profound significance of adjustments in investment levels in the electricity sector and the significant implication that the exchange rate can have on projects of this nature.

5. CONCLUSIONS

This study provides an insight into the other side of the energy transition, focusing on coal-fired power plants. It highlights the current reality that persists after investing in these types of assets and emphasizes the importance of specific measures, strategies, or mechanisms in the financial viability of such projects today. Hence, the negative economic evaluation of this coal-fired power plant indicates a potential slowdown in such investments. Investor hesitancy may impact the coal production chain, affecting jobs and royalties. While the clean energy transition is evident, countries face the significant challenge of phasing out the use of fossil fuels in their generation without compromising their energy security. Therefore, they must aspire to establish a versatile, diverse electric generation matrix. This is crucial for addressing potential challenges effectively and minimizing the impacts that changes in climate conditions may have on the sources of generation.

The strong correlation between operational factors and the financial feasibility of such projects is universally applicable. Scenarios with lower dispatch levels tend to exhibit reduced profit margins, significantly lowering the likelihood of project success. Following this logic, capacity-based income mechanisms play a crucial role. They serve as the primary incentive for ensuring the financial viability of thermal power generation, projects that supply essential backup infrastructure during dry periods. This is particularly desirable for countries whose primary sources of generation rely on water and currently lack a sufficiently reliable backup source to manage the effects of droughts on energy production. This approach contributes to mitigating the impact of the ever-present risk of extreme events, such as excessive depletion of reservoirs in hydroelectric power plants, along with their subsequent repercussions.

Securing the coal supply is a necessary task that must be executed to acquire firm energy obligations through auctions under the capacity payment mechanism. Improved supply contract conditions directly enhance the project's likelihood of success, with significant economic implications based on contract terms. Recognizing minimum consumption clauses as potential fixed costs, it is essential to develop strategies for managing associated risks effectively. Consequently, incorporating additional clauses to enhance buyer flexibility or exploring vertical integration within the energy sector becomes a wise strategy. Companies engaged in both coal mining and power generation hold a distinct competitive advantage in this context.

To conclude, given the significance of the exchange rate for the project's profitability indicators, the implementation of currency hedging strategies is suggested. These strategies would provide a higher degree of certainty regarding cash flows dependent on the dollar, both for expenditures and operational revenues.

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