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Using DNPV Methodology to Unlock SHP's Energy Potential in Colombia for Green Hydrogen Production

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ABSTRACT

Small Hydropower Plants (SHPs), a mature technology with a recognized lower environmental impact, present favorable conditions in Colombia as a primary clean energy alternative for renewable hydrogen production. This paper presents a financial evaluation of the average facility required to support the development of three hydrogen hubs. The analysis of Discounted Free Cash Flows and the use of classical indicators NPV, and IRR, risk metrics VaR, and CvaR, and Monte Carlo simulations, was complemented with the Decoupled Net Present Value (DNPV) methodology. This approach separates identified risks from expected cash flows by including risk premiums into revenues and expenses. DNPV proves to overcome some of the shortcomings of NPV and to be useful when evaluating high-risk investments and long-term initiatives by avoiding project underestimation. Valuation results show an average value 1.35 times higher for the 30-year valuation and 1.47 times higher for the 50-year analysis. This enables the provision of renewable energy at competitive prices and lays the groundwork for the supply required for hydrolysis within the country's short-term renewable hydrogen strategy.

Keywords: Decoupled Net Present Value, Economic Valuation, Renewable Energy, Small Hydropower Plant
JEL Classifications: Q25, Q42

1. INTRODUCTION

Colombia currently has an installed generation capacity of 20.829 GW, predominantly sourced from hydropower, totaling 13.208 GW (63.41%), with 0.971 GW (4.66%) contributed by Small Hydropower Plants (SHPs) (UPME, 2025). The country also possesses a significant total hydroelectric power generation potential of 56.187 GW, of which 4.79 GW belongs to SHPs (UPME, 2015a), 2.69 times the current total generation capacity, and 4.93 times the capacity related to SHPs. Furthermore, there are 127 operational SHP plants across 14 states, with an average age of 30 years, with 30% exceeding that timeframe. Five states account for 85.3% of the installed capacity and 71.7% of the plants (Antioquia, Cundinamarca, Valle del Cauca, Santander, and Caldas).

Power generation through SHPs is recognized as a clean, mature, and relatively low-risk technology (Mohamadi, 2021), with useful life periods exceeding 50 years (Kishore et al., 2021), with high energy conversion efficiency, low OPEX, and relatively low CAPEX levels compared to other technologies, with less intermittency, contrasted with other renewable energies (Paish, 2024), as well as a recognized minimal environmental impact (Duque et al., 2016). The country has favorable conditions for SHP development, given the favorable geographical location and hydrological characteristics (Duque et al., 2016), and the accumulated technical expertise in Engineering, Procurement, and Construction (EPC) and O&M for this type of plant (Ortiz, 2022).

On the other hand, barriers to SHP projects, such as preferences for other alternatives as wind or solar power, to reduce dependence on hydropower (Patiño et al., 2023), a persistent investment deficit over time in research and development, and a weak institutional framework (UNIDO and ICSHP, 2022), have been identified.

However, the country has enacted various laws and regulations to foster the growth of clean energy within its generation mix. These classify SHPs along with biomass, wind, geothermal, solar, and tidal energy as Non-Conventional Renewable Energy Sources (FNCER, for its acronym in Spanish) (Congreso de la República de Colombia, 2014) and (Congreso de la República de Colombia, 2023). This categorization enables SHPs to access a range of tax and tariff incentives until 2051, as well as opportunities for hydrogen (H_2) development (Congreso de la República de Colombia, 2021). Renewable H_2 produced by hydrolysis is recognized if the energy is self-generated using FNCER or managed through the National Interconnected System, with the condition that the delivered renewable energy must be equal to or greater than the energy consumed. SHPs with capacities between 10 MW and 20 MW can choose to participate in the central dispatch system or access the unregulated market, where they can freely negotiate prices (Resolución CREG 086, 1996).

The Colombian government's policy for hydrogen development includes establishing six regions as potential H_2 Hubs, and the states of Antioquia, Caldas, and Valle del Cauca are identified as having a robust potential for renewable energy generation from sources such as solar, wind, biomass, and SHPs (Stuible and Gómez Mejía, 2023). Specifically, in these three states, it is possible to develop 39 SHP projects (distributed as 18, 4, and 17, respectively) with run-of-river operation, ranging from 10 and 20 MW (UPME, 2015a), totaling 74.38% of the 1 GW electrolysis capacity required by the country to cover the potential H_2 demand by 2030 (Stuible and Gómez Mejía, 2023).

2. LITERATURE REVIEW

The renewable energy project evaluation, particularly for Small Hydropower Plants, requires a comprehensive analytical framework employing various financial and risk assessment techniques (Santos et al., 2014). Traditional methods, such as Net Present Value (Miyauchi et al., 2020) and Internal Rate of Return (Karlis and Papadopoulos, 2000), are essential in assessing the profitability of renewable energy projects. Besides, indicators like the Levelized Cost of Electricity (LCOE) provide a benchmark for cost competitiveness (Dranka et al., 2020), while the Capacity Factor reflects the efficiency and operational reliability of the generation facility (Mishra et al., 2011). Furthermore, risk management methodologies, such as Value at Risk (VaR), Conditional Value at Risk (CVaR) (Melo et al., 2018), and Monte Carlo simulations (Razi et al., 2018), are indispensable for the quantification and mitigation of uncertainties inherent in energy projects (Akcay et al., 2017).

Considering uncertainties related to regulatory framework policies, market dynamics, technological evolution, and environmental conditions, among other variables, requires the application of advanced analytical methodologies. Real options analysis is an alternative for evaluating investments in renewable energy, by including the flexibility of decisions with project uncertainty within the evaluation framework (Nunes et al., 2021). Multi-Criteria Decision Analysis considers technical, economic, social, and environmental criteria, when project objectives go beyond economic profitability (Urošević and Marinović, 2021). Similarly, the Decoupled Net Present Value (DNPV) approach emerges as a complementary technique that detaches the risk inherent to the project from the value of money over time (Espinoza and Morris, 2013). This method addresses several shortcomings of the traditional Net Present Value (NPV) analysis, particularly when evaluating high-risk investments and long-term initiatives (Espinoza, 2014).

Opposite to traditional NPV, which merges time and risk into a combined discount rate, DNPV segregates them, offering a clear view of their impact on project value. (Espinoza et al., 2020). This concept was clarified by Robichek and Myers (1966), who started defining time and risk as separate variables that should not be joined into a single discount rate, by warning about the consequences of errors and incorrect decisions in the valuation of investment alternatives in their "certainty-equivalent" framework. As a result, DNPV avoids the undervaluation of high-risk renewable energy projects which can result from the application of high discount rates in traditional valuation methods (Espinoza et al., 2020), and integrates both market risks (e.g. energy prices, interest rates) and non-market risks (e.g. environmental conditions, water availability) into the financial assessment and expresses these risks in monetary terms as tangible costs (Espinoza and Rojo, 2014). This integration enables a better evaluation of how various risks influence project value and the selection of effective risk management strategies (Espinoza and Rojo, 2017).

The essence of DNPV lies in its capacity to disaggregate the conventional NPV calculation into two different elements. The first element is the present value of projected cash flows discounted using a risk-free rate, while the second indicates a separate deduction for the cost of risk from projected revenues or a risk premium added to expenses (López-Marín et al., 2021). All are included and quantified at the earliest stages of the project. DNPV is considered a risk performance metric that requires a positive result as the acceptance criteria, similar to NPV, but it treats NPV as an investor's target financial performance metric only. If both DNPV and NPV results are positive, the project should be considered for acceptance; if not, it is recommended to evaluate financing alternatives (NPV<0) or take different risk management actions (DNPV<0). DNPV has been applied in various areas, including civil infrastructure, climate change, and renewable energy (Shimbar and Ebrahimi, 2020), particularly in solar (Kraemer, 2024), (Martínez-Ruiz et al., 2021), wind (Piel et al., 2018) and waste-to-energy projects (Shimbar and Ebrahimi, 2017).

This study aims to assess the financial viability of a small hydroelectric power project in Colombia, employing the Decoupled Net Present Value approach as a complementary technique to address the limitations of conventional valuation procedures. The analysis specifically examines the risks related to the input variables of the financial model.

3. METHODOLOGY

The analysis focuses on a 19.87 MW average small hydroelectric power generation facility located in Colombia, with the energy production estimate derived from a comparable operational facility. The financial model incorporates investment, revenue, expense, depreciation, financial costs, and tax parameters, and the project's Free Cash Flow was constructed considering the key elements of the regulatory framework for this type of plant in the country. The financial evaluation employed the NPV, IRR, DNPV, and LCOE criteria, utilizing Monte Carlo simulations to assess 10,000 scenarios, and the analysis was supplemented with the risk metrics of VaR and CVaR.

3.1. SHPs' CAPEX and OPEX Data

Using the information from the dataset of projects identified for PCHs in Colombia with a maximum conduction of 1 km (power, area, zone, hydrographic subzone, and location coordinates X, Y) ([Dataset] UPME, 2024). It was possible to locate them in the corresponding municipalities and departments within the maps of Colombia (IGAC, 2024), necessary data to determine the total investment costs [USD/MW], and the annual operation and maintenance (O&M) costs [USD/MW-year], through the parameterized model for Small Hydroelectric Plants for computing the Levelized Costs of Electricity Generation proposed by UPME (GeoLCOE) for each of the 39 projects found (UPME, 2015b). Other parameters used to run the model were as follows: Flow rate: 13.5 m^3/s, Height: 150 m, turbine type: Francis, and RMR: 4,179 COP/USD (CONPES, 2024). Table 1 presents the details of the categories included in the capital investment, and Table 2 shows the aggregate categories of the annual O&M costs.

3.2. SHP Energy Generation Estimation

The information from the Barroso SHP was used to determine the expected behavior of energy production. This facility is located in the municipality of Salgar, Antioquia. It is a plant with similar characteristics to the projected SHP: 19.9 MW, run-of-river, with an average daily production of 0.3606 GWh and a plant factor of 0.7551. It has operating records since November 2012 and collected data until February 2025. The average daily production per month is illustrated in Figure 1 (XM, 2025a).

3.3. Energy Price and Indexation

To determine the price of unregulated energy contracts, this variable was modeled using the minimum and maximum values from January 2023 to March 2025 data and the expected value based on direct consultation with SPH industry members in Colombia, as shown in Table 3.

Prices of unregulated energy contracts in Colombia are normally set based on the PPI domestic supply, as displayed in Figure 2 (Corficolombiana and Casa de Bolsa, 2025). The considered price indexation is the difference between the year-over-year variation in unregulated energy contract prices and the corresponding domestic supply PPI variation. The calculated average was established at 3.5% as seen in Figure 3.

3.4. Energy Production Financial Model

The project was analyzed monthly for 30 and 50 years, with a CPI and PPI projection of 3% (CONPES, 2024), by modeling the variables indicated in Table 3. The cost of capital, K_E = 18.05%, is determined using the CAPM model, and the WACC corresponds to

Table 1: Capital expenditures

Item	Average [USD/kW]	SD [USD/kW]
Civil works (Diversion, sand trap, access roads, pipelines, machine room, discharge channel, loading tank, and others)	652.95	17.01
Mechanical equipment (Turbine, others)	257.64	4.72
Electrical equipment (Generator, substation, and transformer)	505.08	9.26
Indirect costs (Engineering and administration, commissions, and contingencies)	371.17	8.92
Owner costs (Property, socio-environmental investments, grid interconnections, pre-operational, financial, and legal pre-operational insurance)	355.67	11.97
Total CAPEX	2,142.51	51.49

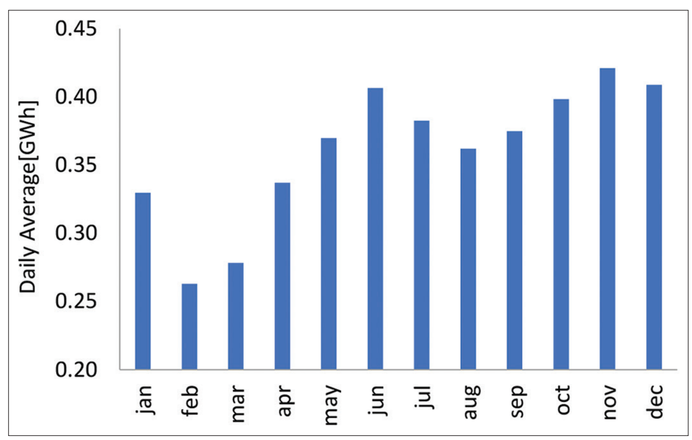
Source: GeoLCOE for 39 SHP Projects, SD: Standard Deviation

Table 2: O&M costs

Item	Average [USD/MW-year]	SD [USD/kW]
Fixed costs (Salaries, line and substation, track and pipeline maintenance, and connection costs)	33.11	0.40
Environmental management costs	30.00	-
Operational insurance	10.71	0.26
Legal charges (industry and commerce tax, property tax, and property surcharge)	0.30	0.08
Total OPEX	74.13	0.67

Source: GeoLCOE for 39 SHP Projects

Figure 1: Barroso SHP generation profile [2012-2025]



Source: Authors based on (XM, 2025a)

15.03% by using the parameters proposed in Table 4. In addition, a 5-year accelerated depreciation of machinery, equipment, and civil works was considered, and the exclusion of VAT on goods and services related to the investment and the tariff exemption on imported machinery, equipment, and materials according to the Colombian Energy Transition Law (Congreso de la República de Colombia, 2021).

The analysis utilized the preferential commercial or corporate credit interest rate (K_D) from Banco de la República, with

Table 3: Financial model variables

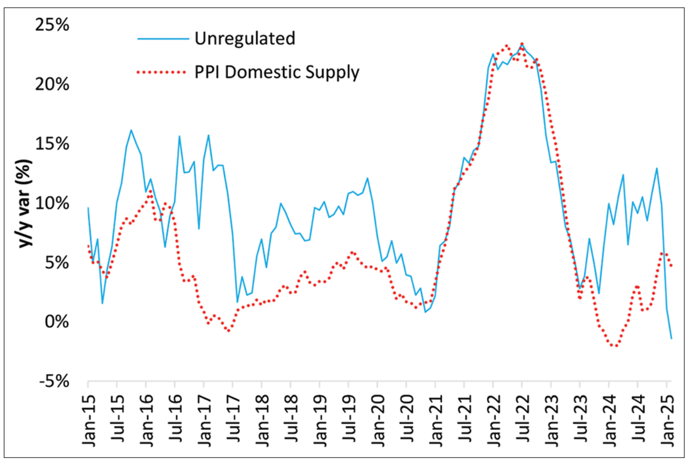
Variable	Description	Units	Distribution	Min	Most Likely	Max	Mean log	SD log	Base Value
I_0	Investment	MCOP	Log Normal				12.089	0.023	177,864
C	O&M Cost	COP/kW-day	Log Normal				6.744	0.009	848.690
E	Daily Energy production	GWh/day	Weibull (for all months)	0.263		0.418			
P	Energy Price	COP/kWh	Pert	273	300	315			298
I_P	Price Index	%	Pert	0	3.5	7.0			3.5

Sources: Authors based on (UPME, 2015b), (XM, 2025a), (XM, 2025b), (DANE, 2025)

Table 4: Financial model parameters

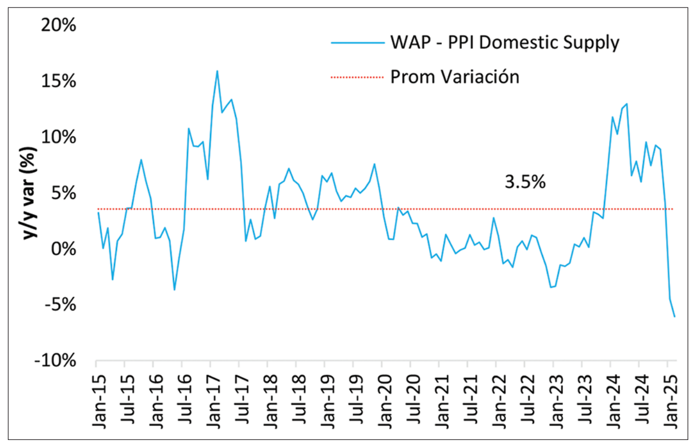
Parameter	Description	Units	Value	Sources
K_D	Interest rate	% Annual rate	15,91	(Banco de la República de Colombia, 2025a)
D	Debt	%	40	
T_D	Time of debt	years	30	
T_G	Debt grace period	years	2	
R_F	Risk-free rate	% Annual rate	12,78	(Banco de la República de Colombia, 2025b)
β_L	Levered beta adjusted for colombia		0,63	(Damodaran, 2025a)
β_U	Unlevered beta corrected for cash		0,44	(Damodaran, 2025a) SIC 4911
M_{RP}	Equity risk premium	%	8,32	(Damodaran, 2025b)
T	Tax rate	%	34	(UPME, 2015b)

Figure 2: Energy price variation unregulated long-term contracts



Sources: (XM, 2025b), (DANE, 2025)

Figure 3: Unregulated energy prices and PPI domestic supply variations difference



Source: Authors based on (XM, 2025b), (DANE, 2025).
WAP: Weighted Average Price

preferential terms exceeding 1,895 days. Additionally, the risk-free rate (R_F) considered was the average yield of a long-term Colombian government treasury security (TES) traded in a primary auction (26/03/2025) with a 31-year maturity (2050).

3.5. Free Cash Flows

The project's free cash flows are determined using the following financial expression:

$$FCF = \text{Energy Sales} - \text{O\&M Costs} - \text{Regional Transfers} - \text{Taxes} \quad (1)$$

FCF arise at the beginning of the third year after the plant's initial operation. Regional Transfers correspond to 6% of gross energy sales (3% for the Autonomous Corporations, 1.5% for the municipalities in the river basin, and 1.5% for the municipalities where SHP is located).

3.6. Levelized Cost Of Energy (LCOE)

The LCOE calculation formula used corresponds to:

$$LCOE = \frac{I_0 + \sum_{t=1}^{n} \frac{C_t}{(1+WACC)^t}}{\sum_{t=1}^{n} \frac{E_t}{(1+WACC)^t}} \quad (2)$$

LCOE represents the relationship between the sum of the investment and the present value of the O&M expenses and costs versus the present value of the energy produced in the analysis period (GIMEL, 2015), which is utilized for comparison between technologies and as an estimator of electricity prices.

3.7. DNPV Analysis

3.7.1. Energy production risk factor and income cost of risk

The variable that links risk to income is daily energy production [GWh/day] according to the month of the year. Risk Premium accounted for potential reduction in expected income according to D. Espinoza and Morris (2013) is detailed in equations (3) and (4):

$$RP_{Em} = (\overline{E_m} - E_m)^* \Pr\left[\overline{E_m} > E_m\right] \quad \forall\ month = m \epsilon\ \{1,2,3,\ldots,12\} \qquad (3)$$

where: RP_{Em} is the Risk Premium of daily energy production of month m, $\overline{E_m}$ is the average of the daily energy production, E_m is the average of the values less than $\overline{E_m}$, $PR\left[\overline{E_m} > E_m\right]$ is the probability that the average exceeds the expected value up to average.

$$_m = RP_{Em} / \overline{E}_m \qquad (4)$$

Where: RP_{Em} is the Risk Factor (RF) of the daily energy production in month m.

Thus, the cost of risk (Income Risk Premium) is set as:

$$RP_{Income} = \eta_m * \text{Energy Sales} \qquad (5)$$

According to the analysis of 13 distributions with a domain [0, +inf] using AIC and BIC criteria, it was established that the Weibull distribution best represents the data of each month for all years analyzed at Barroso SHP. Table 5 presents the results obtained for the Risk Factor (η_m) and Income Risk Premium for the 1st year of operation.

3.7.2. O&M cost risk factor and cost of risk

The variable that represents the risk in costs is the O&M cost [COP/kW-day]. In an analogous way, Espinoza and Morris (2013) incorporate a Risk Premium related to potential increases in projected expenses as described in equations (6) and (7):

$$RP_C = (\tilde{C} - \bar{C}) * \Pr\left[\tilde{C} > \bar{C}\right] \qquad (6)$$

where: RP_C is the daily O&M Cost Risk Premium, $\bar{C}$ is the daily O&M Cost Average, $\tilde{C}$ is the average of values greater than $\bar{C}$, $\Pr\left[\tilde{C} > \bar{C}\right]$ is the probability that expected value over the average exceeds the average.

$$_C = RP_C / \bar{C} \qquad (7)$$

where: η_c is the O&M Cost Risk Factor.

Thus, the cost of risk (O&M Cost Risk Premium) is set as:

$$RP_{Cost} = {}_C^* \text{ O\&M Cost} \qquad (8)$$

Similar to the results in the previous section, it was determined that the log-normal distribution best represented the O&M cost data obtained from the 39 SHPs analyzed. The results obtained from the Risk Factor (η_c) and the O&M Cost Risk Premium (RP_{Cost}) for the year of operation are presented in Table 6, according to $\bar{C}$ = 848.69 [COP/kW-day], $\tilde{C}$ = 854.72 [COP/kW-day] and, $\Pr\left[\tilde{C} > \bar{C}\right] = 49.82\%$

RP_C = 3.00 [COP/Kw-DAY]

η_c = 3/848.69 = 0.35%

The risk-adjusted (decoupled) project-free cash flows for this analysis are determined using the financial expression:

DFCF = (Energy Sales−Income Risk Premium) − (O&M Costs+ O&M Cost Risk Premium) −Regional Transfers−Taxes (9)

And, the DNPV is calculated in a similar way to the NPV, but discounting the risk-adjusted free cash flows by using the risk-free rate (R_F)

$$DNPV = -I_0 + \sum_{t=1}^{n} \frac{DFCF_t}{(1+R_F)^t} \qquad (10)$$

4. RESULTS

4.1. Economic Analysis

After evaluating two different time frame simulations of the project (30 and 50 years) with 10,000 scenarios, it is obtained in the first simulation that the success probability is 99.82% (NPV>0), with an expected value of NPV = 22.5 MUSD (94,102 MCOP) as depicted in Figure 4 and IRR = 19.9%, in the second simulation the probability is 100%, with NPV = 28.3 MUSD (118,381 MCOP, 25.8% higher), with IRR = 20.2% (1.6% higher). Other details are provided in Table 7.

Table 5: Risk factor and first operational year income cost of risk calculation

Months	Days	Energy price [COP/kWh]	$\overline{E_m}$ [GWh/day]	CDF	E_m [GWh/day]	RP_{Em} [GWh/day]	RF η_m (%)	RP_{Income} [MCOP]
January	31	338.00	0.3307	0.4992	0.2456	0.0425	12.85	445.2
February	28	339.78	0.2628	0.5134	0.1838	0.0406	15.44	386.0
March	31	341.57	0.2787	0.5297	0.1819	0.0513	18.41	543.2
April	30	343.36	0.3377	0.5086	0.2410	0.0492	14.57	506.8
May	31	345.17	0.3675	0.4958	0.2768	0.0450	12.23	481.1
June	30	346.99	0.4066	0.4742	0.3358	0.0336	8.25	349.3
July	31	348.81	0.3794	0.4882	0.2951	0.0411	10.84	444.7
August	31	350.65	0.3627	0.4904	0.2796	0.0408	11.25	443.4
September	30	352.49	0.3762	0.4852	0.2965	0.0387	10.28	409.1
October	31	354.35	0.3996	0.4740	0.3303	0.0328	8.22	360.8
November	30	356.21	0.4180	0.4716	0.3491	0.0325	7.78	347.4
December	31	358.08	0.4114	0.4662	0.3515	0.0279	6.78	309.8

CDF: Cumulative distribution function

Table 6: Risk factor and first operational year expense cost of risk calculation

Months	Days	$\bar{C}$ [COP/kW-day]	Power [kW]	CPI factor	O&M Cost [MCOP]	RF [η_C] (%)	RP_{cost} [MCOP]
January	31	848.69	13781.08	1.06	384.65	0.35	1.36
February	28	848.69	10951.48	1.06	276.77	0.35	0.98
March	31	848.69	11613.45	1.07	325.75	0.35	1.15
April	30	848.69	14070.45	1.07	382.88	0.35	1.36
May	31	848.69	15313.15	1.07	431.65	0.35	1.53
June	30	848.69	16941.96	1.07	463.29	0.35	1.64
July	31	848.69	15807.77	1.08	447.79	0.35	1.58
August	31	848.69	15113.65	1.08	429.18	0.35	1.52
September	30	848.69	15676.87	1.08	431.88	0.35	1.53
October	31	848.69	16649.72	1.08	475.14	0.35	1.68
November	30	848.69	17418.18	1.09	482.22	0.35	1.71
December	31	848.69	17140.61	1.09	491.56	0.35	1.74

Table 7: Project summary

Indicator	NPV				IRR			
	Mean	SD	90% C.I.		Mean	SD	90% C.I.	
30 y	22.5	10.3	7.2	40.8	19.9%	1.8%	16.9%	22.9%
50 y	28.3	13.1	9.5	52.4	20.3%	1.8%	17.3%	23.2%

Values in MUSD, C.I.: Confidence interval

Table 8: DNPV results

Indicator	DNPV				IRR_D			
	Mean	SD	90% C.I.		Mean	SD	90% C.I.	
30 y	30.4	11.8	13.1	51.9	18.4%	1.6%	15.7%	21.1%
50 y	41.7	17.4	17.4	74.1	18.8%	1.6%	16.2%	21.5%

Values in MUSD, D: Decoupled

Table 9: Value at risk and conditional value at risk

Indicator	C.L. [%]	NPV		DNPV	
		VaR	CVaR	VaR	CVaR
30 y	90	9.92	6.64	15.66	12.58
	95	7.18	4.60	13.12	10.66
50 y	90	12.63	8.88	20.94	16.87
	95	9.46	6.54	17.36	14.41

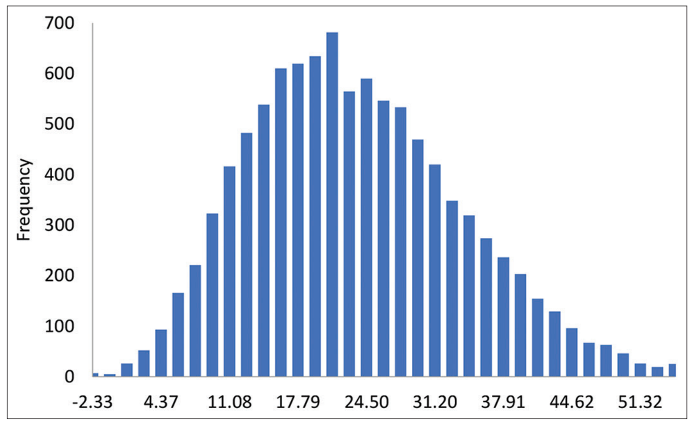
Values in MUSD, C.L.: Confidence level

Table 10: LCOE Summary

LCOE	Mean	SD	90% C.I.		VaR*	CVaR*
30 y	72.8	5.1	65.1	81.8	81.8	84.9
50 y	72.2	5.1	64.6	81.1	81.1	84.2

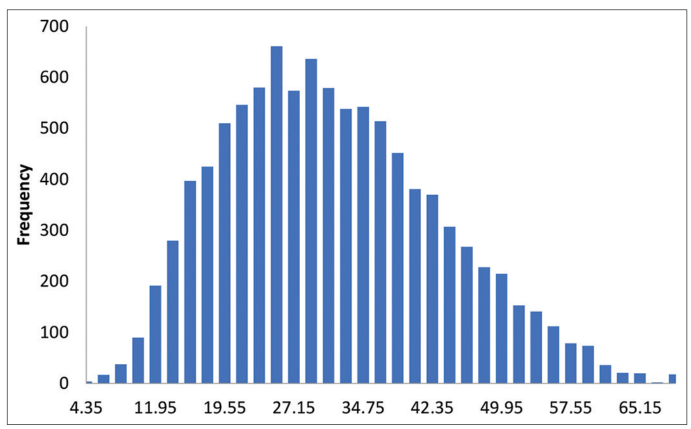
Values in USD/MWh, *90% Confidence level

Figure 4: NPV histogram @ 30 years



Source: Values in MUSD

Figure 5: DNPV histogram @ 30 years



Source: Values in MUSD

4.2. DNPV

With the free cash flows decoupled, that is, adjusted with the quantification obtained from the risk through factors η_m and η_c for both income and costs, the DNPV is determined according to equations (9) and (10). In the 30-year project evaluation, the probability of success using the proposed methodology is 100% (DNPV>0), as shown in Figure 5, with an average expected value of DNPV = 30.4 MUSD; more details are displayed in Table 8.

Value at Risk (VaR) and Expected Shortfall (CVaR) indicators were presented as project risk measures. With a 90% confidence level, the NPV values exceed USD 9.92 million, and the DNPV exceeds USD 15.66 million, as shown in Table 9.

4.3. LCOE

According to the results, the main component corresponds to CAPEX with 85.9% of LCOE, while the remaining 14.1% belongs to OPEX. The expected value in the project is 72.8 USD/MWh with values between 65.1 USD/MWh and 81.8 USD/MWh within a confidence interval of 90%; more details, including risk assessment indicators, are listed in Table 10. As reference, Lazard's Power, Energy & Infrastructure Group (2024) reported US LCOE values in USD/MWh for renewables wind onshore

Figure 6: Nonlinear rank correlation for NPV

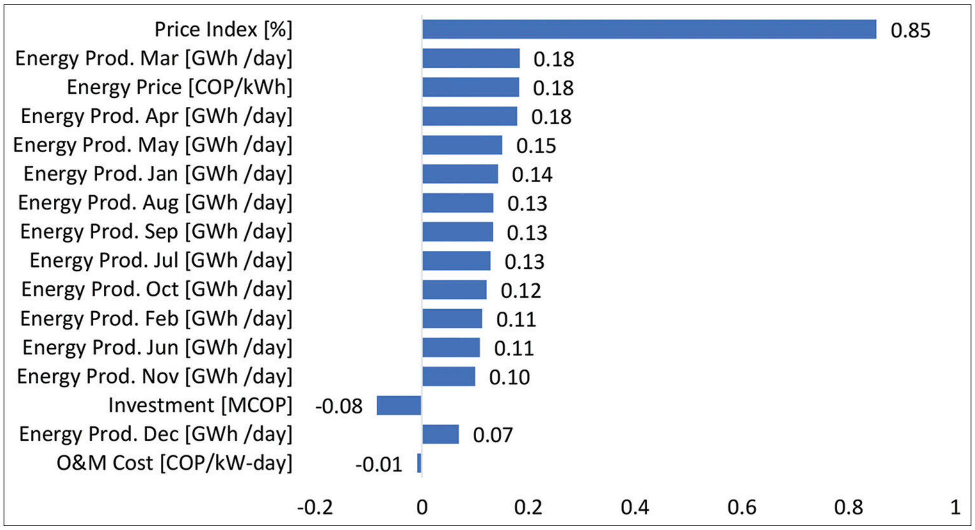


Table 11: PPI versus CPI, NPV behavior

NPV		PPI						
		3%	4%	5%	6%	7%	8%	9%
CPI	3%	92776	122440	156595	196206	242404	296561	360354
	4%	90448	120132	154309	193935	240145	294315	358117
	5%	87789	117499	151697	191337	237563	291745	355557
	6%	84742	114482	148700	188353	234597	288794	352616
	7%	81237	111001	145247	184913	231174	285389	349217
	8%	77177	106969	141245	180930	227207	281438	345278
	9%	72454	102281	136590	176300	222593	276838	340692

Values in MUSD

Table 12: PPI versus CPI, IRR behavior

IRR		PPI (%)						
		3%	4%	5%	6%	7%	8%	9%
CPI	3%	20.1%	21.2%	22.3%	23.4%	24.5%	25.6%	26.6%
	4%	20.0%	21.1%	22.2%	23.3%	24.4%	25.5%	26.6%
	5%	19.9%	21.0%	22.1%	23.2%	24.3%	25.4%	26.5%
	6%	19.7%	20.9%	22.0%	23.1%	24.3%	25.4%	26.4%
	7%	19.6%	20.8%	21.9%	23.0%	24.2%	25.3%	26.4%
	8%	19.4%	20.6%	21.8%	22.9%	24.1%	25.2%	26.3%
	9%	19.2%	20.4%	21.6%	22.8%	23.9%	25.1%	26.2%

Table 13: Energy price limits with fixed parameters

P	NPV > 0	DNPV > 0
30 y	48.01	43.71
50 y	44.59	38.59

Values in USD/MWh

(27-73) and Solar PV utility (29-92), additionally for conventional energy Gas combined Cycle (45-108) and Coal (69-168). On the other hand, IRENA (2024) also reported in USD/MWh, a worldwide mean wind LCOE of 33, and 90% Confidence Levels of (30-55) in North America, (18-37) Brazil and (31-111) Other South America, also, 44 USD/MWh worldwide mean solar PV LCOE, 57 in United States and 59 Brazil, and a worldwide mean hydropower LCOE of 57 USD/MWh, with an average of 70 for SHP in South America ranging between 42 and 130 USD/MWh (90% Confidence Level).

4.4. Capacity Factor

An average Plant Factor of 75.9% was obtained as the operating result of the model plant, with a standard deviation of 6.1% and expected values between 65.9% and 85.9%, within a 90% confidence interval. For reference, IRENA (2024) reported 52% as global weighted average capacity factor for small hydropower with values between 30% and 75% in the same confidence interval.

4.5. Sensitivity Analysis

The impact of the model's input variables on the financial result (NPV) is visualized through a correlation analysis, with the Price Index standing out as the first actor with a correlation factor of 0.85, and the rest of the influence coming from the energy production expected throughout the year, as shown in Figure 6.

The other parameters used in the evaluation are the CPI and PPI; the former drives cost increases, and the latter drives price increases. Their influence was analyzed using a two-way table based on the static base model, holding the other elements of the model constant. High-inflation scenarios where CPI > PPI still maintained favorable project outcomes under the conditions of NPV > 0 and IRR > WACC, as shown in Tables 11 and 12, respectively.

On the other hand, keeping the other elements of the static model constant (Table 13), the Energy Price variable (P) allows NPV values > 0 when P > 48.01 USD/MWh (200.62 COP/kWh). This result is 48.54% lower than the value established within the base model of 71.31 USD/MWh (298 COP/kWh).

5. CONCLUSIONS

In the field of renewable energy, electricity generation through small hydroelectric power plants, a mature and proven technology with favorable conditions in Colombia and recognized for its minimal environmental impact, has been validated as a viable option to support renewable hydrogen production. Evidence is provided through both the conventional evaluation metrics of Net Present Value and Internal Rate of Return, as well as the use of the Decoupled Net Present Value methodology in the evaluation of such projects. The DNPV procedure enables the decoupling of risk from expected cash flows by identifying the origin of these risks and quantifying them. The case model analyzed focused on daily energy output and operational and maintenance expenditures.

The DNPV approach offers a different perspective on the evaluation of renewable energy projects, which are inherently long-term in nature. Traditionally, project value is underestimated by including risk in the discount rate through high-risk premiums, and consequently, it can be pushed toward rejection. This alternative allows the separation of financial risk from operational risk; the first remaining at the rate, while the second is redirected toward cash flows. The case analysis highlights the aforementioned underestimation compared to the NPV traditional method, finding an average value 1.35 times higher for the 30-year valuation and 1.47 times higher for the 50-year valuation.

The Decoupled Net Present Value represents a structured and simple method with the materialization of risk through premiums impacting expected cash flows, providing coverage for potential reductions in projected revenues and increases in expected expenditures. This allows consistent results by requiring early risk consideration in analyses, rather than assuming certainties as in traditional methods, which can lead to inadequate risk coverage in renewable energy initiatives.

The Price Index is identified as the main driver of financial results. Therefore, the importance of a careful selection is emphasized when structuring energy supply agreements, whether for renewable H_2 production projects or for sale in the unregulated market. Setting the base price within the projected evaluation ranges also yielded favorable outcomes.

Complementary factors promote the advancement of this renewable generation technology in Colombia. The LCOE aligns with the expected range for this type of project, as does the resulting plant factor. Additionally, variations in the CPI and PPI demonstrate positive results, even in uncertain environments with shifting macroeconomic conditions.

The case study findings reveal that the development of SHPs in Colombia enables the provision of renewable energy at competitive prices within the unregulated market and lays the groundwork for the supply required for hydrolysis within the short-term renewable hydrogen strategy.

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