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Flexible Valuation of Photovoltaic Projects in Healthcare Institutions in Colombia: A Real Options-Based Approach

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ABSTRACT

This article presents a real options method to value photovoltaic installations in public hospitals in Colombia. It uses a binomial model adapted to local conditions and tests three decisions that matter in practice: Postponing an installation, expanding capacity after early evidence, and rolling out in phases. The cases come from two healthcare providers in Barranquilla, which gives the analysis a concrete setting. The study follows a quantitative design with an applied focus. It works with variables used in routine planning: The initial outlay, projected electricity savings, a risk free rate drawn from local government bonds, volatility estimated from recent tariff movements, and the agreed time horizon. Real-options estimates used the same cash-flow inputs as the baseline NPV, so the comparison is like-for-like. Waiting lifted value by about $100,000 USD, since the team orders only after the tariff bulletin and a supplier's price/lead time are confirmed. A phased rollout added roughly $125,000 USD: Start small, meter output, review costs, then add capacity only if checks hold. Simulations drew on ranges observed in hospital projects, not a single toy case. Results also show uneven regional uptake and that flexible appraisal helps teams work within technical limits, procurement rules, and tight budgets. Practically: Train teams, update evaluation rules to admit staged choices, and use real options alongside standard indicators. Train technical teams in option based valuation so scenarios and decision points are specified clearly. Update evaluation rules so staged decisions are admissible in formal reviews. Use real options alongside familiar indicators when assessing public health energy projects, so the appraisal reflects the way decisions are actually taken as information arrives.

Keywords: Real Options, Project Valuation, Solar Photovoltaic Energy, Health Sector, Binomial Model, Energy Efficiency
JEL Classifications: I15, L94, O33, Q42.

1. INTRODUCTION

Across many developing countries, energy transition and institutional sustainability have moved up the agenda. Health services rely on electricity around the clock to keep care running (Silva et al., 2024). In Colombia the legal framework points in the same direction: Law 1715 promotes nonconventional renewables and efficient consumption, and Law 2099 pushes that effort further (Congreso de la República de Colombia, 2014; Congreso de la República de Colombia, 2021). Even so, photovoltaic systems are still rare in public hospitals. Capital budgets face hard caps, engineering teams are thin, and managers often decide with partial information (Hernández Palma and Hurtado Ibarra, 2020).

Hospitals also live with high power bills, occasional outages, and a dependence on public subsidies (Akhtar et al., 2024). Under those conditions, tools that look beyond NPV or IRR help. A real options view does not force a single route. Teams can wait for a tariff circular, start with a small on site pilot and measure output, or redesign scope when supplier quotes, procurement calendars, or maintenance windows require a change (Jiménez-Gómez and Velásquez-Henao, 2024).

That room to maneuver matters in day-to-day planning, where forecasts are revised often and no one has perfect information. To frame the point, the review draws on three lines of work: How public entities evaluate projects, how managers act under uncertainty, and how renewable energy programs are planned (Cheng et al., 2023). Studies that focus on hospitals reach a practical conclusion, namely that flexibility should be preserved when real options are applied (Palma, 2024). Research from other energy settings points the same way and shows the approach holds across contexts (Puime-Guillén et al., 2021; Gazheli, 2018; Ivanovski and Marinucci, 2021). Taken together, these sources suggest that real options add to established practice by giving managers credible ways to adjust when conditions shift. Even so, analysts still rely on Net Present Value, Internal Rate of Return, and the payback period, and those indicators rest on relatively steady assumptions.

In practice, prices can move within a quarter, regulations can change between budget cycles, procurement windows can close, and technology may advance faster than models anticipate (Hernandez-Palma et al., 2025; Martinez et al., 2020). Under those conditions the tools can be too rigid. Methods that acknowledge uncertainty and treat flexibility as part of the asset help close that gap and bring the analysis closer to how projects actually unfold (Copeland and Antikarov, 2003; Mombello et al., 2023).

In hospitals, financial choices depend on more than internal calculations. Legislation, the flow of public funds, tariff policies, energy inflation, and changes in service demand can all push a project off its initial track (Harikae et al., 2021). Traditional methods rarely embed managerial flexibility once a plan is approved, so they do not specify how to adapt when new information arrives.

Interest in photovoltaic evaluation within the health sector has grown (Al-Rawi et al., 2023). In Colombia, recent studies note that using only traditional tools can understate the value of waiting or adapting (Saldarriaga-Loaiza et al., 2022; De Oliveira et al., 2021). Other national analyses examine financial viability and system design mainly with conventional indicators (Ortega Díaz and Osma, 2022; Bello Aldana and Páez Fino, 2019; Alvarado, 2019). In Latin America, evidence from Brazil and Argentina shows that real options enable more realistic appraisals by considering expansion, delay, or abandonment scenarios in renewable projects (Martins et al., 2023).

For modeling, the binomial approach represents the underlying asset with a branching tree of possible paths, while the Black and Scholes model provides a closed-form solution under stricter assumptions. For non-financial projects with high uncertainty, the binomial method is often preferred because it is flexible and easy to tailor to the case at hand (Cox et al., 1979).

This research therefore adopts the binomial model and follows managerial applications proposed in the literature (Trigeorgis, 1996). The article applies real options to photovoltaic projects in two public hospitals in Barranquilla. The goal is to improve the precision of financial valuation, support institutional management, and align with national sustainability goals. The proposal adapts the binomial model to Colombian conditions and analyzes flexible implementation scenarios using real data and validated technical criteria. The intended contribution is practical and replicable, so that public investment in health-sector energy infrastructure can be planned with clearer rules for acting under uncertainty.

2. METHODOLOGY

To make the methodology easy to scan—without losing the nuance of what you did—here is a concise table. The study was designed as quantitative, exploratory–applied, and non-experimental to test a valuation tool under real operating conditions, avoiding any disruption to hospital routines. A binomial model was deployed to estimate implementation scenarios for photovoltaic systems in two public hospitals in Barranquilla, Colombia (Congreso de la República de Colombia, 2014). The model adapts prior work (Alvarado, 2019; Gazheli and van den Bergh, 2018) by discretizing time into semiannual nodes and, at each node, selecting the action—execute, wait, or expand—that maximizes expected value.

Practically, a Microsoft Excel decision-tree was built to map possible evolution paths, compute the Flexibility-Adjusted Present Value (FAPV), and contrast it with conventional Net Present Value (NPV). The dataset came directly from two public IPS that had expressed interest in renewables and play pivotal roles in the local network, including historical electricity use, prices paid per kilowatt, available capital budgets, and national regulations with tax incentives and clean-energy guidelines. Grounding the model in these institutional and regulatory inputs ensured the valuations reflect real conditions in Colombia's health sector.

The decision-tree implementation in Microsoft Excel clarified each stage's options and the project's potential paths, while the FAPV-versus-NPV comparison made the incremental value of flexibility explicit—particularly the gains from informed waiting or staged expansion. By feeding the model with historical consumption, kilowatt prices, capital budgets, and current incentives, the results remain anchored to real institutional constraints and national policy signals (Congreso de la República de Colombia, 2014; Alvarado, 2019; Gazheli and van den Bergh, 2018). In short, the approach mirrors how decisions are actually made in hospitals facing uncertainty, turning flexibility from an intuition into measurable value for managers.

2.1. Model Parameters

Table 2 summarizes the main variables and parameters used in the project's financial modeling. Values were estimated from data provided by the IPS and national technical sources to ensure local relevance. In particular, the set includes the initial investment required, projected annual savings in energy costs, relevant rates (risk-free discount rate, expected growth, and energy-price volatility), and the evaluation horizon. These parameters underpin the construction of the binomial tree and the estimation of project value under different managerial decisions (Na et al., 2022).

2.2. Evaluated Scenarios

The analysis considered three ways a hospital could proceed with the photovoltaic project. One path was to commit the full installation at once, mirroring a traditional appraisal with no room to adjust later. A second path was to wait a year before investing and to keep the option to walk away if conditions did not improve.

Table 1: Methods overview and application details (with preserved citations)

Section	What was done	Why it matters	Key details/citations
Study design	Quantitative, exploratory–applied, non-experimental; binomial PV scenarios in two Barranquilla public hospitals.	Tests the tool under real constraints without disrupting hospital operations.	Regulatory backdrop acknowledged (Congreso de la República de Colombia, 2014).
Valuation model	Binomial lattice with semiannual nodes; at each node choose the value-maximizing action.	Captures uncertainty and managerial choice that static metrics miss.	Adapted from prior work (Alvarado, 2019; Gazheli and van den Bergh, 2018); FAPV contrasted with NPV.
Application context	Two public IPS; institutional and regulatory data integrated.	Aligns valuation with on-the-ground conditions for actionable insights.	Direct institutional data plus national incentives/guidelines embedded in parameters.

Source: Author's elaboration based on institutional data and financial literature (2025)

Table 2: Parameters considered in the binomial model applied to the photovoltaic project

Parameter	Estimated value	Source/justification
Initial project value (V_0)	\$150,000 USD	Budget estimate from Barranquilla IPS
Projected annual savings	\$45,000 USD	Technical projection of energy-cost reduction
Time horizon (T)	3 years	Institutional project planning
Periods (nodes)	6 (semiannual)	Binomial structure adapted to the context
Risk-free rate (r)	9.5%/year	Colombian TES government bonds (2024)
Expected volatility (σ)	25%	Historical behavior of the energy market
Expected growth rate (μ)	5%	Energy Price Index (UPME)

Source: Author's elaboration based on institutional data and financial literature (2025)

A third path was to start small, measure on-site results, and then add capacity in a second phase if the evidence supported it. In option terms, the first path acts as a baseline without flexibility, the second prices the right to wait, and the third values a staged expansion. Using a binomial model, each path was simulated to estimate present value under its own rules—fixed timing for the all-at-once case and decision points for the two flexible cases where managers act when signals justify it (Heidari and Heravi, 2024).

For the photovoltaic method, the team built a binomial tree in a spreadsheet and mapped future states for prices and policy. The sheet traces how the project would move along each branch under the different paths. With that structure it is possible to compare a standard NPV with a value that includes flexibility, one that records the decisions a hospital would actually take, such as deferring a start date after a tariff bulletin or adding capacity only after a short pilot on site. Set out in this way, the exercise shows in practical, checkable terms why timing and sequencing create value in uncertain settings and why a single static estimate can miss it.

3. RESULTS AND DISCUSSION

3.1. Results Analysis

The simulation results reveal substantial differences between the project's traditional financial valuation (NPV) and the assessment under the real-options approach (FAPV). Table 3 reports the values calculated for each scenario, comparing the baseline NPV with the adjusted value when flexibility is incorporated, as well as the type of real option applied in each case.

The results indicate that making explicit room for managerial choices reveals value that a single path misses. Waiting 1 year before committing, for example, adds roughly \$10,000 USD compared with an immediate start because the team invests after a tariff bulletin or firm supplier quote, not before. Rolling the project out in phases allows gradual expansion with closer control of cash flows and lower operational risk, lifting the adjusted figure to about \$52,500 USD.

When the installation is executed at once and no flexibility is allowed, both readings converge near \$45,000 USD since there are no further actions to price. The picture changes in scenarios that admit real options. A 1 year delay lowers the plain NPV to around \$37,500 USD because benefits arrive later, yet the wait option raises the adjusted value to about \$47,500 USD. The difference reflects the right to hold back until conditions improve. In the phased version of the project, a plain NPV of about \$40,000 USD rises to roughly \$52,500 USD once staged expansion is priced. The team begins with a small array, measures metered output on site, checks operating costs, and adds capacity only after those checks clear. That sequence lowers exposure to bad assumptions and explains the near \$12,500 USD lift.

Looked at together, the numbers show why static tools can miss upside in a volatile setting. A binomial real options model lays out concrete moves and the triggers that unlock them: Wait until the tariff circular is published, slip installation to the next maintenance window, or rescope after a procurement calendar shifts. It also assigns value to choices managers often make by instinct, such as holding under uncertainty or scaling up after a short pilot.

In Colombia's public hospital network, rules, budgets, and demand can change within a year. Under those conditions, this kind of flexibility sharpens the financial read and supports more careful use of public funds. The simulated paths make the point tangible: deferral and stepwise growth add value while keeping service continuity in view, and they give policymakers workable guidance for energy planning in hospitals. This is explained in Table 4.

Read alongside traditional tools, the real options view supports a more strategic and adaptive valuation without forcing a single path. In public hospitals, budgets, regulations, and technology can shift during the year, so managers need room to time investments and to

Table 3: Scenario matrix for valuation (USD)

Metric/scenario	Immediate implementation	Postponement: 1 year	Phased implementation
Traditional NPV (USD)	$45,000	$37,500	$40,000
Value with real options (USD)	$45,000	$47,500	$52,500
Increment versus NPV (USD)	$0	$10,000	$12,500
Option type applied	None (baseline without flexibility)	Wait option	Staged expansion option

Source: Author's elaboration from binomial-model simulations based on Trigeorgis (1996)

Table 4: Comparative evidence on photovoltaic project evaluation in health/energy

Author/source	Application context	Methodological lens	Key takeaway	Limitation/critical note
Palma (2024)	Colombia – Public health	Real-options framework in hospital settings	Adapts a binomial model to Colombia; emphasizes institutional resilience	Context-specific scope (Colombia)
Alzate et al. (2019)	Colombia – Public projects	Discounted-cash-flow (NPV, IRR)	Solid techno-economic baseline	Does not include uncertainty/ flexibility via real options
Boer (2002)	General – Private investment	Sequential decision valuation	Bridges static to dynamic valuation logic	Not a hospital-specific empirical test
Copeland and Antikarov (2003)	USA – Corporate finance	Practical real-options toolkit	Tools are transferable to non-financial sectors	Not focused on public hospitals
Trigeorgis (1996)	Global – Strategic finance	Flexibility and intertemporal choices	Foundational reference for this article's approach	Classic reference; not sector-specific
Martins et al. (2023)	Brazil – Renewable-electricity transition	Real options+simulation	Captures uncertainty and flexibility in energy investments	Results sensitive to assumptions/simulation quality
Gazheli and van den Bergh (2018)	Europe – Solar versus wind	Real-options comparative analysis	Clarifies diversification under uncertainty	Theoretical orientation limits direct policy transfer
Ivanovski and Marinucci (2021)	Global/quasi-public projects	Econometric analysis of political uncertainty	Quantifies uncertainty impacts	Does not model strategic managerial flexibility

Source: Author's elaboration based on institutional data and financial literature (2025)

Table 5: Core financial and strategic variables in modeling photovoltaic projects in IPS

Variable	Description	Unit/estimated value
Initial investment (V_0)	Estimated total cost of the photovoltaic system in the institution	~\$125,000 USD (approx.)
Projected savings	Expected reduction in spending on conventional electricity	$20,000 USD/year
Risk-free rate (r)	Base rate used to discount risk-free future cash flows	6% (TES bonds average, 2023)
Volatility (σ)	Degree of uncertainty in energy prices and project costs	25% (sector estimate)
Time horizon (T)	Duration of the evaluated project, in years	3 years
Decision frequency	Number of nodes where a strategic decision option can be exercised	Every 6 months (6 nodes)
Type of options considered	Integrated managerial alternatives: wait, expand, phase implementation, abandon	Real, flexible, sequential
Valuation model	Mathematical structure used to value the project including flexibility	Binomial model (Cox, Ross, and Rubinstein)

Source: Author's elaboration based on institutional data and financial literature (2025)

stage work. The binomial model used in this study fits that reality and is cited here for its concrete, context specific setup (Palma, 2024). It gives public investment managers a practical benchmark: Price the right to wait, expand after evidence from a pilot, or revise scope when policy or tariffs change (Khamharnphol et al., 2023).

3.2. Study Limitations and Contributions

The binomial model is useful because it lets flexibility enter the valuation, but its performance depends on the inputs and on institutional conditions. Data collection was the first hurdle. Some of the time series were patchy or inconsistent.

These constraints do not erase the method's value, though they do argue for caution. With robust input, the conclusions can credibly guide decisions. With a thin information base, precision drops and choices may lean on assumptions that do not match day to day practice. Strengthening energy data systems in public institutions would raise the quality of future valuations and make flexible planning easier to defend. Readers should interpret the option values with these execution lags in mind.

Finally, the implementation was done in a conventional spreadsheet. That choice helped with access and transparency, but it limited the ability to model complex or interdependent shocks. Future work can test more powerful setups, including Monte Carlo runs and specialized software, to capture correlated risks and produce results with greater depth while keeping the analysis auditable (Palma, 2024).

A comparative table follows (Table 5), synthesizing the main contributions of national and international studies on financial methodologies applied to photovoltaic projects and highlighting similarities, differences, and key contributions that underpin this research.

The comparative analysis shows that, although there is international consensus on the advantages of real options in uncertain environments, their application in the Colombian context remains limited. This reinforces the relevance of adapting the methodology to the national public-hospital system, as proposed in this study.

4. CONCLUSION

The study finds that a real options method can help value renewable energy projects in Colombia's public hospitals. Unlike a one path cash flow view, this approach mirrors how decisions are actually made. A manager can wait for clearer signals, begin with a small array and measure output on site, or add capacity after performance and tariffs are known. In the applied case, the right to wait and the choice to roll out in phases both change the project's value in ways a static calculation does not pick up. These choices do not erode profitability. They buy time and control when conditions are unclear. Set next to a simple Net Present Value, managerial flexibility recovers value that a single point estimate leaves out.

The contribution is larger than a higher total in an analysis file. It steers public funds toward work in stages instead of committing the full budget on day 1. That practice fits national energy transition goals and gives hospital teams technical grounds for decisions under shifting rules. From a planning view, the results turn into steps that staff already recognize. If a tariff circular is still pending, the team holds the order and waits for the bulletin. After a short on-site pilot, they advance in steps rather than in one go. When a supplier revises a quote last minute or a maintenance window tightens, the team reshapes scope instead of forcing the plan. Used this way, the method ties new facts to dated, concrete actions—not just a prettier number.

The same logic fits public agencies beyond hospitals. Write flexibility into handbooks and workshops so adjustments are documented and auditable. Policy asks: Run option-aware reviews before big commitments, pilot before full rollout, and schedule real checkpoint dates. None of this lands without training, so teams need practice with the tools. Future work can test other sectors, add social and environmental lenses, and pair the approach with Monte Carlo when uncertainty runs deeper—all while staying practical for day-to-day management.

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