Technical and Economical Prefeasibility of Repurposing a Coal Fired Power Plant in Colombia

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Just Energy Transition in Coal Regions

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Abstract

This paper presents the technical and economical prefeasibility of repurposing Termoguajira coal fired power plant in Colombia. The Colombian government and GECELCA aimed to identify and choose the two most promising business models for repurposing a power plant. This new setup would involve solar panels, energy storage, and reactive power compensation systems. This research combined quantitative and qualitative methods to analyse energy storage technologies through data collection, analysis, and interpretation. This study evaluated the feasibility of energy storage systems at a thermal power plant. A techno-economic model was developed to optimize storage technology and size for maximum benefit-cost ratio. While promising options were identified, the research highlights the economic challenges posed by the current regulatory framework for energy storage projects in Colombia. Overcoming these obstacles through policy adjustments is essential for unlocking the full potential of energy storage and facilitating the country's transition to a low-carbon energy system.

List of Abbreviations

BESS	Battery Energy Storage System
BCR	Benefit Cost Ratio
B/C	Benefit Cost Ratio
CAPEX	Capital Costs
CFPP	Coal-Fired Power Plant
COP	Colombian Pesos
H_2	Hydrogen
IRR	Internal Rate of Return
LFP	Lithium Iron Phosphate
MME	Ministry of Mines and Energy
MW	Megawatts
MWp	Megawatts Peak
NVP	Net Present Value
OPEX	Operating Costs
PV	Photovoltaics
STATCOM	Static Synchronous Compensator
WACC	Weighted Average Cost of Capital

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1.0 Introduction

The coal-fired power plant (CFPP) Termoguajira will be replaced by the installation of solar PV energy in 2027. As Termoguajira provides energy that stabilizes the grid and allows to react towards flexible fluctuations in demand, Hart Energy & Control Consulting was commissioned by GIZ to assess the different options that would allow Termoguajira to provide these services once the CFPP is closed.

Termoguajira has a 2x162 MW coal & natural gas fuel power plant constructed in Dibulla[1] (La Guajira Colombia). Unit 1 started operations in 1983 and the second unit was erected in 1987 (ANDEG, 2023). GECELCA S.A.E.S.P (hereafter GECELCA) is the utility that owns these power plants, and according to their business plan they aim to diversify its power generation portfolio by 2027 through the repurposing of the power plants based on solar energy using the same point of connection and providing other services to the electrical grid (Ministerio de Minas y Energía, 2023).

Dibulla is a small village within the municipality of the same name, it is located on the coast of the Caribbean Sea and lies close to tourist places such as Palomino beach. By 2022 it had an estimated population of around 43.660 people (DANE, 2018). About 85.4% of those reside in rural areas. Dibulla's economy is based on agriculture (banana, rice, coconut, and cassava), livestock and artisanal fishing (Alcaldía Municipal de Dibulla, La Guajira, 2024). However, in recent years its economy has been boosted thanks to tourism. Termoguajira also provides around 124 direct jobs at the facility and is a major player in the local economy due to the logistic and economical activities derived from its operation.

[1] Dibulla is a village within the municipality of the same name, and it is located on the cost of the Caribbean Sea and lies close to famous and touristy places like Palomino beach.

It is important to indicate that nowadays in addition to supply electricity to the national grid, Termoguajira has an important role to play in the electrical area (called Guajira-Cesar-Magdalena) because it also provides implicit services such as: a) Dynamic voltage control, b) short circuit power, c) control of electricity importation among others. These implicit services contribute to the security and reliability of the local electricity supply, unfortunately under the current regulatory frame of the market they are not remunerated.

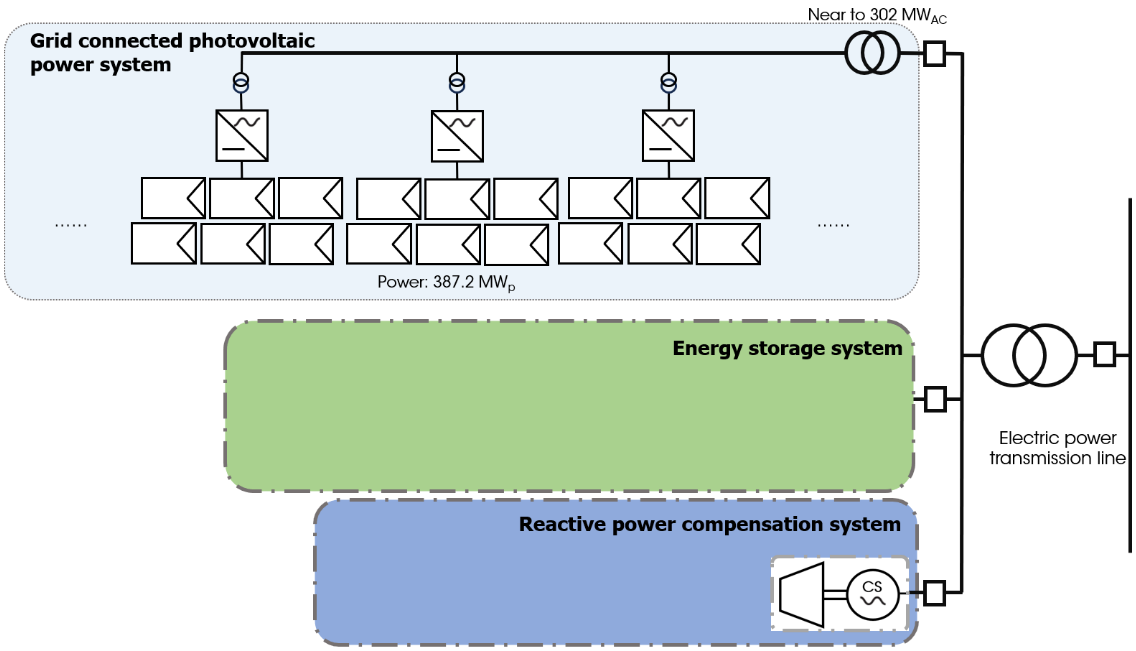
Prior to this study, GECELCA commissioned a study from a consulting firm regarding alternatives of repurposing Termoguajira's operation putting on the table and assessing 6 alternatives such as:

1. Aeroderivative gas turbine (300 MW)
2. Aeroderivative gas turbine (300 MW) and Solar PV (200MWp)
3. Aeroderivative gas turbine (200 MW), Solar PV (300MWp) and BESS (50MW)
4. Aeroderivative gas turbine (150 MW), Solar PV (350MWp) and BESS (50MW)
5. Aeroderivative gas turbine (100 MW), Solar PV (400MWp) and BESS (100MW)
6. Solar PV (300 MWp)

With all this in mind the Colombian Ministry of Mines and Energy (here in after MME) and GECELCA wanted to identify, analyse and select the two best business scenarios to be developed through a repurposed power plant with an utility scale photovoltaic farm (387 MWp), an energy storage system and a reactive power compensation system as is shown in the following block diagram.

Figure 1. Repurposed power plant diagram

Source: Elaborated by Hart consulting



The first block diagram is clearly defined as a photovoltaic system but for the second block diagram the energy storage system there are several technical alternatives to be considered in the analysis as these systems can solve problems related to the balance between power generation and load at different time frames. Those systems have applications such as: a) Primary frequency control, b) Secondary and tertiary frequency control, c) voltage control, d) black start, among others.

Finally, with regards to the third block GECELCA wanted to examine the possibility of reusing the two electric generators to be converted into reactive power compensation plants (synchronous condenser system) and provide a pack of services to the national grid in that electric area. If any agent of the market deploys those technologies, no one will be entitled to any remuneration according to the Colombian market conditions at least for the moment.

2.0 Methodology

To perform this research, both quantitative (numeric) and qualitative (descriptive) information were used. The process comprised collecting, analysing, and interpreting data or information from a variety of sources. Data collection methods were interviews, focus groups, documents and records and case studies.

The methodology applied to carried out this study consists of the following five stages: a) Context setting and review of energy storage technologies, b) Determine optimum energy storage and screening, c) Group discussion, d) Conduct regulatory, financial, and economic analysis and e) Conclusions and recommendations.

Figure 2. Methodology stages

Source: Elaborated by Hart Consulting

During the first stage, data collection began with an inspection of the thermal power plant to identify the existing situation and determine the starting point for the project. Among other things, the facilities, production performance, workforce, and available space, were examined. The consultants also conducted one-one-one interviews with electrical and mechanical maintenance personnel, production, and utility management. Dibulla municipal officials were also interviewed. Furthermore, five groups of energy storage solutions were reviewed, reported, and described on the second deliverable in this phase. These groups are: electrical, thermal, electrochemical, mechanical and chemical energy storage. This report took into consideration their maturity, CAPEX (capital costs), OPEX (operating costs) and performance metrics.

This report also includes information about solutions for reactive power compensation and a comparative table with a list of ancillary services and the possibility to supply the service under different preliminary configurations of repurposing the power generation asset.

Table 1. List of proposed ancillary services

Source: Author's table.

Service	Is TermoGuajira providing the service?	Can a solar plant provide the service?	Is a solar plant + storage system capable of providing the service?	Is a solar plant + storage system + STATCOM capable of providing the service?	Is a solar plant + storage system + synchronous condenser capable of providing the service?
Fast frequency response	No	It can be done at the expense of energy	Yes (Storage < 1h)	Yes (Storage < 1h)	Yes (Storage < 1h)
Primary frequency regulation	Yes	It can be done at the expense of energy	Yes (Storage < 1h)	Yes (Storage < 1h)	Yes (Storage < 1h)
Secondary frequency regulation	No	No	Yes (Storage < 2h)	Yes (Storage < 2h)	Yes (Storage < 2h)
Tertiary regulation	No	No	Yes (Storage < 4h)	Yes (Storage < 4h)	Yes (Storage < 4h)
Contribution to dynamic voltage control through the delivery and absorption of reactive power	Yes	Yes, but smaller capacity than Termoguajira units	Yes, but smaller capacity than Termoguajira units	Yes, the replacement of the 2 Termoguajira units would require a capacity of around 125 MVAr.	Yes, the replacement of the 2 Termoguajira units would require a capacity of around 125 MVAr.
Inertia	Yes	No	No, if it's storage with inverters (batteries).	No, if it's storage with inverters (batteries).	Yes, but due to costs constraints, the inertia would likely be lower than the two Termoguajira units.

Short circuit power/current	Yes	No	Yes, if it's storage with a synchronous interface.	Yes, if it's storage with a synchronous interface.	Yes, but due to costs constraints, the inertia would likely be lower than the two Termoguajira units.
Firm energy for reliability charge (ENFICC by its Spanish acronym)	Yes	Yes, but its contribution would be smaller than Termoguajira			
Security generation	Yes	No	With batteries only for congestion management/ import limits in the area (2 to 6 hours for peak management).	With batteries only for congestion management/ import limits in the area (2 to 6 hours for peak management).	Yes (Storage 2h to 4h)
Black Start	Needs to be validated with GECELCA	No			

The second stage required to solve the main problem of the study that is to find (or determine) the storage system with its source (i.e., the storage technology and its size, as well as the dimension of the solar farm that produces the energy to store) able to maximize the benefit-cost ratio[2] (B/C) subjected to the following restrictions:

- The injection capacity of the current connection point,
- The technical characteristics of the main solar PV farm and its production (although this farm is fixed in its capacity and its panel area, the production is variable because solar radiation is a probabilistic process),

[2] The benefit-cost ratio (BCR) is a profitability indicator used in cost-benefit analysis to determine the viability of cash flows generated.

- The technical and operational conditions of the technologies (both farms and the storage system) and
- Current conditions of the wholesale electricity market.

To address this problem, it was necessary to design and use a search method to optimize the amount of energy to be stored and even a stochastic[3] techno-economic modelling tool[4] (in excel) to set the best alternatives. This search consists of three major steps: 1) Choose an energy storage technology for a defined service, 2) Iterate and maximize benefit-cost ratio for that technology and 3) Check that technology.

The model accounts for probabilistic inputs (solar radiation, exchange prices) and deterministic inputs (CAPEX, OPEX, energy contracts). On the other hand, outputs are: Power generation, revenues, energy discharges and benefit-cost ratio. This iterative process allows the consultant team to suggest eight alternatives discussed with GECELCA and MME, considering different scenarios with their benefits and disadvantages. Two alternatives emerged from the internal discussion and were considered to develop the following stages.

The regulatory analysis is based on the research of international regulations governing energy storage systems and synchronous condenser systems. Financial and economic analysis were developed to prepare a budget, determining if a project is feasible and if the company or project has the financial capability to service its liabilities.

[3] Multiple possible outcomes exist, despite a clear initial state.

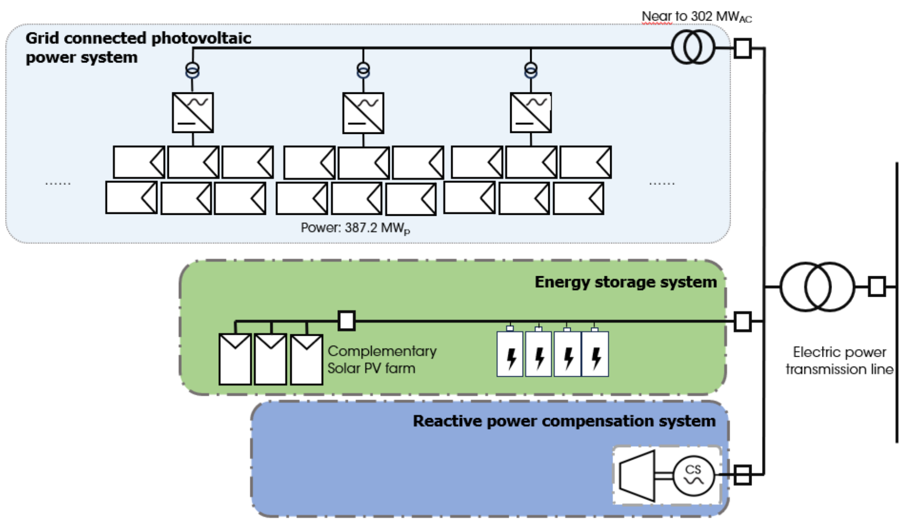
[4] Monte Carlo Simulation: Model to predict the probability of a variety of outcomes when the potential for random variables is present.

3.0 Results

The conceptual configuration of the repurposed power plant at Termoguajira is illustrated as follows.

Figure 3. Repurposed Power Plant at Termoguajira Conceptual Configuration

Source: Elaborated by Hart Consulting



3.1 Storage system optimization

From the simulations and the analysis, the consultant team presented eight alternatives to be considered as shown in the following table.

Table 2. Alternatives Outcomes from the Simulation Results

Source: Author's table.

#	Service	Technology	Complementary Solar PV Farm			Energy Storage System				B/C
			Capacity [MWp]	CAPEX [MUS$]	OPEX [KUS$(Year]	Capacity [MW]	Time [h]	CAPEX [MUS$]	OPEX [KUS$/Year]	
1	Primary frequency control	LFP Batteries	-	-	-	9	1	9.9	0	2.007
2	Support on steep ramps	LFP Batteries	70.0	62.8	188.3	100	4	290.8	408.7	0.881
3	Energy supply during peak demand at night	LFP Batteries	70.0	62.8	188.3	100	4	290.8	408.7	0.863
4	Long capacity using thermal energy system	Thermal Batteries	1,400.0	851.0	2,552.0	300	17	2,508.0	9,528.5	0.662
5	Long capacity using green H2	H2	2,100.0	1,211.0	3,632.0	300	17	2,116.0	3,369.0	0.634
6	Long capacity using Li-LFP Batteries	LFP Batteries	1,000.0	634.8	1,904.5	300	17	3,174.0	4,163.4	0.314
7	Benefit-cost ratio (B/C) = 1	LFP Batteries	70.0	62.8	188.3	95	3	215.7	310.6	1.004
8	Only Solar PV farm-Utility scale	-	387.2	278.1	834.2	-	-	-	-	1.892

Electrochemical batteries (Lithium iron phosphate) are the dominant technology for energy storage. Currently an energy storage system designed to attend primary frequency control, is on top of the alternatives and it does not need a complementary solar PV farm to feed the system. A storage system designed to support steep ramps in demand (between 16:00 and 20:00) is in second place when looking at the benefit-cost ratio, its value is 0.881 and since it is <1 this means that the project is not financially viable, but it is close to the unity. The power supply during night demand peaks (between 18:00 and 22:00) has similar conditions to the previous case. In a few words both projects are identical, the difference is the operating time of service. For services 5 and 6 the benefit-cost ratio decreases to 60%, and CAPEX and OPEX have increased compared to the previous services. In these cases, thermal batteries and green H2 become attractive in different scenarios unlike in Colombia, but they should not be lost of sight. The lowest benefit-cost ratio is 0.314 and refers to the long capacity of service (17 hours) using LFP batteries. The CAPEX and OPEX figures are extremely high.

After discussing these alternatives with interested parties two alternatives were selected for further in the analysis. Those were: a) Support to steep ramps and b) long capacity with Li-LFP batteries

3.2 Reactive power compensation system

At the time of conducting this study, the consultant team was able to verify that there were technical approaches between GECELCA and the manufacturer of the original turbogenerator to assess the technical feasibility of converting these units to synchronous condensers in the future.

Although this possibility has not been confirmed the consultant team was able to determine its CAPEX and OPEX based on secondary information, according to these values are about US$65.6 million and US$116,600/year.

3.3 PV farm-utility scale

One option is just to have this system without a coupled energy storage system. The size of this system has already been estimated at 387.2 MWp. Estimated CAPEX and OPEX for this system are about US$278 million and US$834,000/year (see case number 8 above).

3.4 Group discussion

The consultants presented the alternatives, and the interested parties discussed the suitability of each of them. Case 2 and case 6 were chosen to address the following stages of the study.

3.5 Regulatory analysis

Europe, the UK, and Australia have the most advanced regulations to facilitate the integration of energy storage systems into the electric market. In Latin-American Chile is the leader in regulation in this matter.

Given that reactive power compensation systems in the United States are considered international benchmarks for providing and compensating reactive power, independent system operators have established specific technical requirements for transmission agents and their payment. Australia and China are among the countries interested in developing similar systems.

In Colombia there are five regulations related to energy storage, but they are not sufficiently designed to promote this kind of technology or to support the electricity market. Regarding reactive energy Colombia has thirteen regulations and five complementary services. The UPME (Colombian Planning Unit of Mines and Energy , by its Spanish acronym) announced in an interview that tenders for this type of applications service will be made soon due to the technical needs in different areas of electricity transmission.

Some regulatory suggestions:

- Battery Energy Storage System (BESS) should be considered as a new market electric agent (generation agent), to be regulated independently (either for dispatch or to provide new services related to ramp management and heavy traffic on the grid).
- A repurposed power plant such as Termoguajira could be a pioneering and innovative case of application in the Guajira-Cesar-Magdalena area. This is an opportunity to have in mind and involve stakeholders.
- It is necessary to consider how to establish a remuneration for the contribution to voltage control through special equipment or remuneration for the reconversion of conventional plants to synchronous compensators and benefits on a case-by-case basis. Electrical and technical analysis must be carried out.
- Inclusion of this kind of equipment into the Colombian Grid Code.

3.6 Financial and economic analysis

The figures for the investments for both projects are as follows:

The assumptions used to estimate the main investment components (Capex), such as photovoltaic modules, inverters, and racks at the pre-feasibility-study-level are shown in Table 3.

Regarding the main solar farm, the technical component of the consultancy defined, based on secondary sources, that the approximate investment would amount to US$278 million and that, on average, the photovoltaic modules represent 50% of the total cost (US$137.7 million), the inverters 11% (US$31.2 million), and the racks 39% (US$109.1 million).

The cost of the complementary solar farm depends on the required size, as follows: For the alternative called Support on sleep ramps LFP704, the investment was estimated at US$62.8 million and for the alternative called Long capacity using Li-LFP Batteries LFPGC300, an investment of US$634.8 million. For this investment chapter, the technical component of the consultation found that the modules represent, on average, 50% of the investment, the inverters 11%, and the racks 39%.

In addition to the investments described above, storage requires an investment of US$290.8 million in the alternative called Support on sleep ramps LFP704 and US$3,173.5 million in the alternative called Long capacity using Li-LFP Batteries LFPGC300.

Likewise, in the scenario in which it is decided to invest in the synchronous compensator, this is estimated to cost US$65.6 million in either of the two alternatives.

Similarly, for the two alternatives, the need to invest US$2.68 million in land for the construction of the solar farm and US$19.3 million for the distribution line was estimated.

In total, the investment cost is estimated at US$719.2 million for the alternative called Steep Ramps LFP704 and US$4,173.9 million for the alternative called Long-Term Storage LFPGC300.

The initial investment foreseen for each alternative can be observed in the following table:

Table 3. Investment Costs per Alternative (billion USD)

Source: Author's table

Assets	(2) Support on sleep ramps [US$bn]	(6) Long capacity using Li-LFP Batteries [US$bn]
Grid connected solar PV farm. • PV modules • Inverters • Racks	278.0 50% 11% 39%	278.0 50% 11% 39%
Complementary solar PV system • PV Modules • Inverters • Racks	62.8 50% 11% 39%	634.8 50% 11% 39%
Energy storage system	290.8	3173.5
Synchronous compensator	65.6	65.6

Assets	(2) Support on sleep ramps [US$bn]	(6) Long capacity using Li-LFP Batteries [US$bn]
Land	2.68	2.68
Distribution liner	19.3	19.3
Total	**719.2**	**4173.9**

4.0 Results of evaluation

The results of the financial evaluation of the project for the two alternatives analysed are shown in Table 4.

The first financial evaluation indicator represents the analysis of the net present value of each of the alternatives, measured in millions of COP. The net present value represents the comparison, at present value (at the time when the analysis is carried out, year 2023), of the investments and free cash flows that are estimated for each alternative, discounting the surpluses at the rate that represents the cost of capital (WACC rate).

In this context, it is found that the alternative called Support on sleep ramps LFP704 shows a net present value of COP -444,652 million, which means that it does not generate the required profitability and fails to recover the investment to be made, leaving a pending value to be recovered of COP -444,652. For its part, the alternative called Long capacity using Li-LFP Batteries LFPGC300 shows a net present value of COP -16.29 billion, that is, it does not offer the required profitability based on the risk of the project and the value mentioned above is still pending to be recovered.

The previous analysis shows that neither of the two alternatives is selectable as a project from a financial point of view and that the alternative called Long-Term Storage LFPGC300 is decidedly rejectable, fundamentally because the level of investment it requires is significantly high compared to the capacity to generate income.

The second indicator in the table shows the results of the analysis of the net present value of the investor's flows, that is, it compares the investment to be made by the investor with the flows available to the project promoter, after paying the debt service, discounting the flows at the rate that represents the cost of equity.

The results obtained show that the alternative called Support on sleep ramps LFP704 shows a net present value for the investor of COP -333,456 million, which means that it does not generate the required profitability and fails to recover the investment to be made, leaving a pending value to recover of COP -333,456. On the other hand, the alternative called Long capacity using Li-LFP Batteries LFPGC300 shows a net present value of COP -5.95 billion, that is, it does not offer the required profitability based on the risk of the project and the value mentioned above remains to be recovered.

In addition to the analysis carried out with the net present value criterion, the internal rate of return has been calculated, which measures the rate at which the resources that remain within the project yield. Thus, it has been found that the alternative called Support on sleep ramps LFP704 offers an annual real profitability of 3.73%, which is considerably lower than the WACC rate required by the project. For its part, this same alternative offers an annual rate of return to the investor of 7.09% in real terms, which is also substantially lower than the rate that the investment risk demands for this type of project. Mathematically, it is not possible to calculate the internal rate of return, for the project or for the investor, for the alternative called Long-Term Storage LFPGC300, given that the cash flow results are quite negative.

For its part, the analysis of the financial benefit-cost ratio (RBC) of the two alternatives, which consists of comparing the income offered at present value and comparing it with the present value of the investment to be made, using a WACC rate as a discount rate for the project, offers as a result that, for the alternative called Steep Ramps LFP704, the RBC is 0.87, which means that for each monetary unit invested, in this case COP, only 0.87 cents are recovered, that is, the costs incurred are not recovered. For the alternative called Long capacity using Li-LFP Batteries LFPGC300, the RBC is 0.35, which confirms that it is not an eligible alternative. Finally, the table shows the levelized cost for each of the alternatives analysed, finding that for the alternative called Support on sleep ramps LFP704 the levelized cost is COP 396 for each KWh installed and for the alternative called Long capacity using Li-LFP Batteries LFPGC300 this cost is COP 1,000. To confirm the financial non-viability of the two alternatives, it is found that the levelized income of the first is COP 344 per KWh and for the second COP 347 per KWh, finding that in both cases the cost is greater than the income.

Table 4. Financial Performance of Alternatives

Source: Author's own calculations, constant COP values for the year 2023.

Indicator	(2) Support on sleep ramps	(6) Long capacity using Li-LFP Batteries
Project NPV COP$ MM	-444,652	-16,296,986
Investment NPV COP$ MM	-333.466	-5.950.737
Project IRR %	3.73%	NA
Investment IRR %	7.09%	NA
Financial benefit-cost ratio	0.87	0.35
Levelized cost COP$ / kWh	396	1000
Levelized revenue COP$ / kWh	344	347

Note: USD$ 1.00 = COP$3,850

As can be seen, as a project it does not show results that allow us to affirm that it is an assumable investment, given that none of the alternatives studied shows that it yields income at the WACC rate and that it returns the investment made. Project Number 2 shows the best figures in the evaluation. Project Number 6 is completely unfeasible at this point.

Conclusions and recommendations

It is necessary to make regulatory changes in the Colombian regulations since there are still no signals that would allow incorporating storage technologies as fundamental assets for the energy transition and raise the need to remunerate the storage service.

It is imperative to define the role of the actor that would provide the storage service, since, in the current definitions, generators are not clearly empowered to perform it, and therefore it is proposed to define the "Storage Agent".

It is important to define the methodology for the calculation of the firm energy for storage systems that allow having an intraday energy reserve. This is justified by the immense potential Colombia has in renewable energy that would allow guaranteeing the firm energy required by the system in hours of high demand.

In order to provide services similar to those currently offered by Termoguajira, a significant investment is required due to technology prices, especially those related to the storage service, which means that, for now, the Benefit / Cost analysis does not show a value equal to or greater than one (1), which leads to affirm that from a socioeconomic point of view the project does not generate sufficient benefits to justify its implementation.

The two technical alternatives analysed, the most efficient, called Steep Ramp Support, which requires an initial investment (i.e., without considering reinvestments throughout the life of the project and the projection period) of US$653.7 million, is not financially eligible because its net present value (NPV) is negative US$108.5 million in 2023. The Long-term Storage alternative generates a much more negative NPV of US$ 3,974.9 million. This should be interpreted as neither of the two alternatives manages to show the minimum acceptable profitability required for the project (the WACC rate), nor to return the investment required by each of them, which makes them ineligible.

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