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TOTAL COST OF OWNERSHIP: MAXIMIZING SUPPLY MANAGEMENT PERFORMANCE THROUGH A NON-LINEAR STRATEGIC PERSPECTIVE

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Abstract: This article presents how an analysis based on the premises of TCO can provide a more holistic view of maximizing performance in actions relating to supply strategies. To this end, this research was based on a practical case study which consisted of carrying out a comparative analysis using the principles of TCO modeling to assess the feasibility of a project to optimize the cost of electricity. Among the main results, it could be seen that the scope of TCO's contributions went beyond the limits of the short-term vision by suggesting broader evaluative panoramas regarding the strategic, financial and operational aspects involved in investment decisions in long-term logistics projects - which can be verified through the non-linear vision provided by the quantitative and qualitative optics of TCO that provide the possibility of choosing fully viable logistics project alternatives.
Keywords: Supply Management; Total Cost of Ownership; Supply Chain Management; Comparative Analysis.

INTRODUCTION

According to Bowesox *et al.* (2014), *Supply* Chain Management (SCM) reflects the general arrangement that logically and logistically connects a company to an extensive network of collaborative operations that seeks, through high efficiency rates and high levels of service, to deliver greater value to customers. However, Simchi-Levi, Kaminsky and Simchi-Levi (2010) highlight how challenging it is to design and implement supply strategies that maintain high levels of service while minimizing total system costs, denoting the complexity of identifying the balance point between maximizing company profits and optimizing the costs that contribute to building and maintaining a globally competitive portfolio.

Mankiw (2020) explains that, in this context, maintaining high levels of service directly affects the cost curve over different time horizons, although this effect is perceived to a greater extent when companies make changes to increase the responsiveness of the supply chain. As the author explains, this is because the expansion of an organization's activities results in a natural increase in its total costs, given that certain business expansion parameters require the consumption of more variable inputs in the long term in order to meet production volumes and still maintain the desired service rates.

From the perspective of Wallace and Xia (2014), the big challenge lies in extracting more value from the chain while trying to disengage from the emergency and recurring demand for lower direct costs - a methodology which, for the authors, has become insufficient to stem the erosion of business margins. In this context, Jaspersen and Skøtt-Larsen (2005) cite *Total Cost of Ownership* (TCO) analysis as a line of evaluation that creates metrics for measuring elements that influence decision-making from the perspective of total supply costs, thus placing SCM performance in a broader perspective.

For Corrêa (2019), the TCO approach, due to its premise of evaluating the set that makes up total costs, should be at the center of decision-making in the supply chain spectrum, since it prevails in the view of the performance of production elements and sources of supply, allowing the sensitivity of decisions made to uncertainties or the recommendations of the supply system itself to be explored. This less linear view is proposed by Wallace and Xia (2014) as a transformational strategy more focused on maximizing performance, considering the dynamics of the entire supply network, its links, the risks assigned and their impact on the decision-making process regarding investments aimed at generating efficiency and effectiveness in the medium and long term.

From this context, this article aims to assess how an analysis based on TCO assumptions can provide a more holistic view of maximizing performance in actions relating to supply strategies. To do this, we analyze a practical case study carried out in a medium-sized company in the metalworking sector, located in the mountainous region of Rio Grande do Sul .

After the introduction, the article is structured as follows: section 1 presents the theoretical references that underpin the project; section 2 presents the methodology that guided the study; section 3 presents the results and discussions of the case study; and section 4 presents the final considerations of this study.

Total Cost Of Ownership (TCO)

According to Bowesox *et al.* (2014), the Procurement area carries the responsibility for obtaining the necessary inputs to support operations while at the same time needing to maintain a multidimensional focus. Although it is essential to keep the supply network in full operation, this multidimensionality requires the execution of purchasing strategies that require careful consideration of the *trade-offs* between the purchase price and essential elements for the success of the Supply Chain, such as: the impact on quality, the development of suppliers with logistical skills and the influence of the costs of a particular component or raw material throughout the life cycle of a product.

According to Campos (2015), this requires input management in line with the needs and positioning of the business, requiring the supply function to redirect itself beyond its usual operational activities. For the author, redirecting the supply sector's efforts towards projects with long-term, scalable results is decisive for the success of some business models, especially those whose supply chain is highly sensitive to macro-environmental variations.

Pires (2016) explains that the high volatility of the market has put pressure on companies to deliver high levels of responsiveness from the logistics network. However, this was not the only effect of macro-environmental pressures. In this context, the profile of supply management has naturally expanded to more comprehensive levels by making it its core activity to understand the conversion of fixed costs into variable costs and to understand the supply flow of inputs that impact on service levels.

Bowesox *et al.* (2014) point out, however, that drawing up a supply strategy with this proposal is a complex process, precisely because it requires a considerable analysis of the trade-offs that are part of the life cycle of the purchased input itself. Although traditional purchasing practice may overlook these trade-offs in favor of the lowest monetary value, identifying the elements detached from the purchase price can provide a more integrated view of the various projects aimed at maintaining service levels in the supply chain.

Simchi-Levi, Kaminsky and Simchi-Levi (2010) point out that maintaining an operation with high service levels, while minimizing total system costs, is challenging. However, Batista (2013) warns that excessive cost-cutting could represent an inconsequential move to weaken the responsiveness structure. He therefore proposes that the "cost *vs.* benefit" ratio be measured through an analysis based on total costs. This change in analysis allows parameters to be created to visualize the life cycle of costs in relation to productivity, which increases the perception that a cost generated can be the crucial point when compared to the damage caused by the interruption of essential activities.

Pires (2016) assumes that a systemic approach, within SCM, should be seen as a management philosophy and not as a set of fragmented parts with non-integrated functions and costs. In this sense, Bruni (2018) proposes the *Total Cost of Ownership* (TCO) as an approach that seeks to carefully examine the dimensioning of the impacts incurred throughout the life cycle of an asset or material, encompas-

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sing, in addition to the acquisition cost, operating costs, support, customization, among other aspects that impact on a supply project.

Batista (2013) explains that the concept of TCO was developed by the consulting firm Gartner Group in 1987 as an analysis model that includes all the costs involved throughout the useful life of a given asset or input, from its acquisition to its degradation and scrapping. Because of this, Bowesox *et al.* (2014) ratify that TCO modeling contrasts with the traditional purchasing strategy, based solely on pricing. The authors maintain that price remains an important parameter for the procurement process, although it is only part of the total cost, as shown in Figure 1. Costs that are part of the life cycle of the asset or input should not be ignored.

As this is a cost incurred over the useful life of an asset or input, Rocha and Borinelli (2024) state that the life cycle cost that represents TCO should include the costs involved in the actual life cycle of the item being purchased until it loses its usefulness or wears out completely (Figure 2). From the point of view of the requisitioners, there are categories of costs that are present even after the acquisition of the input, and it is necessary to identify them in order to minimize the temporal differences in the financial effects that will have an impact in the future.

According to Cokins (2002), TCO has given organizations a glimpse of how internal reengineering, when combined with technological investments, affects the costs of various parts of the supply chain. The explanation lies in the principle of creating visibility and transparency for a series of relevant costs, otherwise the company will miss out on supply opportunities that bring better profitability potential. In this vein, Mitsutani (2017) compares TCO to the figure of an iceberg in which a series of relevant costs lie in the depths, below what is visible on the surface. The author clarifies that, in a traditional supply process, these associated costs that remain hidden run the risk of not being observed.

In this conception, Buchanann (2008) points out that the basis of the total cost of ownership lies in understanding the associated costs, recognizing that the acquisition value is only a small part of all the costs involved. For this reason, Corrêa (2019) argues that in an integrated analysis model, such as TCO, indirect values are never neglected, given their impact throughout the economic life of the acquired item. For Ballou (2006), neglecting the associated costs can result in much greater inefficiency than the direct efficiency gains obtained by cutting various costs along the logistics chain.

Dennis and Fitzgerald (2010) argue that, in various segments, supply projects modeled on TCO show higher results than the direct costs involved in the procurement process. However, in order to decide on projects with assertively positive results, the metrics adopted must be based on the assumption that there will be wasted resources and performance losses that should never be omitted. Jaspersen and Skøtt-Larsen (2005) reinforce this idea by stating that many companies prefer to focus on methods that examine only the direct costs in a given investment evaluation, causing them to develop a mistaken perception of the *savings* connected to the supply chain.

Although many of these logistical considerations receive little attention when the aim is solely to achieve the lowest price, Bowesox *et al.* (2014) state that these costs are admittedly important for TCO-based modeling. This is because it is not just about optimizing direct costs in supply projects, but also about eliminating redundant activities in logistics arrangements. This operational integration-oriented vision breaks with the unbridled search for lower-priced projects and redirects supply management towards promoting sophisticated efforts aimed at identifying the lowest TCO.

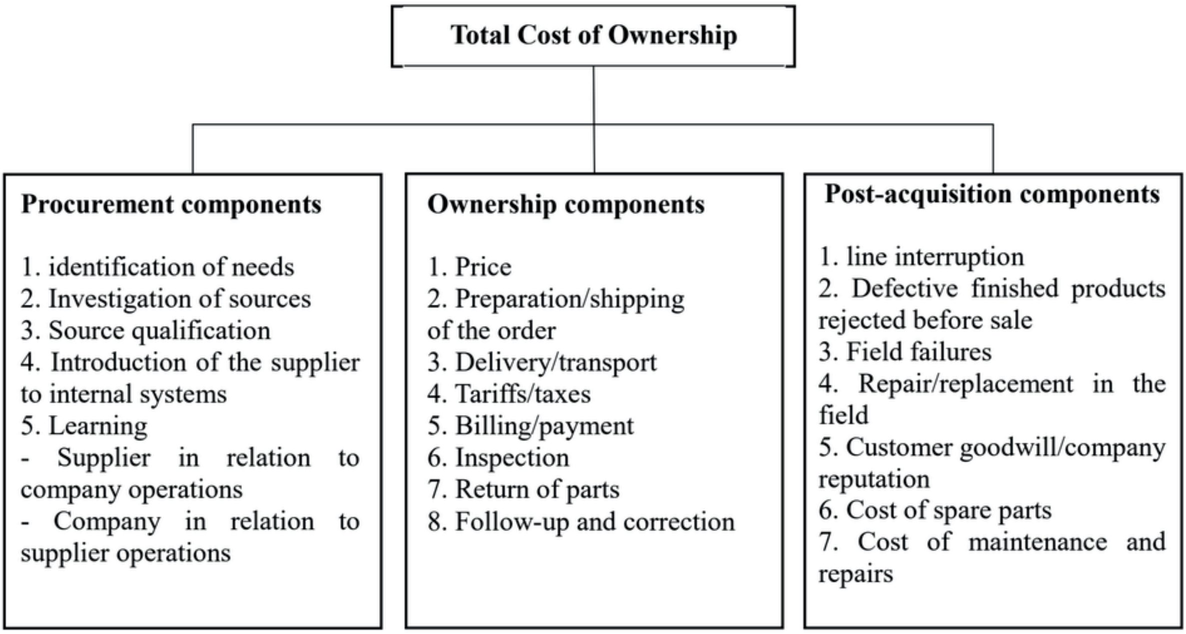

Figure 1. Main Categories of Total Cost of Ownership Components.

Source: Bowesox *et al.* (2014).

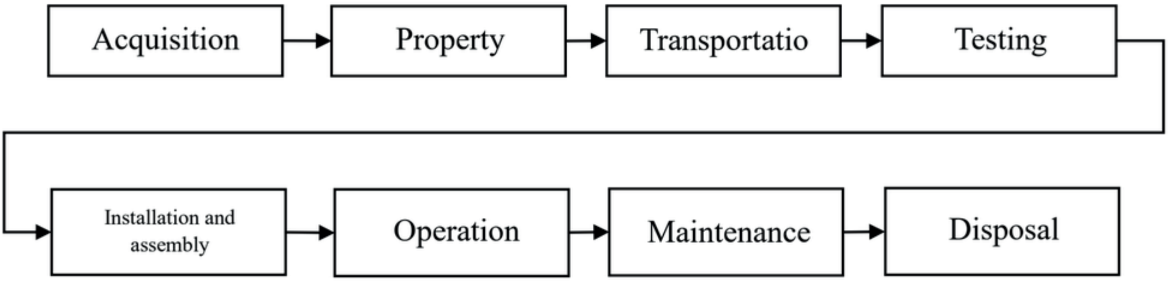

Figure 2 - Useful life of a product or asset.

Source: Rocha and Borinelli (2024).

According to Batista (2013), reducing TCO involves resolving existing imbalances between parameters closely linked to cutting costs and maximizing resources. Because of this, it is recommended that care is taken not to confuse the search for the lowest TCO with the elimination of costs that compromise the performance of essential activities. Kaplan and Cooper (1998) warn that simply cutting costs can lead to overlooking options that best deliver a systematic set of elements that make up the total cost of the acquisition, thus jeopardizing the evaluation of the TCO.

Initiatives to reduce variable costs in the face of increasing production volumes are listed by Jaspersen and Skøtt-Larsen (2005) as determining factors in a TCO project, as they bring more than the usual cost reductions. By helping to avoid the impact of possible inflationary movements, this type of project links elements that provide a balance between improvements in operational performance and the resource optimization objectives that must be achieved by the supply chain.

However, Mitsutani (2017) points out that an analysis based on TCO assumptions must be carried out on a case-by-case basis, as it depends on the specific characteristics of each supply system evaluated. Given the specificities, it is very difficult for a TCO assessment to have exactly the same comparative mechanisms or choice criteria. This characteristic can provide an economic vision in different dimensions and, therefore, should not be used in isolation in decision-making.

Batista (2013) agrees with the author when he argues that the costs presented can vary according to the type of input or asset analyzed. He ratifies that there are several methodologies for calculating TCO and, therefore, simplistic views should be avoided in complex supply maximization strategies. Falvo and Ruvio (2021) argue that projects can adopt different cost, time and place parameters when applying TCO, however similar they may be. Even when comparing identical inputs, a procurement project may need more investigation time and have other associated costs, depending on the type of industry it is targeting.

For this reason, Bowesox *et al.* (2014) recommend that actions based on TCO follow the principles of Value Engineering, which, according to them, involves a thorough analysis of supply needs from the initial stages of the project. In this way, as a supply project progresses, mapping out all the stages makes it possible for alterations or changes of route to be easily accommodated, making it possible to guarantee a balance between the lowest total cost and the quality of operations with little expense.

Magalhães and Pinheiro (2007) support this measure, precisely because they believe that such mapping works as a way of identifying the impacts of total costs within a set of operational objectives, preventing unseen expenses from being transferred from one activity to another within the process. However, Weil and Mahler (2005) confirm that the costs related to associated activities that reflect the chain's performance do not only depend on the parameters of the project, but also on the choice of qualified suppliers to match the planned performance. For the authors, suppliers play a fundamental role in the supply chain to the point of having a positive impact on the customers at the end, either by making it possible to practice more competitive prices or by enabling greater efficiency in the responsiveness indexes.

Even though TCO is understood as a model based on an integrated cost perspective, Moura (2006) maintains that the performance expected in the supply chain is directly linked to the activities that are part of the life cycle of the input or asset. Soula (2012), however, points out that total cost management must also include strategies to mitigate risks that could jeopardize the systematic results of a project. Bearing in mind that the operation is exposed to the total cost of ownership, predicting the risks arising from a procurement project raises the levels of reliability in the decision-making process, enabling an assertive judgment as to the added value that a procurement option can represent in operational and financial performance.

In this search for real cost gains throughout the chain, Weetmann (2019) ratifies that shifts towards performance models with greater monetary value can also dissuade buyers from replacing older assets with more efficient versions, as long as their efficiency over time can be proven. Thus, although Nieminen (2025) recognizes that the techniques applied based on the principles of TCO bring various benefits to the context of the cost structure, he also argues that this methodology needs to be aligned with corporate strategies, the financial situation and other guidelines that impact on the end customer.

Within this concept, Li (2007) states that total cost projects need to have well-defined performance indicators that are in line with the corporate objectives set by the organization. In general, supply metrics linked to TCO need to show performance gains and scale benefits for the chain. This not only helps to set targets, deadlines and proposals for improvements, but also, according to Nieminen (2025), helps to minimize possible restrictions on their implementation, while presenting the best operational solutions and *savings*.

In the view of Roberts and Trent (2010), the non-linearity of the TCO methodology makes it a topic that companies simply should not ignore when it comes to searching for new sources of supply. This is because it can be applied both in the domestic market and in *global sourcing* strategies, given its assumptions that direct the supply sector to see the associated elements, which include expected and unexpected costs. As the authors confirm, the information is present in the various project variables. However, the challenge lies in consolidating it in such a way as to promote an assertive assessment in terms of financial and operational performance.

METHODOLOGICAL PROCEDURES

This article is a practical case study of an exploratory-descriptive nature, with mixed research (qualitative-quantitative) and a survey of documentary data. This study, with the techniques and characteristics described above, was carried out in a medium-sized company in the metal-mechanics sector, located in the mountainous region of Rio Grande do Sul and aimed to evaluate the perspectives provided by TCO modeling when applied to supply projects.

The model was used in an energy supply optimization study which analyzed the Regulated Contracting Environment (ACR) - the current contracting model for this input - and the potential degree of substitution for the Free Contracting Environment (ACL[1]) or for distributed generation through a photovoltaic system.

The main purpose of this study is to verify which scenario generates the greatest competitive advantage for the company, in which all the elements involved in replacing one contracting segment with another will be considered for comparative purposes, following the central assumptions of the TCO. In this sense, although the methods adopted to meet the purposes of this article are found in various bibliographies and are commonly available to the academic community, the identity of the company being studied and its suppliers will be kept confidential in order to preserve their strategic differentials.

The company and the input in question

1. The Free Contracting Environment (ACL) is the segment of the market in which electricity is bought and sold under freely negotiated bilateral contracts, in accordance with specific marketing rules and procedures.

were chosen for this study on the basis of two criteria, the first of which refers to the fact that electricity is one of the inputs with the greatest impact on the ABC Classification. According to Berman (2001), industrial activities related to the metalworking sector consume large amounts of energy for each unit they produce. Based on the principle that work is derived from the flow of energy used to produce goods and services, its efficiency is associated with increasing productivity and conserving it on a sustainable basis, rather than simply reducing consumption.

In line with the aforementioned author, electricity in this case represents 9.5% of Class A items[2] , as well as being the input with the third largest share in the ABC classification. This is an annual amount of R$366,826.99, second only to two direct manufacturing inputs. In this regard, it should be emphasized that this study uses the 2023 database as a reference for calculating consumption, which will be compared in the following sections.

The second criterion is linked to the criticality of this input for the responsiveness of logistics operations in the face of unexpected market movements. In the event of a sudden increase in demand, the prices charged to customers will be pressured by the increase in energy consumption, deteriorating the company's profitability and sacrificing economies of scale.

Vasconcellos (2019) states that the exhaustion of the capacity to respond to operations will lead to an increase in total costs through the decision not to invest in expanding the physical structure - as is the case with the company under study - resulting in the company having to bear excessive costs to maintain its level of service. Kon (2017) places energy as a critical success factor for business, precisely because the interruption of its supply weighs considerably on the cost structure of companies, substantially burdening production costs and making it difficult to supply their respective target markets.

For comparative purposes, the feasibility study for migrating to the other contracting environments will be based on an eight-year horizon, with 2025 being the reference year for implementing the project. This decision was made because the investments evaluated are in long-term fixed assets with substantially significant market values.

As far as scenario projections are concerned, the figures for energy consumption and other costs involved, which are affected by variations in the macroeconomic environment, will be adjusted by the Broad National Consumer Price Index (IPCA) over the same evaluation horizon. The aim is to equalize costs in the current environment compared to investments aimed at migrating to other sources of supply. The index in question was adopted for this annualization because, according to Brito (2016), it is the official indicator chosen by the National Monetary Council (CMN) to measure inflation for a series of products and services sold in retail, as well as being a reference for the Inflation Targeting System.

Based on the Focus Report[3] , which presents inflation projections for five years, Table 1 shows that the company will have an impact of more than R$ 2 million on electricity costs between 2023 and 2027.

Year	IPCA/Focus	Annual energy costs (ACR)
2023	Base	R$ 366.826,99
2024	4,90%	R$ 384.801,51
2025	4,96%	R$ 403.887,67
2026	4,01%	R$ 420.083,56
2027	3,83%	R$ 436.172,76
Total		**R$ 2.011.772,49**

Table 1 Projection of electricity costs between 2023 and 2027.

Note: developed by the authors.

2. Class A is made up of nine SKUs that represent 79.1% of total spending on production materials.
3. Available at: https://www.bcb.gov.br/publicacoes/focus. Accessed on: 05/01/2025.

Bearing in mind that the ACR has an annual contractual cycle that begins in March of each year, it was established that April 2025 will be the cut-off point for implementing the project, thus avoiding the company having to pay the contractual termination fine. Taking into account that the Focus Report does not provide inflation prospects for the entire investment assessment horizon, two actions were chosen.

The first consisted of calculating the average behavior of inflation. By applying the compound interest remuneration technique to the amounts from 2023 to 2027, using the total for the period as the future value, an average rate of 4.62% per year was obtained[4] . Table 2 shows the real proof of this calculation so that it can be used as a reference for projecting energy costs within the investment assessment horizon.

Year	Average IPCA	Annual energy costs (ACR)
2023	Base	R$ 366.826,99
2024	4,62%	R$ 383.788,20
2025	4,62%	R$ 401.533,66
2026	4,62%	R$ 420.099,62
2027	4,62%	R$ 439.524,03
Total		**R$ 2.011.772,49**

Table 2 Actual evidence of the IPCA's effect on energy costs: 2023 and 2027.

Note: developed by the authors.

The second step was to apply the average IPCA in order to project the electricity expenditure curve over the investment assessment horizon. As the year 2025 will be used as the reference for implementing the project, this will be adopted as the new calculation base, with the average IPCA as the reference for annualizing the amounts spent on energy over the following eight years (Table 3). It is worth noting that although the amount projected for the ACR can be calculated using compound interest, using the compensation method for Future Value (FV), it is necessary to break down the cost annually in the ACR, since it will be essential for calculating the degradation rate of the photovoltaic system in subsection 4.2.

Year	Average IPCA	Annual energy costs (ACR)
2025	Base	R$ 401.533,66
2026	4,62%	R$ 420.099,62
2027	4,62%	R$ 439.524,03
2028	4,62%	R$ 459.846,58
2029	4,62%	R$ 481.108,80
2030	4,62%	R$ 503.354,13
2031	4,62%	R$ 526.628,03
2032	4,62%	R$ 550.978,06
2033	4,62%	R$ 576.453,98
Total		**R$ 4.359.526,88**

Table 3 Projection of annual electricity costs in the ACR between 2025 and 2033.

Note: developed by the authors.

The contracts established in the Free Contracting Environment (ACL) are determined by the concessionaires according to the client company's demand. According to documentary data, the company under study has an average monthly consumption of 68.736 MW/h, of which: 2.104 MW/h refers to peak consumption; 64.638 MW/h refers to off-peak energy consumption; and 1.994 MW/h refers to the 3% impact corresponding to Regulatory Non--Technical Losses (PNT) in the same period.

According to the Energy Primer, published by the Ministry of Economy in 2016, the peak tariff period is the period consisting of 3 consecutive daily hours defined by the distributor, except Saturdays, Sundays and national holidays. The off-peak tariff corresponds to all the consecutive hours that complement those that are part of peak consumption - in other words, the other 21 hours of the day.

Understanding the breakdown of the composition of consumption and the concepts of tariff periods is fundamental to understanding the formation of the comparative cost, since the ACL makes use of the distribution

4. The average rate is 4.623763% and its value was used in the simulations, without rounding.

structure of the local concessionaire which, in turn, has pre-established tariffs on demand and the Tariff for Use of the Distribution System (TUSD), as shown in Table 4. It is important to note that the company being studied falls into group A4, made up of consumer units supplied at a voltage equal to or greater than 2.5kV up to 25kW.

Since the amounts are subject to readjustments resulting from market variations, the average IPCA was also applied here as a reference for annualizing the amounts of the usage tariffs, making it possible to establish a comparison between the energy environments. Using the FV capitalization method, expenditure was projected up to the year 2033 (Table 5).

The year 2025 will be treated differently in the financial simulation presented in subsection 4.1, since there will be a need for proportional consumption in the first year of migration from the ACR to the ACL, avoiding the contractual fine corresponding to the termination of the contract with the concessionaire.

In addition to the use of the system, the cost includes three other expenses: a fee of R$ 7,000.00 for joining the Electricity Trading Chamber (CCEE) to enter the ACL, paid in a single installment at the start of the agreed cycle; a structural investment of R$ 20.000.00 for adapting the metering system at the energy substation, paid in a single installment; and a monthly fee of R$1,500.00 paid to a third-party company with expertise in the energy market to manage the contracts with the CCEE. This last amount, equivalent to R$18,000.00 per year according to the 2023 parameters, was also projected up to 2033 using the average IPCA, also highlighting the year 2025, in order to maintain comparative bases using the same indicator (Chart 6).

With regard to PNTs, it is worth noting that, according to Castro *et al.* (2012), they represent all energy losses associated with non-technical factors, such as energy theft, errors in the calculation of meters and/or the absence of metering equipment. According to a report by Anaeel (2019), the percentage in question is calculated using the National Agency's own methodology, which takes into account losses on the net revenue needed to cover the distributors' regulatory costs.

In order to identify a competitive cost benchmark for a long-term contract, a competition was held between two companies supplying the ACL (Table 7). In this study, the companies, which will be referred to as Supplier 1 and Supplier 2, will have their values compared in subsection 4.1 of this article. It is worth noting that, in order to make a fair comparison with the values practiced in the ACR, the quotes in question already include projections of future cost adjustments, as well as not including PIS and COFINS.

Similarly, a competition was held between companies supplying technology for photovoltaic energy generation, which in this article will be referred to as Supplier A and Supplier B. Their respective quotes, which will be compared in subsection 4.2, are not subject to macroeconomic variations, given that the supply provided by the equipment responsible for transforming the particles of sunlight into energy to be distributed to the place of consumption. *On* the other hand, as the photovoltaic distribution system will be connected to the grid, characterizing it as a system known as *on-grid*, the ACR costs involved in this analysis are still subject to market impacts.

Period	Supplier 1	Supplier 2
2025	R$ 263,18	R$ 263,18
2026	R$ 196,93	R$ 196,02
2027	R$ 174,24	R$ 170,61
2028	R$ 162,44	R$ 163,35
2029	R$ 157,91	R$ 156,09
2030	R$ 149,74	R$ 149,74
2031	R$ 147,02	R$ 146,11
2032	R$ 143,39	R$ 144,29
2033	R$ 140,66	R$ 144,29

Table 7 Supplier prices in MWh on the ACL for long-term contracts.

Note: developed by the authors.

This hybridization was due to restrictions that make it technically impossible for the

Subgroup	TUSD kW (applied to off-peak demand)	TUSD kW - 50% (incentive for using renewable sources)	On-peak TUSD	Off-peak TUSD	Connection Charges
A4 (2.3 to 25Kw)	R$ 25,18	R$ 12,59	R$ 1.321,79	R$ 106,84	R$ 500,00

Table 4 Tariffs that make up the cost of electricity in the ACL in 2023.

Note: developed by the authors.

Tariff description	Cost	Unit Total	Unit Total
Connection charge	R$ 500,00	1,000	R$ 500,00
Off-peak demand (kW)	R$ 12,59	500,000	R$ 6.295,00
Peak TUSD (MWh)	R$ 1.321,79	2,104	R$ 2.781,05
Off-peak TUSD (MWh)	R$ 106,84	64,638	R$ 6.905,92
Monthly expenditure using 2023 parameters			**R$ 16.481,97**
Annual expenditure using 2023 parameters			**R$ 197.783,64**
Estimate for 2024 using the average IPCA of 4.62%			R$ 206.928,69
Estimate for 2025 using the average IPCA of 4.62%			R$ 216.496,58
Estimate for 2026 applying the average IPCA of 4.62%			R$ 226.506,87
Estimate for 2027 applying the average IPCA of 4.62%			R$ 236.980,01
Estimate for 2028 applying the average IPCA of 4.62%			R$ 247.937,40
Estimate for 2029 applying the average IPCA of 4.62%			R$ 259.401,44
Estimate for 2030 applying the average IPCA of 4.62%			R$ 271.395,55
Estimate for 2031 applying the average IPCA of 4.62%			R$ 283.944,24
Estimate for 2032 applying the average IPCA of 4.62%			R$ 297.073,14
Estimate for 2033 applying the average IPCA of 4.62%			R$ 310.809,10
Total (2023-2033)			**R$ 2.755.256,66**
Total (2025-2033)			**R$ 2.350.544,34**

Table 5 Projection of network use tariffs in the FTA between 2025 and 2033.

Note: developed by the authors.

Year	Average IPCA	Monthly management cost (FTA)	Annual management cost (ACL)
2023	Base	R$ 1.500,00	R$ 18.000,00
2024	4,62%	***	R$ 18.832,28
2025	4,62%	***	R$ 19.703,04
2026	4,62%	***	R$ 20.614,06
2027	4,62%	***	R$ 21.567,20
2028	4,62%	***	R$ 22.564,42
2029	4,62%	***	R$ 23.607,75
2030	4,62%	***	R$ 24.699,31
2031	4,62%	***	R$ 25.841,35
2032	4,62%	***	R$ 27.036,19
2033	4,62%	***	R$ 28.286,28
Total (2023-2033)			R$ 250.751,88
Total (2025-2033)			R$ 213.919,60

Table 6 Projection with the concessionaire's structural management cost in the ACL: 2023 - 2033.

Note: developed by the authors.

photovoltaic system to cover the entire supply. In order to understand the limitations imposed on the system's efficiency, a survey was carried out of the requirements needed to meet 100% of the supply, starting with capacity sizing, applying the equation:

$$kWp = \frac{Consumo\ Médio\ Mensal\ em\ KWh}{HSP \times Dias \times Coeficiente\ de\ Eficiência} \quad (1)$$

The Watt-peak (Wp) unit, as explained by Zilles *et. al.* (2012), is the energy power associated with photovoltaic modules (panels). The equation above seeks to convert consumption into kilowatts-peak (kWp) in order to determine the maximum power of the panels to meet the demand of the company under study. In this sense, the first step was to convert the monthly consumption to 68,736 kW/h, meeting the unit of measurement required by the equation.

Peak Sun Hours (PSH) correspond to the average number of hours that solar irradiation reaches a peak of 1,000W/m² in a given location. To calculate this figure, a query was made in the SunData program on the website of the Sérgio de S. Brito Reference Center for Solar and Wind Energy (CRESEB), in which latitude and longitude data was entered, indicating that the HSP is 4.43 hours in the city where the company being studied is located.

The efficiency coefficient is an average percentage that represents energy losses within the distribution system. Some of these losses, according to the manufacturers themselves, can occur due to electrical incompatibility, dirt accumulation, problems with the inverter or temperature losses. Supplier companies usually use a coefficient of 20% to represent these losses, although manufacturers admit that some systems can be as high as 25%.

When applying the equation, it was found that the total power of the panels, given monthly consumption, needed to be 646.5kWp. Bearing in mind that solar panels with 0.395kW of power would be budgeted, 1,637 panels would be needed to meet total consumption - a result that was obtained by applying the equation below - thus generating an available power of 646.62kW.

$$Quantidade\ de\ painéis = \frac{Potência\ Total\ Requisitada\ (KWp)}{Potência\ dos\ painéis\ (KW)} \quad (2)$$

By deciding not to purchase or rent an adjoining plot of land, the company under study opted to place the panels on the roof of its main building, a space that can only hold 500 panels - the equivalent of 197.5 kW of total power. This means that the system will generate power to meet only 30.54% of consumption, with the rest of the demand coming from the ACR.

As for the definition of the inverter, it is important to note that the suppliers consider 20% of the system's gross capacity to be a safe margin so that there are no problems with the sizing of the equipment. Since the company under study decided to maintain the current gross capacity of 240kW for the evaluation of investments in photovoltaic energy generation, the inverters needed to meet the needs of between 192kW and 288kW. Based on this reference, it was felt that two 110kW inverters operating together would be within the established safety margins, and would therefore serve as a reference for analyzing the budgets.

Since a 10% target *saving* is common practice for TCO projects, it was decided to keep the same percentage target as the project's viability indicator for both comparisons. This decision was made due to the proposed timeframe for analyzing the return on investment.

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COMPARATIVE ANALYSIS

REGULATED CONTRACTING ENVIRONMENT *VS.* FREE CONTRACTING ENVIRONMENT

Since the analysis based on TCO is based on the premise of not neglecting the overall costs involved in a purchase or contracting operation, the first stage carried out before making the comparisons consisted of mapping the acquisition and possession costs involved in the FTA.

With regard to acquisition costs, the two suppliers who took part in the competition had their commercial proposals compared in order to understand which of them is the most competitive over an eight-year projection. Table 8 shows that Supplier 2 is the best alternative, even though its financial advantage is less than R$1,500.00 when analyzing the total projections for the period compared. It is worth noting that the costs relating to tariffs (peak energy, off-peak energy and losses) should be added to the quotes, as these are part of the cost of using the local utility's distribution structure.

As for the structural adjustments, the investment of R$20,000.00 mentioned in Section 4 is necessary for the implementation of technological resources that make it possible to account for consumption in a clear and objective way, such as: main and back-up meters, Instrument Transformers (IT), Potential Transformers (PT), Current Transformers (CT), among other systems that connect the data relating to the measurement for billing and the suppliers regulated by the Electricity Trading Chamber (CCEE), allowing the inspection to be carried out reliably.

The last acquisition cost, relating to the Chamber of Electricity Trading (CCEE), is the amount of R$7,000.00, paid in a single installment, relating to a membership service that is fundamental to being part of the free energy trading market. Assuming that payment is made when the process is opened with the CCEE, and that withdrawing from the process does not result in reimbursement of the amount invested, it can be said that the interruption of the action plan due to any technical or strategic unfeasibility will therefore imply the reclassification of this cost from ownership to post-ownership.

With regard to ownership costs, the amounts corresponding to usage tariffs and management of the structure need to be paid to the concessionaire, since ACL consumers, although they purchase energy directly from the generator/commercializer, continue to make use of the energy transmission structure present in the ACR.

The last step before the comparison was to calculate the proportional cost of the ACL in the first year, since in 2025 there will still be energy consumption from the ACR for a period of 3 months. According to Abraceel (2016), in the ACL consumers are free to choose their energy suppliers and have the right to negotiate contractual terms. In this case, as the company's contractual cycle begins in March, the announcement of the termination of the legal instrument in the ACR will be made in September of the previous year, avoiding the payment of the termination fine. In this sense, the month of September 2024 was established as the notice point with the concessionaire, while April 2025 was established as the cut-off point for the implementation of the new supply format.

Therefore, the annual costs of energy, usage tariff and structural management in the ACL were proportionally calculated for a period of nine months in 2025, as well as the three months of the ACR in the same year. Based on this calculation, the results are added to the projected values for the years between 2026 and 2033, as well as the other acquisition and ownership costs (Table 9).

Demand (MWh/month)		2,104	64,638	1,994	Supplier 1
Demand (MWh/year)		25,248	775,656	23,928	
Year	Quotation	Peak Energy	Off-peak energy	Losses	**Total Annual**
2025	R$ 263,18	R$ 6.644,64	R$ 204.133,27	R$ 6.297,25	**R$ 217.075,16**
2026	R$ 196,93	R$ 4.972,03	R$ 152.748,00	R$ 4.712,08	**R$ 162.432,10**
2027	R$ 174,24	R$ 4.399,21	R$ 135.150,30	R$ 4.169,21	**R$ 143.718,73**
2028	R$ 162,44	R$ 4.101,35	R$ 125.999,50	R$ 3.886,92	**R$ 133.987,77**
2029	R$ 157,91	R$ 3.986,79	R$ 122.479,96	R$ 3.778,35	**R$ 130.245,10**
2030	R$ 149,74	R$ 3.780,57	R$ 116.144,79	R$ 3.582,92	**R$ 123.508,28**
2031	R$ 147,02	R$ 3.711,83	R$ 114.033,07	R$ 3.517,77	**R$ 121.262,68**
2032	R$ 143,39	R$ 3.620,18	R$ 111.217,44	R$ 3.430,92	**R$ 118.268,54**
2033	R$ 140,66	R$ 3.551,45	R$ 109.105,71	R$ 3.365,77	**R$ 116.022,93**
Total		R$ 38.768,05	R$ 1.191.012,03	R$ 36.741,20	R$ 1.266.521,29
Demand (MWh/month)		2,104	64,638	1,994	**Supplier 2**
Demand (MWh/year)		25,248	775,656	23,928	
Year	Quotation	Peak Energy	Off-peak energy	Losses	**Annual Total**
2025	R$ 263,18	R$ 6.644,64	R$ 204.133,27	R$ 6.297,25	**R$ 217.075,16**
2026	R$ 196,02	R$ 4.949,11	R$ 152.044,09	R$ 4.690,37	**R$ 161.683,57**
2027	R$ 170,61	R$ 4.307,56	R$ 132.334,67	R$ 4.082,36	**R$ 140.724,59**
2028	R$ 163,35	R$ 4.124,26	R$ 126.703,41	R$ 3.908,64	**R$ 134.736,31**
2029	R$ 156,09	R$ 3.940,96	R$ 121.072,15	R$ 3.734,92	**R$ 128.748,03**
2030	R$ 149,74	R$ 3.780,57	R$ 116.144,79	R$ 3.582,92	**R$ 123.508,28**
2031	R$ 146,11	R$ 3.688,92	R$ 113.329,16	R$ 3.496,06	**R$ 120.514,14**
2032	R$ 144,29	R$ 3.643,10	R$ 111.921,34	R$ 3.452,63	**R$ 119.017,07**
2033	R$ 144,29	R$ 3.643,10	R$ 111.921,34	R$ 3.452,63	**R$ 119.017,07**
Total		R$ 38.722,23	R$ 1.189.604,22	R$ 36.697,78	R$ 1.265.024,22

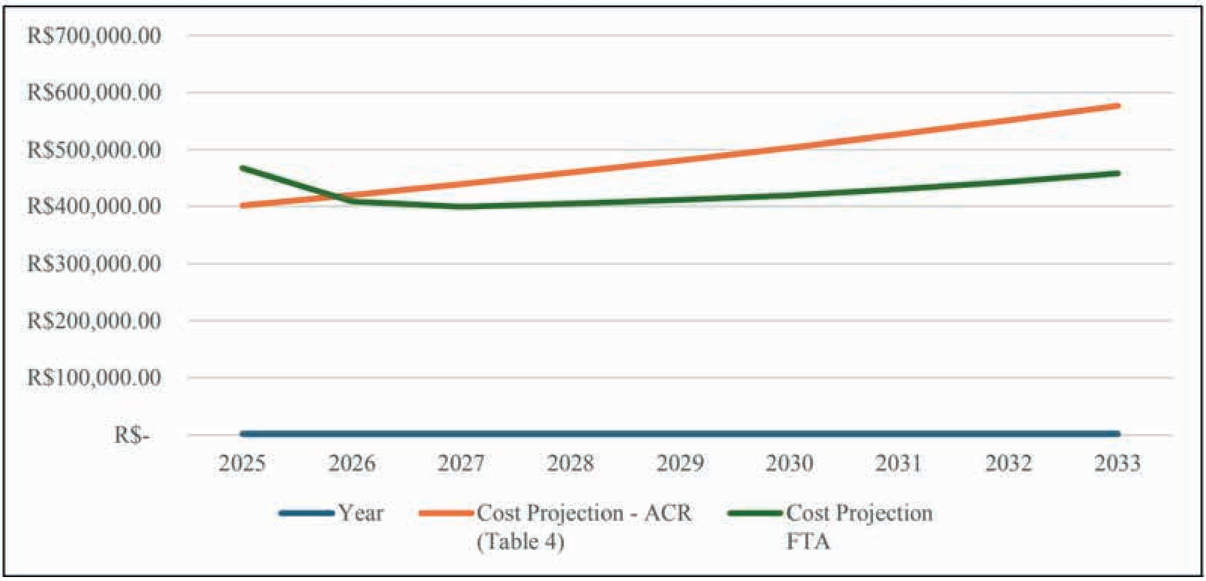
Table 8 Comparison between ACL suppliers - cost projection: from 2025 to 2033.

Note: developed by the authors.

Cost composition	Annual	Proportional
(+) Projection of energy in the FTA - 2025 (9 months)	R$ 217.075,16	R$ 162.806,37
(+) Projected usage tariff in the FTA - 2025 (9 months)	R$ 216.496,58	R$ 162.372,43
(+) Projected structural management for the FTA - 2025 (9 months)	R$ 19.703,04	R$ 14.777,28
(+) Proportion of ACR - 2025 (3 months)	R$ 403.887,67	R$ 100.971,92
(+) Adjustment		R$ 20.000,00
(+) CCEE membership		R$ 7.000,00
1- Total ACL in 2025		R$ 467.928,00
(+) Energy Projection (2026-2033)		R$ 1.047.949,06
(+) Tariffs for ACL use (2026-2033)		R$ 2.134.047,76
(+) Free Market Management (2026-2033)		R$ 194.216,57
2 - Total ACL from 2026 to 2033		R$ 3.376.213,38
Total FTA in 2033 (1+2)		R$ 3.844.141,38
Total ACR in 2033 (Table 4)		R$ 4.359.526,88
Total saving		R$ 515.385,50
Impact		-11,82%
Payback **(years)**		7,46

Table 9 TCO in the FTA - projection of total costs between 2023 and 2033.

Note: developed by the authors.



Flow		Cost Projection - ACR (Table 4)	Cost Projection FTA	Saving
2025	**FC0**	R$ 401.533,66	R$ 467.928,00	-R$ 66.394,35
2026	**FC1**	R$ 420.099,62	R$ 408.804,50	R$ 11.295,12
2027	**FC2**	R$ 439.524,03	R$ 399.271,80	R$ 40.252,23
2028	**FC3**	R$ 459.846,58	R$ 405.238,13	R$ 54.608,45
2029	**FC4**	R$ 481.108,80	R$ 411.757,21	R$ 69.351,58
2030	**FC5**	R$ 503.354,13	R$ 419.603,14	R$ 83.750,98
2031	**FC6**	R$ 526.628,03	R$ 430.299,73	R$ 96.328,30
2032	**FC7**	R$ 550.978,06	R$ 443.126,41	R$ 107.851,65
2033	**FC8**	R$ 576.453,98	R$ 458.112,46	R$ 118.341,52
Total		R$ 4.359.526,88	R$ 3.844.141,38	R$ 515.385,50

Figure 3. Financial feasibility analysis of the project to migrate to the FTA.

Source: developed by the authors.

Description	Supplier A	Supplier B
Equipment and installation of energy generation systems.	**R$ 592.500,00**	**R$ 639.900,00**
System format: connected to the grid (*on-grid*), dispensing with the use of batteries.		
Equipment warranty: 10 years.		

Table 10 Comparison of suppliers for the photovoltaic system.

Note: developed by the authors.

Comparing the two contracting environments, it can be seen that the cost breakdowns presented make the ACL a more competitive option, even if investments are needed to make the switch. From a financial perspective, the implementation of the ACL results in a total reduction of R$515,385.50, an impact of -11.82%. It can be seen that, as well as the result being above the target set for the viability of the project, the *payback* period is seven and a half years - in other words, before the end of the predetermined evaluation period.

Analyzing the behavior of the *saving*, Figure 3 shows that the projections generate favorable impacts for the implementation of the project, unlike what happens with the first year of the investment horizon. However, this is precisely because 2025 is considered to be the zero period (FC0) of the investment flow, a period in which the proportional costs and other technical adjustments for the implementation of the FTA exceed the values forecast for the FTA.

With the exception of 2025, when there are proportional costs between the ACR and the ACL, the ACL cost projections for the other periods include the sum of the ACL tariffs, the management costs in the ACL and the quote approved for the supply of energy.

REGULATED CONTRACTING ENVIRONMENT VS. PHOTOVOLTAIC POWER GENERATION

According to Aneel (2021), distributed generation is the term adopted to define the environment in which consumers can generate electricity from renewable sources, and can even supply the surplus generated to the distribution network. This system, also known as distributed micro- and mini-generation, is characterized by the installation of small generators connected to the distribution network through consumer unit installations, improving the network's voltage level during heavy load periods, diversifying the energy matrix and postponing investments in expanding the distribution and transmission systems.

Considering its installed capacity of 240kW, the company under study, which falls into the distributed mini-generation classification range, will be limited to this gross capacity for regulation and inspection purposes, and must request a load increase if it wishes the power made available to become equal to or greater than the current installed capacity of the generating plant. In this situation, the consumer needs to analyze their need to adapt the distribution system and request an access opinion from the distributor so that the increase in power made available can be met.

Given that the technical and legal aspects of mini-generation are the responsibility of the consumer - as well as the responsibility for analyzing the costs and investments for adapting the system - it is important to note that the company under study chose to work on its investment projections, maintaining the current gross capacity of 240kW, even though the consequences of this decision directly impact on the technical and financial aspects involved in implementing the system.

Along these lines, the investments involved in distributed mini-generation were mapped out, presenting the items involved in acquiring the photovoltaic system, as was done in the previous section, thus maintaining the premise of not neglecting the overall costs involved in a purchase or contracting operation.

As a way of understanding the most competitive scenario for acquiring the equipment, the suppliers who took part in the competition had their quotes compared. The values shown in Table 10 indicate that Supplier A is the most favorable investment option, providing for a contract in which the values for the acquisition of the *on-grid* system were compared based on identical requirements in terms of the brand and technical specifications of the panels, the power of the inverters and the manufacturer's warranty period, avoiding possible distortions in the comparative analysis.

Note: developed by the authors.

As for structural adjustments, the investment of R$ 20,000.00, mentioned in Section 4, closes the list of acquisition costs, given that adaptations to the metering system are necessary to enable reliable accounting of consumption in the *on-grid* mode. This amount is paid in a single installment and does not suffer from macro-environmental market impacts.

As a cost of ownership, preventive maintenance must be carried out to ensure maximum system efficiency. Although various factors influence the need for maintenance and cleaning of the plates, it is recommended that this service be carried out annually and is subject to price changes, depending on market variations. Quoted at around 0.5% of the initial value of the photovoltaic system, the projected maintenance cost is shown in Table 11 in an updated series based on the same references adopted in the other calculations, providing a check on the effects of fluctuations in the business environment.

The degradation rate is the cost of ownership relative to the decline in efficiency over time. It is estimated that boards can operate for 25 years with a minimum efficiency of 80%. According to Zilles *et. al.* (2012), the power output of modules generally tends to degrade the most in the first year, by around 2.5%, decreasing at linear rates of 0.73% each year thereafter.

Year	Average IPCA	Annual cost of maintenance
2025	Base	R$ 2.962,50
2026	4,62%	R$ 3.099,48
2027	4,62%	R$ 3.242,79
2028	4,62%	R$ 3.392,73
2029	4,62%	R$ 3.549,60
2030	4,62%	R$ 3.713,73
2031	4,62%	R$ 3.885,44
2032	4,62%	R$ 4.065,10
2033	4,62%	R$ 4.253,06
Total		R$ 32.164,42

Table 11 Expenditure on preventive maintenance of the system (2025 - 2033).

Applying these rates to the investment horizon, it was found that the accumulated degradation reaches 7.61%, impacting on a loss of 2.32% on the efficiency of the photovoltaic system. Even so, the migration project achieves a potential reduction of R$1,275,795.31 in energy generation, when compared to the costs projected in the Regulated Contracting Environment until 2033 (Table 12).

In this comparison, it was not necessary to calculate the proportional cost for 2025, as the *on-grid* system does not result in the termination of the contract with the distributor. This is because the concessionaire remains responsible for delivering energy at night or when there is less sunshine (rainy periods, cloudy periods, winter, etc.). Based on this calculation, the results are added to the projected values, as well as the other acquisition and ownership costs (Table 13).

The comparison shows that the photovoltaic energy generation system is also more competitive than the ACR, resulting in a *saving of* R$623,695.07; an impact of -14.31%. However, even though the indicator is more attractive, the main objection to photovoltaic distribution may be the high initial investment, even though, from a TCO perspective, the behavior of the savings (Figure 4) shows that the *payback* will be in six years.

With the exception of the year 2025, which was marked by the investment in the photovoltaic system, the other periods of the photovoltaic system were calculated based on the sum of the maintenance costs and the ACR costs, minus the system's degradation rates.

FINAL CONSIDERATIONS

This study has presented a practical *case of* how an analysis based on TCO assumptions can provide a more holistic view of maximizing performance in actions relating to supply strategies, helping to identify elements that

Year	ACR	Degradation	Efficiency %	Efficiency in R$
2025	R$ 401.533,66	100,00%	30,54%	R$ 122.643,14
2026	R$ 420.099,62	97,50%	29,78%	R$ 125.106,03
2027	R$ 439.524,03	96,77%	29,56%	R$ 129.910,63
2028	R$ 459.846,58	96,04%	29,33%	R$ 134.892,08
2029	R$ 481.108,80	95,31%	29,11%	R$ 140.056,44
2030	R$ 503.354,13	94,58%	28,89%	R$ 145.410,00
2031	R$ 526.628,03	93,85%	28,67%	R$ 150.959,20
2032	R$ 550.978,06	93,12%	28,44%	R$ 156.710,68
2033	R$ 576.453,98	92,39%	28,22%	R$ 162.671,30
Total (2025-2033)	**R$ 4.359.526,88**	7,61%	2,32%	R$ 1.268.359,49

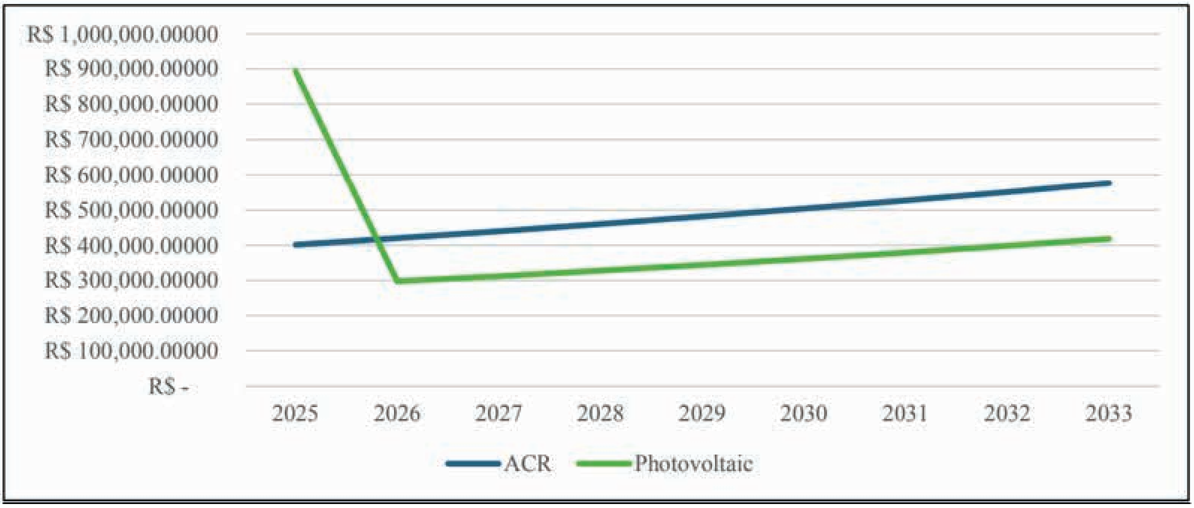
Table 12 Degradation of the photovoltaic system (2025 - 2033).

Note: developed by the authors.

Photovoltaic system	R$ 592.500,00
(+) Adaptation	R$ 20.000,00
1 - Total investment in the system	**R$ 612.500,00**
Projection of energy consumption in the ACR (2025 - 2033)	R$ 4.359.526,88
(-) Energy efficiency - Photovoltaic system (2025 - 2033)	R$ 1.268.359,49
2 - Energy Consumption (2025 - 2033)	**R$ 3.091.167,39**
3 - System maintenance (2025 - 2033)	**R$ 32.164,42**
(1 + 2 + 3) Total consumption using the photovoltaic system (2025 - 2033)	**R$ 3.735.831,81**
Total ACR in 2033 (Table 4)	**R$ 4.359.526,88**
Saving	**R$ 623.695,07**
Percentage impact	**-14,31%**
Payback **(years)**	**5,99**

Table 13 TCO of the photovoltaic system - cost projection between 2025 and 2033.

Note: developed by the authors.



Flow		ACR	Photovoltaic	Saving
2025	FC0	R$ 401.533,66	R$ 894.353,01	-R$ 492.819,36
2026	FC1	R$ 420.099,62	R$ 298.093,07	R$ 122.006,55
2027	FC2	R$ 439.524,03	R$ 312.856,19	R$ 126.667,84
2028	FC3	R$ 459.846,58	R$ 328.347,24	R$ 131.499,35
2029	FC4	R$ 481.108,80	R$ 344.601,96	R$ 136.506,84
2030	FC5	R$ 503.354,13	R$ 361.657,86	R$ 141.696,27
2031	FC6	R$ 526.628,03	R$ 379.554,27	R$ 147.073,75
2032	FC7	R$ 550.978,06	R$ 398.332,47	R$ 152.645,59
2033	FC8	R$ 576.453,98	R$ 418.035,74	R$ 158.418,24
Total		R$ 4.359.526,88	R$ 3.735.831,81	R$ 623.695,07

Figure 4 - Financial viability of the project to migrate to photovoltaic distribution.

Source: developed by the authors.

are above their direct costs. This is due to the fact that a comparative TCO analysis consists of not working with superficial data, but rather identifying future expenses and other hidden costs of a project.

The comparative analyses show that both the ACL and the Distributed Generation System are more competitive than the ACR, with promising investment returns within the evaluation horizon. However, even though the Distributed Generation System presents a more competitive cost reduction curve and faster *payback*, the ACL appears to be the best option from an overall investment point of view, since the initial investment in the photovoltaic system can be an objection for a generation efficiency of 30.54%.

System coverage is another crucial factor in determining the degree of attractiveness. Even if the initial investment makes the Distributed Generation System less attractive, it must be considered that it will be connected to the grid (*on-grid*) in a 30-70 hybrid ratio with the ACR. The benefits of this level of coverage will be better seen in the long term, given that in 25 years the system will suffer less impact from the macroeconomic environment compared to the ACL which, in the first comparison, will account for 100% of demand.

Although the Distributed Generation System requires a large concentration of resources for its implementation and maintenance, the use of clean and renewable energy sources is a factor that meets the sustainability policies envisioned for the coming decades, following a worldwide movement towards cheaper and more environmentally friendly energy matrices.

Given the context in which this article was carried out, it can therefore be said that the scope of TCO's contributions went beyond the limits of the short-term vision by suggesting broader evaluative panoramas regarding the strategic, financial and operational aspects involved in investment decisions in long-term supply projects. This perception can be seen in this study through a non-linear quantitative and qualitative vision that provides the company under study with the possibility of choosing between two fully viable project alternatives.

It is important to note that the research in question was carried out in the midst of various macro-environmental changes, such as: the increase in tariffs due to fluctuations in inflation indices and the approval of the legal framework for distributed energy, which provides for charges linked to the use of distribution systems by customers. A new study is therefore proposed based on this context, including a comparison of analyses that include reverse logistics flows in the process.

Applying the TCO assumptions, the aim would be to compare the environments already studied with a system that combines the FTA and the Distributed Generation System with the respective post-ownership *cost* proposals that form part of a *Total Cost of Ownership* analysis. As was done in this research, the same feasibility indicators would be used, differing only by the 25-year investment horizon, which tends to favor the design of broader assessments and an understanding of the reuse, recycling and disposal processes that can impact on the project.

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