Low voltage Non-Isolated Microgrid integration for increased reliability in Brazil: an economic perspective for utilities

Pedro F. Torres[1], João T. Pinho[1,2] and Roberto Zilles[1]

[1] Universidade de São Paulo, São Paulo (Brazil)

[2] Universidade Federal do Pará, Belém (Brazil)

Abstract

Low voltage non-isolated microgrids, integrated into distribution grids considering the intentional islanding of distributed energy resources, can be an interesting alternative to improve the distribution system reliability, especially considering the need of increased service continuity in several regions. This paper discusses a possible business model for the integration of non-isolated microgrids employed by distribution utilities, considering the current regulatory framework in Brazil, and the incentives for improved reliability. First, key characteristics of power distribution reliability in the Brazilian context are briefly introduced, followed by a description of the current regulatory framework on the incentives for improved reliability and the possible adoption of non-wire alternatives in power distribution planning. Second, a detailed economic analysis of microgrid integration is presented, considering several scenarios for a utility in Brazil, making it possible to identify the main factors that influence the feasibility of microgrid integration from both technical and economic perspectives. The data used for the analysis carried out in this paper is open and can be obtained from the regulatory agency database, while the methodology developed in this paper can be also applied to different scenarios worldwide.

Keywords: Power distribution planning, Low voltage Microgrids, Reliability, Distributed Energy Resources, Economic Analysis

1. Introduction

Power distribution grids have been undergoing a transition in recent years, driven by the expansion of distributed energy resources (DER) and the increasingly active participation of users connected to the distribution grids. In Brazil, the current leading example of DER is photovoltaic generation, in the form of distributed generation, which, as of August 2025, already represented approximately 20 % of the installed capacity of the national generation park (ANEEL, 2025a; ANEEL, 2025b). In the medium to long term, other DER technologies are expected to become popular in the national scenario (EPE, 2019), particularly battery storage systems, electric vehicles, and hydrogen applications.

The expansion of DER must be carried out in a way that leverages the benefits of these resources, such as battery storage capacity, and mitigates the negative effects associated with some technologies, such as the low short-term predictability of solar energy and its reduced simultaneity factor. In this context, DER can be used to integrate microgrids into existing distribution grids as a planning and operation alternative to improve the service continuity during power outages. For instance, Torres *et al*. (2025) investigate this approach from a planning perspective, considering the integration of microgrids in existing low voltage distribution systems in Brazil, and a comprehensive review of hybrid microgrid design considering optimal sizing and energy management is presented by Alilou *et al*. (2026). Furthermore, the role of distribution grid operators, which in many countries operate under concession or permission regimes, and traditionally manage grid infrastructure and resell energy to captive consumers, must be reconsidered. It is understood that the paradigm shift associated with the role of distributors, due to the expansion of DER, must be implemented from a planning and operational perspective.

In this context, this paper addresses, from an economic perspective, the integration of low voltage microgrids in existing distribution grids to improve reliability metrics. Section 2 presents an overview of the current regulatory framework on the incentives for improved reliability and the possible adoption of non-wire alternatives in power distribution planning. Section 3 presents a case study to access the feasibility of microgrid integration as a non-wire planning alternative for a utility in Brazil. Paper conclusions are highlighted in Section 4.

© 2026. The Authors. Published by International Solar Energy Society
Selection and/or peer review under responsibility of Scientific Committee
10.18086/swc.2025.07.07 Available at http://proceedings.ises.org

2. Regulatory Framework for microgrid integration

In recent years, Brazilian regulation has taken favorable steps toward establishing a regulatory framework that sets conditions for the dissemination of energetic resources in power distribution grids, aiming to modernize the system, making it more efficient, reliable, and sustainable. The major milestone in this dissemination is the legal framework for distributed generation, established by Law 14,300/2022 and regulated by ANEEL´s Normative Resolution 1,059/2023. This resolution indicates the maturity of the national distributed generation scenario and seeks to ensure the expansion of this model in a way that is economically feasible and sustainable for the power distribution stakeholders and cost effective for prosumers. Additionally, regulatory provisions for the deployment of energy storage systems have been introduced as a possible alternative for planning improvements in distribution grids, as updated in ANEEL´s Normative Resolution 1,000/2021. Another key point is the establishment of demand response programs, including both incentive-based and tariff-based programs, such as the so-called white-tariff scheme, which applies to low-voltage consumers.

In view of regulatory and economic possibilities, an interesting business model that could be applied to integrate non-isolated microgrids in Brazil, with minimal and feasible changes to the current regulatory framework, is the adoption of utility-owned microgrids with privately-owned distributed generation and storage (*i.e.*, the microgrid forming distributed energy resource). Utilities in Brazil are allowed to supply up to 10 % of their consumer market with energy purchased from distributed generators (DG) within their concession areas (ANEEL´s Normative Resolution 1,009/2022). Despite this possibility, there are currently few contracts between utilities and DG, as the price of energy from distributed generation, which operates at relatively small scale, is not competitive compared to wholesale energy prices in the regulated market. However, by additionally considering the possibility of islanded operation of distributed generation as a microgrid, the resulting reduction in interruption indices could make this alternative economically feasible.

3. Economic Analysis for a Utility in Brazil

In this section, an economic analysis is carried out to evaluate the feasibility of integration of low voltage non-isolated microgrids in the concession area of the utility Equatorial Pará, in the north of Brazil. The scenarios are based on the business model of utility-owned microgrids with privately-owned distributed generation and storage, established by utility and DG owner contracts. For this business model, the financial feasibility analysis is conducted for the DG owner, who may be a generator, a prosumer, or a DG aggregator. Thus, the feasibility analysis must account for the implementation and operation costs, as well as the benefits to the DG owner. The costs should include the capital expenditure (CAPEX) for installing the DG, and the operating expenditure (OPEX) for its operation. The benefits should include the revenues from selling energy to the distribution utility. Table I presents the parameters adopted in the economic feasibility study.

Table 1: Parameters adopted in the economic feasibility study.

Parameter	Value	Symbol	Reference
WACC[1]	11.6 %	i_{WACC}	ANEEL, 2024a
Analysis period	10 years	t	ANEEL, 2024a
BESS[2] degradation rate	0.8 %/year	d_{BESS}	BESS manufacturer
CAPEX Diesel Genset	USD 175.5 / kW	$CAPEX_{DGST}$	EPE, 2024
OPEX Diesel Genset	USD 4.39 / MWh p.a.	$OPEX_{DGST}$	EPE, 2024
CAPEX PV generator	USD 403.5 / kWp	$CAPEX_{PV}$	Greener, 2024
CAPEX BESS 2024	USD 700 / kWh	$CAPEX_{BESS}$	EPE, 2024
CAPEX BESS 2034	USD 490 / kWh	$CAPEX_{BESS}$	EPE, 2024
OPEX BESS	0.5 % of $CAPEX_{BESS}$ p.a.	$OPEX_{BESS}$	EPE, 2024
PV generator average daily yield	3.57 kWh / kWp	Y_{PV}	Monteiro, 2022
Energy tariff (TE), distribution infrastructure use tariffs (TUSD) and low-voltage parcel of TUSD (TUSD Fio B)	TE: USD 50.88 / MWh TUSD: USD 114 / MWh TUSD Fio B: USD 67.77 / MWh	TE $TUSD$ $TUSD_{fio\_b}$	ANEEL, 2024b

[1]Weighted Average Capital Cost, [2]Battery Energy Storage System. [3]1 USD = 5.70 BRL (November 2024)

Four cases are considered to be contracted by the utility: first, systems composed of PV generation and BESS; second, systems composed of PV generation and diesel genset (DGST); third, a combination of PV generation, BESS and DGST, depending on the energy requirements of the load set; fourth, a combination of PV generation, BESS, and demand response (DR) from local consumers of the load set. The study was carried out for different load sets under the concession area of Equatorial Pará, and the energy requirements of each load set was calculated based on the methodology described by Torres *et al*. (2025). In this methodology, a stochastic approach was used to determine the minimum energy storage requirements that a set of DG-based microgrid would need to guarantee that the reliability metrics regarding service interruption comply with the requirements established by regulations. For each load set, which is covered by multiple medium voltage feeders, several low voltage microgrids were integrated into the distribution grid, so that the overall increase in service continuity metrics is meaningful. Table 2 lists the load sets considered in this study, highlighting the minimum aggregated energy requirements of the microgrids and the minimum annual SAIDI (System Average Interruption Duration Index), in hours, required to comply with regulations.

Table 2: Load sets considered in the assessment. Energy Requirements obtained from the work of Torres *et al*. (2025).

Load Set	Energy Requirements (E_{BESS}) [kWh]	Minimum SAIDI [h]
Campo Verde	20,530	39.49
Curralinho	10,324	15.37
Eldorado II	8,215	21.42
Gurupá	6,809	10.62
Almeirim	5,848	11.55
Uruará	4,512	35.25
Itaituba II	3,065	40.95
Tailândia III	2,694	56.52
Vila Concórdia II	2,235	45.66
Rurópolis	1,275	30.88
Altamira III	570	47.81
Bagre	497	17.03
Alenquer II	478	69.94

It is noteworthy that the load sets evaluated in this study currently present low reliability levels, as all of them have a considerable number of hours without service annually. For example, load set *Bagre* needs to have an annual SAIDI no higher than 17 h to comply with regulations. This can be achieved by integrating a set of low voltage microgrids with an aggregated energy storage capacity of 497 kWh. In this study, when considering scenarios with BESS, the initial energy storage capacity was augmented to consider BESS capacity degradation so that by the end of 10-year period of analysis the final BESS capacity would remain within the requirements listed in Table 2 (Equation 3).

Four scenarios for BESS CAPEX were considered in this study: (1) base case, which represents the BESS CAPEX in 2024; (2) 10-year from base case, which represents the expected BESS CAPEX by 2034; (3) Reduced cost scenario 1, with BESS CAPEX at USD 175/kWh; and (4) Reduced cost scenario 2, with BESS CAPEX at USD 88/kWh.

When selling energy to the utility, four scenarios were also considered for selling price c: (1) average price of energy purchased by the Equatorial Pará utility in the Regulated Contracting Environment (RCE) in 2023, of USD 46/MWh; (2) average price of energy purchased by all Brazilian distribution utilities in the RCE in 2023, of USD 53/MWh; (3) reference selling price for photovoltaic solar source established by the Ministry of Energy ordinance 65/2018, in 2018, of USD 79/MWh and (4) reference selling price of photovoltaic solar source corrected by inflation for 2024, of USD 108/MWh.

The costs C_i and C_a (initial and annual, respectively) and benefits (B_a) are calculated from Equations (1) to (5):

$$C_i(\$) = CAPEX_{PV} \times P_{PV} + CAPEX_{BESS} \times E_{AUG} + CAPEX_{DGST} \times P_{DGST} \quad (1)$$

$$C_a(\$) = OPEX_{BESS} \times E_{AUG} + OPEX_{DGST} \times E_{DGST} \times N_{islanding} \quad (2)$$

$$E_{AUG}(kWh) = \frac{E_{BESS}(kWh)}{(1 - \frac{d_{BESS}}{100})^t} \quad (3)$$

$$B_a(\$) = P_{PV} \times Y_{PV} \times 365 \times c \quad (4)$$

$$NPV(\$) = -C_i + \sum_{n=1}^{n=t} \frac{B_a - C_a}{(1 + i_{WACC}/100)^n} \quad (5)$$

$N_{islanding}$ corresponds to how many times a year the system entered islanded operation and is assumed the historic SAIFI (System Average Interruption Frequency Index) of the load set. E_{DGST} is the average energy supplied by the diesel genset during each islanded operation.

3.1. Case 1: PV+BESS and PV+DGST

Figure 1 presents the results of net present value (NPV) analysis considering five scenarios for DG: PV+BESS at different BESS CAPEX (from USD 88/ kWh to USD 700/ kWh) and PV + Diesel Genset. The boxplot indicates the NPV results obtained for the 13 load sets listed in Table 2, where reliability is a concern.

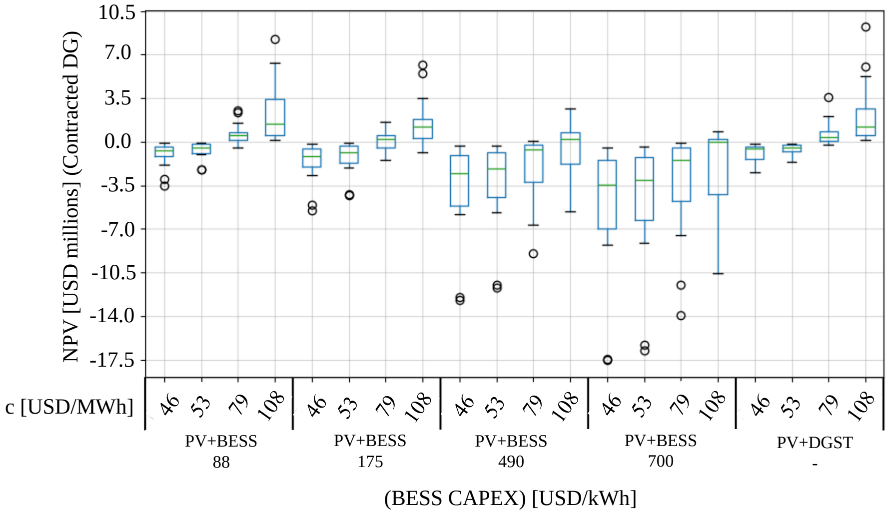

Figure 1: NPV for the different scenarios of Case 1.

The NPV results presented in Figure 1 indicate that, depending on the price of the contracted energy (c), there may be feasibility for generating agents, prosumers or aggregators to invest in DG integration contracts with the utility. It is clear that the higher the price of the contracted energy, the greater the attractiveness of the investment for the DG owner, and the opposite logic applies to the utility. Considering the current CAPEX of BESS, of USD 700/ kWh, and the price cap of contracted energy of USD 108/ MWh, there is a positive NPV (feasibility) in 6 out of the 13 load sets. For the scenario with the diesel genset, feasibility is higher among more load sets.

3.2. Case 2: PV+BESS or PV+DGST

Figure 2 presents the results of NPV analysis considering a combination of scenarios that include PV generation associated with BESS or DGST, depending on the energy requirements of the multiple microgrids within the load set. For example, for small microgrids, with reduced energy requirements, a BESS can be chosen as the energy storage source. Otherwise, diesel gensets can be selected as they are more cost effective for large systems. Specifically, when the energy requirement of the microgrid was up to 20 kWh, BESS solution was considered, and diesel genset otherwise. Therefore, this second analysis represents an optimized version of the analysis in Case 1. The boxplot indicates the NPV results obtained for the 13 load groups listed in Table 2.

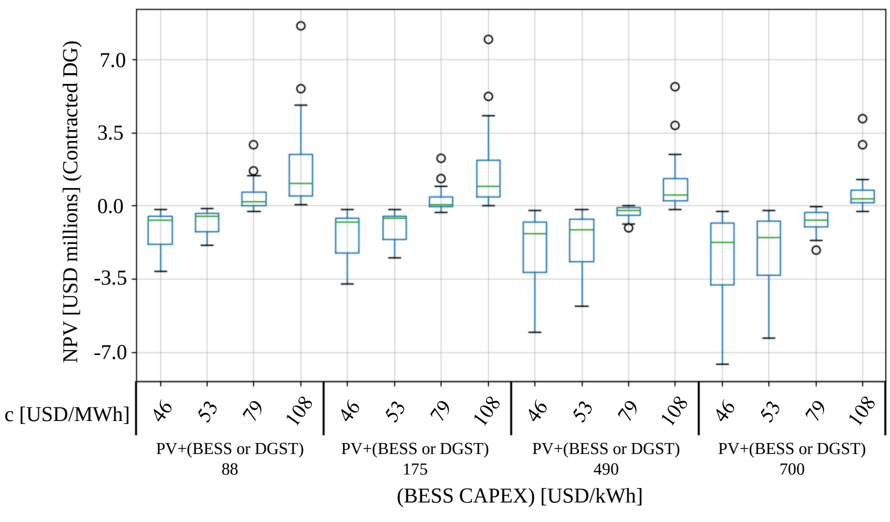

Figure 2: NPV for the different scenarios of Case 2.

The results in Figure 2 show that the microgrid setups with combined PV + BESS and PV + DGST configurations are more attractive, considering the diesel genset option instead of BESS in larger-capacity systems. Even so, the perceptions regarding feasibility observed in the previous case are the same, so investment in this alternative is only justified for energy prices above those practiced in the RCE, even in scenarios with significant reductions in BESS CAPEX.

3.3. Case 3: PV+BESS+DR

The feasibility of utilities contracting DG resources for microgrid integration in combination with demand response (DR) participation can be assessed to reduce DG energy storage requirements. This reduces BESS investment at the expense of increased expenditures related to DR contracts, as mechanisms must be in place to compensate consumers participating in the DR program, to encourage their participation. Such compensation could occur, for example, through the payment of a fixed annual amount to consumers participating in the program, similar to the provision of some ancillary services to generating units.

In the DR case, only PV+BESS based microgrids were considered. The parameter k_{DR} indicates the percentage of demand response participation in the microgrid setup. In the case studies, four levels of DR participation were evaluated: 5 %, 10 %, 15 %, and 20 %. These participation levels were chosen to consider different DR scenarios in terms of consumer participation capacity and considering that these are relatively conservative values that are likely to occur in practice. DR contracts were considered based on a fixed annual fee paid to consumers contracted to participate in the DR program during microgrid islanded operation, regardless of the number of islanding occurrences throughout the year. The amount paid is a function of the contracted energy capacity multiplied by the demand response tariff.

Figure 3 presents the results of this case, considering PV+BESS+DR microgrids, for BESS with different CAPEX and energy price of c = USD 108/MWh.

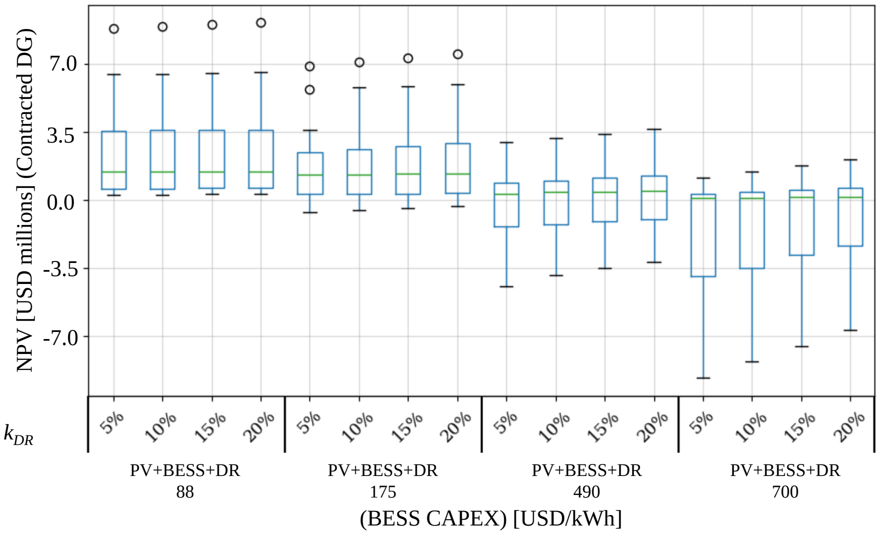

Figure 3: NPV for the different scenarios of Case 3.

The results in Figure 3 show an increase in the number of economically feasible load sets when considering the implementation of a DR mechanism complimentary to DG contracts. There are load sets with positive NPV in all scenarios evaluated.

4. Conclusions

There are already mechanisms in the current regulation that allow the integration of non-isolated microgrids through a business model based on the procurement of distributed generation as a resource forming the microgrid, via public calls, as established by ANEEL´s Normative Resolution 1,009/2022 and complemented by Normative Resolution 1,094/2024. Despite this possibility, there are still no records of its application at commercial scale, being its use limited to pilot projects, such as some microgrids installed within a utility concession area in the south of Brazil. In this context, several points for improvement in the current regulation were identified to promote and enable the dissemination of this type of application, namely: there is still no legal definition for the concept of microgrids, specifically non-isolated microgrids; it is important to regulate the role of the independent aggregator of distributed energy resources, to enable the integration of small- and large-scale microgrids; it is also important to enable the application of special tariff regimes for consumers participating in a microgrid, thus encouraging their involvement in energy resource management, especially during islanded operation.

To validate the developed methodologies, economic feasibility studies were conducted considering the integration of low voltage microgrids in areas with significant reliability violations within the concession area of a utility in the north of Brazil. The results indicate that integrating microgrids via distributed generation contracts with third-party DG owners is generally more suitable than direct utility investment in microgrid resources. Moreover, the current CAPEX of battery energy storage systems still hinders the adoption of this technology in most cases. However, considering a projected CAPEX reduction over a ten-year horizon, feasibility is achieved in some areas.

Another factor directly influencing the viability of this business model is the valuation of energy purchased through DG contracts. In a scenario more favorable to DG owners, where energy is purchased at a higher price cap, as established by current regulations, feasibility is attainable in several areas. As the contracted energy price approaches the average price in the regulated market, the viability for DG investors diminishes. At this point, it is worth discussing to what extent the additional costs of contracting DG, which will be passed on to consumers, justify the investment and the improvement in distribution quality.

Finally, it is noteworthy that reducing consumption during islanded operation through demand response actions is crucial for the economic feasibility of microgrid integration in certain areas.

5. Acknowledgments

The research work was carried out within the scope of the activities of the National Institute for Technological Development of Photovoltaic Solar Energy Applications, INCT-DAESF, CNPq/MCTI/Brazil, Process 408486/2024-4.

6. References

Alilou, M., Younesi, A., Siano, P. "A sustainable approach to hybrid microgrid design: Optimal sizing and energy management". Renewable Energy, v. 256, January 2026. Doi: 10.1016/j.renene.2025.124078.

ANEEL. Agência Nacional de Energia Elétrica. Painel de dados de Geração Distribuída. Disponível em: https://app.powerbi.com/view?r=eyJrIjoiY2VmMmUwN2QtYWFiOS00ZDE3LWI3NDMtZDk0NGI4MGU2NTkxIiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Acesso em: 06 de setembro de 2025. 2025a.

ANEEL. Agência Nacional de Energia Elétrica. Painel de dados da Matriz Elétrica Brasileira. Disponível em: https://app.powerbi.com/view?r=eyJrIjoiNGE3NjVmYjAtNDFkZC00MDY4LTliNTItMTVkZTU4NWYzYzFmIiwidCI6IjQwZDZmOWI4LWVjYTctNDZhMi05MmQ0LWVhNGU5YzAxNzBlMSIsImMiOjR9. Acesso em 06 de setembro de 2025. 2025b.

EPE. Recursos Energéticos Distribuídos - Documento de Apoio ao PNE 2050. Janeiro de 2019.

Torres, P., Manito, A., Williamson, S., Pinho, J., Zilles, R. "Probabilistic Sizing of Low Voltage Microgrid-forming Resources: Technical Approach and Regulatory Assessment in the Brazilian context". Sustainable Energy Grids & Networks, v. 1, 2024b. Doi: https://doi.org/10.1016/j.segan.2024.101611

Torres, P. "Avaliação do potencial de integração de microrredes nos sistemas brasileiros de distribuição de energia elétrica com vistas à melhoria da confiabilidade". 2025. Tese (Doutorado em Tecnologia da Energia) - Instituto de Energia e Ambiente, Universidade de São Paulo, São Paulo, 2025. doi:10.11606/T.106.2025.tde-18032025-133149. Acesso em: 2025-09-06.

EPE. Empresa de Pesquisa Energética, Micro e Minigeração Distribuída & Baterias Atrás do Medidor. Caderno de Estudos do Plano Decenal de Expansão de Energia 2034. PDE 2034. June 2024.

Greener. Estudo Estratégico: Geração Distribuída – Mercado Fotovoltaico. August 2024.

Monteiro, W. L. “Avaliação de Desempenho Operacional de Microgeração e Minigeração Solar Fotovoltaica em Edificações Comercial, Industrial, Residencial e Pública no Estado do Pará”. Master’s Thesis, Graduate Program in Electrical Engineering, PPGEE, Universidade Federal do Pará. 2022.

ANEEL. Agência Nacional de Energia Elétrica, Resolução Normativa 1.094/2024, “Regulamenta os artigos 21 e 24 da Lei nº 14.300, de 6 de janeiro de 2022, que tratam da sobrecontratação involuntária e da venda de excedentes decorrentes do regime de microgeração e minigeração distribuídas, alterando a Resolução Normativa nº 1.009, de 22 de março de 2022.”. May 2024. 2024a.

ANEEL. Agência Nacional de Energia Elétrica, Resolução Homologatória 3.371/2024, “Homologa o resultado do Reajuste Tarifário Anual de 2024, as Tarifas de Energia – TE e as Tarifas de Uso do Sistema de Distribuição – TUSD referentes à Equatorial Pará Distribuidora de Energia S.A. - Equatorial PA, e dá outras providências.”. August 2024. 2024b.