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A Smart Grid System for Reducing Energy Consumption and Energy Cost in Buildings in São Paulo, Brazil

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Abstract: The National Electric Energy Agency (ANEEL) of Brazil, in a bid to encourage energy-conscious energy consumption, has proposed a new sustainable energy tariff modality (the White Tariff) based on off-peak usage. This study aims to compare and contrast situations in which the White Tariff alone is used, and where it is combined with power generation from a generator set or a photovoltaic cell energy system to reduce energy costs. Furthermore, economic, environmental, and social advantages are outlined in the project summaries. Interviews and documentary analyses were conducted in a technology park that uses only the White Tariff and in condominiums that combine the White Tariff with a generator set or a photovoltaic cell system. The data generated was fed into the database of the Horosazonal software to obtain an overview of these companies. Results show that the company adopting the White Tariff alone achieved 19% and US$14,684 in annual savings. However, when the White Tariff is combined with a generator set, the smart grid project proved to be more efficient over time as it obtained an annual benefit of US$35,832 and 62.38% savings. In contrast, the smart grid project combining a photovoltaic cell energy system with the White Tariff achieved an annual benefit of US$52,712, with 68.31% savings and was 1.3 to 5.3 times more profitable than other projects, demonstrating that it was the best smart grip project studied. Furthermore, opting for the White Tariff produced advantages such as a reduction in energy consumption expenses, contributing to a reduction in power outages and blackouts, reduction in greenhouse gas emissions and boosting the company image within society. This study shows that energy-conscious consumption combined with the use of renewable energy sources is environmentally and economically advantageous and can provide future generations with a healthier environment in which people can make use of natural resources in a sustainable manner that is sustainable for planet earth.

Keywords: smart grid; sustainable consumption; White Tariff; software; energy generator; economic feasibility

1. Introduction

1.1. Smart Grid Overview

The fourth industrial revolution known as Industry 4.0 was carried out through the modernization of power systems to manage the increase energy consumption by integrating the energy systems of various countries [1]. This has been achieved by using several modern technologies that allow control and monitoring by energy supply companies. These technologies facilitate measurements, decentralize energy transmission and distribution, making the process more economically viable [1].

According to Al-Turjman and Abujubbeh [2], power quality and reliability issues are significant challenges to both service providers and consumers in conventional power grids. Such peaks and falls in power supply may cause societal damage in the form of economic, material, or public health losses. Current technological advancements in the Internet of things (IoT) provide better solutions for enhancing the management of these challenges and enforcing the measures required for a smart grid (SG). According to Avancini et al. [3], SG are comprised of devices capable of fulfilling their functions in an energy-efficient fashion and possess communication and remote control capabilities. Zhang et al. [4] posited that the smartness in SG usually is a result of two-way communication between the energy supply company and its users as well as monitoring along the transmission lines. Consequently, devices such as energy storage systems, advanced metering infrastructure, and smart energy meters become attractive for use in the power generation and distribution industry because they are enabler technologies that modernize the conventional power grid by uncovering the hidden details of electrical power through the introduction of two-way communication schemes in the power transaction process between utilities and consumers [2,3,5–7].

Smart grids comprising sensors, meters, and software provide measurement, control, communication, power, display, and synchronization capabilities [3] Thus, the right combination of software and sensors is essential for data collection and control in a smart grid [5,7,8]. Therefore, some of these devices, such as smart energy meters and software based on neural networks [9], deep learning [10], cloud computing [11], genetic algorithms [12,13], big data [14,15] Internet of things [2,4,16], simulated annealing [17], bee swarm, ant colonies, and others [18,19], become attractive for use in the power generation and distribution industry, achieving the vision of smart grids. Providing measurement, control, communication, power, display, and synchronization capabilities shall be no easy task for smart meters [7,8].

The initiative to use IoT and smart grids has contributed to significant progress in the updating and improving of power supply company and make it more modern in terms of functionality and architecture. This would ensure grid reliability by controlling the continuous flow of energy in the best way to customers, and if deployed worldwide it would adjust electric energy consumption to decrease CO_2 and other pollutant gaseous emission, minimizing greenhouse effect and the effects of climate change and increasing energy security mitigate, limit pollution, fight climate change, and increase energy security [5,6]. Several studies have been conducted on the use of new meters and new control system methodologies for the storage of sustainable energy, e.g., micro-grid systems using a proposed micro-grid key elements model (MKEM) in the system's architecture that integrates solar power generation units with battery energy storage systems [6]; design of economically viable photovoltaic energy systems for buildings using hybrid batteries [20,21]; development of current sensors based on giant magnetoresistance (GMR), which have compact size, high sensitivity, and cost-effective pricing [5]; software and architecture in waste energy plants based on solid waste incineration of industrial or urban waste [22,23]; biofuel production plants [13,24,25]; dynamic control of the energy flow in electric vehicles [26] with software and hardware forming an intelligent energy network capable of fulfilling individual functions in an energy-efficient fashion, along with communication and remote control capabilities [3].

However, many challenges need to be overcome to achieve a fully-functional and security-aware smart grid. Milchram et al. [27] posit that the increased use of IoT and smart grid technologies raises value conflicts regarding privacy and cyber security, also affecting energy justice. In this regard, Kabalci [28] affirms that the security requirements of the hardware and software in a smart grid must be presented in relation to their cyber and physical structures. According to Neuhauser [29], the security models for smart grids must consider the building blocks of all major known malware types as well as their different propagation methods, access vectors, scanning techniques, control structures, attack methods, triggers, and cleanup mechanisms.

1.2. Smart Grid Policy Around the World

According to Kumar [30], collaboration between engineers and policymakers must be realized to achieve the concept of smart grids in each country, and only through social inclusion, government and funding can the smart grid be more responsible, inclusive and robust. According to Dantas et al. [31], the current policy of government incentives aims at the production of renewable energy; reducing the carbon emission from the economic development, diversifying and improving and increasing the efficiency of the energy matrix of countries (energy, capacity, ancillary services).

Over the past three decades, many countries around the world have adopted policies to improve their electrical systems and combine current energy sources with renewable sources while integrating smart grid technologies to improve the efficiency of the power system and achieve cost reductions [32,33].

Since the issuance of the smart grid guideline in 2006, the European Commission's Joint Research Centre (JRC) frequently monitors and catalogues smart grid projects, focusing on the: public or particular financial incentives in smart grid projects, in the spatial allocation of projects and investments, applications, metering, range and type of organisations in the smart grid sector, consumer roles, obstacles to data collection and disclosure [34]. The first report in 2012 reported a total of 281 smart grid projects identified all over Europe, which had generated roughly €1.8 billion in investment and highlighted investments in demonstration, research, and development projects from countries such as Denmark, UK, Germany, and France [34].

The smart grid of the electrical system in China is focused on mainstream international metering technologies [35] and the development of a low carbon system [36]. Brazil is in a similar situation as China, differentiating itself through intensification of the use of renewable energy [33]. Köktürk and Tokuç [37] show that Turkey needs 6% more energy than the rest of the world and estimates for the following years are that these needs will increase by approximately 50%. This is causing Turkey to invest in new sources of renewable energy, such as wind farms. However, with improvements made in Turkey's energy distribution system, based on the European JCR, which allowed the integration of the energy distribution networks and their evolution to a for smart grid based on renewable energy sources, which enables a 30% growth in energy distribution until 2023 [34].

However, countries that have implemented smart grids in their electrical systems for more extended periods are discussing its advantages. In the United Kingdom (UK), Hiteva and Watson [38] report that the full interaction between electricity and information communication technology sectors in the UK occurred in 2007 and has since been in transition to sustainability.

Connor et al. [39] identified seven sources of uncertainty that will impact the adoption of smarter grid solutions in the UK, such as: markets, users, data and information, supply mix, policy, investment conditions, and networks, which are hindering the full deployment of smart grids in the UK.

The situation in The Netherlands is similar to the UK, according to De Wildt et al. [40], who show that, in particular, the socio-economic disparities caused by the deployment of a smart electricity grid are alarming. Affordable policies are currently limited, and impact in terms of social acceptance may be enormous due to value conflicts underlying the smart electricity grid, such as consumer value versus competitiveness, IT-enabled systems versus data protection, fair spatial distribution of energy systems versus system performance, market performance versus local trading, and individual access versus economies of scale. These are essential considerations for policymakers and the industry to increase the chances of the technology gaining acceptance.

As already experienced in the Netherlands and in the UK, Brazil is also receiving much criticism for imposing abusive tariffs on poor people, which indicates the need to revise its policies [41]. For policymakers and smart grid designers, Milchram et al. [27] recommend they consider the connection between social and moral values in the development of technologies, projects and policies of smart grid.

Apparently, a better solution for smart grid deployment has been found in Canada, where the province's municipally-owned local distribution companies (LDCs) that are responsible for installing smart meters have direct contact with consumers [42]. Developments in technologies for energy measurement sensors have spawned new companies that have forced diversification of energy policies in Canada for each technological niche [42].

In Brazil, the more relevant government policies are on demand-side management, distributed generation and storage, regulatory changes to foster innovation in the energy sector, and regulation of new business models [31]. Since the privatization of state-owned power distribution companies in the 1990s, Brazil has operated a system similar to that of Canada, where a Brazilian power utility company (ELETROBRAS) with several electric plants is responsible for the entire energy generation system and sells this energy to *LCD*s, which then distribute it to consumers [41].

Figure 1 shows a map of the current smart grid of the Brazilian electric system. The hydroelectric, thermoelectric, and wind power plants, as well as their power distribution networks, are interconnected in a smart grid and distributed through five distribution systems (Paraná, Paranapanema, Grande, Paranaíba, and Paulo Afonso) managed by the national operator (ONS) of the Brazilian electric system [43]. This network enables the displacement of electrical energy from one system to another to supply energy deficits between regions and prevent blackouts like those which occurred in the 1990s.

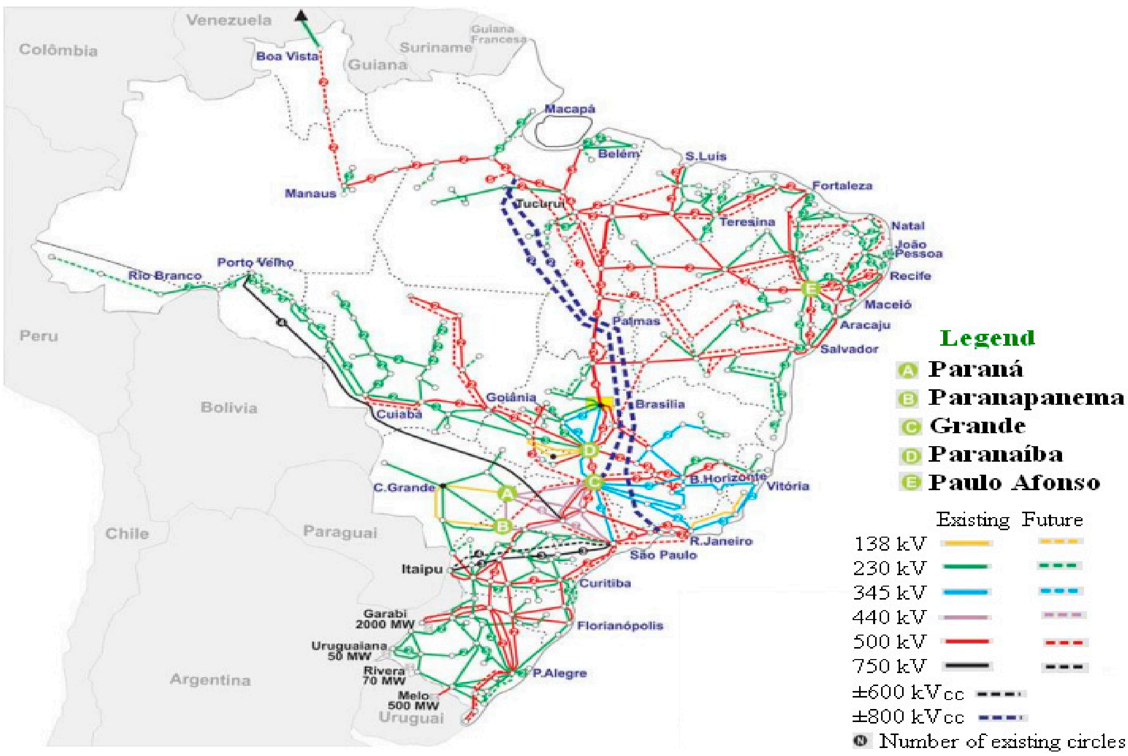


Figure 1. Smart grid of the Brazilian electrical system. Source: Schio [43].

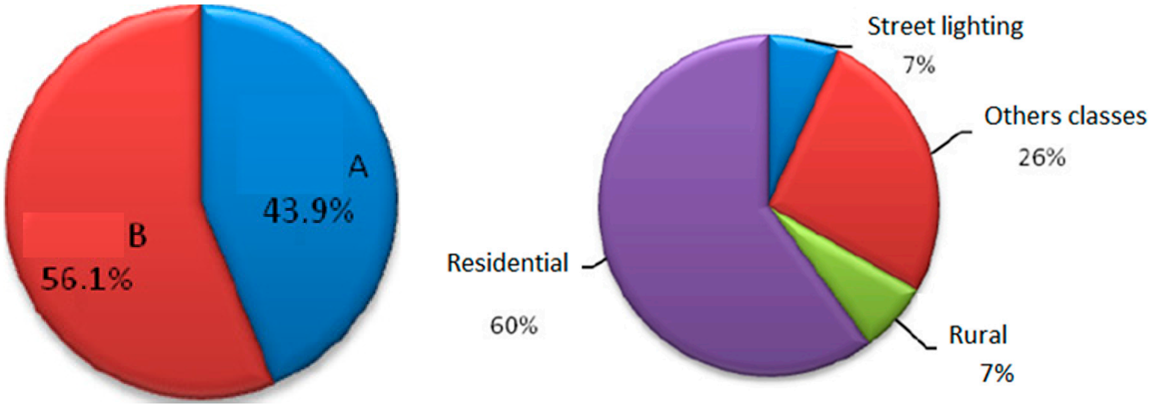
Currently, the system predominantly applied by the Brazilian government, under the management of the National Electricity Agency (ANEEL), for residential consumption is the charging of tariffs based on demand, which is denoted by a green, yellow, and red flags (in order of least to most expensive) [44,45]. However, since 1 January, 2018, all Brazilian distributors have been accepting applications to join the White Tariff system from consumers with a monthly average of over 500 kWh. Under this tariff system, rates are reduced as consumption is prioritized during off-peak hours (5 pm to 10 pm). The consumer who opts for the White Tariff plan now has the possibility of paying different amounts depending on the time and day of the week that he/she consumes the electricity [44]. This is the focus of this research.

1.3. Brazilian Tariff Policy for the Energy Sector

Storing large amounts of energy is impracticable. Thus, it is considered that demand varies over time, and is influenced by the use of equipment that comprise the electrical system (generation, transmission, and distribution). Consequently, its cost is determined by the maximum variation in energy per time unit (power rating), even though this happens only during specific times of the day or a yearly period. A consumer who increases consumption during the period of higher charge by distribution systems tends to be the one who impedes the expansion of the chain or network. Similar to other distribution modalities, the residential modality includes the marginal cost of expansion and varies throughout the day because it is more expensive to serve an additional unit at certain periods, thus justifying the deployment of tariffs based on time. This means that tariffs must reflect the supply costs to consumers based on the theory, and a fundamental attribute of the problem is thus exposed. The current situation calls for a strategy to reduce costs, which can be achieved by controlling and reducing consumption, and consequently, energy costs, or by employing optional incentives or tariff modalities [44]. This study's primary goal is to present the financial viability of using energy cogeneration while opting for the White Tariff during higher tariff periods. It is assumed that this simulation comes from a consumption hypothesis for a residential building and seeks to achieve more economic benefits on energy bills [46].

1.4. Consumption Profile

Energy commercialization presents billing features based on classification by consumer type. For high and medium voltage consumers (group A), the bill value composition is made based on consumption (kWh) and demand (kW), distinguishing values to each tariff based on time (Horo-seasonal). For low voltage in residences, rural areas, public lighting, and others, consumption total value verified over a thirty-day period is billed using conventional tariff and regulated by ANEEL Resolution no. 414/2010. The modality definition implies that the tariffs, besides charging based on system use, encourage the occurrence of marginal consumption preferably at hours in which, statistically, are smaller for its. Figure 2 presents the Brazilian power market according to its composite groups and consumer groupings [47].



(**a**) (**b**)

Figure 2. Brazilian power market. (**a**) Group composition (MWh) and (**b**) Consumer market. Source: ELETROBRAS [47].

The market composition of the low voltage sector is essential for proper allocation of resources, and this impacts low voltage consumers, who are responsible for a higher volume of demand on resources from the electricity sector, as seen in Figure 2b. The White Tariff modality proposed by ANEEL intended to create an additional billing option using consumption and charge profiles based on residential consumption habits [47].

Through circulars, ANEEL has obtained information on residential consumer profiles. For example, 90% of residential consumer units consume less than 200 kWh/month and reach demand peaks during, after, and before on-peak hours. From these data, a new tariff has been proposed. Figure 3 presents the typical curve of these charges [44].

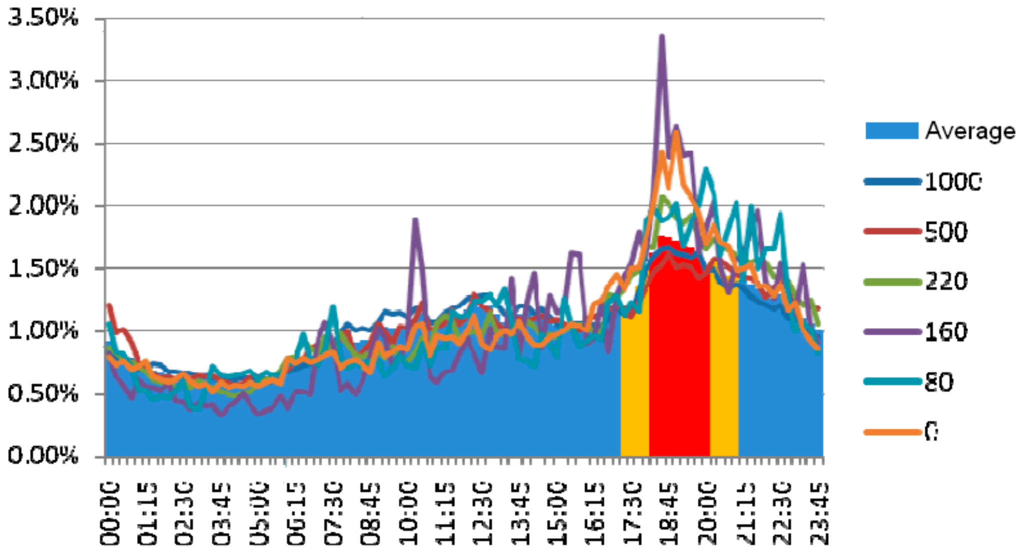


Figure 3. Charge curve of a typical residential consumer. Source: ANEEL [44].

1.5. Regarding the White Tariff

ANEEL offers a new tariff option for low voltage consumers (group B), which gives an opportunity to demonstrate energy variation with respect to the day of the week and consumption hour. Under the White Tariff, the consumer is billed based on energy demand, which is lower during the day and higher during the peak time of the researched consumption profile [44].

During useful days, the White Tariff varies on three periods: intermediate, on-peak, and off-peak, which are homologated by ANEEL. If the consumer chooses this option, it leads to the need to adopt habits that prioritize energy use at times when the distribution is unused. It is recommended to choose this option only after participating in a survey on consumption profiles and a simulation of the values and advantages of the new tariff; otherwise, billing by the conventional tariff remains. Figure 4 presents a comparative graphic representation of the two billing modalities for residential consumption [44].

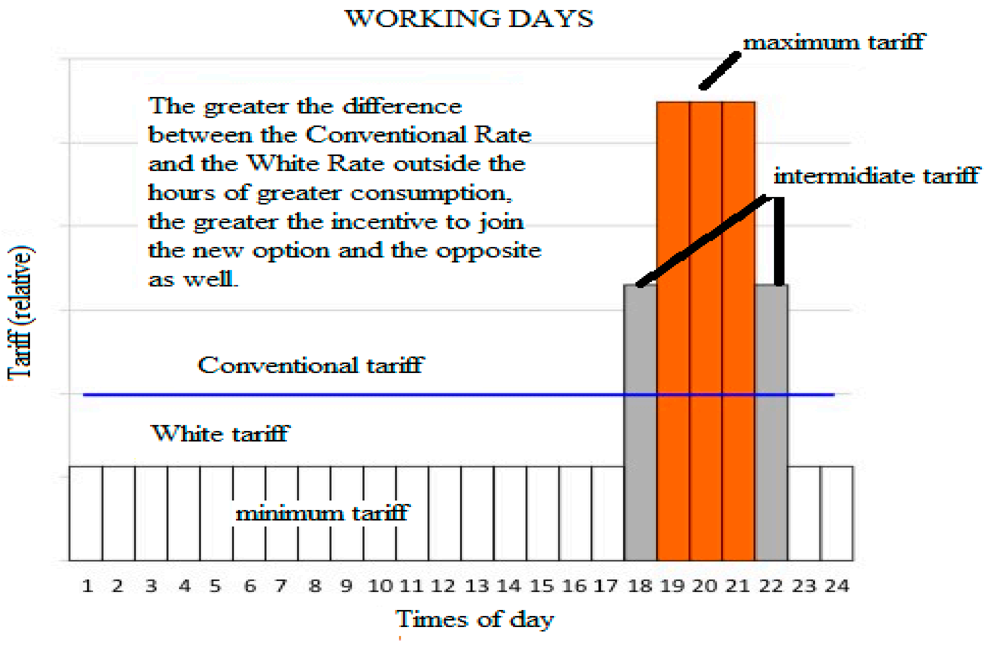


Figure 4. Comparative graphic representation of billing options for residential consumption. Source: ANEEL [44].

Tariff stations will be named peak station, intermediate, and off-peak. Peak station will be applied according to Normative Resolution no. 414, from 9 September, 2010, which establishes the General Conditions of Electricity Supply in an updated and consolidated manner:

- On-peak: period comprised of three consecutive hours per day defined by the distributor based on the charge curve of its electrical system, and approved by ANEEL for the entire concession area, except Saturdays, Sundays, Carnival Tuesday, Good Friday, Corpus Christi, and subsequent holidays;
- Intermediate: period comprised of two hours, being one hour immediately prior to on-peak hours and one hour immediately after on-peak hours;
- Off-peak is the hour that complements on-peak and intermediate hours [44].

This law was effectively implemented in 2018, and by 2019 all Brazilian distributors have complied with requests for adherence to the White Tariff on new calls and consumers with a monthly average of over 250 kWh/month, and from 2020, for low voltage consumers, whatever their consumption [44]. When comparing Brazilian tariff modality options, it is possible to understand that the more the user dislocates consumption to off-peak periods, and the higher the difference between them, the more benefits will be achieved by choosing the White Tariff [48].

This tariff policy is most welcome when consumers adjust 60% or more of their consumption to off-peak hours. In general, users are companies that have some form of energy cogeneration, such as generator sets, turbines, furnaces, photovoltaic systems, or even wind energy. However, the Electric Power Compensation System Brazilian norm presented in the Normative Resolution ANEEL n° 517, of 11 September of 2012, does not allow self-supply of electricity through internal systems owned by consumer companies. It labels this as the generation of excess energy and pays compensation on such at the end of the month as monetary credits in the invoice [44,48].

The global solar radiation values occurring in any region of the Brazilian territory (4200–6700 kWh/m^2) are higher than in most European Union countries, such as Germany (900–1250 kWh/m^2), France (900–,650 kWh/m^2), and Spain (1200–1850 kWh/m^2). It has been shown in other studies that energy production from biodiesel, alcohol, and waste is economically and environmentally friendly. Biodiesel still has the characteristic of being cleaner because it is sulfur-free and emits fewer greenhouse gases than fossil fuels.

These arguments favor the use of this energy source throughout the Brazilian territory. Maybe trying to demonstrate that the conscious use of energy can be very beneficial both environmentally and economically, and perhaps demonstrate a way to provide future generations with a more sustainable planet. Thus, this study aims to show some situations in which the White Tariff is used, in cogeneration with a generator set and/or a photovoltaic cell system, as a way to reduce energy purchase costs [49]. The economic, environmental, and social advantages are also presented in the project summaries.

2. Methodology

2.1. Knowing the Energy Tariffs Charged in Brazil

The amounts charged in Brazilian energy tariffs are subdivided into the following sub-tariffs:

- Distribution System Use Tariff (TUSD) is the tariff paid for the purchase of electricity for the purpose of monetizing the use of the distribution and transmission system.
- The energy tariff (TE) is the tariff actually paid to the energy reseller company.

The cost to consumers is a combination of the two tariffs along with taxes paid to the government; all these values vary with the distributing company.

Taxes on energy tariffs are taxes on the movement of goods and services (ICMS), Contribution to Social Security Financing (COFINS), and Social Integration and Heritage Formation Programs for Public Officer (PIS/PASEP). All taxes are charged on the final price of energy, and for that, their values are used in Equations (1)–(3).

The energy distribution companies addressed in this study are called $LCD1$ and $LCD2$ to avoid unauthorized disclosure of their names. All companies follow the standards required by ANEEL.

2.2. Description of the Companies Studied

All electrical systems of the companies studied have a control panel with software and integrated meters that send data online. These are supplied by the power supply companies. Data collection is done once a month by an operator who uses a meter that collects all panel data and automatically sends it to the utility company's central computer. The operation of data sending, archiving, and computing is based on IoT technology, as cited by Al-Turjman and Abujubbeh [2]. All companies are opting for the White Tariff, and its costs were compared with that of the conventional tariff. Thus, if some projects use only the White Tariff and others use the White Tariff combined with a generator set and a photovoltaic system, this will demonstrate the viability of the tariff proposal.

The first company to apply the White Tariff to reduce energy consumption and energy cost was Sorocaba Technology Park [50]; which is a public-private partnership launched in June 2012 to concentrate and incubate small and medium scale companies in the region. It has incubated biotechnology, energy, information technology, mechanical engineering, and environmental companies in an area of over 3000 m^2 and is located in the city of Sorocaba, São Paulo, Brazil. The authors have the authorization to disclose the name of these companies. Its monthly energy consumption is approximately 32 MWh and it gets power from distribution company $LCD1$ [46,48].

Company A is a condominium located in the metropolitan region of São Paulo that acquires its energy from distribution company $LCD2$ and does not authorize us to name it. It has the following characteristics: it is a residential building consisting of 23 floors, with 4 apartments (53 m^2) per floor and a common area of 11.000 m^2 including parking. The apartments have an average monthly consumption of 220 kWh while the condominium common area has an average monthly consumption of 7300 kWh, which equals a total consumption of 27,540 kWh per month. This condominium opted for the White Tariff and has a generator set in its smart grid to enable the use of its own energy during peak period. The fuel used in the generators was a blend of 10% biodiesel-diesel oil, which makes it possible to reduce emissions and obtain biodiesel. The generator set was always on during peak hours, which is equivalent to a 5 h per day use. The project of choosing the generator set, its financing, and costs was executed using Horosazonal software. The total financing was US$78,947.37, with a down payment of 20% and 36 monthly installments for the remainder at an interest rate of 2% [24,25,46,48].

Company B is a residential condominium with 96 apartments of 110 m^2 and a total built area of 20,000 m^2, located in the city of São Paulo, SP, Brazil, which acquires energy from distribution company *LCD*2 and does not authorize us to name it. Its smart grid is associated with a photovoltaic cell system, which has been part of the condominium infrastructure since the construction of the building and is set up on the smart grid configuration of the condominium to reduce its energy power consumption and costs. Thus, only maintenance costs over the product life span will be considered. The set of photovoltaic cells has 300 m^2, with capacity to generate up to 300 W/m^2.month, which is equivalent to 90,000 kWh. The photovoltaic energy was always on during the last 4 h of peak time, which is equivalent to a 4 h per day use. Monthly energy consumption of the condominium is 37 MWh, and its apartments have an average consumption of around 300 kWh/month while in the common area the energy consumption is of 8.7 MWh/month. Disclosure of the company name was not permitted. Thus, it will be called Company B [7,8,46,48,51].

The best residential tariff modality has been compared and assigned. Then, HOROSAZONAL software was applied as a tool to simulate the use capacity choice of an energy generator on on-peak and intermediate hours [52]. This software considers costs of engines preventive maintenance, such as changing the lubricant filter, air, and fuel, every hour. Based on a database that is already part of the software, it is possible to access tariff values by concessionary, energy generator capacity, fuel average consumption per hour, and tariff values by modality. All these data combined feed formulas that have set the number of generators required, the economy by using energy generators and financing options to determinate payback time [52].

2.3. Cost Analyses

An on-site document analysis was carried out at the companies, which made available energy bills last year. From these data, the average values of the energy consumed were obtained, and for the cost calculations, the values of the tariffs and taxes of the last month were used because they are the most current.

In the case of the conventional tariff, the partial value of the invoice in this mode can be calculated by multiplying the consumption measured by the consumption tariff.

$$Value(\text{US\$}) = Energy{\cdot}TUSD_{tariff} + Energy{\cdot}TE_{Tariff} \quad (1)$$

where energy is the energy consumption in kWh, and value is the cost of energy consumed (US$), without rates.

For the White Tariff, the bill is calculated by the sum of the energy consumption installments realized at each tariff station (peak or off-peak) multiplied by their respective tariffs, according to the following equation:

$$Value(\text{US\$}) = Energy{\cdot}TUSD_{in-peak} + Energy{\cdot}TE_{in-peak} \ldots + Energy{\cdot}TUSD_{off-peak} + Energy{\cdot}TE_{off-peak} \quad (2)$$

The energy cost or final price to be paid by the consumer is given by Equation (3), where the rate is the sum of the taxes to be paid by the consumer on the final invoice.

$$Cost(\text{US\$}) = \frac{Value}{1 - rates} \tag{3}$$

After the final price calculation, the values of each rate were obtained using its respective percentages cited in Table 1.

Table 1. Tariff and rate values used in price composition calculations according to power distributors.

Description	*LCD*1		*LCD*2	
	Conventional	**White**	**Conventional**	**White**
$TUSD_{in\text{-}peak}$ (US$/kWh)	0.058995	0.149047	0.053684	0.088936
$TUSD_{off\text{-}peak}$ (US$/kWh)	0.058995	0.01675	0.053684	0.004837
$TE_{in\text{-}peak}$ (US$/kWh)	0.086511	0.131229	0.067064	0.078289
$TE_{off\text{-}peak}$ (US$/kWh)	0.086511	0.082445	0.067064	0.019307
ICMS (%)	18.0		25.0	
COFINS (%)	4.16		4.54	
PIS/PASEP (%)	0.90		0.99	

For calculating Indirect Emissions from Electricity Purchases, the official GHG Protocol-based Brazilian government calculator was used. From this, the carbon credits associated with the reduction of energy consumption were obtained. Emissions from power generation, transmission, and conversion are considered as carbon credit deficits. This conversion of energy consumed (or surplus) to carbon credits was done using the Official Carbon Credits Calculator developed by Brazilian GHG Protocol certified by LRQA Business Assurance [25].

The use of biodiesel enables the company to reduce CO_2 emissions, and consequently, to acquire 2.5 carbon credits for each ton of CO_2, it is calculated using Equation (4) and its profit by Equation (6) [24,25]. Reducing energy consumption is also considered as a green attitude that reduces emissions from power generation and transmission, and consequently, also enables the company to acquire carbon credits. which allows them to sell them at a price of 28.73 €/ton CO_2 (US$32.18), and consequently, to a reduction in operating costs, beyond improving the image of the company [25,26,33].

$$CC_{Bio}(tonCO_2) = 2.5 \cdot m_{bio} \tag{4}$$

where CC_{bio} is carbon credits from biodiesel and m_{bio} is the biodiesel mass, given by Equation (5) [25].

$$m_{bio}(ton) = V_{bio} \cdot d_{bio} \tag{5}$$

where V_{bio} and d_{bio} (0.88) are the volume and density of biodiesel, respectively.

The profits derived from the sale of carbon credits can be obtained using Equation (6) [25], as follows:

$$CCProfit(\text{US\$}) = tonCO_2 \cdot CurrentPrice(\text{US\$}/tonCO_2) \tag{6}$$

and the profit derived from the sale of excess energy can be obtained using Equation (7) [44], as follows:

$$ExcessEnergyProfit(\text{US\$}) = 0.102232 \cdot (SG_{total} - SG_{LCD}) \tag{7}$$

While SG_{total} is the energy generated by the specific smart grid and SG_{LCD} is the energy from smart grid used to supply a portion of the energy supplied by the specific *LCD*. The value 0.102232 corresponds to the price that the *LCD*s should return (US$) to the consumer for each kWh of excess energy [44].

3. Result and Discussion

3.1. Effect of White Tariff on Energy Cost

In Example 1, the effect of adopting a new tariff on the costs and other benefits to a company was verified. Table 2 shows the composition of the costs with energy consumed by the Sorocaba Technology Park, which chose the White Tariff and provided this research with data from a period of one year. In order to implement the white rate system in its smart grid project, the management made a decision that the technology park companies should shift their working hours until 6 pm, avoiding the use of internal spaces during peak hours.

Table 2. Costs according to the White Tariff for Sorocaba Technology Park.

Description	Energy * (kWh)	Tariff Cost (US$)	Rate Costs (US$)			Unit Cost (US$)
			ICMS	COFINS	PIS/PASEP	
$TUSD_{in\text{-}peak}$	3114.96	464.28	108.62	25.10	5.43	603.43
$TUSD_{off\text{-}peak}$	29,395.54	492.37	115.19	26.62	5.76	639.95
$TE_{in\text{-}peak}$	3114.96	408.77	95.63	22.10	4.78	531.29
$TE_{off\text{-}peak}$	29,395.54	2423.51	566.98	131.03	28.35	3149.87
Total	32,510.50	3788.93		1135.60		4924.52

* This is an average value based on data provided by the company (one-year average).

The calculation used the *LCD*1 tariffs as its basis, (shown in Table 1), as all invoices were issued by this energy supplier. An average monthly consumption of 32 MW is observed and of these less than 10% (3 MW) refers to the peak tariff period. The average monthly energy cost is US$4924; which equals an average price of 0.1515 US$/kWh.

Figure 5 shows the composition of energy costs consumed by the Sorocaba Technology Park, based on the White Tariff. Although the price of energy consumed at peak hours is high, with the reduction of consumption at peak times, its impact has been reduced to 17% of the total cost. As previously mentioned, for a project using the White Tariff to be viable, the contribution of the amount of energy during peak hours must be less than 30% [48].

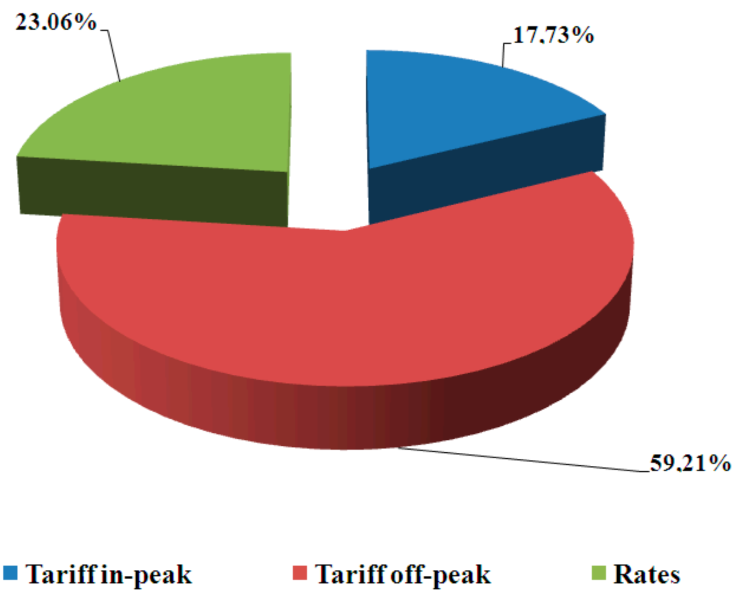


Figure 5. Contribution of energy cost items to White Tariff.

Table 3 shows the composition of the costs with energy consumed from the same company if it chose to use the conventional *LCD*1 tariff, using the data presented in Table 1 and the same average energy consumption for calculations. As noted, the average monthly cost of energy rose to US$6148; which is equivalent to an average price of 0.1891 US$/kWh. After comparing the results obtained for each tariff, it was observed that the use of the White Tariff gave the Sorocaba Technological Park a 19% economy with its energy costs, which is equivalent to saving of US$1223/month or US$14,684 of annual savings, which can be invested in infrastructure improvement, or hiring new employees, or research and development.

Table 3. Energy costs according to the conventional tariff and comparison with the White Tariff.

Description	Energy (kWh)	Tariff (US$)	Rates (US$)			Cost (US$)
			ICMS	COFINS	PIS/PASEP	
TUSD	32,510.50	1917.95	448.70	103.70	22.44	2492.78
TE	32,510.50	2812.50	657.98	152.07	32.90	3655.45
Total	32,510.50	4730.45		1417.79		6148.23
Balance	Monthly savings (US$)			Annual saving (US$)		Economy (%)
	1223.71			14,684.50		19.90

By opting for the White Tariff, the Sorocaba Technologic Park achieved some advantages:

(i) Reduction of expenses with energy consumption;
(ii) Contributes to the reduction of power outages and blackouts;
(iii) Because of its conscious consumption, it contributes to the reduction of environmental impacts, due to the decrease of peak energy consumption reduces the need for thermoelectric plants;
(iv) Consequently, reduces gaseous emissions for power generation;
(v) And improves its image before society [13,24,25,51,53].

According to Connor et al. [39], all sources of risks and uncertainties must be addressed prior to the implementation of a smart grid project so that its success will be achieved, but as noted, even in a proposal without spare power sources, the success of a smart grid project. White fare has been proven, demonstrating that this proposed Brazilian fare is economically viable.

3.2. *Effect of Combining of White Tariff with Generator Set*

In example 2, the effect of adopting a new tariff combined with energy cogeneration in a generator set on the costs and other benefits to a company A was verified. From the data collected in the condominium invoices (company A), which buys energy from distributor *LCD*2. Table 4 could be assembled, which represents the monthly energy costs if the condominium had not opted for the White Tariff combined with the generator set. A total cost of US$4787 per month has been found and a unit energy cost of 0.1738 US$/kWh, which is lower than shown by example 1 indicating that the distribution company *LCD*2 has a lower price of energy than *LCD*1.

Table 4. Energy costs according to the conventional tariff for company A *.

Description	Energy (kWh)	Tariff (US$)	Rates (US$)			Cost (US$)
			ICMS	COFINS	PIS/PASEP	
TUSD	27,540.00	1478.453	532.05	96.62	21.07	2128.19
TE	27,540.00	1846.947	664.66	120.70	26.32	2658.62
Total	27,540.00	3325.4		1461.41		4786.81

* based on a year of data in invoice of *LCD*2.

From the choice of Company A, presented in the methodology, a generator set was used 5 h per day use, exclusively at peak hours, which is equivalent to 5737.50 kWh/month. Under these conditions, the software simulated the possible generator sets that could be used, and of the 20 found in its database, five were indicated (as shown in Table 5) to show the types, characteristics, and costs associated with generators that best fit the smart grid project for the condominium. As noted, the most suitable was the S450 generator set which although having a high fuel consumption have the lowest energy cost, which was 0.126619 US$/kWh. As this value is lower than the peak hour energy tariff (seen Table 1: US$0.088936 + 0.078289 = 0.16723 US$/kWh), its effect is likely to be beneficial in the final conclusion.

Table 5. Characteristics of the main generator and their costs.

Generator Set	Description	Price (US$)	Consumption (unity/h)	Hourly Cost (US$/h)	Energy Cost (US$/kWh)
S250 (200kW Prime)	Biofuel B10 (L) Lubrificant (L) Maintenance *	0.49 1.18 0.92	55.30 0.28 1	26.92 0.33 0.92	0.142105
S275 (224 kW Prime)	Biofuel B10 (L) Lubrificant (L) Maintenance *	0.49 1.18 0.92	60.60 0.30 1	29.50 0.33 0.92	0.137277
S330 (256 kW Prime)	Biofuel B10 (L) Lubrificant (L) Maintenance *	0.49 1.18 1.00	69.10 0.35 1	33.64 0.41 1.00	0.136914
S450 (328 kW Prime)	Biofuel B10 (L) Lubrificant (L) maintenance	0.49 1.18 1.00	0.35 1 1	42.11 0.51 1.00	0.133007
S500 (364 kW Prime)	Biofuel B10 (L) Lubrificant (L) Maintenance *	0.49 1.18 1.00	91.50 0.46 1	44.55 0.54 1.00	0.126619

* Filter changes, engine rectification, pump and turbine overhaul.

The project involving choosing the generator set, financing, and cost analysis was handled with the Horosazonal software. The total financing was US$71,052.63, with a down payment of 20% and the remainder in 36 monthly installments and an interest rate of 2%. Once fed with the financing data on the generator set and data on energy purchased from *LCD*2, along with the associated tariffs and rates, Horosazonal software was able to simulate cost analysis as follows:

Based on the applied simulation, the White Tariff is the best tariff modality, presenting the lowest amount to pay. Considering the equipment depreciation, the demand increasing by adding more electronic equipment, tariff values increase, and others, the correction factor is 25% beyond total. In this simulation, it can already find the implementation costs of the energy generator system and other maintenance expenses.

The Horosazonal software has estimated that energy generator power rating will be 200 kW, considering 0.8 as a power rating factor for on-peak and intermediate consumption profile, which, combined, equal to 19%, considering general supply conditions [52]. The nominal commercial power rating of the energy generator, applied to Equation (8), will be 250 kVA. It appears in the same display as the payable value for White Tariff consumption, without its rates.

$$P_{(\mathrm{kVA})} = \frac{P_{(\mathrm{kW})}}{\cos\varphi} \quad (8)$$

where $P_{(\mathrm{kVA})}$ is the apparent power, $P_{(\mathrm{kW})}$ is the useful power, and $\cos\varphi$ is the power factor.

The investment indicated above for acquiring and installing equipment may be quickly amortized if performed with own resources. Acquiring the equipment can be also done by bank financing, ensuring, from the beginning, a monthly gain even with the payment of benefits. At this point, it is observed that economic viability for deployment will be possible by apportioning costs for all tenants, considering that most of them will pay for this financing. The software returned the input data with an initial value of US$14,921.05 down payment and 36 installments of US$2157.37/month. Figure 6 summarizes the financial feedback from smart grid project presented by company A. The financial feedback occurs from the 16th month, with a profit of more than US$17,000 at the end of the financing and a profit of over US$100,000 at the end of the useful life of the generator set.

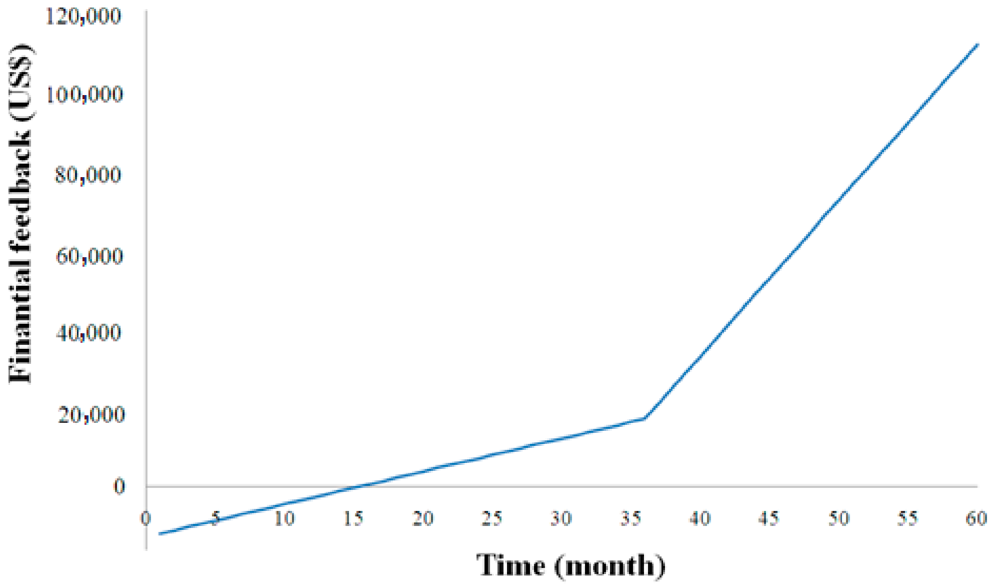


Figure 6. Financial feedback curve of the smart grid project.

Table 6 shows the composition of the costs with energy consumed by the company A (a condominium), which chose the White Tariff combined with a generator set and provided this research with data from a period of one year. The calculation basis used was *LCD*2 tariffs, shown in Table 1, as all invoices were issued by this energy supplier. An average monthly consumption of 27.5 MW is observed, and 0% refers to the peak tariff period. The smart grid divided the energy quota in 21.5 MWh from the power utility from distributor *LCD*2 and at peak time was supplied by the 5737 kWh cogeneration of the generator set. Cogenerated energy cost is exclusively associated with the financing and maintenance of the generator set. The average monthly energy cost is US$3958; which equals an average price of US$0.1437/kWh, which is smaller than the White Tariff project alone (example 1) and after the funding period (36 months) this value drops to US$0.06538/kWh, proving to be more efficient than that.

Monthly profit of $828 (9940 per year) and an economy of 17.31% had been found, which is lower than the savings obtained by example1 (white rate only), but after 36 months of financing the savings are up to US$2986/month (US$35,832/year) and 62.38% savings, which gives an average of 35.34% economy over 5 years of generator set life.

Figure 7 shows the composition of energy costs consumed by company A, based on the White Tariff combined with a generator set. There is a dilution of the costs with the acquisition of energy from distributor *LCD*2, and the cost is borne primarily through financing, such that when the financing ends, the costs are reduced by more than 45%. This explains the sharp rise in the economy and profit after 36 months [13].

Table 6. Energy costs according to the smart grid project of company A, combining White Tariff and generator set for company A *.

Description	Energy ** (kWh)	Tariff Cost (US$)	Rate Costs (US$)			Unit Cost (US$)
			ICMS	COFINS	PIS/PASEP	
$TUSD_{in\text{-}peak}$	0	0	0	0	0	0
$TUSD_{off\text{-}peak}$	21,802.50	151.81	54.63	9.92	2.16	218.54
$TE_{in\text{-}peak}$	0	0	0	0	0	0
$TE_{off\text{-}peak}$	21,802.50	605.94	218,06	39.60	8.64	872.26
Cogenerated Energy	5737.50	2867.36	0	0	0	2867.36
Total	27,540.00	1415.28		333.01		3958.40
Balance	Monthly savings (US$) 828.41		Annual saving (US$) 9940.96		Economy (%) 17.31	

* Rates are from distribution *LCD2*; ** is an average value based on data provided by the company (one-year average).

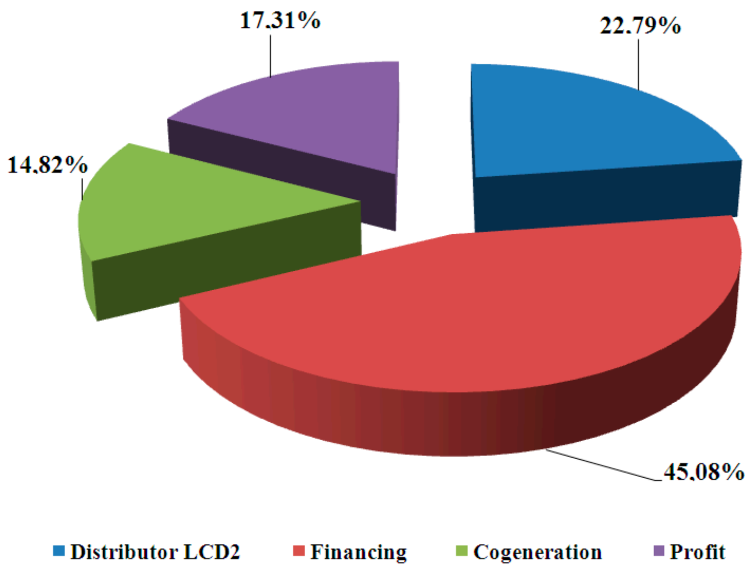


Figure 7. Composition of energy costs for company A.

Several authors have pointed out that software and computer systems are essential in the control of measuring instruments, data collection and processing, and in communication and management of systems, and Horosazonal software is essential because it is specific for decision making, mainly in smart grid project in the area of electrical engineering [2,3,5–13,15,16,18,19].

In addition, Table 7 presents the accounting of carbon credits of the smart grid project. As it turns out, a profit of $103 per month is earned, which can be used to offset maintenance costs and improve project effectiveness. In addition to the economic contribution, the most important of carbon credits is the association with the reduction of greenhouse gas emissions, which in this case were 3.21 tons CO_2, which makes the condominium environmentally friendly. Thus, it can be evidenced that this smart grid project is cleaner than the example1 (with only the White Tariff).

Table 7. Accounting for carbon credits associated with smart grid project.

Description	Consumption	Monthly Use Time (h)	Mass (ton)	CO_2 (ton)	Profit (US$) *
Biodiesel (L)	91.5	150	1.22	3.05	98.16
Cogenerated Energy (kWh)	5737.5	-	-	0.16	5.19
		Total		3.21	103.35

* 1 ton CO_2 = US$32.18.

Good projects have also been reported in the literature, such as Carr et al. [32], who made the comparison the performance of baseline and price responsive controls in a smart grid project in a building, with a power reduction of 60% achieved during a period of peak consumption and grid congestion corresponding to a large price surge. Aleksic and Mujan [54] also showed a similar cost reduction, using software that evaluated it throughout the life cycle of energy production, and underscored its importance.

3.3. Effect of Combining of White Tariff with Photovoltaic Cells

Example 3 presents a smart grid project composed of the photovoltaic system consists of a set of photovoltaic plates with 13% conversion yield, 97–99% efficiency, nominal power of 300 kWh/m^2.month and installed on the roof of the building, occupying a total area of 300 m^2, therefore, the sunroof can produce an energy total equivalent of 90,000 kWh. Where the wiring leads the energy to a string box that is used for direct current (dc) protection, which powers an inverter that turns dc into alternating current, which powers the condominium. Intelligent electrical switchboards are installed in all condominium apartments and a two-dimensional energy meter measures the energy consumed [3,5–7] and surplus (generated by photovoltaic cells), so that compensation is made at the end of the month, as monetary credits to the condominium [44].

However, photovoltaic generators have their generating capacity according to incidence and time of solar irradiation. Thus, based on the average annual global horizontal radiation map of Brazil, in the amount of daily solar irradiation hours of the southeastern region, where the state of São Paulo is located (9 to 12 h of daily irradiation), its photovoltaic cell efficiency drops to 61%, which is equivalent to 183 kWh/m^2.month, reducing the energy produced from 90,000 to 54,900 kWh/month [51].

Table 8 shows the costs associated with this photovoltaic cell system. There was no need to calculate the return on investment because the photovoltaic cells were installed when the building was completed, being part of the internal costs of building the condominium. As it turns out, the annual cost with the photovoltaic system is less than US$600, or simply US$50 per month; which is irrelevant to the cost shown below.

Table 8. Annual cost of photovoltaic system maintenance.

Description	Unitary Value (US$)	Life Cycle (years)	Maintenance (4%, US$)	Unit Cost (US$)
Photovoltaic cell roof	26,315.79	25	42.10	42.10
Photovoltaic kit	10,526.32	5	84.21	84.21
Maintenance technician honorary	473.68	-	-	473.68
	Annual total cost (US$/year)			599.99

Table 9 shows the composition of the costs with energy consumed by Company B, which chose the White Tariff combined with a photovoltaic power generation system and it also made available a year's data for this research. In an interview with the manager, it was shown that the condominium uses one hour a day during peak hours (17–18 h) or 1934 kWh and the other hours (18–22 h) uses the energy stored in the photovoltaic system batteries (7738 kWh), the average energy derived LDC2 peak hour was 1572 kWh/month, as shown in Table 9.

Table 9. Energy costs according to the White Tariff for company B *.

Description	Energy ** (kWh)	Tariff Cost (US$)	Rate Costs (US$)			Unit Cost (US$)
			ICMS	COFINS	PIS/PASEP	
$TUSD_{in\text{-}peak}$	1934.69	247.68	89.13	16.19	3.53	356.66
$TUSD_{off\text{-}peak}$	27,321.60	190.24	68.46	12.43	2.71	273.86
$TUSD_{PV\ in\text{-}peak}$	7738.77	0	0	0	0	0
$TE_{in\text{-}peak}$	1934.69	218.03	78.46	14.25	3.11	313.96
$TE_{off\text{-}peak}$	27,321.60	759.32	273.26	49.62	10.82	1093.05
$TE_{PV\ in\text{-}peak}$	7738.77	0	0	0	0	0
Total	36,995.06	1415.28		621.97		2037.53

* Rates are from distribution *LCD*2; ** is an average value based on data provided by the company (one-year average).

The calculation basis used was *LCD*2 tariffs, shown in Table 1, as all invoices were issued by this energy supplier. As noted, an average monthly consumption of 29.2 MW is observed, and of this only 5.22% (1.9 MW) refers to the peak tariff period. The average monthly energy cost is US$ 2037; which equals an average price of US$0.0696/kWh. Comparing with the use of the tariff without the photovoltaic energy, in example1, it is noted that for similar energy consumption, the energy cost is less than half that of example1 (White Tariff alone) and example 2 (White Tariff and generator set), demonstrating the economic gain of the photovoltaic system.

Figure 8 shows the composition of energy costs consumed by the condominium (company B), based on the White Tariff combined with a photovoltaic cell system. Although the price of energy consumed at peak hours is high, with the reduction of consumption at peak times, its impact has been reduced to 22.86% of the total cost; this is because its price is 7 times higher than the off-peak energy price. However, in the composition of the total energy consumed this value is reduced to 5.23%, which made this project more efficient because the amount of energy used during peak hours was well below the 30% indicated.

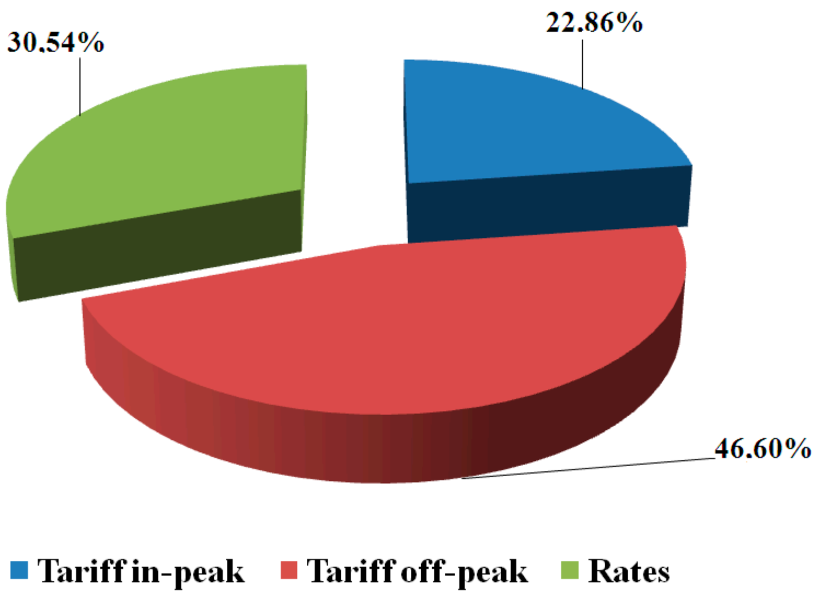


Figure 8. Tariff influences on the cost of a smart grid project that combines the White Tariff with a photovoltaic system (Horosazonal software).

Table 10 presents the composition of the costs, with energy consumed from the same condominium in a prior situation (with no photovoltaic system) using the conventional *LCD*2 tariff, based on the data presented in Table 1 and using the same average energy consumption for calculations. Note that the average energy consumption and cost were 37 MWh/month and 6430.23 US$/month; which is equivalent to an average price of 0.1738 US$/kWh. Seen that, the values are similar to those in example1, which validates the reasoning made about the data. It can see the values are much higher than the current condominium stage (White Tariff and photovoltaic system).

Table 10. Energy costs according to the conventional tariff for company B.

Description	Energy (kWh)	Tariff (US$)	Rates (US$)			Cost (US$)
			ICMS	COFINS	PIS/PASEP	
TUSD	36,995.06	1986.04	714.71	129.79	28.30	2858.84
TE	36,995.06	2481.04	892.85	162.14	35.36	3571.39
Total	36,995.06	4467.08	-	1963.15	-	6430.23
Balance	Monthly savings (US$)		Annual saving (US$)			Economy (%)
	4392.70		52,712.39			68.31

After comparing the results obtained for each tariff, it was observed that the use of the White Tariff combined with photovoltaic cell systems gave company B a 68.31% savings with its energy costs, which is equivalent to savings of US$4393/month or US$52,712 in annual savings, that can be invested in other important condominium activities, such as reducing the internal fees charged to condominium residents. As the conditions are similar, it can be said that the project of combining White Tariff with photovoltaic was 3.6 times more profitable than the project with White Tariff alone (example1) and 1.5 to 5.3 times more profitable than using a combined generator set (example 2). This cost reduction is only similar to that presented by Carr et al. [32], who also used a photovoltaic cell system on the smart grid of a commercial building in the USA.

Table 11 shows other sources of profit from smart grid project of condominium of the condominium that chose to mix the White Tariff with the photovoltaic system. In this table, it is clear that the project reached an amount equivalent to US$5388 profit per month and is 2.4 more than the invoice to be paid to *LCD*2 (seen Table 6). That is, there will be no costs associated with the project, but a profit of over US$2833 per month.

Table 11. Other sources of profit from this smart grid.

Source	Energy (kWh)	Carbon Credit (ton CO_2)	Unit Price (US$)	Monthly Profit (US$)
From Photovoltaic	54,900.00	1.345	32.18	43.28
Excess Energy	47,161.23	-	0.102232	4821.37
Consuption reduction	1738.77	0.190	32.18	6.11
Total		1.535		4870.76

Other sources of profits are the compensation made by *LCD*2 due to excess energy generated by the photovoltaic system that will go to the distribution grid of *LCD*2 and carbon credits due to reduced energy consumption of the distribution system and clean energy generation (photovoltaic). About 99% of the profit is associated with the sale of excess energy.

In addition, the project adopted allows the reduction of emissions by the electricity consumption of the condominium by up to 1.5 tons CO_2 per month, or almost 18.4 tons CO_2 per year. However, the carbon credit profit is not high and is sufficient to pay for the monthly maintenance of the photovoltaic cell system (see Table 5).

Because the reduction of greenhouse gas emissions is associated with public image, a greater contribution of carbon credits will be associated with an improvement in public image as energy consumption is now seen as non-polluting. In this same sense is the use of photovoltaic cells, as it is a source of energy considered renewable and clean energy. Consequently, in terms of energy use, this condominium can be considered as environmentally friendly and improving their image before society [7,8,24,51].

In China, Liwen et al. [36] show that the low-carbon benefit of a smart grid is 224.57 billion yuan (33.1 billion US$), which provides a reference for the construction of smart grid in the coming years. Therefore, the use of tariffs that encourage conscious consumption of energy, besides being environmentally correct, proves to be economically viable, generating profits that, with proper use, can be invested in improvements for society and/or the environment.

According to Carr et al. [32], the advent of the smart grid and smart building concepts have enabled these innovations to be brought to the level of the retail electricity market, where even individual buildings will be able to adjust their consumption based on price signals from the market. This has been proven in this study by demonstrating that a tariff that encourages the conscious use of energy can reduce business costs.

4. Conclusions and Policy Implications

The White Tariff is a way to encourage Brazilian consumers to migrate their energy consumption to off-peak hours, and it was noted that when adopting this tariff, a company achieved 19% economy and US$14,684 of annual savings.

The effect of the insertion of power cogeneration by a generator set in conjunction with the White Tariff in a smart grid project shows that the company achieved an annual benefit of US$9940 and 17.31% savings, which increase after the end of the funding period to US$35,832/year and 62.38% savings, respectively, demonstrating a higher efficiency than the use of White Tariff alone.

The effect of the insertion of photovoltaic cell system combined with the White Tariff in a smart grid project shows that the company achieved an annual profit of US$52,712 and a 68.31% savings and 1.3 to 5.3 times more profitable than other projects, demonstrating that was the best smart project among those studied.

In general, opting for the White Tariff leads to advantages such as reduction of expenses with energy consumption; contributes to the reduction of power outages and blackouts; reduces greenhouse gas emissions and improves the company image with the society.

Thus, it has been shown that encouraging energy-conscious consumption combined with the use of renewable energy sources is environmentally and economically advantageous and can provide future generations with a healthier environment in which people can make use of natural resources in a sustainable manner more sustainable for planet earth.

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