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Calculation of the Cost of Unsupplied Electricity in the Residential, Commercial, and Industrial Sectors of Honduras for the years 2021-2023

Danielle Rodríguez[1]; Maria Celeste Parada-Acosta[2]
[1,2]Faculty of Engineering, Universidad Tecnológica Centroamericana, (UNITEC), Honduras, danielle@unitec.edu, celesteacosta29@unitec.edu

Abstract --- The purpose of this research was to analyze and calculate the Cost of Energy Not Supplied (CENS) in Honduras for the years 2021, 2022, and 2023, with the aim of quantifying the economic losses resulting from power outages. The study employed the calculation methodology established by the Regional Electricity Interconnection Commission (CRIE) in the Regional Electricity Market Regulation, which is based on indirect methods using macroeconomic data and historical records corresponding to the study's baseline years. The analysis estimated the CENS in the residential, commercial, and industrial sectors, distinguishing between costs associated with short- and long-duration outages and considering the specific characteristics of each consumption sector. The results revealed that the commercial and industrial sectors reported the highest CENS costs, primarily due to their high dependency on productive processes. In the residential sector, outages directly impacted on the quality of life and well-being of households. Overall, the cost of outages has shown an upward trend, reflecting the increasing vulnerability of the national electrical system. This research highlights the urgent need to prioritize investments in electrical infrastructure and design more effective regulatory policies to reduce economic losses and improve the reliability of the electricity supply.

Keywords— Cost of Electricity Not Supplied (CENS), Energy losses, Residential, commercial, and industrial sectors.

I. INTRODUCTION

Electricity is a fundamental resource for most activities carried out today. The growing dependence on its supply, together with the high costs still involved in its storage, requires high levels of continuity and reliability in service provision [1]. Although self-generation has gained ground in some countries, most productive activities depend on the electricity supply, and national grids continue to be the main source of energy, which underlines the importance of a continuous and constant electricity supply [2]. Many research studies have focused on the stability of the electrical grid and proposed energy storage options [3], while other studies demonstrate the country's energy potential [4]. These studies show how essential it is to have an energy system that is available, reliable, and secure.

In this context, electricity has become an essential component of modern societies. Interruptions in supply not only paralyze daily activities, but also have a major economic impact on users, who depend on it to carry out their daily activities [5]. Globally, energy consumption is distributed across various sectors of the economy, with transportation, industry, and the residential sector being the main consumers [6].

The lack of a reliable electricity supply has become a critical problem in Honduras. Between April 2022 and April 2024, there were 32,371 hours without electricity supply, representing an average of 4 hours per day without power for citizens and businesses [7].

Power outages and scheduled interruptions can cause significant financial losses and social disruptions in various sectors. In the industrial sector, these outages cause production delays and increase operating costs, as companies must resort to using generators.

In the commercial sector, the lack of a reliable supply impacts retail, hospitality, and services, disrupting their operations, affecting inventories and customer experience, and causing economic losses. Residential power outages affect the well-being of households, where electricity is important for heating, cooling, and food storage, thereby lowering the standard of living [5].

Given that the commercial and industrial sectors account for approximately 32% of Honduras' GDP, power outages not only reduce productivity but also increase operating costs by requiring alternative solutions, such as generators. Therefore, it is crucial to know the Cost of Energy Not Supplied (CENS), defined as the economic value that users fail to receive for each unit of energy not consumed due to power outages. Estimating this cost allows companies and users to better plan their budgets and take measures to mitigate losses associated with power outages [8],[9].

The Cost of Energy Not Supplied (CENS) is not a single value; it depends on the type of user affected, whether residential, commercial, or industrial, and the type of power outage, which can be short or long term. According to CRIE, the Cost of Short-Term Unsupplied Energy (CENSCD) represents the cost incurred by a user due to an unexpected interruption of an essential service, normally supplied through a public network, and which requires high reliability [10]. On the other hand, CRIE defines the Cost of Long-Term Unsupplied Electricity (CENSLD) as the unit cost that a user faces due to the unannounced lack of a good or service [10].

II. METHODOLOGY

This section describes the approaches and techniques used to calculate the Cost of Energy Not Supplied (CENS) in Honduras. The research adopts a quantitative, non-experimental, and descriptive approach, using techniques such as the Labor-Leisure Tradeoff Theory, income elasticity, and backup costs to estimate the economic impact of power outages in the residential, commercial, and industrial sectors.

A. Techniques

The Labor-Leisure Tradeoff Theory is the first technique used in this study and is used to calculate the Cost of Energy Not Supplied (CENS) in the residential sector. This calculation is performed using Equation 1 proposed by the Regional Electric Interconnection Commission [10], which incorporates variables such as average hourly income, peak residential demand, and hours spent on rest, domestic activities, and other activities, weighted according to their relevance. This methodology allows for estimating the economic impact of power outages on households.

$$CENS = \frac{\left(\frac{IM}{DM}\right) * [(H_{DE} * FP_{DE}) + (H_{DO} * FP_{DO}) + (H_{RE} * FP_{RE})]}{(H_{DE} * H_{DO} * H_{RE})} \quad (1)$$

Where:

- CENS = Cost of Energy Not Supplied [USD/MWh]
- IM = Average hourly income, calculated from the average monthly income, assuming an 8-hour working day [USD].
- DM = Maximum demand per residential user, expressed in MW, calculated based on annual energy consumption per residential user in MWh, the total number of residential users in the reference year, 720 hours per month, and a load factor of 0.5.
- H_{DE}, H_{DO}, H_{RE} = Represents the daily hours devoted to Rest (DE), equivalent to 8.5 hours per day, Domestic Activities (DO), with a total of 5.8 hours per day, and Other Activities (RE), which total 9.7 hours per day, such that $H_{DE} + H_{DO} + H_{RE} = 24$ hours
- $FP_{DE}, FP_{DO}, FP_{RE}$ = These are the weighting factors applied to assign value to the hours of the day, with values of 0, 1, and 0.5, respectively.

The added value in the commercial and industrial sectors is calculated using the income elasticity of electricity demand, which measures the proportional relationship between the change in electricity consumption and variations in Gross Domestic Product (GDP). Based on this elasticity and other parameters such as electricity consumption, sectoral GDP, and the electrification index, the Cost of Energy Not Supplied (CENS) in these sectors is determined by using econometric formulas proposed by the Regional Electric Interconnection Commission [10]. This approach allows for the quantification of economic losses due to power outages in terms of lost value added.

$$CENS = \frac{\Delta \text{PIB}}{\Delta \text{C}} = \frac{1}{\varepsilon} * \frac{PIB}{C} * IE\% \quad (2)$$

Where:

- ε = Income elasticity in relation to electricity consumption in the commercial or industrial sector, as applicable, for the base year.
- PIB = Gross Domestic Product of the commercial or industrial sector, as applicable, expressed in current US dollars for the base year.
- C = Electricity consumption in the commercial or industrial sector, as applicable, measured in MWh for the base year.
- $IE\% =$ National electrification index.

The elasticity presented in the Value-Added Equation is calculated using econometric models. This income elasticity (ε) represents the proportional relationship between the increase in electricity consumption (ΔC) of a product and a proportional variation in income (ΔGDP) and is calculated using Equation 3 [10].

$$\varepsilon = \frac{\left(\frac{\Delta \text{C}}{C}\right)}{\left(\frac{\Delta \text{PIB}}{PIB}\right)} \quad (3)$$

Where:

- $\varepsilon =$ Represents elasticity – income [-]
- $C =$ This is electricity consumption [MWh
- $\Delta \text{C} =$ This refers to the proportion of the increase in electricity consumption [MWh]
- $PIB =$ Gross Domestic Product [USD]
- $\Delta \text{PIB} =$ This refers to the change in Gross Domestic Product [USD]

The "backup costs" approach is used to calculate the Long-Term Cost of Energy Not Supplied (CENSLD) in the commercial and industrial sectors, estimating users' willingness to pay for self-generation of energy. This method assumes that companies will invest in backup generation equipment until the benefit of self-generating a kWh equals the loss of an unsupplied kWh. The calculations consider the number of hours of annual outages, the initial and operating costs of the generators, fuel and maintenance costs, and the useful life of the equipment as shown in Equation 4 [10]. In addition, operating and maintenance costs and the price of diesel are included. The scenario of 100 hours of annual operation is considered, with diesel generators of different capacities for each sector.

$$CENS = (E * (C_D * P_D) * t) + OM \quad (4)$$

Where:

- E = Energy Generated by Backup Equipment [MWh]
- C_D = Diesel Fuel Consumption [gal/h

- PD = Diesel Fuel Price [USD/gal]
- t = Time of Use [h]
- OM = Operating and Maintenance Costs [USD]

III. RESULTS

Table I summarizes the results obtained for the cost of short-term energy not supplied to the residential sector for the years 2021, 2022, and 2023.

TABLE I
RESULTS OBTAINED FROM THE CENSCD FOR THE RESIDENTIAL SECTOR

Residential Sector [-]	Results [USD/MWh]
CENSCD 2021	1,301.46
CENSCD 2022	1,525.2
CENSCD 2023	1,612.9

Source: Own elaboration

The results presented in Table 1 showed an increase in the cost per unit of energy not supplied from 2021 to 2023. This increase shows that, over time, power outages have a greater economic impact on the residential sector, which may be due to the following factors:

- Increase in Average Hourly Income: the average income for 2021 was 22.80 [USD] compared to the income for 2023, which was 25.82 [USD] due to the increase in the minimum wage.
- Reduction in Peak Demand: As can be seen in Figure 1, peak demand decreased slightly from 2021 to 2023. This shows that, even though users are consuming less electricity, the cost of an outage remains significant, demonstrating the dependence on electricity in residential activities.

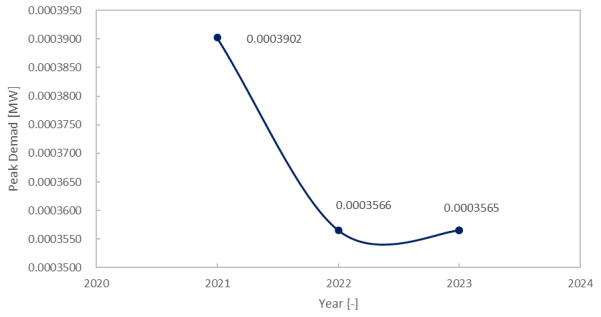

Fig. 1 Peak Demand

Source: Own elaboration with data from [11], [12], [13]

The results obtained for the calculation of the cost of energy not supplied are shown below. Table 2 shows the cost values obtained for the industrial sector for the corresponding years.

TABLE II
RESULTS OBTAINED FROM THE CENSCD FOR THE INDUSTRIAL SECTOR

Industrial Sector [-]	Results [USD/MWh]
CENSCD 2021	19,659.71
CENSCD 2022	130.83
CENSCD 2023	278.06

Source: Own elaboration

Over the three years analyzed (2021-2023), the industrial sector showed notable fluctuations in the costs of energy not supplied, with a significant reduction between 2021 and 2022, followed by a slight increase in 2023.

TABLE III
RESULTS OBTAINED FROM THE CENSCD FOR THE COMMERCIAL SECTOR

Commercial Sector [-]	Results [USD/MWh]
CENSCD 2021	375.85
CENSCD 2022	192.100
CENSCD 2023	177.95

Source: Own elaboration

The results obtained from the analysis of the Cost of Energy Not Supplied (CENSCD) in the commercial sector shown in Table 3 show a significant decrease in costs between 2021 and 2023. In 2021, the cost reached 375.85 USD/MWh (0.379 USD/kWh), while in 2022 and 2023 it fell considerably, registering 192.10 USD/MWh and 177.95 USD/MWh, respectively. This decrease reflects a reduction in the economic impact of power outages for this sector. The results obtained for the industrial and commercial sectors are shown below, which show different behavior with respect to the cost of energy not supplied, depending on the type and size of the generators used. Table 4 shows the cost values obtained for the industrial sector for the corresponding years.

TABLE IV
CENSLD RESULTS FOR THE INDUSTRIAL SECTOR

Industrial Sector [-]	Results [USD/MWh]
CENSCD 2021	1,179.01
CENSCD 2022	1,337.17
CENSCD 2023	1,244.87

Source: Own elaboration

These costs are significantly high, reflecting the sector's heavy dependence on energy to maintain production. The use of higher-capacity generators, such as 150 kW units, increases the need for fuel, especially diesel, which drives up the cost of operating this equipment. It should be noted that the results obtained independently of the sector show an increase in 2022. This is because fuel prices rose significantly in 2022 due to the war in Ukraine, which affected international energy markets.

TABLE V
CENSLD RESULTS FOR THE COMMERCIAL SECTOR

Commercial Sector [-]	Generator type	Results [USD/MWh]
CENSCD 2021	KAMA 12.5 kW	203.77
CENSCD 2022		205.57
CENSCD 2023		204.52
CENSCD 2021	GRUPEL 40 kW	385.10
CENSCD 2022		400.96

Source: Own elaboration

Table 5 shows the results obtained for the cost of long-term unsupplied energy for the commercial sector, considering the two generator capacities. In this sector, the use of lower-capacity generators, such as the 12.5 kW model, results in much lower costs compared to higher-capacity generators, such as the 40 kW model. Businesses tend to opt for smaller generators due to their purchase price and lower operating costs. However, the cost of unsupplied energy remains significant, especially when the generator must work at full capacity for long periods.

It is important to note that the difference in costs between generators of different capacities reflects the nature of each sector: the industrial sector needs more power to sustain continuous, high-volume production processes, while the commercial sector relies on smaller, more affordable solutions.

To measure the impact of the Cost of Energy Not Supplied (CENS) on the national economy of Honduras, an estimate will be made of the annual losses in dollars due to power outages by sector. To do this, the history of Energy Not Supplied (ENS) will be used in accordance with the National Statistical Report of the Electricity Sub-sector. This report categorizes unsupplied energy in two ways: that which occurs due to failures and that which occurs due to maintenance.

For the purposes of this research, unsupplied energy due to failures occurs due to an untimely interruption without prior notice, for the calculation of costs associated with short-term unsupplied energy. On the other hand, energy not supplied due to maintenance is considered for the calculation of costs associated with long-term energy not supplied, which is that which occurs when there is a warning or a scheduled outage (usually for maintenance).

Table 6 shows the estimate of energy not supplied by sector, where the total Energy Not Supplied per year has been obtained and the amount of energy that each sector has failed to receive per year has been estimated according to its percentage of consumption. Energy not supplied (ENS) shows a significant increase between 2021 and 2023, rising from 10,454.50 MWh in 2021 to 22,838.54 MWh in 2023, representing an increase of 118%.

TABLE VI
ENERGY NOT SUPPLIED DUE TO FAILURES (SHORT DURATION)

Year [-]	ENS due to malfunctions [MWh]	ENS Residential Sector [MWh]	ENS Commercial Sector [MWh]	ENS Industrial Sector [MWh]
2021	10,454.50	4,771.43	2,395.13	2,696.22
2022	16,284.96	7,181.67	4,364.37	3,908.39
2023	22,838.54	10,286.48	6,180.11	5,024.48

Source: Own elaboration

Therefore, the costs for short-term energy not supplied to the residential, commercial, and industrial sectors have been obtained. Table 7 shows the annual costs for power outages in each of these sectors.

Between 2021 and 2023, costs due to power outages increased across all sectors. In the industrial sector, costs rose from $53,006,815.81 to $1,397,106.58, reflecting a significant increase possibly due to greater energy not supplied or an increase in affected activities. The commercial sector showed an increase from $900,208.09 to $1,099,750.38, evidencing greater electrical vulnerability, while in the residential sector, costs rose from USD 1,200,448.69 to USD 1,469,630.92, although with a more moderate economic impact compared to the productive sectors.

TABLE VII
SHORT-TERM COSTS FOR ENERGY NOT SUPPLIED

Year [-]	Cost for ENS Residential Sector [USD]	Cost for ENS Commercial Sector [USD]	Cost for ENS Industrial Sector [USD]
2021	1,200,448.69	900,208.09	53,006,815.81
2022	1,359,995.44	838,395.34	511,334.72
2023	1,469,630.92	1,099,750.38	1,397,106.58
Total	***4,030,075.05***	***2,838,353.81***	***54,915,257.10***

Source: Own elaboration

As shown in Figure 2, the industrial sector accounts for 86% of total short-term energy supply interruption (ESI) costs, which are significantly higher than other sectors. This is due to the industrial sector's high dependence on production processes, where even brief interruptions can cause substantial economic losses. The commercial sector contributes 8%, indicating a lower but still significant dependence on the continuity of electricity supply for its operations. The residential sector has the lowest economic impact, accounting for only 6% of total costs. This reflects that, although interruptions affect well-being and quality of life, the direct economic impact is more moderate compared to the productive sectors.

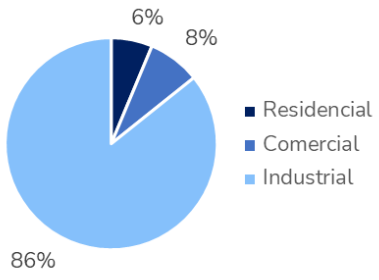

Fig. 2 Percentage of Energy Costs Not Supplied Short Duration
Source: Own elaboration

Table 8 shows the energy not supplied due to long-term maintenance in the residential, commercial, and industrial

sectors for the years 2021 to 2023. There is a sustained increase in ENS in all three sectors, with the residential sector accounting for the largest share. The ENS due to maintenance increases progressively between 2021 and 2023, with a 61% increase in the period analyzed. The residential sector contributes more than 45% of the total ENS, followed by the industrial and commercial sectors.

TABLE VIII
POWER NOT SUPPLIED DUE TO MAINTENANCE (LONG DURATION)

Year [-]	ENS due to maintenance [MWh]	ENS Residential Sector [MWh]	ENS Commercial Sector [MWh]	ENS Industrial Sector [MWh]
2021	12,384.27	5,652.18	2,837.24	3,193.90
2022	17,706.18	7,808.43	4,745.26	4,249.48
2023	19,954.88	8,987.68	5,399.79	4,390.07

Source: Own elaboration

According to Table 9, between 2021 and 2023, the costs of long-term power outages increased in all sectors. In the industrial sector (150 kW), they grew from $3,765,643.85 to $5,465,070.92, reflecting a significant impact. The commercial sector (40 kW) experienced an increase from $1,092,619.68 to $2,115,097.95, while in the commercial sector (12.5 kW), costs rose from USD 578,143.63 to USD 1,104,365.16, showing a more moderate increase compared to the higher capacity sectors.

TABLE IX
LONG-TERM COSTS FOR ENERGY NOT SUPPLIED

Year [-]	Cost for the ENS Commercial Sector 12.5 kW [USD]	Cost per ENS Commercial Sector 40 kW [USD]	Cost per ENS Industrial Sector 150 kW [USD]
2021	578,143.63	1,092,619.68	3,765,643.85
2022	975,482.33	1,902,657.94	5,682,281.45
2023	1,104,365.16	2,115,097.95	5,465,070.92
Total	***2,657,991.12***	***5,110,375.57***	***14,912,996.22***

Source: Own elaboration

As shown in Figure 3, the industrial sector (150 kW) accounts for 66% of the total cost of long-term energy not supplied (ENS), with a cumulative cost of USD 14,912,996.22. This reflects its high sensitivity to prolonged interruptions due to its dependence on continuous production processes. The commercial sector (40 kW) accounts for 23% of the total, with a cumulative cost of USD 5,110,375.57, indicating that this segment also faces a considerable impact from long-term interruptions. The commercial sector (12.5 kW) has the lowest economic impact, with a cumulative cost of USD 2,657,991.12 (12% of the total), suggesting that its impact is lower due to the nature of its operations.

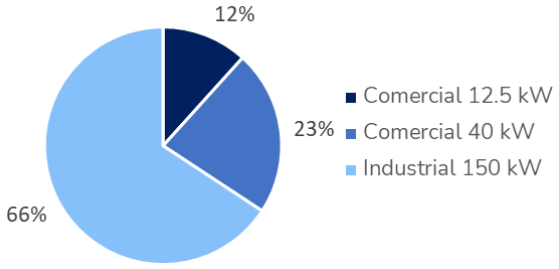

Fig. 3 Percentage of Energy Costs Not Supplied Long Term
Source: Own elaboration

IV. CONCLUSIONS

This study calculated and analyzed the cost of energy not supplied (CENS) in Honduras, using the indirect methodologies of the Regional Electric Interconnection Commission (CRIE). For the residential sector, the labor-leisure trade-off theory was applied, while for the commercial and industrial sectors, the lost value-added method and the backup costs methodology were used. Lost value added estimates the direct economic losses related to production interruptions, considering GDP and income elasticity, while backup costs analyze the expenses incurred by companies when using generators to maintain their operations during outages. An exhaustive data search was conducted to apply these methodologies, and the main findings of the research are presented.

- The results obtained for the Short-Term Cost of Energy Not Supplied (CENSCD) for the residential sector for the years 2021, 2022, and 2023 are 1,301.46 USD/MWh, 30.39 USD/kWh, 1,525.2 USD/MWh, and 1,612.9 USD/MWh, respectively. The results show a progressive increase during the period, driven mainly by the increase in average hourly income, which rose from USD 22.80 in 2021 to USD 25.82 in 2023, directly affecting the cost calculation. These values reflect the dependence on electricity supply for the well-being and daily activities of Honduran households.
- The calculation of the Cost of Short-Term Unsupplied Energy (CENSCD) for the commercial sector, using the lost value-added method, showed evidence of a progressive decrease in costs during the years analyzed. In 2021, the cost was 375.85 USD/MWh, while in 2022 it fell to 192.10 USD/MWh and in 2023 it reached 177.95 USD/MWh. These results reflect a downward trend in the economic impact of power outages in the commercial sector, possibly associated with a stabilization in energy consumption and an improved ability of the sector to adjust to supply conditions.

- The calculation of the Cost of Short-Term Energy Not Supplied (CENSCD) for the industrial sector, using the lost value-added method, showed notable fluctuations over the years analyzed. In 2021, the cost reached an exceptionally high value of $19,659.71/MWh, followed by a sharp decline to $130.83/MWh in 2022 and a moderate increase to $278.06/MWh in 2023. These variations reflect the influence of factors such as GDP performance, which directly impacts the calculation due to the relationship between economic growth and energy consumption, as well as the sector's ability to adapt to power outages.

- In this research, the Long-Term Cost of Energy Not Supplied (CENSLD) for the commercial sector, using the backup cost methodology, was calculated considering two types of generators: one of 12.5 kW and another of 40 kW. The results obtained for both types of generators show a downward trend in costs over the years. For the 12.5 kW generator, the cost was 203.77 USD/MWh in 2021, decreased to 205.57 USD/MWh in 2022, and then to 204.52 USD/MWh in 2023, showing a slight reduction in backup costs. On the other hand, for the 40 kW generator, costs were higher, starting at $385.10/MWh in 2021, increasing to $400.96/MWh in 2022, and decreasing to $391.70/MWh in 2023.
- In the case of the industrial sector, the Long-Term Cost of Energy Not Supplied (CENSLD) using the backup cost methodology showed significant variation between the years studied. In 2021, the cost reached USD 1,179.01/MWh, a high value reflecting the industrial sector's heavy dependence on higher-capacity generators. In 2022, the cost decreased to USD 1,337.17/MWh, partly due to an increase in the price of diesel fuel, which led to an increase in operating costs. In 2023, the cost decreased again to USD 1,244.87/MWh, showing stabilization in backup costs.

Despite the limitations of the research, it is believed that it will be useful for many future studies and that it will highlight the impact of electrical grid instability.

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