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DIAGNOSTIC MODEL FOR ENERGY PERFORMANCE IN THE INDUSTRY: CASE STUDY OF MICRO AND SMALL COMPANIES

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Abstract. *The Brazilian industrial sector is responsible for approximately one-third of all electricity consumption in the country. This work proposes a diagnostic model to analyze the energy consumption of industries in order to increase performance. Developing a comprehensive energy performance diagnostic model requires careful consideration of specific industry standards, regulations, and data availability. The methodology starts with data collection, followed by data preprocessing to clean and preprocess the collected data to ensure accuracy and consistency. The variables are separated by equipment, operation, regime, and analysis group. The company's data is compared against an extensive reference database that serves as an ideal benchmark. The analysis identifies the most relevant features or variables that impact energy performance. A total of 122 variables were analyzed and divided into six different groups: motors, compressed air system, equipment, lighting, air conditioning, and electrical systems. The diagnostic model was applied to 88 micro and small companies located in four different states of Brazil: Rondônia (RO), Rio Grande do Norte (RN), Goiás (GO), and Santa Catarina (SC). The main energy performance of the companies is 55.18%, while the states presented the following results of energy performance: RO 67.38%, RN 39.99%, GO 55.49%, and SC 57.88%.*

Keywords:*Energy conservation, energy efficiency, energy consumption, performance analysis*

1. INTRODUCTION

The need to comply energy consumption with increasingly stringent environmental control requirements pushed industries to ally environmental requirements to economy to maintain competitiveness. The implementation of energy efficiency strategies in companies faces many obstacles. In the European Union, 18.9% of large companies and only 4% of small and medium-sized companies have a comprehensive energy efficiency system (Cagno and Trianni, 2014). In Brazil, the large technical potential for energy conservation in energy-intensive industrial sectors estimated by Bajay *et al.* (2009) has not yet been explored (De Mello Santana and Bajay, 2016). According to the ACEEE report (2018), the country has one of the worst energy efficiency indexes among major world economies (Castro-Alvarez *et al.*, 2018). Issues related to lack of information make up a category among the important barriers for implementation of energy efficiency projects (Cagno and Trianni, 2014; Henriques and Catarino, 2016). Lack of information about consumption patterns and levels of factory efficiency measures, lack of knowledge of energy-saving opportunities, and lack of training and knowledge of technical personnel limit the exploration of such opportunities (Henriques and Catarino, 2016).

International institutions and agreements consider that efficient resource management models are fundamental elements to be developed (UN, 2015). Furthermore, the discussion about the incorporation of ESG (Environment, Social, Governance) practices in companies, to develop their awareness regarding environmental, social, and governance sustainability in front of investors, is becoming increasingly important. Energy efficiency measures are considered as a factor of environmental sustainability in ESG analyses (Boffo and Patalano, 2020), which highlights their importance in productive processes. In Brazil, the National Confederation of Industry considers such measures as a contribution of the Brazilian industry to the mechanisms of the Paris Agreement (CNI, 2019).

In this context, the present paper proposes a diagnostic model to analyze the energy consumption of industries in order to increase performance. The development of a comprehensive energy performance diagnostic model requires careful consideration of specific industry standards, regulations, and data availability.

The methodology has the overall objective of establishing an evaluation of the performance of the use of electric energy in industrial units. It is developed in a way that is based on accessible data and applicable to different sectors of industry, through the establishment of multiple performance indicators. Its application is based on filling out a data spreadsheet that will be quantitatively analyzed along with the energy bill based on its impact on overall performance.

2. METHODOLOGY

The overall evaluation methodology is presented in Figure 1.

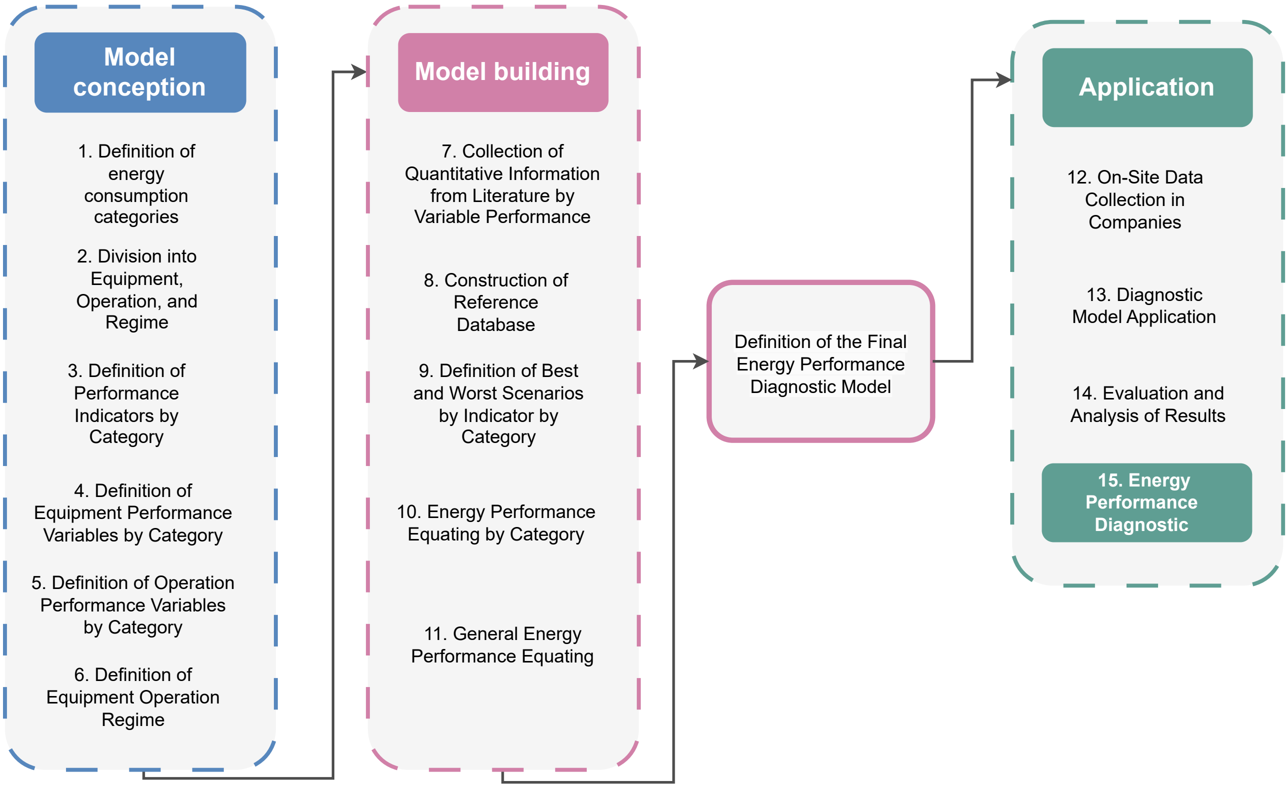

Figure 1. Flowchart: Energy Performance Assessment and Diagnostics

The process consists of three main stages, namely: model conception, model construction, and application. These stages are divided into 15 steps, which focus on energy consumption categorization, performance indicators, data collection, and energy performance diagnostics.

2.1 Model conception

In the first stage, the focus is on creating energy consumption categories and the necessary performance parameters for analysis. The diagnostic model in categories allows for the creation of indicators capable of providing sector-specific information, with the presentation of performance and energy-saving potential by area and assessment levels. This involves defining consumption categories such as motors, air conditioning, lighting, among others, and identifying the performance parameters.

The model conception stage is divided into 6 steps, as follows.

2.1.1 Step 1. Definition of Energy Consumption Categories

In Step 1, the main categories of energy consumption were identified and defined, such as electric motors, lighting, compressed air system, etc. The categories can vary according to the system or organization under analysis, and as the model is used, new categories can be added.

2.1.2 Step 2. Division into Equipment, Operation, and Regime

Analyze each energy consumption category by deconstructing it into three distinct aspects: equipment, operation, and regime. This comprehensive breakdown aims to offer a nuanced understanding of the intricacies of energy utilization. The term 'equipment' pertains to the physical apparatus involved, 'operation' explores into the specific usage patterns and practices, and 'regime' encompasses the temporal aspects, including duration and frequency of utilization within a defined period.

2.1.3 Step 3. Definition of Performance Indicators by Category

Define specific performance indicators for each category to measure energy efficiency, consumption patterns, and other relevant metrics. These performance indicators serve as measurable benchmarks that can provide valuable insights into the effectiveness and impact of each parameter.

2.1.4 Step 4. Definition of Equipment Performance Variables by Category

Identify performance variables related to the equipment within each category, such as power consumption, maintenance intervals, and efficiency ratings. It should be noted that when referring to "equipment," it specifically refers to the physical components and machinery involved.

2.1.5 Step 5. Definition of Operation Performance Variables by Category

Specify performance variables related to the operation of the equipment, such as temperature settings and control. Operation delves into specific usage patterns and practices, in other words, factors that affect its functionality.

2.1.6 Step 6. Definition of Equipment Operation Regime

Define the operating regimes for equipment within each category, including scheduling and operating hours.

2.2 Model building

In the second stage, the focus is on creating the energy diagnosis model. This involves the development of equations and mathematical modeling that relate performance parameters to consumption categories. The construction of the model is divided into five steps, starting with data collection from the literature and ending with the general formulation of energy performance (steps 7 to 11).

A set of equipment forms a category, and the set of categories represents the company's performance. If a company does not have a given category, it is not counted in the calculations.

2.2.1 Step 7. Collection of Quantitative Information from Literature by Variable Performance

Collection of quantitative data from literature, industry standards, and external sources for the performance variables identified in previous steps. Gathering quantitative data from diverse sources ensures a comprehensive and informed analysis of the performance variables.

2.2.2 Step 8. Construction of Reference Database

Create a comprehensive reference database containing the collected data, which will serve as a valuable resource for analysis and benchmarking. The reference database ensures consistency and accuracy in data analysis, as it serves as a central repository for all relevant information.

2.2.3 Step 9. Definition of Best and Worst Scenarios by Indicator by Category

Determine the best and worst-case scenarios for each performance indicator within each category to establish benchmarks for comparison. These scenarios help determine the range of variation between the best and worst possible efficiency and performance results for each variable, as well as the impact of changes on each of them.

2.2.4 Step 10. Energy Performance Equating by Category

Calculate and evaluate energy performance for each category based on collected data and benchmarks, enabling a focused analysis of each aspect. The formulated equations for each category form the foundation for calculating the final energy performance.

2.2.5 Step 11. General Energy Performance Equating and Definition of the Final Energy Performance Diagnostic Model

Calculate the overall energy performance by aggregating results from all categories and define the final energy performance diagnostic model.

2.3 Application

In the third and final stage, the developed model is applied to calculate the energy performance based on the proposed equations. The results are evaluated and used to identify opportunities for energy consumption improvement and energy performance enhancement. The application has been condensed into four steps, beginning with data collection and concluding with the energy performance result.

2.3.1 Step 12. On-Site Data Collection in Companies

To ensure comprehensive data collection on energy usage, it is recommended to conduct on-site visits to companies or facilities. These visits allow for the gathering of specific data, considering the distinct operating conditions and regime of each location. This step is crucial as it enables the collection of data based on the variables defined in the previous steps. The variables have already been categorized and delineated, providing a clear framework for data collection. It is important to gather data on an equipment-by-equipment and system-by-system basis to ensure accuracy and completeness.

2.3.2 Step 13. Diagnostic Model Application

In order to accurately assess the energy performance of the companies, the collected data is analyzed using the energy performance diagnostic model. This model, which follows the established equations, allows for a thorough evaluation of energy efficiency. The analysis is conducted at various levels, starting from individual equipment and extending to different categories. By examining the energy consumption of each piece of equipment and the overall company-wide outcome, a comprehensive understanding of the energy performance can be obtained.

2.3.3 Step 14. Evaluation and Analysis of Results

Thoroughly analyze the results obtained from applying the diagnostic model, identify areas for improvement, and provide recommendations based on the findings. The results provide a detailed analysis, both in general and individually, by category and by equipment, enabling different levels of analysis. This approach allows for a deep understanding of the energy performance, from the operation of each specific equipment to the set of equipment that forms a particular category. Additionally, the results also provide a comprehensive view of the company's overall energy performance.

2.3.4 Step 15. Energy Performance Diagnostic

This represents the final report or presentation of the energy performance diagnostic results, including insights, recommendations, and a roadmap for improving energy consumption within the organization.

These fifteen steps represent the general cycle of the energy performance categorization and diagnosis process, from the model's conception to its application for analysis and improvement. The complete flowchart outlines a systematic approach to assess and rationalize energy consumption, from initial categorization and data collection to in-depth analysis and actionable recommendations, ultimately contributing to improved energy efficiency and sustainability.

2.4 Performance Equating

The performance of a performance factor is obtained by its yield R_i compared to the yield of the best case R_m and the worst case R_p. Its result makes up the range 0% to 100%. The same equation can be used to represent the calculation of component, system and unit performance, from its best case and worst case.

$$F_i = 1 - \frac{R_m - R_i}{R_m - R_p} \tag{1}$$

The motor system, lighting and isolated air conditioning are categories composed of multiple components, being respectively the motors, the illuminated environments and the air-conditioned environments. In these cases, the performance of each component is calculated as shown in Equation 2. The performance of component i, D_i , is the result of multiplying all its n equipment performance factors and m operation performance factors established for its category.

$$D_i = 100\% \prod_n F_{i,En} \prod_m F_{i,Om} \tag{2}$$

The performance of the category composed of these components is calculated by Equation 3, where the performance of the category s, D_s , is given by the ratio between the weighted average and the energy consumption C_i of the performance of each component D_i.

$$D_s = \frac{\sum_i C_i D_i}{\sum_i C_i} \tag{3}$$

If the energy consumption category performance is calculated directly for the system as a whole, such as the centralized air conditioning or compressed air system, the s category performance, D_s, is the result of multiplying all its n equipment performance factors and m operation performance factors.

$$D_s = 100\% \prod_n F_{s,En} \prod_m F_{s,Om} \tag{4}$$

The calculation of the performance D_U of the industrial unit analyzed is presented in Equation 5, being the ratio between the weighted average and the total energy consumption C_s of the performance of each category D_s.

$$D_U = \frac{\sum_s C_s D_s}{\sum_s C_s} \tag{5}$$

3. RESULTS AND DISCUSSION

The proposed methodology for performance diagnosis evaluation was applied in 88 companies from four states of Brazil: Rondônia (RO), Rio Grande do Norte (RN), Goiás (GO), and Santa Catarina (SC). The database considers equipment inventory, operation data, and electricity bills. In total, 1496 general data were analyzed, which include information from two main segments: Agribusiness and Commercial.

The data collection spreadsheet is structured aligning with the specific categories established during the first step of the methodology. Within each of these carefully delineated categories, a comprehensive framework is provided for data collection, encompassing equipment, operation, and regime. Once the data has been successfully collected, it is seamlessly integrated into the energy diagnostic model. The categories are presented in the following list.

- Administrative Actions
- Electric Motors
- Lighting
- Insulated Air Conditioning
- Central air conditioning
- Compressed Air System
- Miscelaneous
- Electrical Systems

The amount of input data varies by categories and accounts for all components in that area. The analysis takes into account the condition of the installed equipment (equipment), the operation patterns (operation) and their contribution to the final energy consumption of the unit (regime). The result at the end of the process is the performance indicators per area and overall plant. From the indicators, the losses, performance and energy saving potential of each system evaluated are estimated.

The largest percentage of energy consumption is attributed to the 'Miscellaneous' category, as there is limited data available for Central and Isolated Air Conditioning and Motors. This indicates a substantial data deficiency for these three sectors in comparison to the well-documented 'Miscellaneous' and 'Lighting' categories. It suggests that certain types of companies may not have significant presence or consumption in these sectors. Furthermore, since these figures pertain to medium and small-sized companies, the 'Motors' sector contributes considerably less to the overall consumption when compared to the 'Miscellaneous' sector. Notably, the 'Electric Systems' column reports no data, signifying zero consumption within this category. Consequently, the most meaningful insights are derived from the initial two columns of Table 1.

Table 1. Total consumption versus Consumption by sector

	Motors	Miscelaneous	Lighting	Central Air Conditioning	Isolated Air Conditioning	Electrical System
Total Consumption	27.94%	46.84%	4.30%	4.37%	16.55%	0.00%

It is evident that lighting consumption accounts for the smallest percentage in relation to the total energy consumption. This observation is expected as lighting typically demands less energy when compared to other electronic devices. On the contrary, the 'Miscellaneous' sector constitutes nearly half of the total consumption. This sector encompasses all electronic devices, such as computers, printers, and various other equipment. As a result, it significantly contributes to the overall energy consumption, reflecting the diverse range of electronic equipment utilized.

Table 2. Data completed percentages of all companies by industry

	Motors	Miscelaneous	Lighting	Central Air Conditioning	Isolated Air Conditioning	Electrical Sytem
Total data	29.54%	94.32%	98.86%	13.41%	69.32%	0.00%

The overall performance results by state are presented in Table 3.

Table 3. Overall performance results by state

	General	Motors	Lighting	Miscelaneous	Central Air conditioning	Isolated Air Conditioning	Electrical System
RO	67.38%	46.61%	75.71%	56.97%		76.19%	68.63%
RN	39.99%		63.15%	34.57%		47.68%	
GO	55.49%	53.57%	70.38%	46.44%	72.01%		
SC	57.88%	49.44%	57.40%	72.80%	12.91%	85.68%	84.61%

Empty cells within the tables signify the absence of the corresponding sector in that particular state. Notably, the state of Rondônia (RO) emerges as the top performer, closely followed by Santa Catarina (SC), Goiás (GO), and Rio Grande do Norte (RN). These results provide a nuanced evaluation of energy consumption performance. As observed, the 'Miscellaneous' category accounts for nearly 50% of total consumption, with its performance at 34% in RN and 46% in GO, suggesting the potential for performance improvements of up to 66%.

The overall performance averages exhibit considerable variation across states. This variance may be attributed to the specific pool of companies under analysis or potentially reflects regional disparities in the adoption of more advanced and efficient technologies.

A larger number of companies should be analyzed for a conclusive result. Nevertheless, the data obtained provides a valuable overview of energy consumption trends across different states. These findings not only highlight disparities in energy performance between regions but also the improving potential that many companies can explore. As more organizations undergo such analysis, additional insights may emerge to guide the implementation of more efficient and sustainable practices.

4. CONCLUSIONS

The present paper proposed a diagnostic model for energy performance assessment in the industry. The growing concern with energy efficiency and sustainability makes this study of significant relevance, since micro and small companies play a crucial role in the economy, and improving their energy performance can bring significant benefits both to these companies and to the environment.

The model was applied in 88 Brazil micro and small companies located in four different states. The analysis considered the overall performance of each state in addition with separate analyses conducted for each sector, which included: Motors, Miscellaneous, Lighting, Central Air Conditioning, Isolated Air Conditioning, Equipment and Electrical Systems.

Sector-specific data allows for a detailed energy mapping, taking into account the energy use in each part of the company. In this way, it is possible to analyze the data at a micro level, for each sector separately, in relation to the general data that represents the complete panorama. The state with the best performance is Rondonia (RO) with 67.38%, followed by Santa Catarina (SC) with 57.88%, Goiás (GO) with 55.49%, and Rio Grande do Norte (RN) with 39.88%.

The results suggest that the scarcity of comparative data available in the literature highlights the need for a method that allows the diagnosis of energy efficiency of companies on a large scale. By implementing such a method, it would be possible to map the current situation of energy consumption by companies and, from there, guide public policies and sustainability and ESG measures. Moreover, it is important to point out that the application of such measures will not only bring environmental benefits, but can also bring financial benefits to companies, such as cost reduction and increased efficiency in energy use.

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