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SELECTION OF ENERGY EFFICIENCY PROJECTS USING TOPSIS METHOD

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ABSTRACT

Energy is essential to the society's progress, and its efficient use is necessary in an environment with finite resources. The Brazilian industrial sector demanded a third of all energy consumed in 2017, while in the United States this share was 22% of primary energy consumption. The American government invests significantly in research and development to promote energy efficiency in all sectors of the economy since the oil crisis in 1973. Energy is the most expensive input for the industry and energy efficiency measures can reduce the structural and production costs, but many projects can imply in high investments. This work classified projects of energy efficiency in order to be used in the decision-making process within the industry for resource allocation. It was used data from 97 energy efficiency projects implemented in 32 companies in the United States available on the Department of Energy website, which were ranked by the TOPSIS multi criteria decision making methodology using financial and sustainability indicators as criteria, varying the criteria weights in 9 scenarios. The final rankings obtained resulted that maintenance projects for leakage, purge traps and insulation should be the starting point independently of the weights assigned to the criteria.

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INTRODUCTION

Energy efficiency is the relation of the energy used to perform a certain activity and that available from its realization. It has been characterized as a form to solve energy costs problems and energy independence, and it provides clear beneficial solutions with high impact and often with a greater financial return than any other energy solution (BIRD, 2012). Moreover, energy efficiency reduces greenhouse gas emissions, improves energy security, affordability of energy and business competitiveness (MALLABURN and EYRE, 2014). The International Energy Agency (IEA) says that investments in energy efficiency in buildings, transportation and industrial processes can bring economic, social and environmental benefits (IEA, 2018). In addition, these investments offer returns that go beyond financial benefits for governments, for industries and individuals: they impact on reducing environmental degradation and investments in basic energy generation as well. Also, the energy security has significantly improved with the increase in energy efficiency.

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In 2017, the countries approached by IEA avoided purchasing $ 30 billion in oil importation (IEA, 2018). The Advanced Manufacturing Office (AMO), formally called Industrial Technologies Program (ITP) and implemented by the Department of Energy (DOE) of the United States, is one of the remaining American federal programs focused on meeting the technological and energy needs of the manufacturing sector in the United States (ACEEE, 2019). Basically, the AMO is divided into three areas:

- Research and Development (R&D): this area aims to develop and demonstrate new process technologies and more energy efficient materials on a laboratory scale, proving their values to industry and stimulate investment;
- Research & Development Consortia: federal funding is invested in order to bring manufacturing innovation, education and collaboration. The stakeholders (manufacturers, small businesses, universities, national laboratories, and state and local governments) pursue coordinated early-stage R&D in high-priority areas essential to energy in manufacturing;

- Technical Partnetships (TP): the goal of this area is conducting technical assistance activities that promote the use of advanced technologies, and improve energy management.

In the area of R&D, all projects have high costs, so they are selected in a competitive way and shared costs with universities to perform basic research, making possible to leverage support from the outside. AMO acts to fill the gap between the public and private sectors (DOE, 2019a). In the TP, AMO supports industries in the development and validation of practices and production technologies, the strategic management of energy, combined heat and power (CHP), aiming to increase productivity and reduce energy consumption (DOE, 2019b). In this program, small and medium companies may be eligible to receive a free evaluation provided by one of the DOE Industrial Assessment Centers (IACs) if they meet the following criteria:

- Location being less than 150 miles away from one of the participating universities;
- Annual revenue of less than $ 100 million;
- Have less than 500 employees in the plant to be evaluated;
- Sum of energy costs between $ 100,000 and $ 2,5 million, and;
- Do not have professional staff who could do the evaluation.

The IACs, located at 24 universities in the country, conduct audits in order to identify opportunities to improve productivity, reduce waste and save energy. An IAC identifies annually more than $ 130,000 in energy savings opportunities in small and medium companies evaluated, on average, with approximately $ 50,000 of this amount implemented during the first year after the audits (DOE, 2019c).

The actions of energy efficiency can imply in high investments, but there are low cost actions also. Classifying energy efficiency projects in order to be used in the process of decision making to allocate resources to energy efficiency actions is required in order to apply the Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) methodology.

The industrial sector was the third largest consumer of energy in the United States in 2017, being accountable for 21.9 quadrillion Btu, or 22%, of the primary energy consumption (EIA, 2019). Given a selection of energy efficiency actions involving some conflicting criteria, it was used the TOPSIS methodology in this paper, a multicriteria analysis to rank these actions. The rankings created took into account the preference of the decision maker, which can be driven by the costs of implementation, payback, annual financial savings generated and the amount of annual saved energy as a criterion of sustainability.

Literature Review

The main sources of energy for the industrial sector are electricity for powering motors and other electrical equipment, and natural gas for generating heat. The coal, fuel oil and diesel are generally used to heat generation, but with very little use, because natural gas is an energy source less costly and easier to transport (HAYDT, 2014). Furthermore, compressed air and steam are widely used as well. Compressed air is widely used throughout the industry, and it is often regarded as relevant in many facilities. However, it is probably the most expensive form of energy due to its low efficiency, typically 10 to 19 % (SAIDUR, 2010). Steam is practically indispensable in industries from many sectors, and it is present in practically all sectors that are energetically intensive.

Energy Efficiency: According to Patterson (1996), energy efficiency is a generic term and there is no unequivocal quantitative measure of energy efficiency. In general, energy efficiency refers to using less energy to produce the same amount of service or producing more service with the same amount of energy. Thus, energy efficiency is broadly defined by the simple reason shown in Equation 1.

$$e = \frac{E_{useful}}{E_{input}} \qquad \text{…………………(1)}$$

Where e stands for energy efficiency, E_{useful} is the useful energy of a process and E_{input} means the energy input in a process.

In the industrial sector, the savings of energy alone is not a major factor or criterion for the decision making by managers responsible for resource allocation. Therefore, the energy savings should be seen as a benefit of an energy efficiency project. What really matters to decision makers are criteria such as increasing productivity, reducing production costs, reducing waste, improving the quality of their products and maximizing profit (TRIANNI, 2014). According to the DOE (2019d), all energy efficiency projects implemented in US industries were evaluated against the following criteria: project investment implemented; annual savings generated by the implementation of the project; simple payback and energy savings. A few projects still mentioned the amount of greenhouse gas that were no longer emitted into the atmosphere.

Multi criteria decision making methods: According to Roy (1998) and Almeida (2013), the decision support methods that consider the use of two or more criteria for evaluating one or more alternatives are defined as Multi Criteria Decision Making (MCDM) methods. The goal of the MCDM methods is to provide support to the decision maker in the process of choosing between alternatives considering more than one criterion, which often can be conflicting. However, there may not be a solution that satisfies all criteria simultaneously. Thus, the solution becomes a compromise solution according to the preferences of the decision maker (GARCÍA-CASCALES, 2012). In energy planning, MCDM methods can provide solutions to complex energy management problems in order to maximize benefits and minimize costs, they also provide a better understanding of the inherent characteristics of the decision problem, which improves the quality of the decision in an explicit, rational and efficient way (POHEKAR and RAMACHANDRAN, 2004). Among several MCDM methods, the most noteworthy are the Analytic Hierarchy Process (AHP), Data Envelopment Analysis (DEA) and TOPSIS. Behzadian *et al*. (2012) shows that among several MCDM methods explored by researchers, the TOPSIS method had a significant increase in use between 2000 and 2009. Due to the simplicity of the TOPSIS methodology, and also to allow the direct use of numerical values, alternatives and criteria, it is the methodology adopted to evaluate the energy efficiency actions in the industry, since the other methodologies use comparative scales that can suffer external interferences as personal opinions.

TOPSIS methodology: Developed by Huang and Yoon (1981), TOPSIS is a simple methodology in concept and easy to apply, it is used to rank alternatives with an unrestricted number of criteria, which must have their numerical values and commensurate units. The concept of the TOPSIS methodology is that the choice of the best alternative should have the lowest possible geometric distance of the positive ideal solution (PIS) and the highest possible geometric distance of the negative ideal solution (NIS) simultaneously (ASSRI, 2012).

The first step is to define the decision matrix D, according to Figure 1. Each alternative must be in a row of the matrix and each column represent a criterion to which the alternatives will be evaluated, so that A_i denotes the alternatives to be evaluated, C_j to the criteria used in the evaluation, d_{ij} representes the numeric value of each alternative for each criteria, i stands for the alternative index (i = 1, 2, ... n) and j the criterion index (j = 1, 2, ... m).

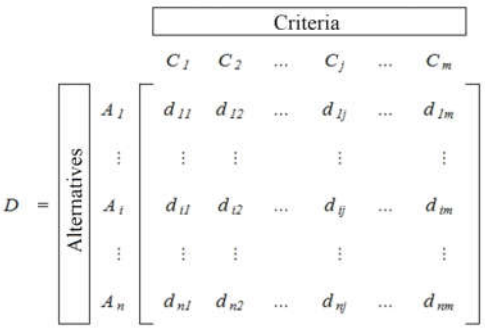

Figure 1. TOPSIS decision matrix

The definition of the vector of weights is made according to Equation 2, which is composed of weights of each criterion Cj, in order to satisfy the Equation 3.

$$W = [w_1, w_2, \dots, w_m] \quad \text{..................(2)}$$

$$\sum_{j=1}^{m} w_j = 1 \quad \text{..................(3)}$$

The next step is to apply the weight vector to the decision matrix D and, at the same time, normalize by the least squares method according to Equation 4, in order to obtain the normalized and weighted matrix N, as shown in Figure 2.

$$n_{ij} = \frac{w_j \cdot d_{ij}^2}{\sqrt{\sum_{i=1}^{n} d_{ij}^2}} \quad \text{.....................(4)}$$

$$N = \begin{bmatrix} n_{11} & n_{12} & \dots & n_{1j} & \dots & n_{1m} \\ \vdots & \vdots & & \vdots & & \vdots \\ n_{i1} & n_{i2} & \dots & n_{ij} & \dots & n_{im} \\ \vdots & \vdots & & \vdots & & \vdots \\ n_{n1} & n_{n2} & \dots & n_{nj} & \dots & n_{nm} \end{bmatrix}$$

Figure 2. Normalized and weighted matrix

Where N represents a standard decision matrix, n_{ij} the numerical value of each alternative and normalized criterion, d_{ij} the numerical value of each alternative for each criterion, i stands for the number of alternatives (i = 1, 2, ... n) and j is the number of criteria (j = 1, 2, ... m).

The PIS is the highest numerical value in each criterion, or column, if for a criterion the maximum value is sought as the best solution. The NIS is the smallest numerical value in each criterion, or column, if for that criterion the minimum value is the best solution. Then, the ideal solution – PIS, A^+ – and the ideal negative solution – NIS, A^- – are determined according to Equation 5 and Equation 6.

$$A^+ = \{n_1^+, n_j^+, \dots, n_m^+\} \quad \text{................(5)}$$

Where $n_j^+ = \{MAX\,(n_{ij})\ if\ j\ \in J\ ;\ MIN\,(n_{ij})\ if\ j\ \in J^-\}$

$$A^- = \{n_1^-, n_j^-, \dots, n_m^-\} \quad \text{................(6)}$$

Where $n_j^- = \{MIN\,(n_{ij})\ if\ j\ \in J\ ;\ MAX\,(n_{ij})\ if\ j\ \in J^-\}$

After PIS and NIS are obtained, the method calculates the distances of each alternative of the matrix N for the ideal positive – D_i^+ – and negative – D_i^- – solutions, according to Equations 7 and Equation 8, respectively.

$$D_i^+ = \sqrt{\sum_{i=1}^{n} (n_i^+ - n_{ij})^2 \text{v}} \quad \text{..................(7)}$$

$$D_i^- = \sqrt{\sum_{i=1}^{n} (n_{ij} - n_i^-)^2} \quad \text{................(8)}$$

Where D_i^+ and D_i^- mean the alternatives to be evaluated, n_{ij} the numerical value of each alternative and normalized criterion, n_i^+ the PIS and n_i^- the NIS.

Finally, the closeness coefficient (CC_i) is calculated according to Equation 9.

$$CC_i = \frac{D_i^-}{(D_i^+ + D_i^-)} \quad \text{........................(9)}$$

Then, the alternatives must be ranked in descending order according to the values. The best alternatives are those with the value closest to 1, i.e., that simultaneously is the closest to the PIS and farthest from the NIS.

MATERIALS AND METHODS

This research has applied nature with exploratory objective and quantitative approach due to modeling and simulation, and qualitative in relation to the case study. Data were collected from energy efficiency projects that were implemented in industries in the United States and published on the DOE website. Case studies of 32 companies were collected resulting in 97 projects for evaluation. These companies are mostly large manufacturing industries in the United States that were assisted by the AMO between 1994 and 2012. All data, investment values, annual savings values, payback and energy savings are real numbers of projects that have been implemented. Figure 3 shows the distribution of the 97 projects, from the 32 selected companies, in the sectors of the economy. After the data collect, the data treatment started and the energy efficiency projects were classified into maintenance or technical intervention actions, according to the following criteria:

- Maintenance according to the type of maintenance performed: traps, leaks and insulation, equipment control, equipment update, installation of ESV (electronic speed variator) in electric motors;
- Technical intervention according to the type of intervention performed: equipment update, heat recovery, installation of ESV in electric motors and Electricity generation.

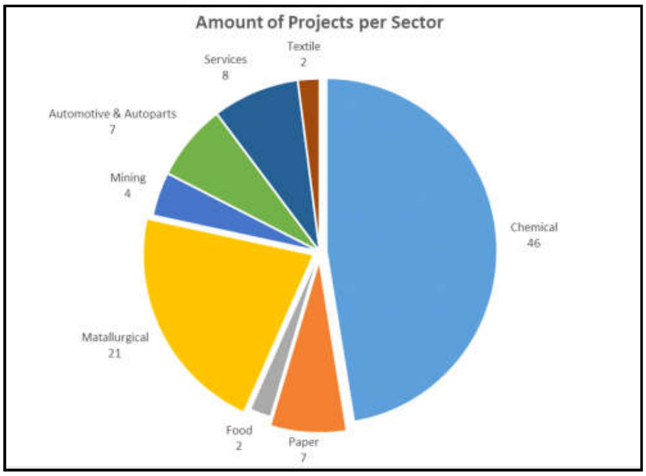

Figure 3. Distribution of projects according to the sectors of the economy

Calculation of present value of costs and annual savings: All investment and annual money savings reported in this paper were updated to the present value based on the first day of 2019, according to the inflation of the United States in the period.

Definition of the decision matrix: In order to apply the TOPSIS methodology, the projects were grouped according to the type of energy efficiency action. Each type of action represents an alternative to be evaluated in the decision matrix. Thus, the decision matrix was composed of the following alternatives, according to Table 1.

Table 1. Subdivision and abbreviation of energy efficiency projects

Energy Efficiency Projects		Abbreviation
Maintenance	Traps, Leaks and Insulation	M-TLI
Maintenance	Equipment Control	M-EC
Maintenance	Equipment Update	M-EU
Maintenance	Installation of electronic speed variator	M-ESV
Technical Intervention	Equipment Update	TI-EU
Technical Intervention	Heat recovery	TI-HR
Technical Intervention	Installation of electronic speed variator	TI-ESV
Technical Intervention	Electricity generation	TI-EG

The definition of the criteria to be adopted for the application of the TOPSIS methodology took into account two types of criteria: three financial criteria and one sustainability criterion. The three financial criteria taken into account were the sum of investment, annual saving and simple payback. As sustainability criterion the sum of energy saving was taken into consideration. Then, the criteria considered in the decision matrix are shown in Table 2.

Decision Matrix: The Table 3 shows the decision matrix with the criteria values of each alternative for the TOPSIS evaluations, from 1 to 9. These values correspond to the sum of the investment, annual savings, simple payback and energy savings for each group of projects, categorized according to Table 2.

Table 2. Criteria adopted in the decision matrix

∑ Investment	∑ Annual Savings	∑ Simple Payback	∑ Energy Savings
(USD)	(USD)	(Month)	(GJ)

Table 3. Decision Matrix

Project	∑ Investment	∑ Annual Savings	∑ Simple Payback	∑ Energy Savings
M-TLI	1,943,516.21	6,945,748.17	121	768.544
M-EC	6,374,096.37	6,835,505.23	258	574.575
M-UE	7,570,521.70	6,678,769.35	331	533,646
M-ESV	4,944,806.01	2,734,541.27	133	87,630
TI-UE	6,080,934.79	5,753,451.27	124	602,601
TI-HR	6,211,034.89	4,973,859.52	222	649,667
TI-ESV	786,287.56	482,892.77	30	13,716
TI-EG	992,347.75	307,226.08	68	11,675

Calculation of weights: Nine different combinations of weights were defined in order to evaluate the ranking behavior, according to the variation of the weights assigned to each type of criteria. The main idea was to balance the financial and sustainability criteria from 1% for each financial criteria and 97% for the sustainability one to 33% for each financial criteria and 1% for the sustainability criterion. In order to prepare the intermediate TOPSIS scenarios, from TOPSIS 2 to TOPSIS 9, a step of 4% for each financial criteria was made and the difference to 100% was assigned to the sustainability criterion. The aftermath of the weighting process is shown in the Table 4, with nine TOPSIS evaluations.

Table 4. Composition of the weights for each evaluation TOPSIS

Evaluation	∑ Investment	∑ Annual Savings	∑ Simple Payback	∑ Energy Savings
TOPSIS 1	1 %	1 %	1 %	97%
TOPSIS 2	5%	5%	5%	85%
TOPSIS 3	9%	9%	9%	73%
TOPSIS 4	13%	13%	13%	61%
TOPSIS 5	17%	17%	17%	49%
TOPSIS 6	21%	21%	21%	37%
TOPSIS 7	25%	25%	25%	25%
TOPSIS 8	29%	29%	29%	13%
TOPSIS 9	33%	33%	33%	1 %

Then, with the weight vector it could be possible to run the TOPSIS method. The results for each nine assessments are shown in Table 5.

RESULTS AND DISCUSSION

Figure 4 brings a chart of the results shown in Table 5 after applying the TOPSIS methodology for the nine weight options, applied according to Table 4. The abscissa axis indicates the variation of weights of financial criteria from 0 to 100%. The value of 0% of financial criteria indicates 100% for the criterion of sustainability. It is observed in Figure 4 that the M-TLI project group is the winner, regardless of the distribution of the weights.

Table 5. Consolidated CC_i values of the nine TOPSIS assessments

Project Type	TOPSIS 1	TOPSIS 2	TOPSIS 3	TOPSIS 4	TOPSIS 5	TOPSIS 6	TOPSIS 7	TOPSIS 8	TOPSIS 9
M-TLI	0.9964	0.9796	0.9586	0.9322	0.8997	0.8623	0.8261	0.8011	0.7928
M-EC	0.7436	0.7384	0.7221	0.6895	0.6385	0.5742	0.5109	0.4675	0.4531
M-EU	0.6894	0.6830	0.6630	0.6242	0.5661	0.497	0.4316	0.3886	0.3746
M-ESV	0.1007	0.1105	0.1375	0.1831	0.2460	0.3234	0.4060	0.4716	0.4962
TI-EU	0.7807	0.7775	0.7675	0.7464	0.7110	0.6635	0.6148	0.5811	0.5699
TI-HR	0.8426	0.8340	0.8084	0.7622	0.6954	0.6118	0.5220	0.4498	0.4222
TI-ESV	0.0144	0.0756	0.1457	0.2259	0.3165	0.4159	0.5152	0.5926	0.6220
TI-EG	0.0129	0.0693	0.1345	0.2098	0.2961	0.3918	0.4880	0.5628	0.5910

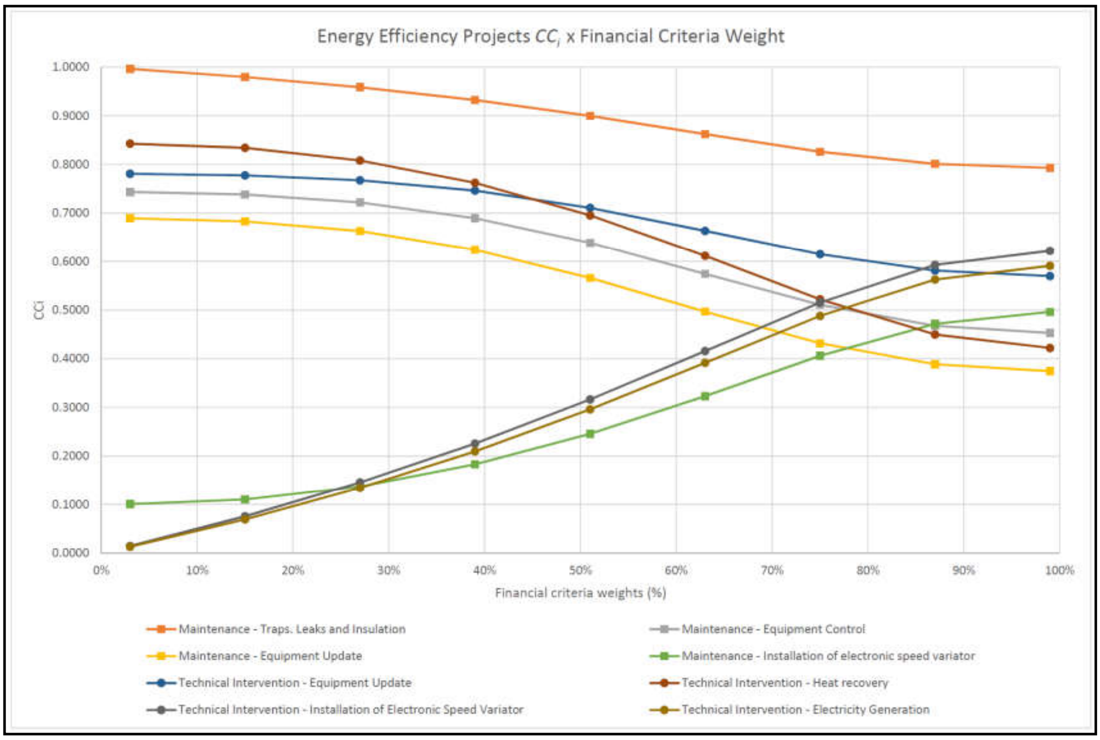

Figure 4. Classification of energy efficiency projects according to the financial criteria weights

When the weight of the financial criteria reached 27%, TOPSIS 3, a reversal in the ranking order happened, when TI-ESV outperformed M-ESV's CC_i. Another variation in the classification order occurred in 51% for financial criteria, TOPSIS 5, when TI-EU became more interesting than TI-HR. In the range of 70% of the weight for financial criteria, TOPSIS 6, there is a convergence of all groups of projects until the end of the chart, TOPSIS 9. It can be verified that, as the weights of the criteria vary, the classification order changes. This allows the decision maker to consider which criteria are the most convenient for his decision making, according to industry strategy, which can focus on reducing structural and manufacturing costs or meeting government sustainability requirements. However, it is clear that energy efficiency projects focused on M-TLI should always be the starting point, since it is the winning project group independently of the values of the weights assigned to each criterion adopted in this work.

Conclusion

The classification of the energy efficiency projects to be implemented in the industrial sector aiming to maximize the financial criteria by the decision makers is ordered as follows:

1st - Maintenance - traps, leaks and insulation;
2nd - Technical intervention - installation of electronic speed variator;
3rd - Technical intervention - electric power generation;
4th - Technical intervention - updating equipment;
5th - Maintenance - installation of electronic speed variator;
6th - Maintenance - equipment control;
7th - Technical intervention - heat recovery;
8th - Maintenance - equipment update.

The maintenance actions on traps, leaks and insulation (M-TLI) are the winners, regardless of the distribution of the weights of the financial and sustainability criteria, and these projects must be the first to be implemented by decision makers (managers in industries).

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