Energy consumption assessment supporting ISO 14001 Environmental Management Systems

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Abstract: Nowadays, changes in global environmental conditions, such as pollution and global warming, have put major challenges to governments, industries and societies which are often charged of being the sources of these problems. The growing awareness of the protection of this topic has encouraged the development of environmental management systems (EMS). This work aims to build a methodology that is able to assess energy consumption and support environmental management systems within a research centre certified according ISO 14001 Norms. Four types of energy consumption have been selected and a critical index has been associated to each activity in order to define a ranking with respect to the energy impact.

Keywords: energy consumption; environmental management systems (EMS); ISO 14001; Eco-management Audit Scheme (EMAS)

1. Introduction

Adoption of environmental management systems (EMS) constitutes one of the most important elements of corporate sustainability in recent years (Gianni et. al, 2017; Oliveira et. al, 2016). An EMS is part of the organizational management system used to design, implement and manage environmental policy. It includes interdependent elements, such as organization structure, sharing of responsibilities and planning of practices, procedures and resources needed to determine and achieve the referred to policy and its objectives (de Oliveira et al., 2010). Businesses today face not only market competitions but also new regulatory environment. The main environmental regulations are in energy and water consumption, greenhouse gas emissions, hazardous materials, and the disposal of waste. In compliance with these laws and regulations, companies must create environmental management systems to monitor their daily operations (Chou and Chou, 2012).

Besides social responsibility and the creation of conditions to comply with legislation in effect, these systems permit identifying opportunities to reduce material and energy consumption, as well as improve process efficiency (Chan and Wong, 2006). A survey of the literature revealed that the establishment of an environmental management system by adopting the ISO 14000 standards led to clean or green operations, such as waste minimization or elimination or reduction in energy consumption (Tan, 2005).

Although the ISO 14001 standard does not imply the establishment of precise indicators, it does require that organizations supervise and measure their environmental performance on a regular basis (Boiral et.al., 2018). Therefore, one might assume that ISO 14001 certification tends to encourage the consideration of different environmental performance indicators such as the use of energy and water, atmospheric emissions, regulatory compliance, etc. (Boiral and Henri, 2012). On the same line, Castka and Prajogo (2013) assumed that operational benefits by adopting international environmental standard include improvements in environmental issues. These improvements concern the reduction of pollution or energy consumption and it is expected that firms will generate better improvements if the standards' requirements were adopted rigorously.

2. EMS and ISO 14001

The first environmental management standard, BS7750, was prepared in 1992. In 1993, the Eco-management Audit Scheme (EMAS), prepared by the European Union, started to be applied. Following the BS7750 and EMAS, various countries developed their own EMS (Kein et al., 1999). Later, ISO 14001 environmental management system standard was introduced in 1996. In this sense, two EMS standards, i.e. EMAS and ISO 14001, have been available in Europe for the last 25 years where, according to Neugebauer (2012), ISO 14001 is often applied as a response to external pressure while EMAS tends to be motivated internally. In addition, it is argued that EMAS and ISO 14001 are likely in a situation of direct competition at present which may well turn into complementarity in the future.

ISO 14001 provides guidelines allowing firms or organizations to design and implement an Environmental Management System (EMS) that identifies the organization's environmental policy, the environmental aspects of its operations, legal and other requirements, a set of clearly defined objectives and targets for environmental improvement and a set of environmental management programs (Jackson, 1997). The ISO 14001 is a set of guidelines by which a facility can establish or strengthen its environmental policy, identify environmental aspects of its operations, define environmental objectives and targets, implement a program to attain environmental performance goals, monitor and measure effectiveness, correct deficiencies and problems and review its management systems to promote continuous improvement (Weaver, 1996). More in general, the whole ISO 14000 family provides management tools for organizations to control their environmental aspects and to improve their environmental performance. Together, these tools can provide significant tangible economic benefits, including: reduced raw material/resource use; reduced energy consumption; improved process efficiency; reduced waste generation and disposal costs, and utilization of recoverable resources.

EMSs based on ISO 14001 were developed to evaluate and improve the environmental behavior of organizations, thus establishing measurement, evaluation and monitoring processes for all relevant environmental aspects. Most of these environmental aspects, when imported to the management system, are translated to metrological requisites, that is, they are defined as quantitative variables that need to be measured to evaluate their compliance by comparing those measurements with the specifications previously established for the requisites (Beltrán et al., 2010).

In analyzing certified EMS, Zobel (2013) analyzed environmental data referred to six different areas, i.e. air emissions, water emissions, resource use, energy use, waste and overall environmental performance while Castka and Prajogo (2013) measured environmental benefits using three measurement items: reduced pollution, reduced energy and material consumptions, and reduced risks of environmental hazards.

MacDonald (2005) proposed a strategic sustainable development model in ISO 14001 by (i) describing inputs of energy and materials (solid, liquid, gas) into the organization and their origins, (ii) drawing a systems map of the organization detailing process energy and material inputs and (iii) preparing a list of identified environmental aspects based on energy and material inputs and outputs. The aim was to provide a clear understanding (i) of all materials and energy entering the organization and their origins, (ii) of the origin and destination of critical flows of energy and materials in the organization and their relationship to the ecosphere and (iii) a list of all environmental aspects associated with the organization's operations.

Several case studies of ISO 14001 certified companies have shown that implementation of the standard has helped reduce environmental impacts, including the volume of waste generated, water and energy consumption, and atmospheric emissions (Boiral and Henri, 2012). Radonjic and Tominc (2007) identified a relationship between ISO 14001 and improvement of working staff safety and reduction in emissions and energy consumption in the metal sector.

More in general, for standardized EMS to be environmentally effective tools, they should affect important environmental aspects related to flows of materials and energy, which for manufacturing companies are closely connected to their products

(Ammenberg and Sundin, 2005). EMS, according to the standard ISO14001, concentrate on environmental aspects and in some cases include energy issues. In the ISO 14001 requirements for EMS, the procedure is regulated according to the Deming control cycle (plan-do-check-act) (Ates and Durakbasa, 2012).

3. Research methodology and approach

3.1 Methodology

The work is aimed to design an approach for energy consumption assessment in the framework of ISO 14001 regulation. Such approach can be integrated into EMS to define and classify (or rank) a set of energy-consumption activities in the firm to be handled to achieve environmental sustainability.
The research methodology is built according to the following points:

- A set of environmental aspects strictly related to energy field are selected according to ISO 14000 standards; energy consumption is particularly stressed along the proposed methodology where a deepened analysis of all possible sources of energy consumption related to company activities is performed. Power and fuel consumption are two examples of indicators referred to energy consumption in accordance with guidelines coming from international regulations.
- A set of representative company activities according to processes identified in the ISO14000 certification, are selected for the further energy assessment; these actions imply an energy consumption and are monitored evaluating their impact toward environmental sustainability according to some selected drivers of the methodology.
- Company activities are connected to the respective energy consumption typology through a vectoral graph. Each connection is characterized by four drivers:
    - (i) legislation compliance - LC,
    - (ii) impact entity – IE based on detectability, dangerousness and importance,
    - (iii) control degree – CD according to type of control and reaction capability,
    - (iv) territorial sensitivity – TS considering territorial context and claims frequency.

  The four drivers define a four components vector {LC, IE, CD, TS} associated to a given activity generating an energy consumption typology.
- According to the four drivers, the energy assessment is performed through the evaluation of the environmental impact of each activity. In this way, a criticality order can be assigned to the company activities according to their energy consumption typology and overall impact suggested by the selected drivers.

Figure 1 summarizes the research methodology.

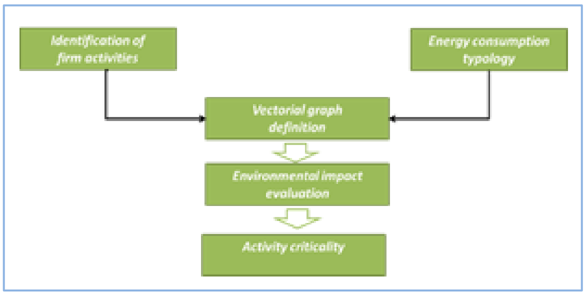

Figure 1. Research methodology

3.2 Approach

The approach for energy assessment of firm activities is based on the vector graph. This graph (Figure 2) connects each firm activity to one or more energy consumption typologies generated by the given activity. In details, on the left of the graph a first level with M firm activities is presented while on the right-hand N energy consumption typologies are shown. An arch links the company activity with the generated energy consumption typology when applicable; as an example, company activity #1 of Figure 2 is linked to the first and third energy typology.

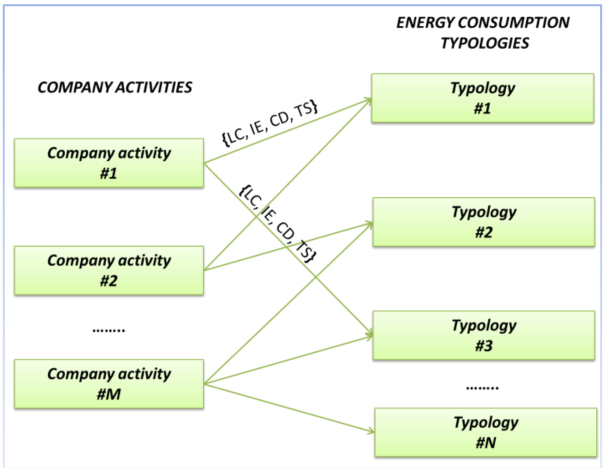

Figure 2. Vector Graph

A four components vector characterizes each activity through the four drivers which are shown in more details:

- Legislation Compliance (LC) defines the compliance of the activity to regulations and norms of environmental sector with respect to predefined boundaries. It can assume five values: 0 in case of a lack of regulation boundaries, 1 in case of a full compliance (strong boundaries satisfaction), 2 in case of a good compliance, 3 in case of a marginal compliance and 4 in case of un-compliance.

- Impact Entity (IE) is based on the following three parameters:
  - (i) Severity of the impact -C,
  - (ii) Dangerousness -D
  - (iii) Degree of Detectability -DD.

  C assumes the following values according to some conditions related to consistency: 1 - negligible, 2 – low, 3 – medium, 4 – high.
  D is the dangerousness toward environment and health assuming values: 1 – no dangerousness, 2 – dangerous, 3 – very dangerous, 4 – extremely dangerous.
  Finally, DD can assume values 1 in case of immediate and simple detectability, 2 in case of detectability performed by proper instruments, 3 in case of detectability through bio-chemical analysis and 4 in case of impossible detectability.
  The value IE is obtained by the average of these three parameters.

- CD, Control Degree, is the average of two contributions: (i.) Control Typology –CT and (ii.) Reaction Ability –RA.
  CT can assume the following values: 0 if a complete procedure is foreseen, 1 if a non-standardized procedure is foreseen, 2 if a partial procedure is foreseen, 3 if there is a lack of procedure.
  RA measures the ability of the company to front an impact: it can assume value 1 for a good ability, 2 for a sufficient ability, 3 for a poor ability, 4 for an insufficient ability.

- Territorial Sensitivity (TS), measures the operating context of the company evaluated as the maximum between (i.) Territorial Context – TC, and (ii.) Claims Frequency (CF).
  TC is equal to 1 for high sensitivity of the context, 2 for medium sensitivity, 3 for low sensitivity and 4 for lack of sensitivity. CF is equal to 1 for a lack of claims, 2 for isolated claims, 3 for periodic claims, 4 for continuous claims.

To each activity, a set from 1 to N vectors can be associated in accordance to the generated energy consumption typology. As an example, Table 1 reports the values for activity #1.

Energy Consumption	***LC***	***IE***	***CD***	***TS***
Typology #1	LC_1	IE_1	CD_1	TS_1
Typology #3	LC_2	IE_2	CD_2	TS_2

Table 1 – Example for Company Activity #1

To classify activities according to their criticality, an index (CI) can be associated through the assigned values. Each column can be synthetized through normalized values of LC, IE, CD and TS (respectively labeled as $\overline{LC}$, $\overline{IE}$, $\overline{CD}$ *and* $\overline{TS}$) obtained by summing values of the column and dividing for the maximum values with respect to the number of rows R, i.e. the energy typologies used to carry out that activity:

$$\overline{LC} = \frac{\sum_{i=1}^{R} LC_i}{R * \max[0,4]} \quad \varepsilon\ [0,1] \quad (1)$$

$$\overline{IE} = \frac{\sum_{i=1}^{R} IE_i}{R * \max[0,4]} \quad \varepsilon\ [0,1] \quad (2)$$

$$\overline{CD} = \frac{\sum_{i=1}^{R} CD_i}{R * \max[0{,}3.5]} \ \varepsilon\ [0{,}1] \quad (3)$$

$$\overline{TS} = \frac{\sum_{i=1}^{R} TS_i}{R * \max[0{,}4]} \ \varepsilon\ [0{,}1] \quad (4)$$

Normalization allows to get the four parameters in the same range, each with the same weight in the Criticality Index calculation (eq. 6).

As an example, with reference to Table 1, since each LC can take on values in the range [0,4], R=2, $\overline{LC}$ is

$$\overline{LC} = \frac{LC_1 + LC_2}{2 \times 4} \qquad (5)$$

For each activity, criticality index CI_1 and CI_2 are evaluated as in (6) and (7):

$$CI_1 = \mathrm{R} * \ \mathrm{mean}\ (\overline{LC} + \overline{IE} + \overline{CD} + \overline{TS}\,) \quad (6)$$

$$CI_2 = \max\ (\overline{LC} + \overline{IE} + \overline{CD} + \overline{TS}\,) \quad (7)$$

CI_1 can assume values in the range [0,R] where 0 indicates low criticality while R indicates high criticality in terms of energy consumption. In this sense, by ordering activities for decreasing values of CI_1, it is possible to focus and highlight critical ones requiring possible corrective actions for impact reduction.

CI_2 is used to compare activity with same value of CI_1; activity with higher value of CI_2 is considered more critical because it has a peak of consumption in one of the types of energy involved for its realization.

Application case and results

The approach for energy assessment has been tested in a chemical laboratory of a genetic research center. For simplicity, two main activities of the company are reported and assessed: (1) animal breeding and (2) laboratory activities. Referring to energy consumption typology, the following sources are considered: (i) power consumption, (ii) gas consumption, (iii) fuel consumption, (iv) methane consumption. Figure 3 shows the application scenario.

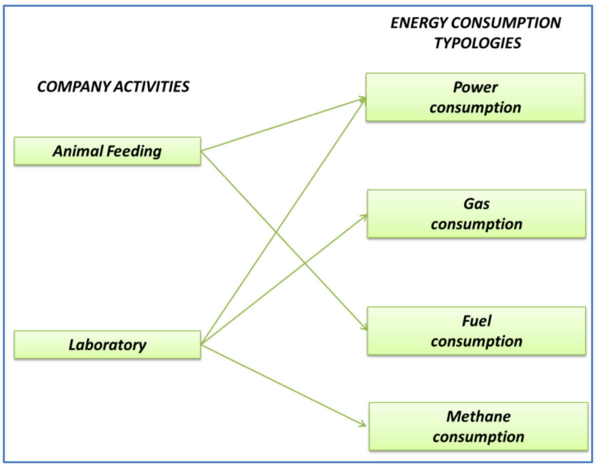

Figure 3

Animal feeding is responsible of power and fuel consumption for its activities while laboratory activities generates power consumption, gas consumption and methane consumption. For the definition of the four components vector associated to each activity, values of Tables 2a and 2b are considered.

Activity: Animal Feeding					
Energy Consumption	***LC***	***IE***	***CD***	***TS***	***Mean Max***
Power consumption	2	2.5	1	2	1.87 2.5
Fuel consumption	1	2.9	2.5	2	2.1 2.9
R=2	$\overline{LC} = 0.38$	$\overline{IE} = 0.68$	$\overline{CD} = 0.5$	$\overline{TS} = 0.5$	
	$CI_1 = 2 * mean(0.38; 0.68; 0.50; 0.50) = 1.03$ $CI_2 = max(0.38; 0.55; 0.50; 0.50) = 0.55$				

Activity: Laboratory					
Energy Consumption	***LC***	***IE***	***CD***	***TS***	***Mean Max***
Power consumption	2	2.2	1	2	1.8 2.2
Gas consumption	1	1.4	1	1	1.1 1.4
Methane consumption	1	1	1	1	1 1
R=3	$\overline{LC} = 0.33$	$\overline{IE} = 0.38$	$\overline{CD} = 0.29$	$\overline{TS} = 0{,}33$	
	$CI_1 = 3 * mean(0.33; 0.38; 0.29; 0.33) = 0.99$ $CI_2 = max(0.33; 0.38; 0.29; 0.33) = 0.38$				

Table 2a and 2b

According to the values, it is possible to associate the criticality indexes CI_1 and CI_2 to each activity indicating a priority between several actions to reduce overall energy consumption. With respect to the application case, to animal feeding is associated the higher value of CI_1 despite it is involved in two typologies of energy consumption instead of three as for the laboratory activity. The high value of CI_2 still recommends investigating why it indicates a peak in one of the drivers associated with the typologies of energy used.

Finally, the direction of intervention for the typologies of energy involved in the activity is given by the mean/max of each row of Table 2a and 2b; in the case of animal feeding, the energy typology with higher average among the 4 driver is Fuel Consumption (2.1). The maximum among the 4 drivers is evaluated as a secondary choice criterion for rows with the same average.

4. Conclusions

The approach described in this work has been tested in an application case represented by a genetic research center where four energy consumption typologies have been selected for the present case. The assessment has been able to classify activities providing an overall state about their energy specifications and requirements.
The method has its strong point in the ease of application, which allows to obtain a rapid comparison between the activities to quickly identify the causes of the criticality. In addition, this type of assessment lends itself to being evolved through the insertion of weighted indices in the equations, which can take into account the environmental context and the energy profile of the company, and to be implemented through software that suggests the best intervention strategy to the user.
Further improvements of the work can be aimed to reduce the subjectivity of values assignment composing the four drivers. This can be done by using fuzzy values through the application of fuzzy set theory and fuzzy techniques where an inference engine is able to provide the criticality index to each activity for a fairer energy assessment.

The possibility of extending the proposed calculation methodology to other environmental aspects not strictly related to energy consumption, such as emissions or the production of waste, must also be considered.

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