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A Structured Method for Energy Performance Evaluation within ISO 14001 Environmental Management Systems

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Abstract

Environmental management systems based on ISO 14001 require organizations to monitor and control the main environmental aspects associated with their activities. Among these aspects, energy consumption represents a relevant factor affecting both environmental performance and operational efficiency. However, in many certified organizations the evaluation of energy consumption is still based on fragmented indicators that do not allow a clear prioritization of improvement actions. This work proposes a structured approach for the assessment of energy consumption within an Environmental Management System to support monitoring and control activities. The methodology is based on the identification of representative company activities and on the classification of the related energy consumption typologies. The relationships between activities and energy sources are represented through a vector-based structure and evaluated using four drivers: legislation compliance, impact entity, control degree and territorial sensitivity. Based on these drivers, a Criticality Index (CI) is calculated in order to rank activities according to their relevance in terms of energy impact and management priority. The methodology has been applied to a research laboratory operating under ISO 14001 certification, where four main energy consumption typologies have been considered. Results show that the proposed framework supports the identification of critical activities and facilitates the organization of information required during internal and external environmental audits.

Keywords
Environmental management systems; ISO 14001; energy consumption; environmental performance; audit support.

1. Introduction

In recent years, environmental sustainability has become an important element in organizational management and industrial decision-making processes. Companies are required to control their environmental impacts not only to comply with regulations but also to improve operational efficiency and corporate image. In this context, Environmental Management Systems (EMS) represent one of the most adopted tools to structure environmental policies and to monitor environmental performance over time.

An Environmental Management System can be defined as an integrated set of procedures and practices aimed at identifying, monitoring and reducing the environmental impacts generated by company activities. The ISO 14001 standard provides a reference framework for the implementation of such systems by defining requirements related to environmental policy, planning of objectives, operational control and performance monitoring. Through this structure, organizations are required to identify significant environmental aspects and to establish suitable monitoring and control procedures.

The adoption of an EMS is often driven by regulatory pressure and by the need to demonstrate compliance with environmental legislation. Current regulations increasingly focus on energy consumption, emissions, waste management and use of natural resources. For this reason, organizations are required to implement monitoring systems able to provide reliable information on environmental performance and to support corrective and preventive actions. In addition to compliance aspects, EMS implementation allows companies to identify opportunities for improving efficiency and reducing resource consumption.

Several studies have shown that ISO 14001 implementation can contribute to the reduction of environmental impacts and to a more rational use of resources in both industrial and service contexts. Improvements in energy efficiency and reductions in waste generation are among the most common benefits reported in the literature. These results are generally achieved when the environmental management system is effectively integrated into operational activities and not implemented only for certification purposes.

Despite its relevance, ISO 14001 does not define specific quantitative indicators for environmental performance evaluation. Organizations are therefore required to define internal monitoring criteria and to select appropriate indicators for the evaluation of environmental aspects. This flexibility allows adaptation to different operational contexts but may also lead to heterogeneous evaluation practices and difficulties in comparing results over time. For this reason, structured methodologies able to support the identification and evaluation of environmental aspects are needed.

Among the environmental variables monitored within an EMS, energy consumption represents a key aspect. Energy use is directly connected to operational activities and has relevant implications in terms of environmental impact, operating costs and regulatory compliance. Nevertheless, the evaluation of energy consumption is often based on aggregated indicators that do not provide detailed information on the contribution of single activities. This limitation may reduce the effectiveness of improvement actions and complicate audit phases, where detailed and structured information is required.

From an audit perspective, both internal and external verification processes require the availability of organized data related to environmental aspects and control measures. A clear identification of critical activities and of the related environmental impacts facilitates audit procedures and supports the demonstration of system effectiveness. In this sense, methodologies able to classify and prioritize energy-related activities can support both environmental management and audit activities. However, existing EMS monitoring practices often rely on aggregated energy indicators that do not provide a structured prioritization of activities or a transparent link between operational processes and energy-related impacts.

Starting from these considerations, this work proposes a structured approach for the evaluation of energy consumption within organizations operating under ISO 14001 Environmental Management Systems. The objective is to support environmental managers in identifying critical activities, defining monitoring priorities and facilitating audit and review phases through a transparent and replicable assessment procedure. The proposed methodology introduces a set of evaluation drivers and a criticality index able to provide an overall representation of the energy impact associated with company activities.

2. Literature Review

The diffusion of Environmental Management Systems in Europe was initially supported by both national and international initiatives. The British standard BS 7750 (1992) is generally considered one of the first structured references for EMS implementation, while the Eco-Management and Audit Scheme (EMAS) was introduced by the European Union in the early 1990s to promote verified environmental performance and transparency. Starting from these experiences, several countries developed their own EMS-oriented schemes, and the International Organization for Standardization later consolidated the main requirements through the publication of ISO 14001, first issued in 1996 and subsequently revised. In practical terms, ISO 14001 became the most widely adopted certifiable EMS model, while EMAS has often been adopted in contexts characterized by strong internal motivation and higher transparency requirements (Neugebauer, 2012).

The current reference version, ISO 14001:2015, defines the requirements for an Environmental Management System that can be integrated into organizational processes and aimed at improving environmental performance through planning, operational control and monitoring activities (ISO, 2015). Compared to previous versions, the 2015 revision introduced elements such as risk-based thinking, life-cycle perspective and stronger involvement of top management. Organizations are required to identify significant environmental aspects and to translate them into operational controls and measurable elements. For this reason, the EMS should not be limited to a documentary system but must be connected with daily activities and decision processes.

ISO 14001 is generally interpreted as a management framework supporting the identification of environmental aspects and compliance obligations, the definition of objectives and targets, operational control and performance monitoring through continuous improvement cycles. Early contributions described ISO 14001 mainly as a tool for formalizing environmental policy and responsibilities, while more recent studies emphasize that the effectiveness of certification depends on how the system is implemented and internalized within the organization. Empirical evidence shows that ISO 14001 adoption can be associated with improvements in environmental and, in some cases, economic performance, although results may vary according to company size and external pressures (Arocena et al., 2021).

A relevant issue in EMS literature concerns the definition and measurement of environmental performance. Since ISO 14001 does not prescribe specific indicators, organizations are required to define their own monitoring criteria. As a consequence, performance evaluation often relies on organization-specific indicators, leading to heterogeneous practices. Recent studies highlight that environmental performance is a multidimensional concept including operational, environmental and organizational aspects, and that the selection of indicators may influence the effectiveness of the system (Johnstone, 2020). This aspect is particularly relevant for energy consumption, where aggregated indicators may not allow the identification of critical activities and where more structured monitoring systems can improve internal control (Marrucci et al., 2023).

Additional guidance on environmental performance evaluation is provided by ISO 14031, which supports the definition and use of environmental performance indicators and structured evaluation procedures (ISO, 2021). Although not certifiable, this standard provides useful indications for the selection of indicators and for the organization of reliable environmental information, especially when energy consumption must be monitored across different activities.

From an audit perspective, performance evaluation and documentation management are strictly connected to the structure of the Environmental Management System. In ISO-based systems, audits are not limited to compliance verification but are aimed at evaluating the effectiveness and implementation of procedures. ISO 19011:2018 provides guidelines for the management of audit programmes and for the execution of internal and external audits (ISO, 2018). Audit effectiveness depends on the availability of organized information, traceable records and a clear link between environmental aspects, controls and performance indicators.

Recent contributions underline that certification and audit processes may also support the development of internal control tools and structured monitoring practices. In particular, the certification process often leads organizations to formalize environmental management control systems and to integrate monitoring activities into routine operations (Johnstone, 2022). A structured approach to energy performance evaluation can therefore support both EMS implementation and audit activities by improving traceability of information and facilitating evidence collection.

Based on the literature, two main considerations motivate the present work. First, the effectiveness of ISO 14001 is strongly related to the way environmental performance is monitored and evaluated. Second, audit and certification activities benefit from structured prioritization criteria and reliable measurement systems, particularly when energy consumption represents a significant environmental aspect. However, existing approaches mainly rely on general environmental performance indicators and do not provide a structured method to prioritize energy-related activities within an Environmental Management System. This gap highlights the need for operational tools capable of linking energy consumption sources to organizational activities and supporting monitoring and audit processes in a systematic way.

3. Methods

The work aims to define a structured approach for the assessment of energy consumption within the framework of ISO 14001 Environmental Management Systems. The proposed methodology is conceived as a supporting tool for environmental managers to monitor energy-related aspects and to identify the most critical activities requiring control and improvement actions.

The approach can be integrated into an existing Environmental Management System in order to evaluate the energy consumption associated with company activities and to support decision-making during monitoring and audit phases. The objective is to provide a clear representation of how different activities contribute to energy use and environmental impact, allowing the organization to define priorities for intervention.

The research methodology is developed according to the following steps.
First, a set of environmental aspects strictly related to the energy field is identified. Particular attention is devoted to the analysis of the main sources of energy consumption associated with organizational activities. Electrical power and fuel consumption are considered as representative indicators, in accordance with the main requirements of international environmental standards and energy monitoring practices. This phase allows the identification of the most relevant energy consumption typologies to be monitored within the Environmental Management System.

Second, a set of representative company activities is selected for the assessment. Each activity is characterized by a specific energy demand and contributes, in different ways, to the overall environmental impact of the organization. The selected activities are analyzed with respect to their relevance in terms of energy consumption and environmental sustainability. This step allows the definition of the system boundaries and ensures that the assessment focuses on the most significant operational processes.

Third, company activities are connected to the corresponding energy consumption typologies through a vectorial representation. The relationship between activities and energy use is not limited to quantitative consumption values but is evaluated through a set of drivers describing regulatory, environmental and operational aspects. Each connection between activity and energy consumption typology is characterized by four drivers:

- legislation compliance (LC);
- impact entity (IE);
- control degree (CD);
- territorial sensitivity (TS).

These four drivers define a four-position vector {LC, IE, CD, TS} associated with each activity and with the related energy consumption typology. This representation allows a structured evaluation of the environmental relevance of each activity.

Finally, the overall energy assessment is performed by combining the four drivers and by evaluating the criticality associated with each activity. Based on the obtained values, company activities can be ranked according to their energy impact and environmental relevance. The ranking supports the identification of priorities for monitoring and improvement actions within the Environmental Management System and facilitates the organization of information required during internal and external audits.

Figure 1 summarizes the overall research methodology and shows the sequence from the identification of energy aspects to the definition of the criticality index.

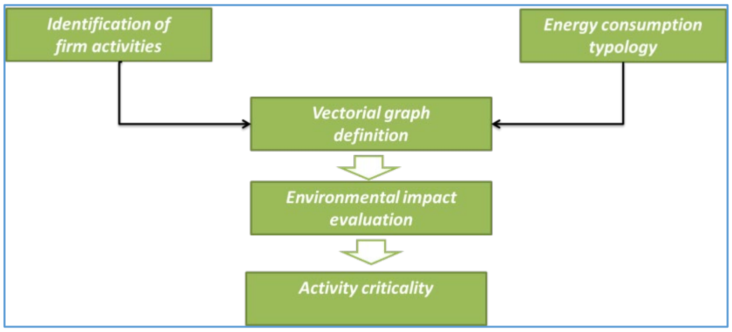

Figure 1. Research Methodology

3.1. Approach for energy consumption assessment

The proposed approach for energy assessment is based on a vectorial graph able to represent the relationships between company activities and the different typologies of energy consumption generated within the organization.

The vectorial graph connects each company activity to one or more energy consumption typologies associated with that activity. On the left side of the graph a first level including M company activities is represented, while on the right side N energy consumption typologies are reported. A link between an activity and an energy typology is defined whenever the activity generates or requires that specific form of energy. In this way, each activity can be associated with one or more energy consumption typologies according to its operational characteristics.

Figure 2 illustrates the structure of the vectorial graph and the connections between activities and energy consumption typologies.

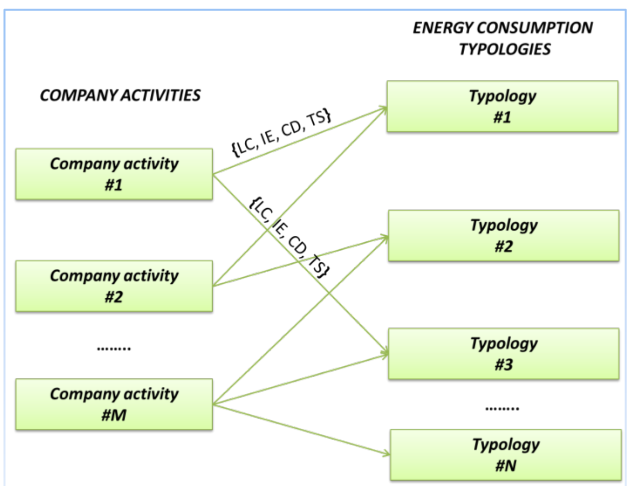

Figure 2. Vector Graph

Each activity is characterized by a four-position evaluation vector based on the following drivers.

Legislation Compliance (LC)

The LC parameter evaluates the level of compliance of the activity with environmental regulations and internal procedures. It expresses how the activity satisfies the applicable requirements and can assume values from 0 to 4:

0 – absence of specific regulatory boundaries;
1 – full compliance;
2 – good compliance;
3 – marginal compliance;
4 – non-compliance.

This parameter allows consideration of the regulatory relevance of each activity within the Environmental Management System.

Impact Entity (IE)

The impact entity evaluates the environmental relevance of the activity and is determined as the average of three parameters:

- consistency of the impact (C);
- dangerousness (D);
- degree of detectability (DD).

Consistency expresses the magnitude of the impact and can assume values from 1 (negligible) to 4 (high). Dangerousness evaluates potential effects on environment and health and varies from 1 (no dangerousness) to 4 (extremely dangerous).
Detectability measures the difficulty in identifying the impact and assumes values from 1 (immediate detectability) to 4 (impossible detectability).
The IE value is obtained as the average of these three parameters.

Control Degree (CD)

The control degree evaluates the capability of the organization to monitor and manage the environmental impact associated with the activity. It is calculated as the average of:

- control typology (CT);
- reaction ability (RA).

CT evaluates the presence and completeness of operational procedures:
0 – complete procedure available;
1 – non-standardized procedure;
2 – partial procedure;
3 – absence of procedure.
RA measures the organizational capability to react to environmental impacts:
1 – good ability;
2 – sufficient ability;
3 – poor ability;
4 – insufficient ability.

Territorial Sensitivity (TS)

Territorial sensitivity evaluates the operating context of the organization and is defined as the maximum between:

- territorial context (TC);
- claims frequency (CF).

TC expresses environmental sensitivity of the area (1 high – 4 low).
CF represents the frequency of claims or complaints related to environmental aspects (1 none – 4 continuous).
For each activity, one or more vectors can be associated according to the number of generated energy consumption typologies. The normalized value of each driver is calculated according to the following expression:

$$\bar{X} = \frac{1}{n \cdot X_{max}} \sum_{i=1}^{n} X_i$$

where:

- X represents the considered driver (LC, IE, CD or TS)
- X_i is the value associated with the i-th energy consumption typology
- X_{max} is the maximum possible value of the driver
- n is the number of energy consumption typologies associated with the activity.

This normalization allows the drivers to assume dimensionless values in the range [0,1], enabling their aggregation in the overall criticality index.

For example, if an activity is associated with two energy consumption typologies and the LC values are equal to 2 and 1, the normalized value is calculated as:

$$\bar{LC} = \frac{2 + 1}{2 \cdot 4} = 0.375$$

where 4 represents the maximum value of the LC parameter.

Table 1 shows an example related to a generic activity connected to two energy consumption typologies.

Table 1. Example for Company 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

To classify activities according to their relevance, a criticality index (CI) is defined. For each activity, dimensionless values of LC, IE, CD and TS are calculated by normalizing the respective parameters with respect to their maximum possible values and to the number of associated energy typologies.

The overall criticality index is obtained by summing the normalized values:

$$CI = L\overline{C} + I\overline{E} + C\overline{D} + T\overline{S}$$

In this formulation, all drivers are considered with equal weight in order to provide a balanced evaluation of regulatory, environmental and operational aspects. The CI assumes values in the range **[0,4]**, where low values indicate limited criticality and high values correspond to activities characterized by higher energy and environmental impact. The CI therefore represents a synthetic indicator summarizing the overall relevance of each activity in terms of energy consumption and environmental impact.

By ordering activities according to decreasing CI values, it is possible to identify priority areas for intervention and to support improvement actions aimed at reducing energy consumption and environmental impact. This evaluation provides a clear representation of energy-related aspects within the Environmental Management System and supports the preparation of documentation required during environmental audits.

4. Case study

The proposed methodology has been applied within a genetic research center operating under an Environmental Management System compliant with ISO 14001 requirements. The objective of the application is to verify the capability of the approach to support the identification and prioritization of activities characterized by relevant energy consumption.

The analysis has been conducted within a chemical and biological laboratory where several activities require continuous use of electrical equipment and utilities. To simplify the presentation of the case study while maintaining its representativeness, two main activities have been selected for the assessment:

(i) animal breeding and feeding;
(ii) laboratory activities.
These activities are representative of the operational processes generating the most relevant energy consumption within the organization.
With reference to energy consumption typologies, four main sources have been considered:

- electrical power consumption;
- gas consumption;

- fuel consumption;
- methane consumption.

Each activity is associated with one or more of these energy sources according to its operational characteristics. Animal breeding and feeding activities mainly involve electrical power and fuel consumption, while laboratory activities are characterized by electrical power, gas and methane consumption.

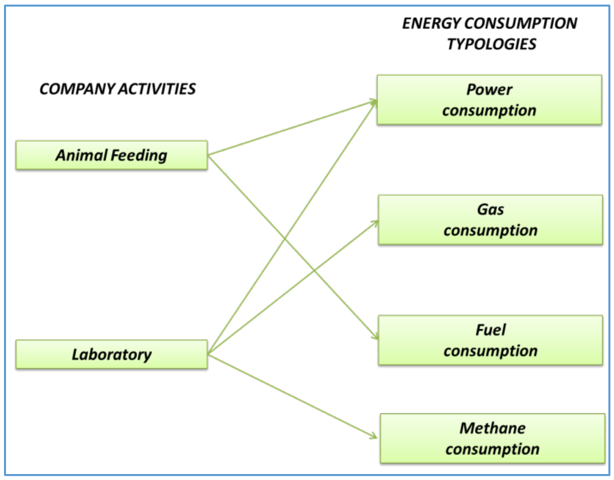

Figure 3. Application Scenario

The application scenario and the relationship between activities and energy consumption typologies are summarized in Figure 3. The representation highlights how each activity contributes to one or more forms of energy consumption within the organization.

For each activity and for each associated energy consumption typology, the four evaluation drivers previously introduced (LC, IE, CD and TS) have been assigned. The values have been defined on the basis of internal procedures, environmental documentation and operational characteristics of the analyzed processes. The obtained values have then been used to calculate the normalized parameters and the corresponding criticality index for each activity. The assessment was conducted using internal environmental documentation, operational procedures and monitoring records available within the Environmental Management System.

5. Results and Discussion

The results of the assessment allow the calculation of the criticality index associated with each analyzed activity. The index provides a synthetic representation of the relevance of each activity with respect to energy consumption and related environmental aspects. Animal breeding and feeding activities generate both electrical power and fuel consumption. The evaluation of the four drivers for each energy typology leads to the values reported in Table 2.

Table 2. Animal feeding

Activity: Animal Feeding			
Energy Consumption	*LC*	*IE*	*CD*
Power consumption	2	2.5	1
Fuel consumption	1	1.9	2.5
	$\overline{LC} = 0.38$	$\overline{IE} = 0.55$	$\overline{CD} = 0.5$
	$CI = \overline{LC} + \overline{IE} + \overline{CD} + \overline{TS} = 1.93$		

This value indicates a relatively high level of criticality associated with the activity, mainly due to the combined effect of environmental impact and control-related aspects.

Laboratory activities involve multiple energy consumption typologies, including electrical power, gas and methane. The same evaluation procedure has been applied to determine the normalized parameters and the overall criticality index (Table 3).

Table 3. Laboratory

Activity: Laboratory			
Energy Consumption	***LC***	***IE***	***CD***
Power consumption	2	2.2	1
Gas consumption	1	1.4	1
Methane consumption	1	1	1
	$\overline{LC} = 0.33$	$\overline{IE} = 0.38$	$\overline{CD} = 0.29$
	$CI = \overline{LC} + \overline{IE} + \overline{CD} + \overline{TS} = 1.34$		

The comparison between the two activities highlights that animal breeding and feeding shows a higher criticality index than laboratory activities, despite being associated with a lower number of energy consumption typologies (Figure 4).

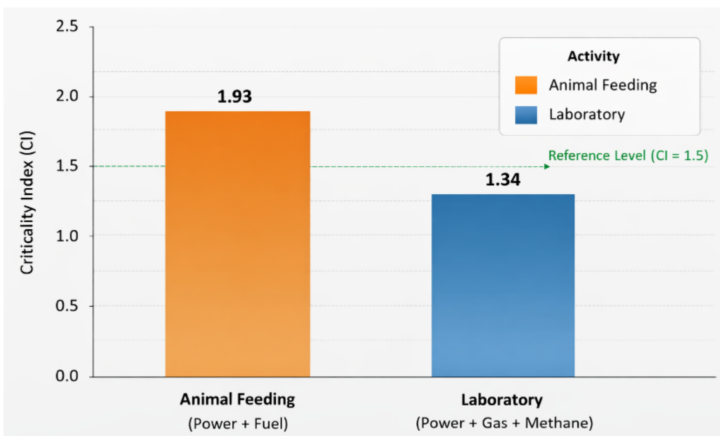

Figure 4. Comparison of Criticality Index values for analyzed activities

This result indicates that the relevance of an activity in terms of energy impact is not only related to the number of energy sources involved but also to regulatory aspects, impact entity and control capability.

The ranking obtained through the proposed index supports the identification of priority areas for intervention within the Environmental Management System. Activities characterized by higher criticality values can be considered for targeted monitoring and improvement actions aimed at reducing energy consumption and environmental impact.

From a management perspective, the methodology provides a structured evaluation framework that can support both internal monitoring and audit phases. The availability of a synthetic index and clearly defined evaluation drivers facilitates the organization of environmental documentation required during verification activities.

In comparison with traditional Environmental Management System monitoring practices, which often rely on aggregated energy indicators, the proposed framework provides a more structured representation of the relationship between operational activities and energy consumption sources. The use of the Criticality Index allows organizations to prioritize monitoring and improvement actions based on multiple evaluation drivers rather than relying only on absolute consumption values. This structured representation may facilitate environmental audits by providing traceable information linking activities, environmental impacts and control measures.

6. Conclusion

This work proposes a structured approach for the assessment of energy consumption within organizations operating under ISO 14001 Environmental Management Systems. The methodology is intended to support environmental managers in monitoring energy-related aspects and in identifying the most relevant activities with respect to environmental impact and regulatory compliance.

The approach is based on the definition of four evaluation drivers: legislation compliance, impact entity, control degree and territorial sensitivity, used to characterize each activity in relation to the corresponding energy consumption typologies. Through a vectorial representation, company activities are connected to the different forms of energy consumption generated within the organization. The evaluation is completed by calculating a criticality index that allows the ranking of activities according to their relevance in terms of energy impact.

The application of the methodology to a research laboratory within a genetic research center has shown its capability to provide a clear classification of activities. The results highlight how the proposed index can support the identification of priority areas for intervention and provide a synthetic representation of the energy profile of the organization. Even in a simplified application scenario, the approach allows comparison between different activities and supports decision-making related to monitoring and improvement actions.

From an operational perspective, the availability of a structured evaluation framework contributes to improving the organization of environmental information and facilitates both internal and external audit activities. The definition of evaluation drivers and of the related criticality index provides traceable elements for the assessment of environmental aspects and supports the demonstration of the effectiveness of the Environmental Management System.

Further developments of the work may be oriented toward the reduction of subjectivity in the assignment of values to the evaluation drivers. Future research may explore the use of fuzzy logic or multi-criteria decision methods in order to provide a more robust evaluation of environmental criticality and to strengthen the integration between energy monitoring tools and environmental management systems.

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Biographies

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