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Energy management: A practice-based assessment model

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HIGHLIGHTS:

- A model based on practices for industrial energy management assessment is provided.
- A novel energy management practice definition and characterisation is offered.
- Attributes of energy management practices drive assessment of energy management.
- Benchmarking energy management practices facilitates assessment.
- Mapping energy management practices highlights companies' strengths and weaknesses.

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ABSTRACT

Industrial energy efficiency is crucial for energy cost saving and sustainable competitiveness, but its potential is not exploited due to several barriers. Previous literature has pointed out that, among the most effective means, energy management in industrial companies could bring a valuable contribution. Therefore, it is crucial to assess and evaluate the energy management status in an organisation so to undertake the most appropriate improvement actions. So far, literature has neither described the fundamental characteristics of energy management practices, nor specifically developed an assessment model to support industrial decision-makers. Stemming from those research gaps, the present work presents and discusses an innovative energy management assessment model based on a novel characterization of energy management practices. We validated and applied the model through case studies among large Italian and Swedish manufacturing companies, both proving the model to be able to thoroughly describe the energy management status and benchmarking the adoption level of energy management practices with respect to specific baselines. The model highlights both strengths and critical areas in an industrial company's energy management, thus offering a valuable support to drive further improvement activities. The work concludes with interesting suggestions for industrial decision-makers and policy-makers, sketching also some further research avenues.

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Abstract

Industrial energy efficiency is crucial for energy cost saving and sustainable competitiveness, but its potential is not exploited due to several barriers. Previous literature has pointed out that, among the most effective means, energy management in industrial companies could bring a valuable contribution. Therefore, it is crucial to assess and evaluate the energy management status in an organisation so to undertake the most appropriate improvement actions. So far, literature has neither described the fundamental characteristics of energy management practices, nor specifically developed an assessment model to support industrial decision-makers. Stemming from those research gaps, the present work presents and discusses an innovative energy management assessment model based on a novel characterization of energy management practices. We validated and applied the model through case studies among large Italian and Swedish manufacturing companies, both proving the model to be able to thoroughly describe the energy management status and benchmarking the adoption level of energy management practices with respect to specific baselines. The model highlights both strengths and critical areas in an industrial company's energy management, thus offering a valuable support to drive further improvement activities. The work concludes with interesting suggestions for industrial decision-makers and policy-makers, sketching also some further research avenues.

Keywords:

Energy management; energy efficiency; energy management practices; practices characterization; assessment model; industry.

List of Abbreviations:

EEM – Energy Efficiency Measure
EM – Energy Management
EMP – Energy Management Practice
EMS – Energy Management Systems
GHG – Green House Gases
SMEs – Small- and Medium-sized Enterprises

1. INTRODUCTION

The future energy trends [1], represents a serious threat for the environment [2], and could lead to multiple issues in terms of energy security [1]. In this turbulent scenario, the industrial sector plays a very critical role, accounting worldwide for 54% of the total delivered energy [1] and for more than 30% of GHG emissions [2-3].

According to recent studies [2,4], energy efficiency is recognized as the best solution implying multiple benefits [5], being crucial not only in terms of energy cost saving, but also for a more sustainable competitiveness [4,6]. Nevertheless, its full potential remains unexploited leading to an ''*energy efficiency gap''* [7], which entails a low implementation rate of energy efficiency measures (EEMs), e.g., [8-9], due to several barriers [10]. Barriers have been widely discussed in several literature contributions, both theoretical, e.g., [11], and empirical, e.g., [12]. Their presence calls for the promotion of so-called drivers for industrial energy efficiency [13-14]. Regarding this matter, literature has mainly concentrated on empirical studies, e.g., [15-16].

The energy efficiency gap has historically been discussed with primary relevance over technological issues and appliances e.g., [17], but it consists of behavioural issues as well [18]. This was introduced by scholars [19] as the concept of "*extended energy efficiency gap*", inferring that the gap consists of both a technological and a managerial component. Thus, energy efficiency investments in new technologies must be accompanied by the promotion of good energy management (EM) through the adoption of energy management practices (EMPs) [19]. Nevertheless, albeit the EM potential has been highlighted several times in literature [20], its contribution differs depending on company-specific characteristics such as the size, energy intensity and production type (see, e.g., [19]). Furthermore, for industrial applications, there is a large untapped market potential called "*energy-service gap"* due to the high transaction costs [21], although energy services represent a promising market-based solution for improved energy efficiency [22].

Notwithstanding EMPs and energy services are recognized as crucial solutions, little effort has been paid in characterizing them [23] and an assessment model to support industrial decision-makers highlighting specific actions for improved EM is lacking. In this regard, it is important to note that EMPs differ in various types to be taken into account, as studies have noted [18], according to the multidisciplinary nature of EM [24] and the complexity of industrial energy systems [25]. Stemming from those research gaps, the present work aims at developing an innovative model for assessing industrial EM, relying on a novel characterization of EMPs. According to the above-mentioned purpose, the model would benefit industrial decision-makers by highlighting improvement opportunities in their EM activity, stakeholders in the energy efficiency supply chain for supporting companies and policy makers for addressing more effectively EM in the regulations. The paper is delimited to focus on large manufacturing enterprises.

The remainder of the work is structured as follows. In Section 2 we discuss a thorough literature review highlighting the gaps addressed by the novel model presented in Section 3. Section 4 deals with the model validation, whilst Section 5 discusses an application in an industrial company, where we also critically evaluate the model's and practices characterization's innovativeness. Lastly, Section 6 presents the conclusions, limitations and suggestions for further research.

2. LITERATURE BACKGROUND

The review of existing models about EM assessment, EMPs and approaches for their characterisation followed the methodology summarized in Table 1. Conceptual or theoretical studies are the most common methods for EM and energy services, whilst EMPs are mostly investigated through empirical studies. However, we noted a lower attention towards EMPs and their characterization. Finally, regarding applications, the largest part of the studies covers medium- and large-sized enterprises (MLEs) in energy-intensive sectors, with a particular focus in Sweden.

<< Table 1 >>

The following section presents models for the assessment of EM (Section 2.1), the various approaches to EM (Section 2.2), and the need for a novel model (Section 2.3).

2.1. Models for the assessment of energy management

Regarding research proposing models for assessing EM, four research streams are discerned (summarised in Table 2): Minimum requirements, Maturity models, EM matrixes, and EEMs characterization framework. The proposed models differ in terms of approach, objectives, perspective and level of detail. The first stream regards a basic attempt for evaluating EM [26-27], limiting the analysis to verify whether a company practices EM or not, without any metrics for assessing each requirement. The ISO 50001 standard is also included in the first stream, as it mainly provides general guidelines for implementing an energy management system (EMS), without critically assessing e.g. a company's effectiveness of undertaking a specific EMP [28].

The second stream assumes a systemic perspective, focusing on EM maturity models assessing an organization's ability to manage energy [29], e.g. an analysis of the maturity level of required steps to establish an EMS [30]. However, only a few studies [31-32] describe the maturity stages of practices at activity level.

The third stream is focused on EM matrixes, e.g. [33-34], which share various commonalities with maturity models: (i) high standpoint of analysis; (ii) concept of maturity translated into a level of sophistication; and, (iii) self-assessment approach based on the company's perception. Therefore, these models do not provide any additional benefit in terms of approach and elements considered for the analysis. Nonetheless, previous studies [33,35] bring an advancement by proposing assessment models that take into account a detailed list of activities considered as EMPs, but neither of them defines the critical factors on which the evaluation is based.

In the fourth research stream the characteristics of EEMs are explored, e.g. [36-37]. Fleiter, Hirzel and Worrell [37] provide a thorough description of characterization of EEMs, which facilitates the understanding of adoption process of EEMs, and Trianni, Cagno and De Donatis [37] designed a framework that to some extent could be exploited for EMPs. However, critical factors for obtaining a comprehensive overview of EM activities are not characterized.

Thus, while research studies have emphasized the importance of adopting EMPs within an organization (e.g. [38-39], the concept of EMPs are yet to be thoroughly defined. Thus, there is a need for an in-depth understanding of the fundamental characteristics of EMPs to analyse and objectively evaluate the EM activities. This boils down to a research gap addressed in this work: a model that specifically addresses the challenges of assessing EM in the industrial sector with an operational perspective.

<< Table 2 >>

2.2. The Energy Management concept

To develop an EM assessment model, a definition of EM is necessary. The definitions found in the literature have been categorized into four main clusters (Table 3).

<< Table 3 >>

The first two clusters offer a limited view as no additional insight regarding the managerial activity nor for the organizational aspects of EM is given. The first cluster regards a specific focus on the activities linked with the energy supply, conversion and use, however without linking how energy is managed with respect to other resources (e.g. [42]). The second cluster provides a pure strategic vision of EM. Here, the perspective is focused on the company's energy strategy, thus beyond the operations (e.g. [43]). The third cluster points out a comprehensive concept of EM, recognizing EM as "*multidisciplinary in nature*" [24] and as a systematic process integrated into the organization that has to be reviewed periodically [33-34], interestingly showing the link between technical as well as managerial capabilities. Lastly, the fourth group points out the crucial role of people in EM, thus highlighting the connection with behavioural aspects of managing technologies during operations (e.g. [25]).

The definition proposed by Schulze, Nehler, Ottosson & Thollander [25] is the most comprehensive, as it includes all the essential EM elements and formalizes the idea that EM is composed of EMPs (as also suggested by other scholars [23]), which in turn confirms the need to adopt an operational perspective for the assessment.

However, a clear definition of EMP is lacking. Caffal [20] argues that the EMP is a "*relevant saving without capital or with limited investment*", and other scholars that it is an equipment replacement and energy saving calculation [34]. Other studies [18,23] take a more systemic approach where including both technical and managerial elements in EMPs, and also put emphasis on the need of a continuous or very frequent adoption of EMPs. However, the broad range of EMPs has yet to be thoroughly formalized and described, and confusion of the term with other terms might arise, such as e.g., EEMs, programs, organizational decisions and favourable contextual factors [44-45]. Therefore, in addition to the need for an EM assessment model, there is a lack of a precise and consolidated EMP definition. Moreover, considering the definition of energy service [46] and the activities recognized as EMPs in the literature, an energy service could be either an EMP performed for the customer or a specific support service offered to the customer. In other words, there is also a lack of an integrative view of energy services adopted by a company within the broader set of EMPs.

To the authors' knowledge, the EM strategies of previous scholars [23,47] are the only frameworks so far presented in the literature organising the EMPs based on the strategies to which they belong. Nonetheless, it cannot be recognized as a characterization framework since it does not define any fundamental feature to consider. On the other side, regarding energy services, it is possible to appreciate three contributions, summarized in Table 4. Firstly, Sorrell [48] defines the role of the energy services in terms of *scope* and *depth* with respect to the internal EM. However, the model is limited to the analysis of energy service contracts with a customer-perspective. Other scholars [49] built their model upon Sorrell [48] by taking into account a product-service system perspective, but is quite market-oriented and therefore out of scope for the present work. Finally, Kindström & Ottosson [50] proposed a model more focused on the type of energy services, mixing the contract perspective with that of industrial adoption, highlighting relevant features like the energy efficiency potential and the type of impact on the customer. Yet, also, in this case, none of the previous studies offers a comprehensive view over the topic.

<< Table 4 >>

The lack of a comprehensive set of critical elements is arguably ascribable to the lack of an inclusive theoretical study due to the attention to other research objectives. In general, the empirical approach used for exploratory purposes is preferred instead of a clear focus on the identification and description of the concept. Moreover, scholars [25,51] note a lack of attention to the industrial application for energy services, further calling for the identification and definition of major features to thoroughly conceptualize and describe the EMPs and energy services, as well as their implementation and operational aspects.

2.3. Need for a novel assessment model for energy management in industrial companies

The literature background suggests key points highlighting the need for a novel assessment model and representing its foundations. Firstly, it must adopt an operational perspective to address the challenges of assessing EM in the industrial sector. In this way, it considers EMPs as the basic element for the analysis of the EM activity. To better understand EM activity, characterization of EMPs is important [23]. Due to the absence of a definition of the EMP concept, it is fundamental to clearly define the EMP concept, which additionally must account for its not-yet addressed relation with energy services. Furthermore, in order to support the new definition, a reference list of the most important EMPs debated in literature is created to represent both a guideline in using the model, as well as further clarifying and avoiding the misuse of the term. Lastly, according to the highlighted issue regarding the evaluation system, it is necessary to formalize the key attributes required for defining and characterizing an EMP.

3. Energy Management Assessment model

3.1. A novel definition of Energy Management Practice

The definition is based on the fact that EMPs are the components of EM [23,25]. Hence, their fundamental elements should be consistent with the EM characteristics, given that, as aforementioned, EMP may substantially differ. Subsequently, since EM affects the company's energy efficiency performance in different ways and targets different stakeholders [27], the practices should be characterized on where and how they improve the energy efficiency performance, as previous research suggests [23]. Lastly, following this rationale, each EMP belongs to a specific element of the generic EM setting in industrial companies [27]. Along with the fundamental elements, taking inspiration by previous work [27], an EMP could be considered either as a technique, a method, a procedure, a routine, or a rule that a company applies in order to improve its energy efficiency performance. Finally, it is essential to consider the relationship with energy services. The managerial activity to adopt a pure service should be considered as an additional specific type of EMP, because we are referring to services not limited to EM, rather supporting the internal technical and managerial processes in general. Instead, when considering an EMP offered as energy service by a third party, it falls under the list of aforementioned activities.

The points above discussed lead to a novel definition of EMP, as follows:

"*an energy management practice is a technique, method, procedure, routine or rule adopted at a precise stage of the industrial energy management setting in order to achieve the company's energy efficiency objectives. It acts on technological, non-technological, or of support aspects, by improving the energy performance directly or indirectly in a specific area of the company*."

3.2. Attributes of Energy Management Practices

In order to shape the EM assessment model, we need to point out the attributes to define and properly characterize EMPs, so to offer a complete and detailed picture of EM in industrial companies (Table 5). First, some attributes are particularly relevant for defining an EMP:

- *type of EM practice*, representing the aspects on which the practice acts (i.e. *technology-related*, *non-technology-related* or *support*) in accordance to the multidisciplinary nature of EM [20];
- *type of energy efficiency improvement,* defining how the practice impacts the energy flow, similarly to what proposed by Kindström & Ottosson [50] for the effect of energy services on customers;
- *target of the EMP*, indicating the stakeholders/processes targeted by the practice [23]; and,
- *position in the industrial EM setting*, linking the practice to an element of the industrial EM setting [27].

Table 5 shows also ten key attributes that help characterize EMPs, in accordance to the specific purpose of performing an assessment of the EMPs' adoption in industrial companies. We have purposely selected the attributes, among the broad range of variables and relationships worthy of consideration (e.g., production, safety, maintenance), based on the interesting perspective for the analysis offered by each of them. First, the *development stage*, revising the maturity concept of EMPs [31] in order to define the stage reached in the EMP's lifecycle. Nonetheless, it is worth noting the difference from analysing the maturity level, since it does neither address organizational capabilities nor details of the practice; rather, it gives an indication of the company's experience and level of progress. Second, the *method of adoption* perspective, modelling the company's methodology for the practice adoption with the following axes:

- the *sourcing strategy*, specifying whether an EMP or service is adopted internally or outsourced;
- the *degree of criticality for the operations*, considering the practice's impact on the company's operation, offering an additional indication to the *target of the EMP* axis to be evaluated along with the *sourcing strategy*; and,
- the *frequency of adoption*, as hinted in previous definitions [18,23], which affects significantly the required managerial effort.

Third, the *extent of adoption,* since it is possible to infer that an EMP might influence one or more technologies, a single process or the whole company, for one day or several years. Therefore, this perspective is defined in terms of:

- the *technological scope*, which defines the number and type of machines or fixtures involved;
- the *organizational scope*, which defines the portion of the organization encompassed; and,
- the *temporal scope*, which defines the practice's lifetime that depends on its nature as well as the short or long-term company's EM approach.

Fourth, the *organizational involvement* perspective, investigating important roles (i.e. *decision-maker*, *responsible/supervisor*, *user*) in the adoption of EMPs, given the relevance of the organizational aspects for this phase (e.g., [26]). This perspective allows to evaluate specific organizational elements for the success of EMPs highlighted in literature, such as: energy manager position in the organizational structure (e.g., [12], top management commitment (e.g., 43] or hierarchical proximity of the decision maker to the CEO [51], employees involvement [52,53] and cross-functional energy teams [34,54].

<< Table 5 >>

3.3. EMPs benchmarking baselines

Following the novel definition and characterization of EMPs, it is essential to offer a tool for evaluating the adoption of EMPs with respect to benchmarking baselines. For this purpose, an extensive collection of the proposed set of EMPs and energy services from the literature has been performed, integrating scientific and industrial literature, also considering the valuable support of the US DOE Industrial Assessment Center Database (IAC), so to create a benchmarking tool. The resulted reference list of 58 EMPs is reported in Table 6.

<< Table 6 >>

Regarding benchmarking, by considering additional specific literature contributions, we designed a four-level practice-specific baseline. Starting from the reference list and the four major axes detailed above, the baseline defines the minimum requirements identifying the progressive performance levels of EM. Compared to the maturity models, e.g. [31], such practice-specific baseline has three main advantages. First, it gives focus on the practice rather than on an EM process, which is essential in order to take specific corrective actions. Second, it focuses on practice's characteristics (i.e. how the practice should be implemented) rather than on the required organizational capabilities (i.e. what the company should do in general). Third, it is apparent that a company should not necessarily act in a predefined way when it comes to specific EMPs: a one-size-fits-all approach is inappropriate [27], and several company-specific information and contextual factors regarding EM must be taken into account [19]. Hence, the main advantage of an optimality threshold is offering a relative concept, rather than being a fixed level of a predetermined maturity scale, and thus the final result is relative to the specific case. Therefore, as shown in Table 7 for the practice "Measurement of energy use", we defined different benchmarking levels with respect to previous literature, also taking inspiration from other research [72]. Table 8 reports the proposed baselines for the 58 analysed EMPs.

<< Table 7 >>

<< Table 8 >>

4. MODEL VALIDATION

The model has been validated for the analytic concept generalization [81] and to demonstrate the framework's potential to assess EM. To do so, the process is structured with a theoretical validation (phase i), followed by an on-field validation (phase ii).

Basing on scientific and industrial literature contributions, phase (i) aims at testing the attributes of the model and showing its potential to describe the reference list of EMPs. Subsequently, basing on an on-field validation conducted through a multiple case study, phase (ii) aims at critically discussing with industrial managers each framework's element to evaluate them on a set of indicators. During the validation, we critically discussed with industrial managers the novel definition of an EMP, the attributes defining and characterizing EMPs, as well as the rationale behind the benchmarking baselines and the attributes. Furthermore, interviewees tried to apply the novel model to well-known practices. Each interview, overall, took between 1.5 and 2.5 hours, plus about 1 hour for the collection of secondary data (e.g., from company website).

For what concerns the on-field validation (i.e. phase (ii)), the research is carried out as an analysis of single case studies, since the three conditions defined by Yin [81] for the adoption of the method are met and the contingency factors assume a high relevance, not aiming to do a comparative analysis among cases. Furthermore, the validation is based on a qualitative approach; hence, the cases studied are investigated through semi-structured interview, which allows the necessary flexibility, and are adapted in case of a single interview [82].

4.1. Theoretical validation

The validation phase is focused on the capability of the model to characterize EMPs. In fact, the validation is accomplished through an in-depth revision of the literature references linked to each EMP focused on the detailed information regarding the practice.

Regarding the attributes' definition, for the first three axes (*type of EMP*, *type of energy efficiency improvement* and *target of the EMP*), the description of each axis is exploited in order to organize the findings from the literature. Whereas, regarding the axis *position in the industrial EM setting*, the allocation is based on the description of each EM element provided by previous literature [25].

This phase offers a theoretical definition of the reference list of EMPs based on the model as reported in Table 9. As this trial validation demonstrates, firstly, the model can classify the reference EMPs according to the four axes defined; and, secondly, it could be scaled according to a different detail of the information provided.

<< Table 9 >>

4.2. On-field validation

Companies have been selected by looking at two primary criteria: the company size and the presence of a manager with energy-related responsibilities. The former is required to ensure the relevance of EMPs increases with the size [27]. The second criterion aims at finding an interviewee deeply acknowledgeable about energy issues. For this reason, we have interviewed an Energy Country Coordinator & EHS Manager (for S1), a Maintenance Manager (for S2), as well as a Process Development and Environment Manager plus Senior Technology Manager (for S3), ensuring that, in the company, they were the most acknowledgeable figures for energy efficiency and EM issues. Further details regarding sampled enterprises are reported in Table 10.

<< Table 10 >>

The data collection from the interview aimed at gathering an amount of information about the company, such as:

- *company profile* (sector, company size, energy intensity, markets, overall annual energy consumption);
- *approach to energy efficiency* (information regarding company energy strategy, such as targets, investments, policy, action plan in place, certifications, as well as detail over the plant visited, such as products, types of production and degree of automation, energy intensity of processes, consumption, energy efficiency potential estimation);
- *status of EM*, collecting information on profile of the interviewee (role and experience, EM responsibilities);
- *EM organizational structure*, role over the decision-making process on EMP (interaction with other managerial roles, degree of autonomy in decision-making); and
- several judgments over the model, in terms of composition, attributes, etc., plus important performance indicators.

Regarding the performance indicators, we asked interviewees to evaluate five framework's elements (*theoretical approach*, *axes*, *attributes*, *framework use* and its *result*) according to eight indicators as follows: *relevance*, *clearness*, *completeness*, *absence of overlapping*, *effectiveness*, *effort required*, *user-friendliness*, *reliability of result.* For the indicators evaluation, an even-numbered Likert scale ranging from 1 (very poor) to 4 (optimal) has been used, taking inspiration from previous research (e.g. [83], so to encourage the interviewee to take a precise stand and avoid neutral positions. Annex 1 reports the detailed distribution of the indicators for each element of the model.

The discussion dealt also with the indicators scores, as well as with a trial model application to one practice, which is compared with the models of Kindström & Ottosson [50] and Sa, Paromonova, Thollander & Cagno [23]. Annex 2 reports the detailed indicators scores for the three companies. In a nutshell, all the interviewees evaluate the framework in a positive way. Each of them confirms the framework completeness, missing in previous studies, and innovativeness. Interviewee S1 particularly highlights its relevance, its *development stage* axis, as well as the consideration of frequency and extension of each adoption. As preliminarily confirmed by both interviewees at company S1 and S2, the level of detail and focus offered in the description and analysis of EMPs is higher compared with the two similar models from previous literature [23,50].

Interviewees at company S3 emphasize the possibility to in detail analyse qualitative and practical aspects to investigate EM problems.

To conclude, phase (ii) confirms the innovativeness and solidity of the proposed assessment framework along with the interest of industrial practitioners. In terms of *innovativeness*, results highlight the significance of the identified literature gaps. In fact, it is confirmed the novel approach's *relevance*, with respect to the one usually followed in literature (e.g. [31,33]), as well as the one of set of characterization factors, with respect to the existing models (e.g. [49-50]). In terms of c*learness* and *absence of overlapping*, all the framework's elements have a clear meaning and are easily distinguishable. Overall, interviewees have also appreciated the *completeness*, highlighting that no essential factors were missing.

Finally, the trial characterization has further upheld the usefulness and novelty of a precise EMP description that would not be obtainable with the compared frameworks [23,50]. Regarding the interest by practitioners, they clearly acknowledge the usefulness of the suggested approach to the EM assessment. Indeed, it is empirically validated the *effectiveness* and *reliability* of the EMP mapping to better understand the EM status and solve real problems. Furthermore, it is acknowledged the usability in industrial application as an intuitive and easy-to-use tool (*user-friendliness*), even though a lot seems to depend on the practical implementation. Finally, the *effort required* is judged in general in line with the managers' expectations. In short, as from this on-field validation, the proposed model seems to be appreciated by the interviewees, both in terms of theoretical approach (structure, factors) as well as in the capability of being used.

5. MODEL APPLICATION

The case study presented below aimed at showing an on-field application of the EM assessment model, showing the capability of the proposed model to effectively assess EM into companies, as well as to comprehensively describe and benchmark the adopted EMPs. Firstly, a complete mapping of their EMPs is conducted, representing the fundamental data set to be exploited for further analyses, also showing the detail of the performed EM assessment. Secondly, the analysis of the adoption phase for each practice: by considering the adopted reference to EMPs, a benchmarking against the baseline is carried out to assess the company's performance for each activity. Thirdly, as a complement to the previous step, an analysis of EMP by each characterization factor has been conducted, in order to evaluate the overall EM activity. Lastly, we conducted a distribution analysis for a cross-factor assessment regarding three significant pairs of axes to highlight further details and considerations.

The company is located in Sweden, has 258 employees, with an annual turnover of over 70 million €. It works in the pulp and paper sector, with an annual consumption of respectively 28.1 GWh for electricity and 258 GWh for natural gas. It has not received ISO 50001 certification. The interview, that allowed us to perform the EM assessment of the company, required about 1.5 hours, plus about 1 hour for the collection of additional secondary data (e.g. from company website).

Status of energy management

The interviewee (Process Development and Energy Coordinator) leads the energy efficiency activities and is responsible for any related projects. He is not full-time dedicated to EM, serving also as Process Development manager, in contrast with recommendations from recent literature [39]. Nonetheless, the operational responsibility and in-depth knowledge of the production processes of this position are crucial according to research [43]. Moreover, he seems to be quite familiar with the concept and relevance of EMP, and driven by a strong awareness about energy efficiency, whilst the company is experiencing economic/financial barriers.

The interviewee is part of the mill's management team, thus with optimal link to the top management [61]. Thanks to this position, he is involved in the operational decision-making process, in which he believes to have a relevant weight. The strategic issues are instead handled by the top-level management, subsequently delegated to the medium-level management. Finally, the interviewee is supported by an energy group [25,47] with complementary important skills for EM (e.g. maintenance, project leader, production) as proposed by Kaman [52]. Overall, this organizational structure with a mill's lead team and an energy group seems to fit with previous literature [54].

Mapping of the energy management practices

The noteworthy EMPs discussed during the interview, together with additional details emerged in the discussion, led to a complete EM mapping (Table 11). The model allows a very detailed characterization of EMPs, similar to the output of a previously developed framework [37], and more comprehensive than the classification achievable with previous models [23,50]. Furthermore, so far no model considering EMPs for the EM assessment basically relying on a checklist of implemented practices [31,35], offers such a detailed view, thus without specific focus on their main features.

<< Table 11>>

The presented mapping allows to draw several considerations over the EM status of the company. Overall, the company adopts 39 EMPs (corresponding to 32 references considered here). Thanks to the benchmarking baselines (Figure 1), we can highlight both the company's strengths and critical areas. Firstly, we can note some interesting cases of extra-commitment on EM, in particular regarding preventive and predictive maintenance, energy performance monitoring, documentation and record management, as well as energy efficiency procurement. Secondly, the model highlights that, as of now, essential activities such as the control and optimization of operational parameters, energy audit, housekeeping and measurement of energy use seem to be adopted at the optimal level. Thirdly, the model highlights that the exploitation of renewable energy generation, benchmarking activities, measurement of CO_2 emissions, communication with stakeholders, as well as involvement with key personnel are critical areas where the company is lagging behind.

<< Figure 1>>

The analysis shows the relevance to consider the axes mentioned in order to set a precise baseline and thus possible improvement actions. Compared to the most advanced approaches in literature relying on the analysis of EMPs [31,35], we can note that the model offers specific directions for improvement and corrective actions, representing a crucial difference and innovation. Previous approaches in fact rather provide, with different means, only a generic indication about the adoption for each EMP with respect to a standard ideal case (percentage distance from the maximum score for each practice's feature [33]; predefined three-level scale of implementation [35]; maturity level for each practice based on the defined knowledge-base [31]). According to previous approaches, the user would have to rely only on the brief description provided for each maturity level [31], implementation level [35] or practice feature [33]. Whereas, the novel assessment model specifically highlights further actions to be undertaken. As a complement to the benchmarking, the assessment model also allows a thorough and specific analysis of current efforts by the company regarding EM activities (with detailed comments, as in Figure 2) , plus a multi-level analysis to investigate the EMPs (Table 12).

Firstly, by jointly considering the *type of EMP* and the related *type of energy efficiency improvement*, we can note that the company shows a rather comprehensive approach to energy efficiency (Table 12 – top table). Nevertheless, the company should follow two additional pathways to strengthen its EM: *(i)* increasing the attention on the *procurement* activities in terms of energy procurement optimization addressing the *supply side* (especially for the quota of purchased electricity) and additional procedures considering the overall lifecycle of the purchases with an *indirect effect*; and *(ii)* strengthening the *staff-related* practices acting *directly* and *indirectly* on the energy flow.

Secondly, the analysis of the *position in the industrial EM setting* considering also the *organizational scope* allows the company to monitor its approach and to control the consistency of future developments (Table 12 – central table). As of now, the company seems to be overall acting correctly: *i)* for *strategic, organizational* and *cultural* activities, the focus is on the entire firm, which is necessary in order to set up the contextual factors affecting positively EM; and *ii)* the *implementation/operation* and *controlling* elements are extended to the plant and single process. Thirdly, the investigation of the organizational level of the *decision maker* for each *target of the EMP* is important for assessing the decision-making processes (Table 12 – bottom table). The distribution of the practices seems to confirm a correct approach, with the *medium-level operation management* overseeing most of the internal activities (and especially all the production-related ones), relieving the *top-level management* and *medium-level general management* from those activities, thus allowing them to focus on more strategic decisions.

<< Figure 2>>

<< Table 12>>

6. CONCLUDING DISCUSSION AND SUGGESTIONS FOR FURTHER RESEARCH

This paper aims at proposing a novel model for the assessment of industrial EM, based on the benchmarking of EMPs. Firstly, a new EMP definition that also embodies the concept of energy services is proposed. Subsequently, the novel assessment model is developed including the essential perspectives for a detailed EM evaluation, offering both the key attributes to fully define and characterize EMPs for assessing their adoption in industrial companies, as well as benchmarking baselines for EMPs.

Three elements characterize the novel model: firstly, the comprehensive reference list of EMPs to evaluate EMPs' adoption; secondly, the practice-specific baseline created to perform a benchmark of the adoption phase; lastly, regarding its use, the relative nature of the optimal threshold adopted in the assessment. Two distinct features are unique with the model: first, it enables evaluation of EMP adoption, and second is based on the scientific literature, e.g. unlike the EM matrix model.

The validation process shows the uniqueness of the indications achievable with the novel model. So far, EM assessment models presented in literature neither allow such detail in encompassing and detailing all those aspects nor interpret the status of EM in light of corrective and improvement actions, as done here. As our application further shows, the model's output is more comprehensive than a mere evaluation of the maturity level [29,31], or the proficiency in performing certain activities [33,35], or even the EM strategies followed [23]. On the contrary, the novel model offers a detailed assessment of the EM approach, capabilities and organization based on the perspectives individuated as essential for a proper evaluation of EMPs. In this way, the company could find the key factors affecting their strengths and weaknesses, and thus laying the foundation for a specific action plan. For this reason, at the backbone of the assessment model, we have developed a benchmarking baseline, achievable with the defined set of attributes, so to provide a comprehensive and clear representation of the EM status, indicating the current strengths and weaknesses of the company. Moreover, this allows multiple fundamental perspectives to assess EM approach, capabilities and organization based on the ones deemed essential for the specific case in order to indicate targeted and specific improvement actions for each EMP.

The proposed model implies relevant consequences for industrial decision-makers, actors operating in the energy efficiency services supply chain, as well as policy-makers. Beside considerations over further corrective actions, as shown in the application, the model could be used in assisting companies to develop EM tailored to their needs (in case of greenfield). In fact, the model finds its application as an assessment tool for EM, therefore suitable for any companies wishing to improve their approach towards EM. In this regard, the application case study has shown that the model best supports the EM function, or process improvement, to benchmark the current adoption of EMP with respect to best practices gathered from literature evaluated according to company features. When it comes to stakeholders operating in the energy efficiency value chain, the model could be useful to consult a final user in designing the energy services by assessing its EM and the adoption of EMPs in quite a short time (as we noted in the application, the overall assessment took no longer than 2.5 hours). Regarding policy-makers, the proposed knowledge structure about EMPs could represent an important support for designing policies to more effectively promote EM in the industrial sector by acting on a set of the presented essential factors.

The present paper has two main limitations concerning the specific company sample used for both on-field validation phases and the practice-specific baseline. Regarding the first, the limitation concerns the exclusion of SMEs as well as the narrow sectoral and geographical scope. Our choice of specifically addressing LEs has been done with the aim is to appreciate and test all the features of the assessment model. Nevertheless, the features of the model seem compatible also for SMEs, at least where a structured approach for EM can be found or needed. For what concerns the practice-specific baseline, the limitation stems from the absence of empirical data, i.e. a database of adopted EMPs, to support and customized for the specific case the definition of the EM performance levels.

Therefore, in light of these limitations, the study offers hints for further research involving a more extended empirical investigation in parallel to further theoretical studies about EMPs. Further research should empirically investigate a wider set of companies, thus exploring a higher variety of contexts (different organization types, management structure, presence of energy manager, production processes energy intensity, industrial context, EM culture and purpose of the model use). In particular, it would be very important for SMEs, where the relevance of energy issue could be different and the approach to energy management could be less structured and more casual. Additionally, a widespread application of the model could lead to a first database of adopted EMPs. The model application would foster an auto-feeding mechanism for which the higher is the number of the companies assessed, the more precise and robust the database. In practical term, this data set could then be exploited for a benchmarking analysis against an empirically defined baseline, so to study significant trends and companies' behaviours. Finally, further theoretical research could exploit the model to characterize the stakeholders acting in the energy efficiency value chain (e.g. OEMs, distributors, ESCOs, etc.). The model could assess the completeness of the services offered, allowing to develop a more tailored energy service. This in turn could lead to further research assessing the behaviour of such stakeholders with respect to the potential. as well as exploring and evaluating possible synergies with other stakeholders.

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Table 1 – Review methodology

Keywords for the scientific literature research

Subject	**Keywords**
(a) *Industrial energy management*	“energy management”, “industry”, “framework”, “model”
(b) *Energy management practices*	“energy management practices”, “management practice”; “energy efficiency”; “classification”, “characterization”
(c) *Energy services*	“energy service”, “energy efficiency”, "classification", “characterization”

Criteria used for the scientific literature research

Publication type	All types of publication	*Availability*	Available online as full text
Language	English	*Research discipline*	Energy; Engineering; Business, Management and accounting
Time period	Focus on the most recent	*Sector*	Industrial sector
Contents	(a) energy management framework OR energy management models (b) articles addressing explicitly the topic OR articles presenting a characterization framework OR articles addressing the topic indirectly by considering in general management practices and energy efficiency performances (c) articles addressing the topic from the perspective of the adoption in industrial company OR articles presenting a characterization framework		

Table 2 – Summary of existing models for the energy management assessment

Type	Reference	Model Description
Minimum requirements	Christoffersen, Larsen & Togeby [27]	Essential elements: energy policy, quantitative goals for energy savings or objectives concerning energy-saving projects and the implementation of energy-saving projects. At least one among energy-efficient purchases, clear allocation of energy responsibility and tasks and the active involvement of employees by informing, motivating and finally educating them.
	Ates & Durakbasa [26]	Revised the (27)'s set of minimum requirements by adding the metering of main processes and the presence of an appointed energy manager.
	ISO 50001 [28]	Guidelines for the implementation of an energy management system based on the PDCA cycle. Requirements: management responsibility; energy policy; legal requirements and other requirements; energy review; energy baseline; energy performance indicators; energy objectives, energy targets and energy management action plans; competence, training and awareness; communication; documentation; operation and control; design; procurement of energy services, products, equipment and energy; monitoring, measurement and analysis; evaluation of compliance with legal requirements and other requirements; internal audit of the energy management system; nonconformities, corrective action and preventive action; control of records; management review.
Maturity models	O'Sullivan [32]	5 levels of maturity: Emerging, Defining, Integrating, Optimizing and Innovating. 4 domains based on the PDCA cycle, 16 pillars and 63 sub-pillars. For each sub-pillar, the model provides 5 attribution statements to assess the maturity.
	Ngai, Chau, Poon & To [40]	5 maturity levels: initial, managed, defined, quantitatively managed and optimized. Each one institutionalizes new process areas for process maturation with an environmental management perspective. 4 phases of maturity: practice establishment, practice standardization, performance management and continuous improvement.
	Antunes, Carreira & Mira da Silva [38]	Guideline for achieving higher energy efficiency and compliance with energy management standards such as ISO 50001. Energy management activities derived from the literature organized into 5 maturity levels following the PDCA cycle. The model also takes into account activities deemed as good practice in the Capability Maturity Model Integration. Identification of challenges that organizations will face for each maturity level.
	Introna, Cesarotti, Benedetti, Biagiotti & Rotunno [29]	Key issues for the management of energy consumption, in accordance with ISO 50001. 5 maturity levels: initial, occasional, planning, managerial, optimal. 5 dimensions identifying the essential elements for success: awareness, knowledge and skills (the most important one); methodological approach; energy performance management and information system; organizational structure; strategy and alignment.
	Jovanović & Filipović [31]	It merges ISO 50001 processes, PDCA cycle and Capability Maturity Model Integration criteria to establish a knowledge base that is meant to be used for self- assessment, monitoring and improvements after the initial ISO 50001 certification. Maturity levels inspired by [40] described in detail for each ISO 50001 process.
	Sa, Thollander and Cagno [30]	It assesses the driving factors for energy management program adoption. It contributes to a better understanding of suitable energy management configuration through the evaluation of its maturity level analyzing the required steps to establish an energy management according to the energy strategy.
Energy management matrixes	Ashford [41]	5 level energy management matrixes assessing 6 organizational issues: policy, organization, motivation, information systems, marketing and investment.
	Gordic, Babic, Jovicic, Sustersic, Koncalovic & Jelic [34]	5 level energy management matrixes assessing 6 organizational issues: energy management policy, organization, staff motivation, tracking, monitoring and reporting systems, staff awareness/training and promotion, and investment.
	Carbon Trust [33]	5 level energy management matrixes assessing 6 organizational issues: policy, organizing, training, performance measurement, communicating and investment. Assessment model investigating the following elements considered as energy management practices: energy policy, energy strategy, organizational structure; regulatory compliance; procurement policy, investment procedures, monitoring and analysis of energy use, target setting; opportunities identification; staff engagement and training; operational procedures; communications.
	Energy Star [35]	Assessment model investigating the following elements considered as energy management practices: appoint an energy director, establish an energy team, institute an energy policy; data collection and management, baselining and benchmarking, analysis, technical assessments and audits; determine scope, estimate potential for improvement, establish goals; define technical steps and targets, determine roles and resources; create a communication plan, raise awareness, build capacity, motivate, track and monitor; measure results, review action plan; providing internal recognition, receiving external recognition.
EEMs characterization framework	Fleiter, Hirzel, & Worrell [36]	*Relative advantage* = Internal rate of return; Payback time; Initial expenditure; Non-energy benefits. *Technical context* = Distance to core process; Time of modification; Scope of impact; Lifetime. *Information context* = Transaction costs; Knowledge for planning & implementation; Diffusion progress; Sectorial applicability.
	Trianni, Cagno & De Donatis [37]	*Economic* = Payback time; Implementation Costs. | *Energy* = Resource Stream; Amount of Saved Energy. | *Environmental* = Emission reduction; Waste reduction. | *Production-related* = Productivity; Operation & Maintenance; Working Environment. | *Implementation-related* = Saving strategy; Activity Type; Ease of Implementation; Likelihood of success/acceptance; Corporate Involvement; Distance to core processes; Check-up frequency. | *Interaction-related* = Indirect effects

Table 3 – Clusters of energy management definitions and related literature references

Cluster	References
(1) Focus on energy use	[42,53,78-79]
(2) Strategic perspective	[39,43,55,80]
(3) Inclusion of managerial aspects	[24,26,33-34,47,55,73]
(4) Relevance of people	[20,25,67]

Table 4 – Overview of the characterization frameworks for energy management practices and energy services

Reference	Focus	Framework
Sa, Paronomova, Thollander & Cagno [23]	Energy Management Practices	Exploitation of the energy management strategies classification presented by (47). He defines five types of strategies and the related programs: reliability (maintenance program; modernization; operations; training; contingency planning); efficiency (plant property evaluation; measurement; control; energy organizational efficiency); low cost/no cost (alternatives for energy sources; negotiation; time of use; elimination); funding (stabilize funding; return saving to customer; short-term funding; economic analysis training); awareness (training; communication; behavior modification; program evaluation).
Sorrell [48]	Energy Service Contracts (Customer perspective)	Three-dimensional classification framework: (1) Scope = "defines the number of useful energy streams and/or final energy services that are wholly or partially under the control of the contractor". Attributes = delivered energy, primary conversion equipment, useful energy, secondary conversion equipment, final energy service, controls. (2) Depth = "the number of organizational activities required to provide that stream or service that is under the control of the contractor". Attributes = purchase of energy commodities, energy audits, project design and engineering, project financing, equipment specification and purchasing, installation, commissioning and maintenance of equipment, operation and control of equipment, monitoring and verification of performance, staff training. (3) Finance = the method of finance for the contract that "refers to the source of capital for investment in new energy conversion and control equipment". Attributes = internal financing (capital provided either by the contractor of the client), lease financing (operational or capital), third-party financing (debt undertaken either by the contractor or the client), project financing.
Benedetti, Cesarotti, Holgado, Introna & Macchi [49]	Energy Service Contracts (Market perspective)	Three-dimensional classification framework adopting a PSS perspective: (1) Scope, as presented by (48). Attributes = one service, several services, all client's services. (2) Intangibility of the contract that recalls the product-service-system classification. Attributes = product-oriented, use-oriented, result-oriented. (3) Degree of risk accepted by the parties of the contract, which is linked to the method of finance presented by Sorrell [48], but that in the opinion of the authors is "*more up-to-date considering the modern Energy Services context*". Attributes = high risk for the client, shared risk, high risk for the provider.
Kindström & Ottosson [50]	Energy Service Types	"*Service ladder*" ▪ Four service categories (steps): information, analysis, activities and performance. ▪ Two dimensions for sorting in ascending order the categories: energy efficiency potential and service complexity. ▪ Distinction between direct (activities and performances) and indirect (information and analysis) services. The difference is in the way with which they affect the customers: directly or indirectly and respectively tangibly or intangibly. ▪ Division based on the customer involvement in the value creation process, which can be passive, emphasizing the transfer of value (information and analysis), or active, emphasizing the value-in-use (activities and performances).

Table 5 – Attributes of Energy Management Practices

Attrribute		Detail of attribute	Description
Type of energy management practice		Technology-related	Practices concerning the development, implementation, functioning and optimization of the technologies extensively discussed in literature (e.g. [23-24,52-53,55-56]).
		Non-technology-related	Bulk of pure managerial and organizational activities subdivided taking inspiration from energy management matrixes.
		Administrative	Practices regarding the management of energy efficiency investments and energy costs.
		Energy-performance-related	Practices focused on the calculation and analysis of the company energy performance and targets.
		Informative	Practices related to the information flow both within and outside the company regarding the energy subject.
		Procurement	Practices related to energy efficiency principles on both internal procedures and relationship with suppliers.
		Staff-related	Practices concerning the energy efficiency awareness, motivation, training and management of people.
		Support	Practices to adopt support services for the internal energy management based on [57-58].
		Engineering	Support concerning the design of the intervention.
		Financial	Support related to the external financing of the intervention and incentives.
		Managerial	Generic support for the management or improvement of energy efficiency performance.
Type of energy efficiency improvement		Direct	Practices directly influencing the energy flow.
		Supply side	Impact on generation and transmission.
		Demand side	Impact on distribution and final use.
		Indirect	Practices acting on contextual factors that are likely to trigger a future action involving a direct impact on the energy flow.
Target of the energy management practice		Internal stakeholder	Practices targeting, in general, the company and internal stakeholders.
		Production processes	Practices focused on production processes, which is an area highlighted also by [23,56].
		Technology processes	Practices specific for technology/core processes.
		Ancillary processes	Practices specific for ancillary processes.
		Non-production processes	Practices targeting non-production areas or processes of the company.
		External stakeholders	Practice devoted to a specific critical stakeholder to increase the company's energy efficiency performance (e.g. supplier, regulating bodies, national institutions, financial institutions, technology manufacturers, competitors, partners and customers) [13,27].
Position in the industrial energy management setting		Strategy/Planning	Elements of the industrial energy management setting presented by [25].
		Implementation/Operation	
		Controlling	
		Organization	
		Culture	
Development stage		Initial phase	Practice at an embryonal stage and not adopted yet (i.e. under planning or design).
		Testing phase	Practice in a trial phase in which the company evaluates the actual results and possible improvements.
		Fully Operational phase	Practice correctly fine-tuned and in full operations.
		Revision phase	Practice still applicable but it needs to be revised in order to update the specifications.
		Abolishment phase	Practice considered obsolete and not adapted anymore to the changed context.
Method of adoption	Sourcing strategy	In-sourcing	The company is completely autonomous in the adoption of the practice.
		Out-sourcing	The company exploits an energy service to perform the practice.
	Degree of criticality for the operations	Low	The impact is absent or almost irrelevant.
		Medium	The practice's effect is circumscribed to non-critical phases of the operations.
		High	The practice impacts the performance of a critical phase or equipment of the operations.
	Frequency of adoption	On-time	Practice adopted in case of a specific circumstance and it requires managerial attention only in that specific moment.

		Continuous base	Practice adopted with a specific frequency and involving a continuous management effort.
		Daily/Weekly/Monthly/Quarterly/Annually/Less than annually	
Extent of adoption	Technological scope	Single Type of Equipment/Fixture	Practice specifically dedicated to one equipment or a building fixture.
		Specific Group	Practice referring to various possibilities of grouping defined by the company (e.g., by fuel, by production phase).
		All Technologies Installed	Practice affecting all the technologies installed within the organization.
	Organizational scope	Process	Practice dedicated to a specific process.
		Function/Department	Practice adopted within a specific function or department.
		Plant	Practice affecting an entire plant.
		Business Unit	Practice specifically defined for a business unit of a company/group.
		Company-wide	Practice affecting the entire company/group.
	Temporal scope	Less than 1 year	It indicates either an extreme short-term view or a temporal activity.
		1 to 3 years	It indicates a common short-term view considered in the decision-making process of several organizational decisions.
		3 to 5 years	It indicates a long-term view and a relevant activity for the company.
		More than 5 years	It indicates a strategic energy management practice and full commitment from the company.
Organizational Involvement	Decision maker	Specification of the organizational level and number of people involved	The person who makes the final decision to adopt the practice.
	Responsible/Supervisor		The person in charge for the adoption and the results of the practice.
	User		The person who is actively involved in the adoption and use of the practice.

Table 6 – Reference list of energy management practices

#	Energy management practice	References	IAC DB Matches
1	Acquisition/Management of Financing and Incentives	[44,58-60]	2.8121; 4.812
2	Adoption of Adequate Investment Criteria for Energy Efficiency Investment	[12,23,53-54,61-62]	
3	Adoption of Energy Performance Contracting for Energy-Efficiency Investments	[15,52,63]	4.422
4	Adoption of External Financing	[12,48,50,57-59,62-63]	
5	Benchmarking	[56,64-66]	
6	Collection of Information and Analysis of Energy Policies and Regulation	[58,60-61]	
7	Control and Optimization of Operational Parameters		2,2161; 2,2211; 2,2515; 2,4323; 2,6222; 2,7226; 3,4156; 2,1111; 2,1114; 2,1116; 2,2223; 2,6231; 2,7134; 2,7316; 2,8122; 3,1194; 3,7221; 2,1133; 2,2141; 2,5196; 2,6211; 2,6221; 2,7143; 3,1121
8	Definition of Energy-Efficiency KPIs	[20,56,67]	
9	Definition of Energy-Efficiency KPIs for Managers and Employees	[20,53,68]	
10	Definition of Energy-Efficiency Targets	[23,27,61-62,68]	
11	Definition of Energy Responsibilities	[52-53,60]	
12	Demand Side Management Techniques	[23,56,59	2.3131; 2.3212; 2.3191; 2.3111; 2.3113; 2.3132; 2.3137
13	Documentation and Record Management regarding Energy Use	[53]	
14	Documentation and Record Management regarding Energy Using Characteristics and Maintenance History of Equipment	[53,68]	
15	Documentation and Record Management regarding Implemented Energy Efficiency Projects	[53]	
16	Energy Audit	[12,19,21,24,27,45-46,48,50,53,55,57-62,66,69-70]	
17	Energy Cost Allocation	[12,19,45,52-54,56,67]	4.712
18	Energy Demand Budgeting	[15,24,67	
19	Energy-Efficiency based Maintenance	[52-53]	
20	Energy Efficiency Capital Budgeting	[52]	
21	Energy Efficiency Training for Employees	[20,23-24,27,48,53-55,60-61,65,67,69,71]	4.431; 4.432
22	Energy Efficient Building/Facility Design	[53,69]	
23	Energy Efficient Procurement of Equipment, Direct and Indirect Materials	[27,53]	2.1391; 2.1392; 2.4226; 2.8113; 3.5315; 4.211; 4.214; 4.222; 4.231
24	Energy Efficient Product Design	[58,60-61]	2.5195
25	Energy Efficient System/Process/Equipment Design	[27,52-53,56,61,69]	2.5121; 2.5194; 2.2313; 2.7233; 4.125; 4.131
26	Energy Management Position covered by an External Consultant	[46,53,57]	
27	Energy Recycling	[67]	2.2411; 2.2413; 2.2422; 2.2426; 2.2427; 2.2431; 2.2432; 2.2433; 2.2434; 2.2435; 2.2436; 2.2437; 2.2441; 2.2442; 2.2443;

			2.2445; 2.2446; 2.2494; 2.2624; 2.2693; 2.3412; 2.3417; 2.4311; 2.7313; 2.1243; 2.2412; 2.2424; 2.2444; 2.2447; 2.2495; 2.2696
28	Energy-Aware Production Scheduling	[56]	4.321; 4.323; 4.426
29	Exploit Manufacturing Techniques to Improve Energy Efficiency	[52,68]	4.711
30	Exploitation of Renewable Energy	[56,58]	
31	Green Energy Procurement	[23, 60-61]	
32	Housekeeping	[20,24,55,60-62,66-67,71]	2.1134; 2.2133; 2.2134; 2.2151; 2.2615; 2.7211; 2.7425; 3.4133; 3.7142; 3.7143; 4.121; 2.2135; 2.4236; 2.6123; 3.4154; 3.7311; 3.7312; 2.7441; 2.7444
33	Identification of Energy-Efficiency Opportunities	[23,46,52-53,57,69]	
34	Internal Communication regarding Energy Topics	[12,23,53,56-57,62]	
35	Internal Incentive and Recognition System for Employees	[20,27,53,61,66,68-69]	4.421
36	Maintenance Planning	[23,71]	2.1231; 2.3135; 2.6124; 3.7312
37	Marketing Energy Efficiency Actions and Results to External Stakeholders	[25,56]	
38	Measurement of Energy Use	[20,45,52-54,57,60-61,65,67,69);	
39	Measurement of GHG/Air Emissions/CO2 footprint	[23,56, 71]	
40	Monitoring and Evaluation of Energy Performance	[20,24-25,27 ; 46,48,52,54,56-58,61,67-69]	
41	Negotiation with Energy Suppliers for Optimizing Energy Procurement	[56]	2.8115
42	Networking	[23]	
43	Optimize Energy Procurement based on Energy Data	[56,58]	
44	Optimize Logistic Activities to Reduce Energy Use	[60-61]	2.8211; 4.311; 4.513; 4.514; 4.632
45	Outsourcing of Engineering and Project Design	[12,46,48,57-58]	
46	Outsourcing of Operation and Maintenance Activities	[12,46,48,50,53,57,62,70]	4.612
47	Outsourcing of Project Management and Commissioning of an Intervention	[48,53,57-58]	
48	Outsourcing of Property/Facility Management Activities	[46,57]	
49	Outsourcing of the Project Installation or Repair Activities	[12,48,53,57-58,62,66,71]	
50	Participation to External Events regarding Energy Efficiency	[53,60-61]	
51	Preventive and/or Predictive Maintenance	[24,53,56,67]	2.4156; 2.4157; 4.611
52	Procurement of Delivered Energy through Energy Service Contracts	[12,46,48,50,57-58]	
53	Procurement of Equipment through Energy Service Contracts	[46,48,57]	
54	Procurement of Useful Energy through Energy Supply Contracting	[50,53,57]	
55	Promotion of Simple Behavioral Changes	[24,60-61]	2.4238; 2.7442; 2.7121; 2.7222; 2.7442

56	Reduction and Minimization of Energy Use and Losses		2,1113; 2,1241; 2,2162; 2,2523; 2,3131; 2,3521; 2,3522; 2,4231; 2,4232; 2,6121; 2,6212; 2,6241; 2,7111; 2,7112; 2,7224; 2,7314; 2,7315; 2,7423; 2,8212; 3,1161; 3,1192; 3,1222; 3,1227; 3,7198; 4,425; 2,1242; 2,2163; 2,2212; 2,2312; 2,2623; 2,6122; 2,7312; 3,4131; 3,4151; 3,4158; 3,6111; 3,7222; 3,8121
57	Reporting of Energy Performance	[23,53-54,58,69]	
58	Shut/Close/Turn Off Machines when not Used		2,2114; 2,2153; 2,2164; 2,2223; 2,2691; 2,4235; 2,6213; 2,6214; 2,6215; 2,6216; 2,6217; 2,6218; 2,7124; 2,7133; 2,7311

Table 7 – Practice-specific baseline vs. EMMM50001 [31] – Exemplificative difference

	ISO 50001 Process	**5. Optimized**
Jovanović & Filipović, 2016 [31]	Monitoring, measurement and analysis of energy indicators	Monitoring and measurement are performed daily. Measuring equipment and techniques are updated. Statistical models are a basis for forecasting and improvement.
	Practice	**Level 3**
New baseline	#38 Measurement of Energy Use	- Energy bills tracking; - All energy sources considered; - Equipment and plant level; - Sectional and individual sub-metering for energy-intensive and/or critical equipment and processes [73]

Table 8 – EMPs-specific baseline Code for abbreviations: PBT = Pay-back time, NPV = Net present value, EE = Energy efficiency, NEBs = Non-energy benefits, IEEN = industrial energy efficiency network.

#	Energy Management Practice	Level 0	Level 1	Level 2	Level 3	References
1	Acquisition/Management of Financing and Incentives	Not financing/incentives adopted	Outsourced through energy service contract	Internal management		
2	Adoption of Adequate Investment Criteria for Energy Efficiency Investment	No investments differentiation	PBT threshold < 3 years	- PBT threshold > 3 years - Different threshold based on the investment criticality	- NPV/IRR evaluation - Specific evaluation process for EE investments - Consideration of NEBs	[12,45,61]
3	Adoption of Energy Performance Contracting for Energy-Efficiency Investments	EPC not adopted	Adopted due to a lack of internal know-how	Adopted for relevant EE interventions	Widely adopted to leverage on internal resources	[52]
4	Adoption of External Financing	External financing not adopted	Adopted for EE interventions requiring investment above a certain threshold	Extensively Adopted for all EE interventions		
5	Benchmarking	No forms of benchmarking performed	- Historical benchmarking - Plant level - Product-based - Annually	- Historical, company-wide and across sector benchmarking - Consideration of EE indicators and best practices - Product-based - Monthly and Annually	- Historical, company-wide and across sector benchmarking - Consideration of EE indicators and best practices - Process-based - Monthly and Annually	[73-75]
6	Collection of Information and Analysis of Energy Policies and Regulation	No interest for energy policies and regulation	- Passive approach - Information collected only after legal issues have arisen and for pure compliance with the minimum requirements	- Pro-active approach/Always updated - In-depth analysis of the applicable regulation to be fully compliant - Strategic relevance	- Pro-active approach/Always updated - In-depth analysis of the regulation - Relationship with influential external stakeholders in order to be at the front-line and influence the energy policy/regulation	
7	Control and Optimization of Operational Parameters	No control of operational parameters for EE purposes	Optimization procedures implemented energy-intensive equipment	Optimization procedures for all production equipment	Optimization procedures for all equipment installed	
8	Definition of Energy Efficiency KPIs	No EE KPIs	Mainly economic indicators at company/plant level	- EE scorecard - Economic indicators at company/plant level - Process-specific physical indicators	- EE scorecard - Consideration of sector-specific indicators - Economic indicators at company/plant level - Process-specific physical indicators - Equipment-specific indicators	[73]
9	Definition of Energy Efficiency KPIs for Managers and Employees	No EE KPIs for managers or employees	EE KPIs included in the manager scorecards with operational roles	EE scorecard for all managers and employees with operational roles	- Institutionalization of EE KPIs specific per BU/Division/Function - All managers and employees involved - Strategic evaluation	
10	Definition of Energy Efficiency Targets	No EE targets	- Weak targets of energy consumption, energy saving and GHG emission	- Stringent targets (absolute and relative) of energy consumption, energy saving, GHG emission, resources	- Stringent targets (absolute and relative) of energy consumption, energy saving, GHG emission, resources	[61-62,68]

			- Generic for the company - Short term perspective - Limited accountability - Limited awareness	consumption - Generic for the company - Short and long-term perspective - Defined responsibilities - Clearly communicated	consumption - Detailed allocation to all plants/Bus/Functions/Divisions - Short and long term perspective - Defined responsibilities - Strategically defined and evaluated - Widespread communication to all employees and strong company involvement	
11	Definition of Energy Responsibilities	No specific energy responsibilities	Responsibility limited to operational managers	Allocation of responsibilities between managers (also non-operational roles) and energy coordinators		[47]
12	Demand Side Management Techniques	DSM techniques not implemented	Application of demand-side management techniques (e.g. load shifting, load shedding, etc.)			[56, 76]
13	Documentation and Record Management regarding Energy Use	No energy use records	Energy bills collection	- Energy bills collection - Database of energy use records of energy-intensive equipment	- Energy bills collection - Detailed energy use records of all energy-consuming equipment - Open access to information within the company	
14	Documentation and Record Management regarding Energy Using Characteristics and Maintenance History of Equipment	No database regarding equipment characteristics	- Database of energy-specific information regarding energy-intensive equipment - Maintenance records of specific equipment	- Database of energy-specific information of production equipment - Records of production maintenance - Open access to information within the company	- Database of energy-specific information of all energy-using equipment - Records of all maintenance activities - Records of all process modifications - Open access to information within the company	
15	Documentation and Record Management regarding Implemented Energy Efficiency Projects	No records of past EE projects	Documentation of all EE projects	Database of implemented EE projects	- Database of implemented EE projects - Database of EE suggestions - Open access to information within the company	
16	Energy Audit	No energy audit performed	General audit	Investment-grade audit	- Investment-grade audit - Follow up energy audit - Internal and external auditors	[24,55]
17	Energy Cost Allocation	- No energy-specific cost allocation - Energy considered within indirect costs	Per unit m^2/number of employees/unit of output	Department/Division level	Process Specific	[12,45,53-54,62]
18	Energy Demand Budgeting	No energy demand budget	- Rough forecast of electricity and fuel quantity - Focus on production processes	- Detailed evaluation of future needs of electricity and fuel quantity/costs - Focus on the entire company	- Detailed evaluation of future needs of electricity and fuel quantity/costs - Forecast of air emission and environmental impact projection - Strategic relevance of the analysis - Focus on the entire company	[24]

19	Energy Efficiency based Maintenance	EE not considered in maintenance activities	Non-specific guidelines/rules regarding EE in maintenance activities	- EE formally considered in maintenance decisions - Scope: production processes	- EE formally considered in maintenance decisions - Scope: equipment and facilities	[53]
20	Energy Efficiency Capital Budgeting	No EE capital budget	EE investments included in a general capital budget	Specific budget for important EE investments	- Dedicated budget for all EE investments - Strategic relevance	
21	Energy Efficiency Training for Employees	No forms of EE-related training	- One-time basic awareness courses regarding EE - Training limited to management positions	- One-time basic awareness courses regarding EE for all employees - Training for management positions - Specific training for employees with operational roles	- EE awareness program for all employees - Specific training for managers, energy team and employees with operational roles - Continuous Activity - Certifications in technology and best practices	[20,27,47,53,67]
22	Energy Efficient Building/Facility Design	EE not considered in Building/Facility Design	Consideration of EE in the review of certain portions of the facility/building	EE criteria in the design of all new buildings		
23	Energy Efficient Procurement of Equipment, Direct and Indirect Materials	No energy efficient procurement	Sporadic implementation of green procurement best practices	- Formalized guidelines of EE procurement best practices - Inclusion of EE-related terms in supply agreements - Adopted for specific categories of purchases	- Formalized guidelines of green procurement best practices - Inclusion of EE-related terms in supply agreements - Partnership with suppliers - Full-scale adoption	
24	Energy Efficient Product Design	EE not considered in Product Design	- Sporadic consideration of EE performance in the design phase - Low collaboration between internal stakeholders involved	- Systematic adoption of DfE approach, practices and tools - High collaboration between internal stakeholders involved		
25	Energy Efficient System/Process/Equipment Design	EE not considered in System/Process/Equipment Design	- Sporadic consideration of EE performance in the design phase - Low collaboration between internal stakeholders involved	- Systematic adoption of DfE approach, practices and tools - High collaboration between internal stakeholders involved		
26	Energy Management Position covered by an External Consultant	Internal energy management	Role partially outsourced	- Role and responsibilities fully outsourced - or, participation to IEEN		
27	Energy Recycling	No energy recycling	- Energy recycling for certain energy sources and for specific areas - Practices not systematically adopted	- Energy recycling for certain energy sources and for specific areas - Formalized practices	- Extensive application of energy recycling - Formalized practices	[67]
28	Energy-aware Production Scheduling	Energy not considered in production scheduling	Non-standardized methods of energy-aware production scheduling for energy-intensive machines	Formalized application of energy-aware production scheduling for energy-intensive machines	Extensive and formalized energy-aware production scheduling	[56]

29	Exploit Manufacturing Techniques to Improve Energy Efficiency	No implementation of modern manufacturing techniques	Sporadic and not formal application of some principles to specific processes	- Application of modern manufacturing techniques focused on critical processes - Specific EE objectives	- Institutionalization of modern manufacturing techniques - Specific EE objectives - Adopted at every stage of the production processes	
30	Exploitation of Renewable Energy	No RES exploited	- Isolated RES installations - No interests and commitment	- RES adoption in selected cases - Focus on projects with the highest return - Interest for the topic	- Extensive RES adoption - Full exploitation of all the possibilities - Strategic relevance and full commitment	
31	Green Energy Procurement	No Green Energy Procurement	Occasional choice to opt for green energies	Focus on one source (electricity, biogas, bio-fuels)	- Full green energy - Strategic choice - Specific negotiations with suppliers	
32	Housekeeping	No housekeeping activities performed	Rarely adopted in production areas	Adopted for critical production processes and areas	- Widely adopted in all areas - Organization, absence of obstruction and cleanliness are part of the company culture	[55,77]
33	Identification of Energy-Efficiency Opportunities	No specific activity of opportunity identification	- Periodical (low frequency) opportunities appraisal - Focus on energy-intensive areas	- Periodical (high frequency) opportunities appraisal - Company-wide focus - Dedicated team	- Continuous improvement mindset - Monitoring of industry best practices - All employees can suggest improvements	[25,52-53]
34	Internal Communication regarding Energy Topics	No internal communication regarding EE topics	- Mainly passive communication - Low company involvement	- Active and passive communication - All employees involved - Part of the company culture		[27,53,75]
35	Internal Incentive and Recognition System for Employees	No internal incentive and recognition system for EE	Incentives to reach the targets for managers and employees with operational role	- Several EE specific incentives to foster commitment and awareness - General recognition program - Intangible reward - All employees involved	- Several EE specific incentives to foster commitment and awareness - Institutionalized recognition program for EE goals - Tangible and intangible reward - All employees involved - Part of the company culture	[53,69]
36	Maintenance Planning	No maintenance planning	- Maintenance plan for core equipment - Short-term (1 year)	- Maintenance plan for core equipment - Maintenance plan for specific part of the facility - Short-term (1 year)	- Maintenance plan for all equipment installed - Maintenance plan for the facility - Short and long-term (1-3 years)	[25]
37	Marketing Energy Efficiency Actions and Results to External Stakeholders	No specific EE marketing	General sustainability section and performance included in the annual company reports and website	- Specific communication of EE projects implemented, performance achieved and future plans - Tools: annual company reports, web presence (website, social media, press)	- Specific communication of EE projects implemented, performance achieved and future plans - Tools: annual company reports, web presence (website, social media, press), seminars at the plant	[25,56]
38	Measurement of Energy Use	No specific measurement activities	- Overall energy use - Energy bills tracking - Some or all energy sources	- Energy bills tracking - All energy sources - Equipment and plant level - Sub-metering for some energy-intensive and critical equipment	- Energy bills tracking - All energy sources - Equipment and plant level - Sectional and individual sub-metering	[45,52-53,60,75]

					for energy-intensive and critical equipment and processes	
39	Measurement of GHG/Air Emissions/CO2 footprint	Environmental impact not measured	Measurement of the company's environmental impact only for regulatory purpose	- Detailed measurement of the company's environmental impact considering several indicators - Strategically driven		
40	Monitoring and Evaluation of Energy Performance	No monitoring of EE performance	- Focus on energy-intensive equipment - Mainly analysis by time, product, process and energy source - Deferred monitoring - Annual frequency	- Focus on all production processes and energy-intensive equipment - Mainly analysis by time, product, process and energy source - Deferred monitoring - Annual and monthly frequency	- Real-time monitoring - IoT technologies - Focus on all final energy uses - Multi-level analysis (department, time, product, process, energy source, final service, functional category) - Consequence management	[56,67-68,73]
41	Negotiation with Energy Suppliers for Optimizing Energy Procurement	No negotiation with energy suppliers	- Applied to some supplier - Sporadic, not constant	- Applied to all energy sources - Unofficial but constantly adopted	- Applied to all energy sources - Formalized practice with specific internal guidelines	
42	Networking	The company is not part of any network	Participation to few industrial networks	- Participation in industrial networks sector specific - Participation to EM networks - Activity strategically relevant		
43	Optimize Energy Procurement based on Energy Data	Energy procurement not optimized	Procurement based on internally collected energy data for certain energy sources	Formalized practice of procurement based on the internally collected energy data for all energy sources		
44	Optimize Logistic Activities to Reduce Energy Use	Energy-issues not considered in any logistic activity	Energy-based optimization of internal logistics	Energy-based optimization of internal logistics and external activities by adopting GSCM principles		
45	Outsourcing of Engineering and Project Design	Internal engineering and project design for all EE interventions	- External consultancies adopted only for verifying specific element of the projects that require specific know-how - External engineering and project design only for big and significant interventions that require specific know-how	External engineering and project design for all EE interventions		
46	Outsourcing of Operation and Maintenance Activities	All O&M activities performed internally	- Outsourcing O&M in case of a lack of internal resources or know-how - Outsourcing O&M of support equipment	Outsourcing O&M of process and support equipment		
47	Outsourcing of Project Management and Commissioning of the Intervention	No commissioning and internal PM for all EE interventions	- Outsourcing PM and Commissioning in case of a lack of internal resources or know-how - Outsourcing PM and Commissioning of non-critical EE interventions	Extensive adoption of external PM and Commissioning for EE interventions		

48	Outsourcing of Property/Facility Management Activities	All support activities for the core business managed and performed internally	Partial outsourcing of support activities for the core business	Outsourcing of all support activities for the core business		
49	Outsourcing of the Project Installation or Repair Activities	Internal installation and repairs of all equipment	- Outsourcing installation and repair activities in case of a lack of internal resources or know-how - Outsourcing installation and repair activities of support equipment	Outsourcing installation and repair activities of process and support equipment		
50	Participation to External Events regarding Energy Efficiency	No interest in participating at external events regarding EE	- Sporadic participation - No real commitment	- Consistent participation - Perceived as an important opportunity to gain knowledge and exchange information		
51	Preventive and/or Predictive Maintenance	Not preventive or predictive maintenance policy in place	- Preventive maintenance - Critical production equipment	- Preventive maintenance - Both production and support equipment	- Preventive maintenance for all production and support equipment - Predictive maintenance for critical equipment	
52	Procurement of Delivered Energy through Energy Service Contracts	Internal procurement of delivered energy	Only for a specific energy source	Adopted for all energy sources		
53	Procurement of Equipment through Energy Service Contracts	Internal procurement of all equipment	Only for support equipment	Adopted for both process and support equipment		
54	Procurement of Useful Energy through Energy Supply Contracting	Internal production of useful energy	Adoption ESC for some forms of useful energy	Full exploitation of ESC for all forms of useful energy required in the plant		
55	Promotion of Simple Behavioral Changes	No policies implemented to stimulate energy efficient behavioural changes	- Unofficial activity - Occasional practice	- Attempts to formalize the practice and increase awareness of employees - Concentrate in office/production areas	- Practice formalized - Part of the company culture - Adopted company-wide in all functions	
56	Reduction and Minimization of Energy Use and Losses	Activities not considered	Adopted sporadically based on employee's personal judgment	- Practice formalized and communicated - Focus on building energy services	- Practice formalized and communicated - Widely adopted in all the feasible cases	
57	Reporting of Energy Performance	No energy-related reporting	- Reporting of EE results at company level - Annual to monthly frequency	- Detailed reporting of EE results at various level: company, BU, plant, division/function and processes - Annual to daily frequency		[25,54]
58	Shut/Close/Turn Off Machines and Devices when not Used	Activities not considered	Adopted sporadically based on employee's personal judgment	- Practice formalized and communicated - Focus on critical energy uses	- Practice formalized and communicated - Widely adopted in all the feasible cases	

Table 9 – Theoretical validation of the model with respect to its capability to describe EMPs

#	Energy management practice	Type of energy management practice [1]	Type of energy efficiency improvement [2]	Target of the energy management practice [3]	Position in the industrial energy management setting [4]
1	Acquisition/Management of Financing and Incentives	Adm	I	ES	Imp
2	Adoption of Adequate Investment Criteria for Energy Efficiency Investment	Adm	I	NP	Imp
3	Adoption of Energy Performance Contracting for Energy-Efficiency Investments	Tec	I	I	Imp
4	Adoption of External Financing	Fin	I	ES	Imp
5	Benchmarking	EnP	I	I	Con
6	Collection of Information and Analysis of Energy Policies and Regulation	Adm	I	NP	Str
7	Control and Optimization of Operational Parameters	Tec	D	I	Imp
8	Definition of Energy Efficiency KPIs	EnP	I	I	Con
9	Definition of Energy Efficiency KPIs for Managers and Employees	EnP	I	I	Con
10	Definition of Energy Efficiency Targets	EnP	I	I	Str
11	Definition of Energy Responsibilities	Sta	I	I	Org
12	Demand Side Management Techniques	Tec	DD	I	Imp
13	Documentation and Record Management regarding Energy Use	Inf	I	I	Imp
14	Documentation and Record Management regarding Energy Using Characteristics and Maintenance History of Equipment	Inf	I	I	Imp
15	Documentation and Record Management regarding Implemented Energy Efficiency Projects	Inf	I	I	Imp
16	Energy Audit	Tec	I	I	Imp
17	Energy Cost Allocation	Adm	I	NP	Con
18	Energy Demand Budgeting	Adm	I	NP	Str
19	Energy Efficiency based Maintenance	Tec	D	I	Imp
20	Energy Efficiency Capital Budgeting	Adm	I	NP	Str
21	Energy Efficiency Training for Employees	Sta	D	I	Cul
22	Energy Efficient Building/Facility Design	Tec	DD	NP	Imp
23	Energy Efficient Procurement of Equipment, Direct and Indirect Materials	Pro	I	I	Imp
24	Energy Efficient Product Design	Tec	DD	I	Imp
25	Energy Efficient System/Process/Equipment Design	Tec	DD	P	Imp
26	Energy Management Position covered by an External Consultant	Man	I	I	Org

27	Energy Recycling	Tec	D	I	Imp
28	Energy-aware Production Scheduling	Tec	DD	P	Imp
29	Exploit Manufacturing Techniques to Improve Energy Efficiency	Tec	DD	P	Imp
30	Exploitation of Renewable Energy	Tec	DS	I	Imp
31	Green Energy Procurement	Pro	DS	NP	Imp
32	Housekeeping	Tec	D	I	Imp
33	Identification of Energy-Efficiency Opportunities	Tec	I	I	Imp
34	Internal Communication regarding Energy Topics	Inf	I	NP	Cul
35	Internal Incentive and Recognition System for Employees	Sta	I	NP	Cul
36	Maintenance Planning	Tec	D	I	Imp
37	Marketing Energy Efficiency Actions and Results to External Stakeholders	Inf	I	ES	Cul
38	Measurement of Energy Use	EnP	I	I	Con
39	Measurement of GHG/Air Emissions/CO_2 footprint	EnP	I	I	Con
40	Monitoring and Evaluation of Energy Performance	EnP	I	I	Con
41	Negotiation with Energy Suppliers for Optimizing Energy Procurement	Pro	DS	ES	Imp
42	Networking	Inf	I	ES	Org
43	Optimize Energy Procurement based on Energy Data	Pro	DS	NP	Imp
44	Optimize Logistic Activities to Reduce Energy Use	Tec	DD	I	Imp
45	Outsourcing of Engineering and Project Design	Eng	I	I	Imp
46	Outsourcing of Operation and Maintenance Activities	Tec	D	I	Imp
47	Outsourcing of Project Management and Commissioning of the Intervention	Man	I	I	Imp
48	Outsourcing of Property/Facility Management Activities	Man	I	I	Imp
49	Outsourcing of the Project Installation or Repair Activities	Tec	I	I	Imp
50	Participation to External Events regarding Energy Efficiency	Inf	I	ES	Cul
51	Preventive and/or Predictive Maintenance	Tec	D	I	Imp
52	Procurement of Delivered Energy through Energy Service Contracts	Pro	DS	I	Imp
53	Procurement of Equipment through Energy Service Contracts	Pro	D	I	Imp
54	Procurement of Useful Energy through Energy Supply Contracting	Pro	DS	P	Imp
55	Promotion of Simple Behavioral Changes	Sta	DD	I	Cul
56	Reduction and Minimization of Energy Use and Losses	Tec	DD	I	Imp
57	Reporting of Energy Performance	Inf	I	I	Con
58	Shut/Close/Turn Off Machines and Devices when not Used	Tec	DD	I	Imp

Legend:

[1] Tec = Technology-related; Adm = Administrative; EnP = Energy-performance-related; Inf = Informative; Pro = Procurement; Sta = Staff-related; Eng = Engineering Support; Fin = Financial Support; Man = Managerial Support. [2] D = Direct; DS = Direct - Supply Side; DD = Direct - Demand Side; I = Indirect. [3] I = Internal Stakeholder/Process; P = Production process; PT = Technology process; AT = Ancillary process; NP = Non Production process; ES = External Stakeholder. [4] Str = Strategy/Planning; Imp = Implementation/Operation; Con = Controlling; Org = Organization; Cul = Culture.

Table 10 – Company sample – On-field validation of the assessment model

ID	Workforce [# of employees]	Annual Turnover	Interviewee(s)	Company Location	Sector	Annual Energy Consumption	Energy certification (ISO 50001)
S1	1200	€ 911 M	Energy Country Coordinator & EHS Manager	Airasca (TO), Italy	Primary metal	E: 60 GWh G: 1.5 mil smc	Yes
S2	165	€ 82 M	Maintenance Manager & Energy Manager	Kisa, , Sweden	Pulp and Paper	O: 175.8 GWh (2.93 MWh/ton)	Yes
S3	640	€ 2.22 B	(i) Process Development and Environment Manager (ii) Senior Technology Manager	Skärblacka, Sweden	Pulp and Paper	5.44 MWh/ton	Yes

Table 11 – Mapping of the EMPs of the studied case.

#	Energy management practice	Attributes of EMPs													
							Method of adoption			Extent of adoption			Organizational involvement [12]		
		Type of energy management practice [1]	Type of energy efficiency improvement [2]	Target of the energy management practice [3]	Position in the industrial EM setting [4]	Development stage [5]	Sourcing strategy [6]	Degree of criticality for the operations [7]	Frequency of adoption [8]	Technological scope [9]	Organizational scope [10]	Temporal scope [11]	Decision maker	Responsible	User
7	Control and Optimization of Operational Parameters [Mill]	Tec	DD	PT	Imp	FO	IN	H	D	S	PR	5+	MM-O	MM-O	FM, E
7	Control and Optimization of Operational Parameters [Power Plant]	Tec	DS	NP	Imp	FO	IN	H	D	S	PR	5+	MM-O	MM-O	FM, E
16	Internal Energy Audit	Tec	I	I	Imp	FO	IN	L	A	A	C	5+	MM-O	MM-O	MM-O
16	External Energy Audit	Tec	I	I	Imp	FO	OUT	L	LA	A	C	5+	MM-O	MM-O	n/a
19	Energy Efficiency based Maintenance	Tec	DD	P	Imp	FO	IN	L	C	A	PL	5+	MM-O	MM-O	MM-O, FM, E
27	Process Heat Recovery	Tec	DS	PT	Imp	FO	IN	H	D	1	PR	5+	MM-O	MM-O	n/a
30	Exploitation of Biogas	Tec	DS	P	Imp	FO	IN	H	D	1	PR	5+	MM-O	MM-O	n/a
32	Housekeeping	Tec	D	P	Imp	FO	IN	M	D	A	PL	5+	MM-O	MM-O	FM, E
33	Internal Surveys	Tec	I	I	Imp	FO	IN	L	C	S	C	5+	MM-O	MM-O	All
33	Reference List for Project Improvement	Tec	I	I	Imp	FO	IN	L	OT	S	C	5+	MM-O	MM-O	MM-O
36	Maintenance Planning	Tec	DD	P	Imp	FO	IN	L	C	S	C	5+	MM-O	MM-O	MM-O, FM, E
44	Optimization of Internal Logistic Activities	Tec	DD	I	Imp	FO	IN	L	C	S	PR	5+	MM-O	MM-O	FM, E
46	Outsourcing of Operation and Maintenance Activities	Tec	DD	P	Imp	FO	n/a	L	OT	S	PR	5+	MM-O	MM-O	n/a
49	Outsourcing of the Project Installation or Repair Activities	Tec	I	P	Imp	FO	n/a	L	OT	S	PR	5+	MM-O	MM-O	n/a
51	Preventive and Predictive Maintenance	Tec	DD	P	Imp	FO	IN	L	C	A	C	5+	MM-O	MM-O	FM, E
6	Collection of Information and Analysis of Energy Policies and Regulation	Adm	I	NP	Str	FO	IN	L	C	n/a	C	5+	MM-O	MM-O	E
17	Energy Cost Allocation on the Production Output	Adm	I	NP	Con	FO	IN	L	A	n/a	C	5+	MM-O	MM-O	E
18	Energy Demand Budgeting	Adm	I	NP	Str	FO	IN	L	A	n/a	C	5+	TM	TM	TM, MM
5	Internal Benchmarking	EnP	I	P	Con	FO	IN	L	A	n/a	C	5+	MM-O	MM-O	All
8	Energy Efficiency Dashboard	EnP	I	I	Con	FO	IN	L	M	n/a	C	5+	MM-O	MM-O	All
10	Energy Targets	EnP	I	I	Str	FO	IN	L	A	n/a	C	5+	TM	TM	TM, MM
38	Measurement of Main Energy Uses	EnP	I	P	Con	FO	IN	L	D	S	C	5+	MM-O	MM-O	MM-O
39	Measurement of Carbon Dioxide Emissions	EnP	I	I	Con	FO	IN	L	A	n/a	C	5+	MM-O	MM-O	MM-O
40	Top Management Monitoring	EnP	I	I	Con	FO	IN	L	M	n/a	C	5+	TM	TM	TM
40	Energy Trend Analysis	EnP	I	P	Con	FO	IN	L	Q	n/a	PL	5+	MM-O	MM-O	MM-O

40	Power Plant Performance Monitoring	EnP	I	NP	Con	FO	IN	M	D	S	PL	5+	MM-G	MM-G	MM-G
40	Process Monitoring	EnP	I	NP	Con	FO	IN	M	M	S	F	5+	MM-O	MM-O	MM-O
13	Documentation and Record Management regarding Energy Use	Inf	I	I	Imp	FO	IN	L	C	n/a	C	5+	MM-G	MM-G	All
14	Documentation and Record Management regarding Energy Using Characteristics and Maintenance History of Equipment	Inf	I	I	Imp	FO	IN	L	C	n/a	C	5+	MM-G	MM-G	All
15	Documentation and Record Management regarding Implemented Energy Efficiency Projects	Inf	I	I	Imp	FO	IN	L	C	n/a	C	5+	MM-G	MM-G	All
34	Energy Data published in the Company Intranet	Inf	I	NP	Cul	FO	IN	L	A	n/a	C	5+	MM-G	MM-G	All
37	Communication of Energy Efficiency and Environmental Actions on the website	Inf	I	ES	Cul	FO	IN	L	C	n/a	C	5+	TM	MM-G	MM-G, FM, E
57	Internal Reporting of Energy and Environmental Performance	Inf	I	I	Con	FO	IN	L	C	n/a	C	5+	MM-G	MM-G	All
57	External Reporting to the Swedish Energy Agency	Inf	I	ES	Con	FO	IN	L	A	n/a	C	5+	TM	MM-G	MM-G
23	Energy Efficiency Supplier Agreement	Pro	DD	ES	Imp	FO	IN	L	C	A	C	5+	MM-G	MM-G	E
11	Definition of Energy Responsibilities	Sta	I	I	Org	FO	IN	L	C	n/a	C	5+	MM-O	MM-O	MM-O
21	Energy Efficiency Training for Employees	Sta	DD	P	Cul	FO	IN	L	C	n/a	F	5+	MM-O	MM-O	MM-O, FM, E
45	Outsourcing of Engineering and Project Design	Eng	I	P	Imp	FO	n/a	L	OT	S	PR	1-	MM-O	MM-O	n/a
47	Outsourcing of Project Management and Commissioning of the Intervention	Man	I	P	Imp	FO	n/a	L	OT	S	PR	1-	MM-O	MM-O	n/a

Legend:

[1] Tec = Technology-related; Adm = Administrative; EnP = Energy-performance-related; Inf = Informative; Pro = Procurement; Sta = Staff-related; Eng = Engineering Support; Fin = Financial Support; Man = Managerial Support. [2] D = Direct; DS = Direct - Supply Side; DD = Direct - Demand Side; I = Indirect. [3] I = Internal Stakeholder/Process; P = Production process; PT = Technology process; AT = Ancillary process; NP = Non Production process; ES = External Stakeholder. [4] Str = Strategy/Planning; Imp = Implementation/Operation; Con = Controlling; Org = Organization; Cul = Culture. [5] I = Initial phase; T = Testing phase; FO = Fully Operational phase; R = Revision phase; A = Abolishment phase. [6] IN = In-sourcing; OUT = Out-sourcing. [7] L = Low; M = Medium; H = High. [8] OT = On-time; C = Continuous base; D = Daily; W = Weekly; M = Monthly; Q = Quarterly; A = Annually; LA = Less than annually. [9] 1 = Single Type of Equipment/Fixture; S = Specific Group; A = All Technologies Installed. [10] PR = Process; F = Function/Department; PL = Plant; BU = Business Unit; C = Company-wide. [11] Unit of measure = year. [12] TM = Top-level Management; MM = Middle-level Management; FM = First-level Management; E = Employees/Staff; All = All levels; - G = General role; - O = Operation role.

Note:

[12] In the mapping the number of resources involved is not specified. Nonetheless, in general, when referring to top-level management, the interviewee considers the board of the company. Whereas, when referring to medium-level management, he indicates a specific manager. For what concerns the first-level management and the employees, in general, the interviewee means the workers within the defined organizational scope.

Table 12 – Distribution analysis [# of EMPs] (the practices adopted are indicated in light blue and the potential opportunities in yellow)

Type of energy management practice vs. type of energy efficiency improvement

Type of energy management practice	Type of energy efficiency improvement: Direct	Direct - Supply	Direct - Demand	Indirect	Total
Technology-related	1	3	6	5	15
Administrative				3	3
Energy-performance-related				9	9
Informative				7	7
Procurement			1		1
Staff-related			1	1	2
Engineering Support				1	1
Financial Support					0
Managerial Support				1	1
Total	1	3	8	27	39

Position in the industrial energy management setting vs. organizational scope

Position in the industrial energy management setting	Organizational scope: Company-wide	Function/Department	Plant	Process	Total
Strategy/Planning	3				3
Implementation/Operation	10		2	9	21
Controlling	8	1	2		11
Organization	1				1
Culture	2	1			3
Total	24	2	4	9	39

Target of the energy management practice vs. decision maker

Target of the energy management practice	Decision maker: Top-level Management	Medium-level Management (General)	Medium-level Management (Operation)	Total
External Stakeholder	2	1		3
Internal Stakeholder/Process	2	4	8	14
Non Production Process	1	2	4	7
Production Process			13	13
Technology Process			2	2
Total	5	7	27	39

Annex 1 – Overview of the indicators adopted in the on-field validation of the theoretical framework

Indicators	Description based on the element's characteristic
Ratio of the framework	*Relevance* = The perspective adopted in the framework is adapted and interesting for the evaluation.
Definitions	*Clearness* = The meaning of the definition is literally clear. *Completeness* = All the essential elements are included in the definitions.
Reference list	*Clearness* = The names of the energy management practices in the reference list are clear. *Completeness* = The reference list is representative of all the most important energy management practices.
Definition and adoption model structures	*Completeness* = The model structures include all the essential factors to define an energy management practice and analyze the adoption phase respectively. *Absence of overlapping* = Each axis represents a clearly distinguishable fundamental factor.
Axes	*Relevance* = The axis represents relevant aspect for the definition of energy management practices and the evaluation of its adoption. *Clearness* = The name of the axis and its meaning is clear.
Attributes	*Relevance* = The attributes model relevant features for the description of the specific axis. *Clearness* = The name of the attribute and its meaning are clear. *Completeness* = The attributes of the axis model all the essential possibilities. *Absence of overlapping* = Each attribute represents a clearly distinguishable possibility.
Framework use	*User-friendliness = The framework is intuitive and easy to use.* *Effort required = The application is not disruptive on the energy manager and is in line with expectations.*
Results	*Effectiveness = The outcome of the model is helpful and solves a practical problem for the energy manager.* *Reliability of the result = The result is reasonable and it can be applied in practice for improvement.*

Annex 2 – On-field validation of the theoretical framework: indicators score details

Element Investigated		Company S1				Company S2				Company S3			
		Relevance	**Clearness**	**Completeness**	**Absence of overlapping**	**Relevance**	**Clearness**	**Completeness**	**Absence of overlapping**	**Relevance**	**Clearness**	**Completeness**	**Absence of overlapping**
Theoretical approach	Ratio of the framework	4				4				4			
Theoretical approach	Energy management definition		4	4			4	4			4	3	
Theoretical approach	Energy management practice definition		3	4			4	4			4	4	
Theoretical approach	Reference list		4	4	4		4	4	4		4	3	4
Theoretical approach	Definition model			4	4			4	4			4	4
Theoretical approach	Adoption model			4	4			4	4			4	4
Axes / Attributes	Type of energy management practice	4	4			4	4			4	4		
		4	4	4	4	4	4	4	3	3	4	3	4
Axes / Attributes	Type of energy efficiency improvement	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Target of the energy management practice	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Positioning in the industrial energy management setting	3	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Development stage	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Sourcing strategy	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Degree of criticality for the operations	4	3			4	4			4	4		
		4	3	3	4	4	4	4	4	4	4	4	4
Axes / Attributes	Frequency of adoption	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	3
Axes / Attributes	Technological scope	4	4			4	4			4	4		
		4	3	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Organizational scope	4	4			4	4			4	4		
		4	3	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Temporal scope	4	4			4	4			4	4		
		4	4	4	4	4	4	3	4	4	4	4	4
Axes / Attributes	Decision-maker	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	Responsible	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4
Axes / Attributes	User	4	4			4	4			4	4		
		4	4	4	4	4	4	4	4	4	4	4	4

	Effectiveness	Reliability of the result	User-friendliness	Effort required	Effectiveness	Reliability of the result	User-friendliness	Effort required	Effectiveness	Reliability of the result	User-friendliness	Effort required
Framework use	3	4			4	4			4	4		
Result			4	4			4	3			4	4