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Overcoming Internal Barriers to Industrial Energy Efficiency through Energy Audit: a Case Study of a Large Manufacturing Company in the Home Appliances Industry

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ABSTRACT

Energy efficiency plays a key role in reducing global energy consumption, especially in the industrial sector, with an indirect positive impact on the competitiveness of industrial firms. Although a cultural shift toward recognizing the strategic importance of energy efficient and environmental friendly solutions is diffusing among industrial companies, also pushed by the evolution of local and international regulatory frameworks, strong barriers hampering the adoption of Energy Efficiency Measures (EEMs) still exist. These barriers, and in particular those linked to behavioral issues, may be overcome by the use of a well-designed energy audit methodology. However, how energy audit can help overcome behavioral barriers to industrial energy efficiency remains an under-researched topic in literature. This paper presents and discusses a novel methodology for energy audit developed and implemented by a large manufacturing company. The methodology is built around four phases and it pays special emphasis to the initial step of the audit, where the strongest resistance to the implementation of EEMs is typically found due to a lack of awareness and commitment which hampers the identification of needs and opportunities associated with the adoption of EEMs. The proposed methodology has been able to overcome in practice the typical behavioral barriers that affect the implementation of EEMs in the manufacturing sector, and has strong applicability in other firms and industries.

Keywords: energy efficiency, energy audit, energy efficiency barriers, manufacturing sector

1. Introduction

The global energy consumption is expected to grow by 50% between 2010 and 2040, mainly due to the increasing use of energy in the industrial sector, which accounts for approximately 37% of the global energy consumption (International Energy Agency, 2014), and for 25.1% of the energy consumption at the European Union (EU) level (Eurostat, 2015). In this scenario, energy efficiency can provide a huge contribution in reducing industrial energy consumption and in improving the competitiveness of industrial firms (Boyd & Pang, 2000) (Worrell, Laitner, Ruth, & Finman , 2003) (Ponsa, Bikfalvia, Llacha, & Palcicb, 2013), (Gestlberger, Dachs, Knudsen, & Schroter, 2016). It would also force industrial companies to raise the importance of energy management at a strategic level, thus contributing to move the world towards a more sustainable development (Rudberg, Waldemarsson, & Lidestam, 2013).

A new culture promoting Energy Efficiency Measures (EEMs) and environmental friendly solutions is diffusing among industrial companies (Laitner, 2013), which are increasingly implementing EEMs with the aim to analyze and reduce energy consumption patterns and, consequently, achieve important cost savings in the energy bill (Duflou, et al., 2012) (Benedetti, Cesarotti, & Introna, 2015) (Kang & Lee, 2016). This is of paramount importance at the EU level, where electricity prices for industrial companies have increased compared to other countries (Astrov, et al., 2015). As part of such a cultural shift, energy costs are now treated as a real cost category impacting manufacturing costs, and energy consumption variables are integrated into the decision making processes regarding operations and facility management (O'Driscoll & O'Donnel, 2013). As a result, energy efficiency is becoming an important issue in the definition of strategic plans and investment decisions (Blok, et al., 2015). Nevertheless, in the last years industrial companies have experienced, due to the recent financial crisis, a strong reduction of their capital expenditures (Makridou, Andriosopoulos, Doumpos, & Zopounidis, 2016). This explains why, at the EU level, for example, investments in EEMs in the industrial sector have shrinked from a Compound Annual Growth Rate (CAGR) of 1.9% in the 2000-2007 period to a 0.9% CAGR in the 2007-2013 period (Odyssee-Mure, 2015).

An important role in the promotion of energy efficiency is played by the regulatory frameworks at the local and international level, where provisions such as the EU Energy Efficiency Directive (EED) (EU DIRECTIVE 27, 2012) and voluntary standards such as those developed by the International Organization for Standardization (ISO, 2016)[1] provide obligations, incentives and guidelines for industrial, manufacturing and commercial companies to manage energy (including all aspects, ranging from procurement to use) in a proper and effective way (Dasheng & Chin-Chi, 2016).

The EED establishes a set of binding measures to help EU countries reach the 20% energy efficiency target by 2020. In particular, among the different areas of intervention, the EED promotes the introduction of high quality energy audits, defined as systematic procedures used to identify, quantify and report existing energy consumption profiles and energy savings opportunities in buildings, industrial or commercial operations or installations, and in private or public services. The aim of any energy audit, therefore, is to enable the realization of EEMs through the analysis of all the aspects related with energy consumption and use in a facility. According to the EED, energy audits are

[1] The following are the ISO standards relevant to the present paper: The Energy Management standards (ISO 50001; ISO50003; ISO 50004; ISO 50006; 50015), the Energy Audits standard (ISO 50002), the activities relating to Energy Services standard (ISO 50007), and the Commercial Building Energy Data Management for Energy Performance standard (ISO 50008).

mandatory for large enterprises, i.e., with more than 250 employees, or with an annual turnover higher than € 50 million. Furthermore, the European Commission (European Commission, 2016), endorsing the agreement reached at the United Nations Conference of Climate Change (COP21, 2015), has highlighted the importance of effective energy audits and EEMs for enhancing the competitiveness of industrial companies.

Despite the general consensus regarding the importance of EEMs, there are still several barriers that hamper a large scale and successful implementation of these measures (Cagno, Worrell, Trianni, & Pugliese, 2013) (Lozano, 2013) (Hirst & Brown, 1990). These barriers are related to both external and internal factors. The external barriers refer to exogenous factors such as market variables (e.g., energy price distortions) and governmental policies (e.g., the dynamics of the regulatory framework). Instead, the internal barriers refer to endogenous factors, mainly related to how firms are organized, as well as to behavioral and economic issues, such as the costs of the investments required to implement EEMs. Table 1 provides a comprehensive list of barriers to the adoption of EEMs, which has been developed in a recent study (Cagno, Worrell, Trianni, & Pugliese, 2013).

Table 1: Barriers to the adoption of EEMs. Adapted from (Cagno, Worrell, Trianni, & Pugliese, 2013)

Origin	**Category**	**Barrier**	**Main sector where the barrier is particularly strong**
External	Market	Energy prices distortion	All sectors
		Low diffusion of technologies	Industrial sectors
		Low diffusion of information	Industrial sectors – low energy intense
		Market risks	All sectors
		Difficult in gathering external skills	Industrial sectors – low energy intense
	Government/politics	Lack of proper regulation	All Sectors
		Distortion in fiscal policies	All sectors
	Technology/service suppliers	Lack of interest in energy efficiency	Industrial sectors – low energy intense sector
		Technology suppliers not updated	Industrial sectors - manufacturing
		Scarce communication skills	Industrial sectors - SMEs
	Manufacturer	Technical characteristics not adequate	Industrial sectors
		High initial costs	Industrial sectors – high energy intense sector
	Energy suppliers	Scarce communication skills	All sectors
		Distortion in energy policies	All sectors
		Lack of interest in energy efficiency	Industrial sectors - low energy intense sector
	Capital Suppliers	Cost for investing capital availability	Industrial sectors – high energy intense sector
		Difficult in identifying the quality of the investment	Industrial sectors - low energy intense sector
Internal	Economic	Low capital availability	All sectors
		Hidden costs	Industrial sectors – low energy intense sector
		Intervention-related risks	Industrial sectors – high energy intense sector
	Behavioral	Lack of interest in energy efficiency	Industrial sectors – low energy intense, SMEs, commerce, service

		Other priorities	Industrial sectors – low energy intense, SMEs, commerce, service
		Split incentive	Industrial sectors – low energy intense, SMEs, commerce, service
		Inertia	Industrial sectors – low energy intense, SMEs, commerce, service
		Imperfect evaluation criteria	SMEs
		Lack of sharing the objectives	SMEs
	Organizational	Low status of energy efficiency	Industrial sectors - low energy intense.
		Divergent interests	All sectors
		Complex decision chain	All sectors
		Lack of time	All sectors
		Lack of internal control	All sectors
	Barriers related to competence	Identifying the inefficiencies	Industrial sectors
		Implementing the interventions	All sectors
	Awareness	Lack of awareness or ignorance	All sectors

The available empirical evidence suggests, on the one hand, that both industrial and commercial companies perceive economic or financial barriers as the main obstacles to adopting EEMs (Timilsina, Hochman, & Fedets, 2016). On the other hand, some recent studies (Trianni, Cagno, & Farnè, 2016) show that the strongest resistance to the implementation of EEMs is found in the first steps of the energy audit process. In particular, behavioral barriers play a key role in the initial stages of the audit, whilst their relevance decreases from the generation of awareness stage to the final implementation of EEMs (Cagno E. , Trianni, Worrell, & Miggiano, 2014).

In line with these recent studies, this paper focuses on the barriers to the adoption of EEMs, caused by both lack of awareness and behavioral issues, since these barriers tend to impact in the very beginning the decision-making process related to the punctual identification and evaluation of feasible EEMs. Indeed, companies typically show a substantial lack (or at least a low) interest towards a proactive management of energy efficiency to the point that, even when financial resources are available, they tend to invest such resources in projects strictly related to their core activities, with EEMs pushed back by more contingent issues (Cagno & Trianni, 2014). In Italy, for example, the attitude towards energy efficiency is still low among industrial companies, and the sector more inclined to the implementation of EEMs – i.e., the paper industry - invested in EEMs an amount of money which is less than 3% of the annual value of their energy bill in 2015 (Energy & Strategy Group, 2016). Moreover, recent studies suggest that, the more radical the change in existing practices and processes resulting from the adoption of EEMs, the higher the perceived behavioral barriers, which can result in a preference for investments in EEMs with fast returns (i.e., short Pay Back Time), compared with the more relevant and impacting ones (Chiaroni, et al., 2016).

In this scenario, most of the studies on the barriers to energy efficiency in the industrial sector have focused either on samples of energy intensive industries (Chan & Kantamaneni, 2015), or on specific sectors such as pulp and paper (Blomberg, Henriksson, & Lundmark, 2012), chemicals (Broeren, Saygin, & Patel, 2014), electric power (Sueyoshia & Goto, 2012), cement (Oggioni, Riccardi, & Toninelli, 2011) (Amrina & Lutfia Vilsi, 2015), which offer a higher potential for the implementation of EEMs (Schulze, Nehler, Ottosson, & Thollander, 2016). However, existing studies have left the manufacturing sector, which is considered a low energy intensive industry, relatively under-researched. Furthermore, how energy audits can help overcome barriers to energy efficiency in industrial companies remains an under-researched topic in literature. This despite the wealth of research on barriers to energy efficiency (Trianni, Cagno, & Farnè, 2016) (Langlois-Bertrand, Benhaddadi, Jegen, & Pineau, 2015) (Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011), and although energy audit is considered a key component of broader energy management programs for industrial companies aimed at reducing energy costs and minimizing the environmental impacts of their operations (Abdelaziz, Saidur, & Mekhiler, 2011) (Timilsina, Hochman, & Fedets, 2016). Recently, a holistic approach to energy efficiency, which connects EEMs with the concepts of cleaner production and energy audit, has been proposed for the manufacturing sector (Petek, Glavic, & Kostevšek, 2016). This shows that manufacturing companies are raising the interest of scholars working in the field of energy efficiency, in a time when companies strive to identify the most effective measures to increase the productivity of their internal processes (Meath, Linnenluecke, & Griffiths, 2016).

1.1 Aims, methodology and structure of the paper

This paper builds on a single-case study of a large manufacturing company in the home appliances industry. Singe-case studies are particularly suited to answer to "how" and "why" questions, and to investigate a phenomenon in its whole complexity (Eisenhardt, 1989) (Yin, 1989). The case study has been selected following theoretical and convenience sampling criteria (Siggelkow, 2007) and has been used to answer to the following research question: how does a manufacturing company implement an energy audit to overcome the (behavioral) barriers that hinder the adoption of EEMs? To address this question, the paper presents and discusses the energy audit methodology developed and applied by a large manufacturing company working in the home appliances industry (called "Home Appliances Company" for confidentiality reasons). Such methodology for energy audit has proved to be effective in overcoming the typical internal barriers that hamper the implementation of EEMs in the manufacturing sector, by creating a strong awareness about the value of EEMs and their potential impact on the reduction of operational costs. Home Appliances Company has been chosen for the case study because they have developed the audit methodology within a collaborative project in which two of the authors have actively participated. This allowed the authors to have direct access to detailed information and data about how the energy audit has been conducted and about its results. Besides giving detailed insights on how Home Appliances Company has conducted an effective energy audit and has overcome (behavioral) barriers to energy efficiency, this case study has a number of important implications for energy managers working in other manufacturing companies, who are facing strong behavioral barriers in their attempt to adopt EEMs.

In terms of data collection, the two authors involved in the collaborative project with Home Appliances Company participated in several meetings held at the premises of Home Appliances Company during the design and implementation of the energy audit, had access to the reports and documentation produced during and after the completion of the audit, and had the opportunity to conduct a number of interviews with key respondents from the Home Appliances Company, i.e., a member of the Top Management Team, the Energy Manager, the Health, Safety and Environment (HSE) Manager, the Operation Manager and the Plant Manager. The interviews have been conducted in 3 main phases, with the support of an interview protocol built around a set of open-ended questions.

Table 2 provides details about the number of interviews conducted during the 3 main phases of the interview process.

Table 2: Number of interviews for each key respondent

Key respondent	Number of interviews		
	Phase 1	Phase 2	Phase 3
Top Manager	1	0	0
Energy Manager	2	3	3
HSE Manager	1	0	1
Operation Manager	2	3	1
Plant Manager	1	2	1
Total number of interviews	21		

In the first phase the respondents were asked to provide a general description of Home Appliances Company, the characteristics of the manufacturing plants and processes, the people responsible for energy management activities, data about energy consumption, information on the behavioral barriers that have hampered, in the past, the implementation of EEMs. In the second phase the interviews were focused on understanding how the audit methodology was designed and implemented, how it helped overcome the behavioral barriers to the adoption of EEMs, who participated in the different phases of the energy audit. The third phase was focused on collecting data about the results of the application of the energy audit methodology, the benefits it has produced, the acceptance of the EEMs identified and evaluated during the audit process. The data and information collected through the interviews were triangulated to ensure internal validity, and follow-up interviews were conducted with the key respondents to discuss, share and corroborate the findings of our analysis.

The paper is organized as follows: Section 2 illustrates the case study, with particular focus on the energy audit methodology developed by Home Appliances Company. In Section 3 the main findings of the case study are discussed, including an illustration of the main critical issues faced in conducting the energy audit, and Section 4 contains conclusions and illustrates avenues for future research.

2. The case study: designing and implementing the energy audit in Home Appliances Company

2.1 Background

Home Appliances Company is an American multinational home appliances manufacturer, which operates in more than 170 countries around the world. The headquarters for Europe, Middle-East and Africa (EMEA) markets are located in the North of Italy. In the EMEA market the Home Appliances Company has a sales presence in more than 30 countries and manufacturing plants in 9 of such countries.

Following an increased awareness of the impact of the energy cost on the total operational costs and of the importance of improving energy efficiency, in 2011 Home Appliances Company decided to launch an energy audit process to assess the energy footprint of its plants and identify energy efficiency opportunities. The aim was to satisfy both the internal request to exploit cost-saving opportunities, and to encompass the new demand from the market for a sustainable and eco-friendly product portfolio. Ideas for reducing energy costs were analyzed at each level (machines, production lines, utilities, buildings, production sites) and for each energy carrier (electricity, natural gas, hot water, steam).

As a multi-site company, the energy audit started as a pilot project in one plant, and was then standardized to make it repeatable in all other Home Appliances Company's plants. This case study focuses on the project that led to the implementation and execution of the energy audit in one of the largest plants of Home Appliances Company, which is located in Italy (the "Plant"). This Plant is made of three main production lines. i.e., refrigeration, cooking (ovens and hobs) and microwaves (MW) (Figure 1). Table 3 shows the total energy consumption breakdown of the Plant for the year 2015, while Figure 2 provides a graphical representation of the consumption breakdown.

Figure 1: Plant layout

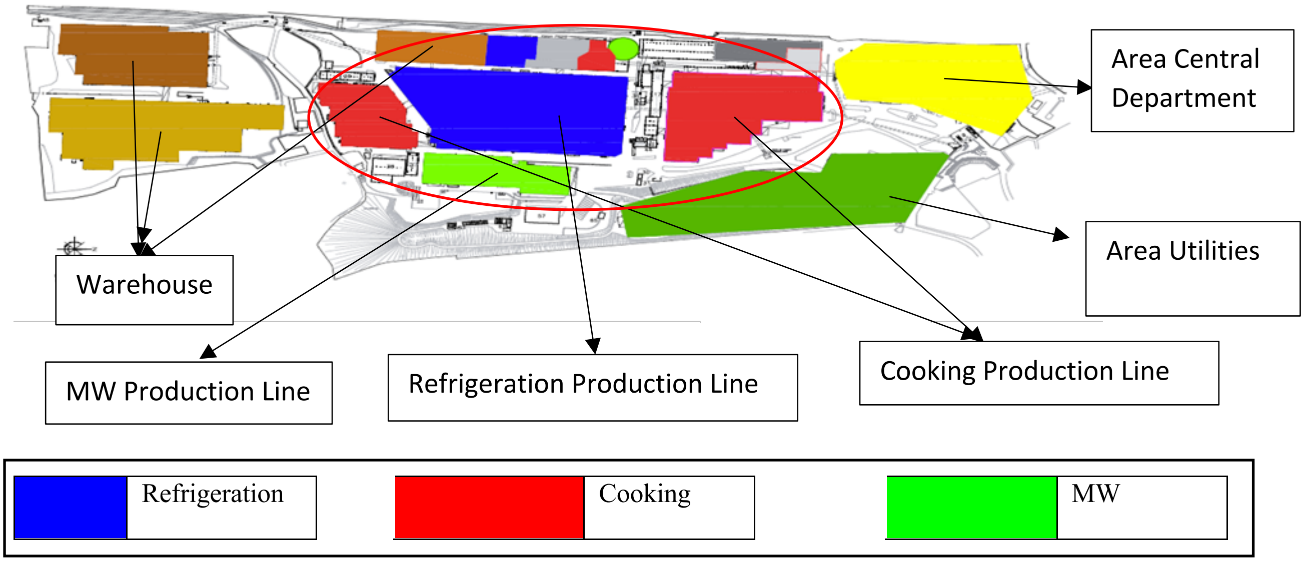
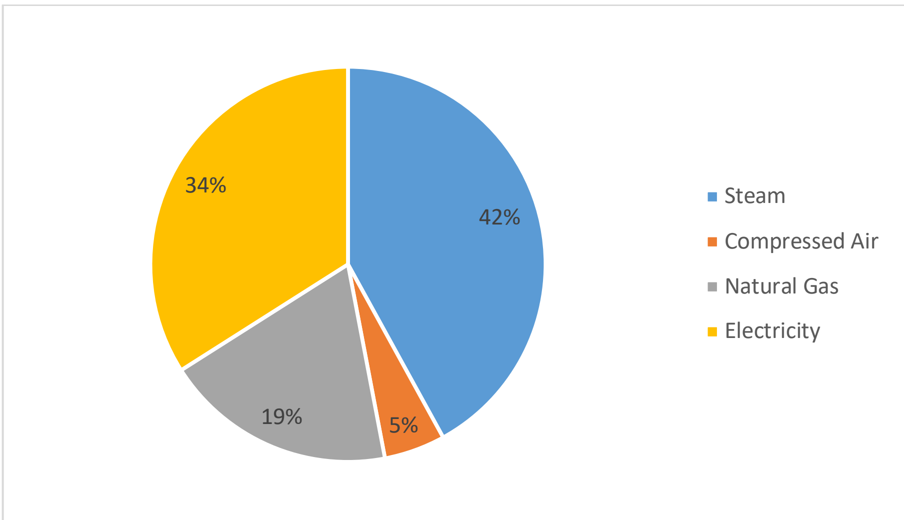


Table 3: Energy consumption breakdown of the Plant (year 2015)

Energy carrier	Energy consumption	Percentage of total consumption
Electricity	31,661 MWh	34%
Natural gas	17,606 m^3	19%
Steam	39,145 MWh	42%
Compressed air	5,114 m^3	5%

Figure 2: Energy consumption breakdown of the Plant (year 2015)



2.2 The energy audit process

The energy audit process developed by Home Appliances Company includes the following phases (Figure 3 and Table 4).

Figure 3: The phases of the energy audit

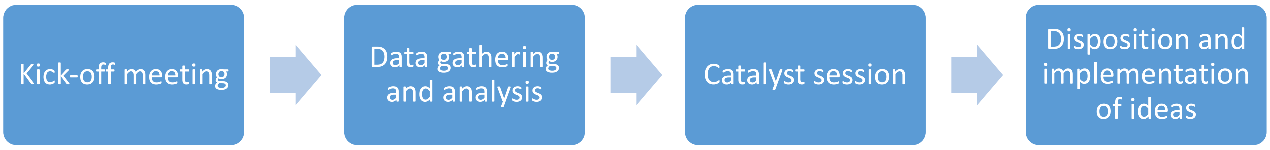


Table 4: Description of each phase of the energy audit process

Phases	Description
Kick-off meeting	• To introduce the energy audit process, providing to the personnel to whom the energy audit is intended an overview of its scope, processes, technical and managerial tools to be used during the following phases. • To identify areas (e.g., in terms of production processes or energy carriers) to be investigated during the following phases. • To identify already available data and, for not-available ones, to define data gathering campaigns. • To assign roles and responsibilities within the Home Appliances Company and define internal milestones and deadlines.
Data gathering & analysis	• To systematize the already available energy consumption data. • To collect the missing energy consumption data. • To conduct a benchmark with other companies in terms of energy consumption patterns and technologies adopted.
Catalyst session	• To generate new ideas for the reduction of energy consumption. • To technically evaluate these ideas.
Disposition & implementation of ideas	• To economically evaluate the generated ideas. • To prioritize and select ideas according to their cost/benefit ratio. • To implement the selected ideas.

2.2.1 The kick-off meeting phase

The kick-off meeting phase was the preliminary step which aimed to introduce and launch the energy audit, engaging the Energy Manager, the HSE Manager, the Operation Manager, the Plant Manager, one person from the General Service Department, one person from the Procurement Department as well as 3 people for each production line involved (Cooking, Refrigeration, Microwaves). Furthermore, a member of the Top Management Team participated in this first phase to endorse the energy audit process and to clarify its strategic importance, consistently with the mission of Home Appliances Company to develop a more sustainable business. This phase was organized as an all-day meeting conducted within the premises of the Plant. People participating to the kick-off meeting were free to propose their ideas for the reduction of energy consumption, without any preliminary consideration of the technicalities and feasibility of each idea proposed. The moderators of this brainstorming phase were the Energy Manager, the HSE Manager, the Operation Manager and the Plant Manager.

In order to spread and share a culture which recognizes the potential benefits of energy efficiency among the people involved in the energy audit, and to make them familiar with the tools and methodologies to be used during the following phases of the energy audit, a specific training program was carried out the week before the kick-off meeting (which took place in January, 2016), by trained and certified external professionals coming from an Energy Service Company (ESCo). The intent of this training program was to disseminate best practices and tools for easing the institutionalization and implementation of EEMs. The training program was intended for all the people coming from the departments involved in the energy audit. It lasted for 2 full days and was delivered inside the premises of Home Appliance Company. During the first day, in the morning session the trainers explained both the importance of reducing the energy consumption and how energy saving positively impacts financial performance and operational costs. The trainers stressed also the importance of energy saving with regard to decarbonization measures and the general trend towards green manufacturing, which is becoming a hot topic for practitioners, policy makers and the public opinion. In the afternoon, the trainers offered a general overview of all the technologies available today to reduce energy consumption, and of the major areas of intervention with specific regard to the manufacturing sector. In the second day of the training program, in the morning the trainers offered a specific insight into Home Appliance Company potential areas of intervention, with regard to the production lines involved in the audit process (i.e., cooking, microwaves and refrigeration). In this session, the typical EEMs adopted in similar manufacturing companies were showed, explaining how and why they positively contributed to the reduction of energy consumption. In the afternoon session, the trainers explained how practically an energy audit could be successfully conducted.

Moreover, in this phase an ad hoc database was created by the Energy Manager, with the aim to identify sources of energy consumption and collect available energy consumption data provided by the Operation Manager. The sources of energy consumption were ranked from 0 to 4 based on the availability of energy consumption data, following this criterion:

0. in case of absence of any energy meter (no consumption data measured);
1. in case of presence of an energy meter, but with consumption data not collected or recorded;
2. in case of presence of an energy meter, and with consumption data periodically and manually collected;
3. in case of presence of an energy meter, and with consumption data automatically recorded in local data loggers;
4. in case of presence of an energy meter, and with consumption data automatically recorded, stored in an ad hoc database and analyzed through an energy management software.

In case no energy consumption data were available, the Plant Manager and Operation Manager launched ad-hoc data gathering campaigns for collecting missing data, working in close collaboration with the three production lines (refrigeration, cooking and microwaves) involved in the energy audit.

2.2.2 The data gathering and analysis phase

This phase involved three people for each of the three production lines, in addition to two external consultants from an ESCo, who worked with people from Home Appliances Company over a period of four weeks (between February and March, 2016). Specific data gathering campaigns were launched for every energy consumption source (i.e., primary processes, assembly lines, and utilities), through the installation of ad-hoc energy meters and other tools such as ammeters and grid analyzers. Often, it happened that portions of the Plant layout for each production line analyzed were missing or incomplete, hampering the clear mapping of the energy flows and consumption points around the Plant. Consumption data, when available and/or measurable (e.g., consumption data for chillers, for presses in the plastic shop, for lighting devices, for compressed air) were gathered into a database to be compared with the equivalent data for other Plants of Home Appliances Company, to create an energy consumption benchmark. Indeed, absolute energy consumption data in a given period, by themselves, do not provide useful information to identify areas of improvement for the different machines and pieces of equipment: such data need to be combined into specific Key Performance indicators (KPIs) to define a more detailed and realistic picture, as shown in the next phase of the audit. The results of the measuring campaigns were analyzed to establish specific improvement measures and carry out an economic and financial analysis of performance improvement projects.

2.2.3 The catalyst session phase

In this phase, a first evaluation of ideas in terms of cost for implementation and technical feasibility was developed by the people involved, i.e., the Energy Manager, the HSE Manager, the Operation Manager, the Plant Manager, plus a representative from the Procurement Department and the Cost Deployment Project Leader, which gave a preliminary evaluation in terms of cost and potential expenditure. The support of two external consultants from an ESCo was important for conducting a detailed technical feasibility analysis of ideas generated internally by Home Appliances Company, with specific regard to (i) assessment of ideas in terms of technical specifications; (ii) estimation of energy savings; (iii) calculation of implementation cost. The people from the ESCo helped Home Appliances Company to assess the most suitable options to build the best business case for valuing the ideas generated and take the final decision with regard to which EEM to implement. Table 5 shows the comprehensive list of EEMs that were identified and the evaluation of their technical feasibility, in terms of (i) level of complexity of the technology involved, (ii) time required for energy consumption data gathering and analysis.

Table 5: List of the EEMs identified and their technical feasibility

Energy Efficiency Measures	Energy source	Technical feasibility
Building LED relamping	Electricity	yes
Installation of new efficient small electric motors (≤5 kW)	Electricity	yes
Installation of new efficient large electric motors (> 5 kW)	Electricity	yes
Replacement of existing chillers	Electricity	yes
Thermal Insulation of 8 big presses (75 kW) in the plastic shop	Electricity	yes
Thermal Insulation of 1 medium press (55 kW) in the plastic shop	Electricity	yes
Thermal Insulation of 2 small presses (45 kW) in the plastic shop	Electricity	yes
Installation of new efficient transformation station	Electricity	yes
Installation of new efficient presses in the metal stamping area	Electricity	yes
Heat recovery from foaming injection process	Electricity	no
Heat recovery from exhaust gas in the enameling process	Natural Gas	yes
Installation of air destratification fans where production lines are located	Heating	no
Installation of new efficient compressed air robotic tools for the handling process	Compressed Air	no
Revamping of roofs	Heating	yes
Revamping of windows	Heating	yes
Revamping of skylights	Heating	yes
Revamping of doors/gates	Heating	yes

Three EEMs have not been considered feasible under a technical point of view (i.e., heat recovery from foaming injection process, installation of air destratification fans, installation of new efficient compressed air robotic tools for the handling process), mainly because the data gathering phase failed to collect relevant data to measure consumption in order to establish specific performance improvement measures and carry out an economic and financial analysis of relevant EEMs.

In this phase, the definition and use of energy KPIs, in addition to the installation of energy meters to measure, track and compare energy consumption, represented an important step in the deployment of the energy audit. It allowed, on one hand, to better understand energy consumption patterns and identify areas of improvement, on the other hand, it gave the opportunity to compare the current energy performance of machines and pieces of equipment with the performance offered by EEMs under evaluation.

Several energy KPIs and energy benchmarking approaches have been developed and used worldwide (Saygin, Worrell, Patel, & Gielen, 2011). Home Appliances Company started from a systematic analysis of these approaches, and identified specific KPIs to analyze energy consumption patterns. These KPIs were:

- energy consumption per unit of production or per hour/day/week;
- maximum power absorbed;

- energy consumption in stand-by mode;
- thermal energy consumption normalized per degree day.

The main goal of this activity was to define a scorecard of KPIs to be applied in different plants of Home Appliances Company. The value associated to each KPI was estimated starting from the information already available or collected from the installed meters (during the Phase 2 of the energy audit), and then compared with the values of the same KPI for other Home Appliances Company's plants located in the EMEA region, with comparable processes. Once the value associated to a KPI for a plant was compared to its equivalent for other plants, it became possible to measure the differences and infer about the areas of improvement and intervention, and it represented therefore an important input for the generation of ideas for reducing energy consumption.

2.2.4 The disposition & implementation of ideas phase

This phase involved a group of 3 technical people, one for each production line (Refrigeration, Cooking, Microwaves). In addition, at the beginning of this phase, the Financial and Procurement departments were involved in the economic evaluation of the ideas. The people involved in this phase analyzed the generated ideas, with the aim to select those to be prioritized and implemented.

The indicator used to evaluate the economic viability of each EEM was the Pay-Back Time (PBT). The PBT of an investment is a measure of the time required to reach the point when the sum of the differential (discounted) cash inflows is equal to the sum of the differential (discounted) cash outflows resulting from an investment, as shown in the following formula:

$$\sum_{t=1}^{PBT} NCF(t)/(1+\mathrm{i})^{\wedge}\mathrm{t} = 0$$

where:

PBT = Pay-Back Time,

i = discount rate,

NCF (Net Cash Flow) = expected net benefit at the end of each year (i.e., differential cash inflows minus the differential cash outflows).

This indicator explains how much time a specific EEM takes to pay back. The maximum PBT to accept the economic feasibility of an investment is called "cut-off time". In the present case study, Home Appliances Company set the cut-off time at approximately 2 years, with a tolerance of few months, to be decided for each EEM. The discount rate adopted by the Home Appliances Company is equal to its Weighted Average Cost of Capital (WACC), i.e., 8%.

The EEMs were prioritized starting from "quick-win" projects, i.e., the ones with the shortest PBT. Home Appliances Company decided not to take into consideration other financial indicators, such as the Internal Rate of Return (IRR) or the Net Present Value (NPV).

Table 6 below shows the results of the economic viability analysis (in terms of PBT) performed after the technical feasibility analysis reported in Table 5 above. Those EEMs that were considered not feasible from a technical point of view have not been subject to the economic viability analysis.

Table 6: Analysis of the Economic Viability of the EEMs

Energy Efficiency Measures	Estimated PBT
Workshop Area relamping (LED technology)	≤2 years
Installation of new efficient small electric motors (< 5 kW)	≤2 years
Thermal insulation of 8 big presses (75 kW) in the plastic shop	≤2 years
Replacement of existing chillers	≤2 years
Installation of new efficient large electric motors (> 5 kW)	3-6 years
Insulation of 2 small presses (45 kW) in the plastic shop	3-6 years
Installation of new efficient transformation station	3-6 years
Installation of new efficient presses in the metal stamping area	3-6 years
Heat recovery from exhaust gas in the enameling process	3-6 years
Insulation of 1 medium press (55 kW) in the plastic shop	≥7 years
Revamping of roofs	≥7 years
Revamping of windows	≥7 years
Revamping of skylights	≥7 years
Revamping of doors/gates	≥7 years

3. Results and discussion

3.1 Results

In this section is provided a description of the four EEMs that Home Appliances Company decided to implement, given their PBT of around 2 years.

3.1.1 The relamping of the 55,000 m^2 workshop area

The relamping has been realized through the conversion of the existing lighting system (based on fluorescent lighting sources) into LED technology.

Table 7: Details about the Relamping of the workshop area

	AS IS scenario (Fluorescent lighting sources)	**TO BE scenario (LED lighting sources)**
No. of lighting sources	673	407
Installed capacity (kW)	196 kW	71 kW
Tot. consumption (kWh/year)	883,000 kWh/year	320,000 kWh/year
Saving (kWh/year)	563,000 kWh/year	
Electricity price (€/kWh)	0.15 €/kWh	
Total electricity cost (€/year)	132,450 €/year	48,000 €/year
Total saving (€/year)	84,450 €/year	
Cost of investment (€)	150,000 €	
PBT (years)	2 years	

The LED lighting system was designed in a way to satisfy the requirements set by the European standard EN 12 464-1 for Lighting of the Workplace, which deals with the quality aspects of a lighting installation for workstations (European Standard EN 12464 - 1, 2016). Furthermore, the LED system now works with automatic lighting control systems such as movement sensors, voltage reduction units and time of day control timers (with the possibility to set the timing from remote), for a proper switch off of the lights according to the working shifts. This solution would not be feasible with fluorescent lights because a high frequency of on/off dramatically decreases their life span.

3.1.2 The replacement of existing electric motors

The replacement of existing small size (< 5 kW) electric motors in Class 1 of the International Efficiency class (IE1) with new high efficient motors in Class 3 (IE3) (International Electrotecnical Commission, 2014), which are on average 12% - 15% more efficient than previous IE1 motors, generates savings for approximately 2,800 kWh per year per motor, with PBT shorter than 2 years for electric motors working approximately 4,000 h/year. Table 8 reports the cost breakdown, in percentage terms, associated to a small IE3 electric motor working 4,000 h/year.

Table 8: Cost breakdown, in percentage terms, associated to a small IE3 electric motors.

Operating hours per year	4,000 h
Purchase price	1.9%
Maintenance and repair	1%
Energy costs	97.1%

Table 9 reports the details about the replacement of 50 small IE1 electric motors with new IE3 motors.

Table 9: Details about the replacement of 50 small IE1 electric motors

	AS IS scenario	TO BE scenario
Operating hours (h/year)	4,000 h/year	
Rate Power (kW)	4 kW	
Electricity Price (€/kWh)	0.15 € /kWh	
No. of motors	50	
Consumption (kWh/ton)	7 kWh/ton	6.3 kWh/ton
Consumption (kWh/ton) per 4,000 hours	28,000 kWh/ton	25,200 kWh/ton
Saving (kWh h/year) per each IE3 motor	2,800 kWh/year	
Total saving (kWh h/year) per 50 IE3 motors	140,000 kWh/year	
Total saving (€h/year) per 50 IE3 motors	21,000 € h/year	
Cost of investment (€)	15,000 €	
PBT (year)	1 year	

3.1.3 The replacement of existing chillers with a new air conditioning system

The replacement of existing chillers with a new air conditioning system equipped with a rotary-screw compressor and brushless motor in direct current (DC), with an electric controller provided with a specific management software and remote control system., reduced the installed capacity from 213 kW to 134 kW, and the energy consumption from 426,000 kWh/year to 268,000 kWh/year, with a PBT of about 25 months. Table 10 reports the details about the EEM regarding the replacement of existing chillers.

Table 10: Details about the replacement of existing chillers

	AS IS Scenario	TO BE scenario
Working hours (h/year)	2,000 h/year	
Electricity price (€/kWh)	0.15 €/kWh	
Installed capacity (kW)	213 kW	134 kW
Consumption (kWh/year)	426,363 kWh/year	268,000 kWh/year
Tot. electricity cost (€/year)	63,954 €/year	40,200 €/year
Saving (kWh/year)	158,363 kWh/year	
Total saving (€/year)	23,754 €/year	
Cost of investment (€)	€ 50,000	
PBT (year)	2 years	

3.1.4 The thermal insulation of 8 big presses in the plastic shop for fridges manufacturing

Presses are responsible for 52% of the total consumption of the refrigeration production line. This is mainly due to the quantities of presses installed. The actions considered to reduce energy consumption were related to the warm up phases of the presses, through a proper insulation of presses using thermo-covers. The relevant factors impacting the consumption of each press were the number of cycle per month, and the rate power (kW). As an example, a big press with a rate power of 75 kW working 5,280 hours/year consumed 231,146 kWh/year. Using thermos-covers, the insulation led to a reduction of the ramp up time from 35 minutes to 25, which meant 4kWh of saving for each ramp up phase, and to a reduction of 50% of the consumption of the heating element (2kWh), both during working time and standby. This solution allowed to save approximately 23,000 kWh/year per each of the eight big presses, with a PBT shorter than 2 years.

Table 11 reports the details about the savings generated by the thermal insulation interventions.

Table 11: Details about the thermal insulation

	AS IS Scenario	TO BE Scenario
Rate Power (kW)	75 kW	
Number of big presses	8	
Working hours (h/year)	5,280 h/year	
Electricity price (€/kWh)	0.15 €/kWh	
Consumption (kWh/year) per press	231,146 kWh/year	208,146 kWh/year
Saving (kWh/year) per press obtained with the insulation process	23,000 kWh/year	
Saving (kWh/year) per 8 presses	184,000 kWh/year	
Saving (€/year) per 8 presses	27,600 €/year	
Cost of investment (€)	€ 20,000	
PBT (year)	1 year	

Thanks to the adoption of the four EEMs described above, Home Appliances Company has saved approximately 1,000,000 kWh/year (1,000 MWh/year), equal to more than 2% of the overall Plant energy consumption, as shown in Table 12.

Table 12: Total savings from the adoption of the four EEMs

Tot. saving (kWh/year)	1,045,000 kWh/year
Electricity price (€/kWh)	0.15 €/kWh
Tot. saving (€/year)	156,750 €/year
Tot. cost of investment (€)	235,000 €
PBT (years) for the four EEMs	< 2 years

3.2 Discussion

The case study provides useful insights about how an energy audit can help overcome the most critical barriers to the adoption of EEMs in a manufacturing company. The goal of developing a structured energy audit methodology was, indeed, twofold: (i) to realize cost-saving opportunities in the short term, (ii) to create an acknowledgement of the energy efficiency topic and related cost saving opportunities inside the Home Appliances Company. Table 13 reports the main barriers faced by Home Appliances Company in the implementation of the EEMs and it summarizes how the audit process helped overcome them.

Table 13: Barriers to EEMs adoption and how the energy audit helped overcome them

Category	Barrier	How the energy audit helped overcome the barriers
Behavioral	Lack of interest in energy efficiency	• Early involvement of personnel in the energy audit process through cross-functional meetings.
	Other priorities	• Early involvement of personnel in the energy audit process through cross-functional meetings. • Top management commitment.
	Lack of sharing the objectives	• Top management commitment.
	Divergent interests	• Early involvement of personnel in the energy audit process through cross-functional meetings. • Top management commitment.
	Complex decision chain	• Clear definition of roles and responsibilities within the energy audit process.

Barriers related to competence	Identifying the inefficiencies	• Installation of energy meters and energy management software. • Energy consumption benchmarking through energy KPIs. • Training and communication programs.

As it is clear from Table 13, the most critical barriers to the implementation of EEMs were related to behavioral aspects. As noted by (Trianni, Cagno, & Farnè, 2016), the highest resistance to the adoption of EEMs is faced at the beginning of the energy audit process. It refers to lack of awareness about the needs in terms of energy efficiency and the opportunity for energy saving resulting from the adoption of EEMs, as well to lack of commitment of the people involved to pursue these opportunities. The energy audit designed and implemented by Home Appliances Company takes this aspect into particular account and kicks-off with a number of cross-functional meetings, which involve people coming from different departments, who are free to propose their ideas for energy saving with an informal approach, without taking into account technical constraints or cost considerations which might hinder creativity and reduce the commitment of key people to participate actively in the audit process. In parallel, Home Appliances Company launched an ad hoc training program at the beginning of the audit, which was designed to increase the awareness of the key people involved about the impact of energy costs on total operational costs, and of the importance of improving energy efficiency through the adoption of EEMs. The employees of Home Appliances Company had indeed an insufficient level of training on the available technologies and solutions for EEMs. Furthermore, they had limited motivation toward the implementation of EEMs, mostly related to a lack of awareness of the benefits that these measures can allow to achieve. In the words of the Energy Manager, "the training program delivered right before the kick-off of the energy audit helped generate awareness in the people involved, thus creating positive effects in terms of commitment throughout the energy audit process, when energy consumption data had to be gathered and analyzed". Data gathering and analysis, indeed, tend to be a time-consuming activity, which requires a proper commitment of the people involved. It is known, indeed, that most of the delays in an energy audit process are due to problems and lack of commitment during the data collection phases.

Therefore, involving all the relevant personnel since the early phases of the energy audit helped Home Appliances Company to gather consensus and commitment, fostering an internal positive attitude towards energy efficiency and the required EEMs. In this regard, the HSE Manager noted that "people attending the training program were not aware of the direct connection between energy saving and carbon footprint in Home Appliances Company, and did not consider how of EEMs would help encompass the new general customers' demand for a sustainable and eco-friendly product portfolio". Training, indeed, "plays the lion's part in tackling the most relevant barriers at the very beginning of the decision making process, thus releasing enterprises from the status of being unaware of either the relevance of energy efficiency or its viable opportunities" (Trianni, Cagno, & Farnè, 2016).

Another important barrier that was evident in the case study was related to a lack of knowledge about the real energy consumption of the different machines and pieces of equipment in the Plant. This was due to the absence of specific energy measurement systems for each machine (especially the eldest ones) and, more broadly, to a lack of a clear mapping of the Plant's layout, in terms of location of machines and meters. Indeed, due to the complexity of the Plant, which has been growing along the last fifty years, meters were not installed on all the machines and production lines. The majority of the 180 electric meters installed measured the energy consumption of relevant portions of the Plant (e.g., assembly lines), but offering only aggregate data. Although the awareness of the importance of a detailed system for measuring punctual energy consumption for the successful implementation of EEMs, the situation of Home Appliances Company is common to many industrial and manufacturing companies (Salonitis & Ball, 2013). Due to the costs, time and complexity that overcoming this lack of knowledge requires, very often the decision-making process that leads to the choice and implementation of EEMs is accelerated without properly collecting these data. In this regard, the Operation Manager said that "measuring punctual energy consumption is not an easy task in a Plant engineered more than fifty years ago, when the only company's concern was to increase the number of products manufactured per day, to satisfy a roaring demand for home appliances. There was no real internal concern about manufacturing costs, the breakdown of operational costs was not well investigated and analyzed to identify inefficiencies and areas of improvement. Specifically, energy efficiency was not considered as an issue at all, and this has characterized the internal attitude of Home Appliances Company until 5-6 years ago. This explains why having a proper measurement system in place for each machine is simply unrealistic". The case of Home Appliances Company points to the importance of taking time to collect energy consumption data, by implementing a proper technological infrastructure to this aim. Home Appliances Company decided indeed to implement a set of meters and a dedicated cloud computing software, with the aim to record energy consumption data and deliver automatic monthly reports with detailed consumption analysis and optimization patterns. In parallel, Home Appliances Company launched an internal recognition process, adopting additional devices (such as ammeters and grid analyzers), to measure the punctual consumption of machines. This activity was not only useful to collect more precise data to properly evaluate the benefits of adopting EEMs, but it also helped increase the awareness of the key people involved in the audit about the importance and value of EEMs. As noted by the Plant Manager, during an open conversation had together with the Operation Manager and one of the authors, "the internal recognition process that we have launched to measure the consumption of machines is something that needs to become part of the regular procedures of Home Appliances Company. It has to be standardized and deployed during the following years, to build a clear consumption data-log, useful to understand consumption patterns and fully exploit the potential of cloud computing software and data-analytics". Another important barrier to the adoption of EEMs refers to the problems linked to the identification and understanding of the magnitude of the energy inefficiencies, highlighted by a properly designed campaign of data collection. In this regard, the energy audit process implemented by Home Appliances Company introduced a benchmarking approach, whereby the collected data were used to create set of KPIs to be compared with the value of the same KPIs for other plants of the Home Appliances Company (El Maraghy, Youssed, & Marzouk, 2016). Although creating such a scorecard of KPIs required a strong collaboration among the different departments involved (May, Barletta, Stahl, & Taisch, 2015), and a strong effort for collecting data for comparable plants, this benchmarking exercise was very useful to clarify and to clearly communicate the need for introducing EEMs to all the key people involved. The value of these benchmarks is well known in research applying behavioral approaches to the study of the adoption of green technologies and energy efficiency solutions (Cataldo, Scattolini, & Tolio, 2015). Specifically, as noted by the Energy Manager, "the benchmark with other plants belonging to the EMEA region of Home Appliances Company was a key point in the success of the energy audit. Indeed, the people involved showed a high commitment and enthusiasm in comparing the Plant's consumption data with similar data coming from other plants located in Italy and abroad. Moreover, some of the personnel involved in the process had the chance to personally travel to other plants to understand comparable consumption patterns and machines' performance. This activity helped consolidate the positive cultural attitude toward the energy audit process that was being created, and spread the awareness of the potential EEMs that could be adopted to realize effective energy savings".

Furthermore, Home Appliances Company suffered from another typical barrier to the adoption of EEMs, i.e., the presence of divergent interests between the Energy Manager and the Operation Manager (and their respective departments), with the operations team more focused on the core business of the company. In an interview held with the Operation Manager, he stressed the fact that "although energy efficiency has become an important issue in the last years - and today there is a lot of pressure coming from the top management team on this topic - my main concern remains on how to keep production going to meet the demand in the most effective way. Therefore, switching off machines for installing meters and other devices, as well as having people around the workshop area asking for consumption data, to me is a hassle because I have to reschedule production process and have my team working extra hours". The case study shows that divergent interests among different departments can be overcome by ensuring a continuous and strong commitment from the top management throughout the energy audit process, which gives clear indications about the objectives the company is determined to pursue in terms of energy efficiency and the time and conditions within which these aims have to be achieved. In the interview held with one top manager from Home Appliance Company, he explained that "nowadays the central headquarters, and not only the EMEA area, is well committed to performing energy audits in all the plants worldwide. This is part of the general effort Home Appliances Company is undertaking to investigate all the potential opportunities for cost reduction, specifically in countries like Italy where energy prices are higher than other countries belonging to the same region. It becomes therefore of paramount important to have the full commitment of all the people involved in finding, investigating and valuing opportunities to reduce costs through energy savings". A related problem to the one of the divergent interests among different departments stems from the complex decision chain which leads to the evaluation and implementation of EEMs, due to the relative novelty of the energy audit process and to the existence of an unstructured decision making process across the energy audit. In Home Appliances Company, this problem was fixed by paying special attention to identify precise roles and responsibilities for the different people involved, as it is clear in the words of the Energy Manager, who underlined that "the top management of Home Appliances Company cascaded a specific message alongside an ad-hoc internal procedure according to which, during the execution of the energy audit, the highest priority should be given to the activities related to the audit. Therefore, a collaborative attitude among different teams and departments was encouraged, together with a proactive participation of the people involved in the data gathering and analysis phase, supporting and facilitating the works of the external consultants".

Finally, it is interesting to highlight that Home Appliances Company purposefully decided to select, among the viable EEMs identified in the energy audit process, those characterized by the shortest PBT, without considering other parameters such as NPV and IRR. Indeed, Home Appliances Company wanted to start with a small number of energy efficiency initiatives that deliver fast and visible returns, to be used as "quick-win" projects which communicate and prove in a tangible way, to the entire organization, the benefits and feasibility of EEMs. This seems to be especially important as an approach to overcome inertia to change and lack of interest toward energy efficiency, as it is clear from the words of the Energy Manager, according to whom "showing to the entire organization, and specifically to the Financial Department, that the energy audit process is not just a theoretical exercise, but something that can add a relevant contribution to the reduction of the production cost in the short term, and that the specific investments undertaken can be paid back in less than two years, was of extreme importance in gaining the support and collaboration of all the people involved in the energy audit process. The adoption of quick-win EEMs would then pave the way to the realization of more complex and expensive projects, which may be directly funded by the cost savings generated by the quick-win projects now adopted".

4. Conclusions

This paper presents and discusses a novel methodology for energy audit developed and implemented by a large manufacturing company active in the home appliances industry. This energy audit was effective in overcoming the typical barriers that hamper the adoption of EEMs in the first phases of the energy audit process, as reported in Table 13 above, by introducing: (i) a cross-functional, informal meeting at the beginning of the audit, which is useful to create commitment among the key people involved in the audit; (ii) a set of training sessions designed to increase the awareness of the key people involved in the audit about the impact of energy costs on total operational costs, and of the importance of improving energy efficiency through the adoption of EEMs; (iii) a proper technological infrastructure made of a set of meters and a cloud computing software, which was used to collect detailed energy consumption data and deliver automatic monthly reports with detailed energy consumption analyses; (iv) a benchmarking approach, through which detailed energy consumption data were used to create set of KPIs to be compared with the value of the same KPIs for other plants of the company and for the plants of similar manufacturing companies; (v) a criterion for selecting EEMs (i.e., PBT) which prioritizes those energy efficiency initiatives that deliver fast and visible returns, to be used as "quick-win" projects which communicate and prove in a tangible way the benefits and feasibility of EEMs.

This case study adds to the existing knowledge by studying the case of a company in the manufacturing industry, a sector that has been relatively overlooked by industrial energy management scholars so far. Moreover, it is one of the very few studies, to the best knowledge of the authors, that explicitly look at how energy audit can be designed and used to overcome the typical behavioral barriers which hamper the adoption of EEMs since the first steps of the decision making process. Of course, given the research methodology used in this paper, the findings cannot be generalized to any population of companies or industries. The aim of this research was to produce new empirical evidence which will inform future researches on energy audits and their role in overcoming barriers to the implementation of EEMs in manufacturing companies. Furthermore, the present case study may offer interesting insights to energy managers working in manufacturing companies and involved in designing and implementing effective energy audits.

Besides its theoretical and practical implications, the paper points to some interesting opportunities for future research. First, in this paper energy efficiency in a home appliance company is studied by focusing on the production processes taking place in its plant. However, from a broader perspective, it is important to keep in mind that the majority of the energy impact of a home appliance takes place during its in-home use, and it is generally 10 to 20 times higher than the energy impact created during the production, distribution and disposal phases of the life cycle. In this regard, as a further stream of research, it would be interesting to study how a company can implement the novel concept of Resource Conservative Manufacturing, or ResCoM (May, Barletta, Stahl, & Taisch, 2015), as a means to rethink and redesign the supply chain model of manufacturing companies towards a new approach to production, where product and supply chain design are strictly integrated to minimize energy consumption and prevent excess in waste production. Second, corporate social sustainability, which has become essential to most companies in the last decades, goes beyond the mere consideration of EEMs, stipulating that environmental requirements should be incorporated into diverse business processes (Brones, Monteiro de Carvalho, & de Senzi Zancul, 2016). Therefore, a further line of research could study how to effectively integrate energy efficiencies issues into broader corporate social responsibility processes, thus helping manufacturing companies evolve toward a more effective sustainable manufacturing approach. Third, it would be interesting to conduct further analysis in other manufacturing companies and sectors to understand whether and how the principles which underlie the audit approach developed in Home Appliances Company can be applied in other contexts, therefore assessing its external validity and generalizability.

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