Introducing a New Perspective for the Economic Evaluation of Industrial Energy Efficiency Technologies: an Empirical Analysis in Italy

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ABSTRACT

An empirical analysis involving 130 Italian industrial firms showed that the economic viability of investments in energy efficiency technologies is mostly evaluated through indicators such as Pay-Back Time (PBT) and Internal Rate of Return (IRR), whose acceptability thresholds are affected by decision makers' risk propensity and other contingencies, such as the firm's financial health.

Our analysis suggests that these evaluation approaches hinder the adoption of several energy efficiency technologies, such as combined heat and power (CHP) plants, electric motors, variable speed drives (VSD), uninterruptible power supply (UPS), which are in fact economically viable if analyzed from a life cycle cost perspective, but appear to be unsustainable if analyzed through PBT or IRR indicators.

This paper addresses this issue by introducing a new evaluation perspective for investments in industrial energy efficiency technologies. Inspired by the life cycle economic assessment methodology for energy production plants – the so-called Levelized Cost Of

Electricity (LCOE) - our indicator, called Levelized Energy Efficiency Cost (LEEC), correlates the energy savings that can be achieved through the implementation of an energy efficiency technology and the total costs incurred throughout the entire life cycle of the technology, e.g., initial investments, Operation & Maintenance (O&M), disposal costs. Accordingly, a technology can be considered as economically viable if the LEEC is lower than the energy price incurred by the firm, because in this case the economic benefits resulting from the energy saving due to the adoption of the technology is higher than the cost paid to obtain and operate it during its entire life cycle.

The application of such methodology in different Italian energy-intensive industrial sectors (e.g., automotive, cement, iron&steel and pulp&paper) shows that most of the considered technologies are economically viable, from the life cycle perspective on which this methodology is grounded. Therefore we suggest that the LEEC is a clear and simple tool for companies' decision makers to evaluate energy efficiency projects, to be used in combination with more traditional PBT or IRR indicators to gain a better understanding of the real economic viability of energy efficiency technologies.

KEYWORDS: economic evaluation, energy efficiency, feasibility study, LCA, industrial sector.

1. Introduction

In recent years, energy efficiency has become a hot topic in national and international policy discussion, being recognized as one of the most important factors for environmental and economic sustainable growth (Geller et al, 2006; Ministero dello Sviluppo Economico, 2013). The industrial sector represents one of the greatest potential sources of energy efficiency. For instance, in Italy the industrial sector accounts for 24% of the national energy consumption (Enea, 2014), and its weight is similar to other European countries such as France (18%), Germany (25%) and UK (19%).

The European Union, through the well-known "20-20-20 package" (European Commission, 2008), settled a non-binding target of 20% improvement in energy efficiency of the EU compared to projections for 2020, and recently approved the Energy Efficiency Directive - 2012/27/EU (The European Parliament and the Council of the European Union, 2012) -, which indicates to Member States how to achieve the 20% target on energy efficiency by 2020. Each Member State shall set its own non-binding national energy efficiency target, subsequently monitored by the European Commission. If necessary, the Commission will intervene with binding measures and adjustments for those nations that fall short of meeting their performance targets. Member States have brought into force the laws, regulations and administrative provisions necessary to comply with this Directive before 5 June 2014. Among the others, the Directive requires industrial and other large enterprises to conduct energy audits. Recently, a new framework in order to achieve a more competitive, secure and sustainable energy system and to meet EU 2050 greenhouse gas reductions target (European Commission, 2011) has been agreed upon by EU countries, which includes new targets amending the former ones: a 40% cut in greenhouse gas emissions compared to 1990 levels, at least a 27% share of renewable energy consumption and at least 27% energy savings compared with the business-as-usual scenario and policy objectives for the period between 2020 and 2030 (European Commission, 2014).

The Italian National Energy Strategy prioritizes energy efficiency as a cornerstone for a secure energy supply, for reducing energy costs for citizens and businesses, and for ensuring environmental protection through greenhouse gas reductions (Ministero dello Sviluppo Economico, 2013). Among the current energy efficiency incentives available in Italy, the White Certificates scheme[1] is the most relevant for the industrial sector. Also thanks to a proactive legislation, important results have been already achieved in Italy, which ranks second worldwide among the most efficient countries (ACEEE, 2014).

However, much remains to be done, not only at Italian level, but also at the European one. Indeed, there are several barriers to energy efficiency, one being the proper economic evaluation of investments in energy efficiency technologies. Starting from an empirical analysis of Italian industrial companies, the aim of this paper is to analyze the decision making process for investments in industrial energy efficiency technologies, with a focus on the economic evaluation methods currently used and their drawbacks. The analysis focuses on the Italian market for energy efficiency because it is a relatively well-developed one and may be considered as a reference point for less-developed countries (ACEEE, 2014). In this paper, a new indicator - the so-called Levelized Energy Efficiency Cost - is proposed and applied in different industrial fields and for different technologies that can be used in industrial processes. The energy consumption of industrial processes represents the highest part (around 90%) of the overall energy consumption in the Italian industrial sectors, with the remaining part due to the energy needs of industrial buildings.

[1] White Certificates, also known as "Energy Efficiency Certificates" (EEC), are tradable instruments giving proof of the achievement of end-use energy savings through energy efficiency improvement initiatives and projects. The white certificates scheme was introduced into the Italian legislation by the Ministerial Decrees of 20 July 2004.

The paper is organized as follows. Section 2 contains a literature review on the main indicators used to evaluate the economic viability of energy efficiency technologies. Section 3 presents an empirical analysis of the Italian industrial firms aimed at identifying the most common criteria used to evaluate investments in energy efficiency technologies. Section 4 introduces a new indicator, called Levelized Energy Efficiency Cost, to evaluate the economic viability of energy efficiency technologies and compare the economic viability of different energy efficiency technologies calculated with a traditional methodology (i.e. PBT) and with the LEEC indicator. Finally, concluding remarks are presented in Section 5.

2. Literature review

This section contains an analysis of the literature on the main indicators used to evaluate the economic viability of energy efficiency technologies, in both industrial as well as other sectors, such as households, services and public sectors.

In particular, we conducted an extensive review of the relative literature, considering the leading journals on this topic (Applied Energy, Applied Thermal Engineering, Energy, Energy and Buildings, Energy Conversion and Management, Energy Procedia, Renewable and Sustainable Energy Reviews, Renewable Energy, Sustainable Energy Technologies and Assessments). In addition to this, we searched in Google Scholar publications with “energy efficiency”, “energy efficiency technology”, “economic evaluation” and “feasibility study” among the keywords. This has led to the identification of many additional papers and highly cited books and book chapters.

From the 63 publications identified and analyzed in our literature review, these indicators emerge as most commonly used to evaluate the economic viability of energy efficiency technologies:

- Net Present Value (NPV);
- Net Present Cost (NPC);
- Pay-Back Time (PBT);
- Internal Rate of Return (IRR).

The NPV indicators uses the discounted differential cash flows generated by the investment during its operation, applying a discount rate that measures the risk level of the investment (Tudisca et al. 2014). In other words, the NPV compares the present values of the net cash inflow forecasted for the future, with the initial capex investment to determine the profitability of the investment or project (Samba Sowe et al. 2013).

The NPV is calculated as follows:

$$NPV = \Sigma_{t=0}^{T} CF_t/(1+i)^t$$

T = project duration in years,

i = discount rate,

CF (Cash Flow) = expected net benefit at the end of the each year.

With reference to energy efficiency investments, the annual cash flow includes the costs of the preliminary activities (before the implementation of the energy efficiency technology, such as audit, design and planning), the cost of purchase and installation of the energy efficiency technology (net of funds eventually obtained through third party financing) and the annual cost of operation and maintenance of the energy efficiency technology (including the cost of debt due to third party financing and the repayment of the obtained funds) as cash outflows, and the monetary value of the annual energy savings as cash inflows. Incentives may also be considered as cash inflows (van Blommestein and Daim, 2013). Besides, T represents the expected useful life of the energy efficiency technology. According to this method, an investment is acceptable if the NPV is positive. Morrone et al (2014), Bartela et al. (2014), Vahl et al. (2013) have adopted, among the others, NPV as the indicator to evaluate the economic feasibility of energy efficiency investments. A first issue related to NPV calculation regards cash flow estimation, which is inherently uncertain. Second, companies have different ways of identifying the discount rate, although a common method entails using the expected return of other investment choices with a similar level of risk (Xinjing Zhang et al. 2014).

A similar tool for evaluating energy efficiency investments is the Net Present Cost (NPC), which represents the total discounted cost of an asset during its entire lifetime (Rohani et al. 2013). Such costs refer to the cash outflows mentioned above for the Net Present Value calculation. When comparing two or more alternative investments, the one with the smallest NPC is preferred. Ren and Gao (2010), Tempesti and Fiaschi, (2013) and Diez et al. (2009) have adopted, among the others, NPC as the indicator to evaluate the economic viability of energy efficiency investments.

The Pay-Back Time (PBT) of an investment is a measure of the time that is required to reach the point at which the sum of the differential cash inflows (discounted or not discounted) is equal to the sum of the differential cash outflows (again, discounted or not discounted). Both cash inflows and outflows are the same as the ones mentioned above for the NPV calculation. Differently from NPV, the PBT is more subjective in its application, as the decision-maker has to define a maximum acceptable time (generally called cut-off time) to define the economic feasibility of an investment. As will be discussed ahead, in the Italian industrial field a typical acceptable payback threshold is around 2-3 years. The PBT is often used because it is easy to apply and understand for the decision maker. Wong et al. (2007), Aste et al. (2012), Salata et al. (2014) have adopted, among the others, PBT as the indicator to evaluate the economic viability of energy efficiency investments.

The Internal Rate of Return (IRR) is a measure of the average profitability of an investment, because it represents the discount rate that adjusts future cash flows so that they are equal to the investment outlay. Both cash inflows and outflows are the same as the ones mentioned above for the NPV calculation. The IRR is a relative indicator therefore, a subjective threshold has to be defined for the investment economic evaluation (Tudisca et al. 2014), such as the cost of capital[2]. Kempegowda et al. (2012), Nikolaidis et al. (2009), Vahl et al. (2013) have adopted, among the others, IRR as the indicator to evaluate the economic viability of energy efficiency investments.

From this brief analysis it clearly emerges that PBT, NPV and NPC are the most used indicators in the papers considered in our literature review (they are used respectively in 41%, 27% and 21% of the analyzed papers), followed by the IRR (11% of the analyzed papers). Table 1 provides more details about the results of this literature analysis, considering different application fields (i.e. distinguishing between industrial sectors and buildings, i.e. households/services/public sectors buildings) and different energy efficiency technologies (e.g., CHP plants, heat pumps, electric motors).

Table 1. Summary of the results of the literature review.

[2] The cost of capital is defined as the cost of a company's funds, including both debt and equity.

Energy efficiency technology	**NPV**		**NPC**		**PBT**		**IRR**	
	Production processes applications	Buildings applications	Production processes applications	Buildings applications	Production processes applications	Buildings applications	Production processes applications	Buildings applications
CHP plants	(A.Verbruggena et al., 1993) (G. Streckiene et al., 2009) (R.S. Kempegowdaa et al., 2012) (Q. Bartela et al., 2013) (A.S. Osikowska et al., 2013)	(R. Possidente et al., 2005) (R. L. Vollaro et al., 2013)	(R. E. Klaassena and M. K. Patel, 2012) (D. Tempesti and D. Fiaschi, 2012)	(H. Ren and W. Gao, 2009)	(C.D.Monè et al., 2000) (Zhi-Gao Sun, 2006) (C. Rosellia et al., 2009) (G. Streckiene et al., 2009) (F. Teymouri-Hamzehkolaei, 2011) (M. Lantz, 2011) (G. Conroy, 2013) (Q. Bartela et al., 2013)	(R. Possidente et al., 2005) (Zhi-Gao Sun, 2006) (H. Ren and W. Gao, 2010) (R. L. Vollaro et al., 2013)	(I. Keppo and T. Savola, 2006) (R.S. Kempegowdaa et al., 2012)	(R. L. Vollaro et al., 2013)
Heat pumps	(S. Sanaye and B. Niroomand, 2009) (H. Li et al., 2011) (B. Hebenstreit et al., 2012) (B. Morrone et al., 2014)	(Y. Nikolaidis et al., 2008) (R. M. Lazzarin, 2011) (R. Thygesen and B. Karlsson, 2012)	(F. Karaca et al., 2002) (M. A. Lambert and A. Beyene, 2007) (E. Díez et al., 2009) (S. Sanaye and B. Niroomand, 2010) (M. van der Pal at al., 2013) (I. J. Esfahani at al., 2013) (E. Khorasaninejad and H. Hajabdollahi, 2013)	(S. Sanaye and B. Niroomand, 2008) (S. Zhanga et al., 2011) (H. Sammouda and R. Chargui, 2014)	(H. Esena et at., 2006) (G. Mader et al., 2013) (M. De Carli et al., 2013) (S. M. A. Rahman et al., 2013) W. Wu et al., 2013)	(S. Sanaye et al., 2009) (R. M. Lazzarin, 2011) (U. Desideri et al., 2011) (Y. Guo et al., 2011) (M. Qu et al., 2012)	(S. Spoelstra et al., 2002) (S. M. A. Rahman et al., 2013) (B. Morrone et al., 2014)	(H. Sammouda and R. Chargui, 2014) (Y. Nikolaidis et al., 2008)
Lighting	-	(N. R. Velaga and A. Kumar, 2012) (F. P. Vahl et al., 2013)	-	-	-	(M. S. Wu et al. 2009) C. K. Gan et sl. 2012) (F. Salata et al., 2014)	-	(F. P. Vahl et al., 2013)
Electric motor	(M. A. de Paiva Delgado and M. T. Tolmasquim, 2001)	-	-	-	(V. Prakash et al., 2008) (A. B. Avaci et al. 2012)	-	-	-
UPS	(X. Zhang et al., 2014)	-	L. Xiangli and Q. Hanhong, 2012)	-	(H. Jawaida, 2013)	-	-	-
Compressed air	-	-	(R. Dindorf, 2011)	-	(A. Yucekaya, 2013)	-	-	-
Other technologies for thermal energy savings	(C. Cormos, 2014)	(A. M. Papadopulos et al., 2002) (N. Aste et al., 2012)	-	-	-	(I.L. Wong and P.C. Eames, 2007) (F. Balo, 2014)	-	-

3. Empirical analysis

This section contains the results of the empirical analysis focused on Italian industrial firms and conducted to identify the most common criteria used to evaluate investments in energy efficiency technologies. To this purpose, we conducted interviews with 130 companies that are representative of the different industrial sectors in Italy. Within each industrial sector, firms to be interviewed were chosen among the ones with the highest turnover in each sub-sector, because on average they are the most proactive toward energy efficiency investments, due to the high energy bill (Energy&Strategy Group, 2012), and have more than one production plants. Moreover, such firms have already implemented more than one energy efficiency technology in the last 7 years, as shown by the transactions of White Certificates (Gestore Mercati Energetici, 2015). The most common energy efficiency technologies already implemented by the Italian industrial firms in our sample are: (i) replacement of old lighting systems with LED technology; (ii) improvements in compressed air systems; (iii) technologies for heat recovery from production processes; (iv) replacement of obsolete electric motors with more efficient ones (e.g., "IE3" class according to the Regulation EC No 640/2009); (v) installation of CHP plants. For each company, the Energy Manager[3] has been targeted for the interviews, or alternatively other people (such as the Operation Manager or Facility Manager) in those cases in which the Energy Manager was not available or not present into a company's organizational chart.

Table 2 provides details about the interviewed companies.

Table 2. Characteristics of the interviewed companies.

[3] The Energy Manager is the person that, within a company's organizational chart, is typically in charge for the management of the energy issues and is usually involved in energy efficiency projects.

Industry	**Number of companies interviewed** [#]	**Average annual turnover** [million €]	**Market coverage** [ratio between the turnover of companies interviewed and the industry turnover]	**Average annual energy bill** [million €]
Food&beverage	20	1,060	19%	21
Textile industry	10	450	7%	9
Pulp&paper	18	395	35%	24
Chemical and Petrochemical	8	1,380	6%	30
Metallurgy	25	900	40%	56
Buildings materials	15	330	18%	25
Mechanical	34	1,720	19%	26

Table 3 contains the protocol that was used during the interviews to support them.

Table 3. Interview protocol.

Topic	**Content**
Topic #1 "Description of the energy efficiency technologies implemented"	• Which are the main characteristics of the production processes, especially in terms of main stages and level of energy consumption? • Which energy efficiency technologies have been already implemented within the company'? Please distinguishing between "production process" and "building applications". • Which energy efficiency technologies have been chosen? Why (because of investments economics, providers availability, technology knowledge within the company)? • How many sites have been included? • Which are the main benefits achieved through the energy efficiency technologies implementation?
Topic #2 "Description of the decision making process that has led to the decision to install the energy efficiency technologies"	• Can you describe the typical decision-making process for the implementation of an energy efficiency technology? • Which are the figures within the company's organizational chart generally promoting the implementation of energy efficiency technologies? • Which are the figures within the company's organizational chart generally having the final decision-power about the implementation of energy efficiency technologies? • Which external players are usually involved in the decision-making process for the implementation of energy efficiency technologies?

Topic #3 “Description of the evaluation methods used to measure the viability of energy efficiency technologies”	• How the economic viability of the investments is evaluated? • Which kind of metrics do you usually use (e.g. IRR, NPV, PBT etc.)? • What threshold values do you consider in case of using PBT or IRR?
Topic #4 “Description of the implementation barriers for energy efficiency technologies”	• Which are the main barriers to the real exploitation of energy efficiency potential within your company? o Financials (e.g. lack of equity, difficulty to access to bank loans) o Organizational (e.g. poor awareness by the top management about the energy issues) o Technological (e.g. technologies maturity) o Value Chain (e.g. lack of integrated providers able to deal with all energy efficiency investment aspects) o Others (please specify).

The decision-making process that leads to the adoption of an energy efficiency technology adopted by the firms in our sample can be organized around six main steps, from idea generation to project execution, as shown in Fig. 1.

Fig. 1. The energy efficiency decision-making process.

Each step may involve different players, belonging or not to the firm adopting the energy efficiency technology, which are summarized in Table 4 (with reference to internal players) and in Table 5 (with reference to external players).

Table 4. Internal players involved in the energy efficiency decision-making process.

Internal players
Energy Manager
Facility Manager/ Operation Manager
Top Management

Table 5. External players involved in the energy efficiency decision-making process.

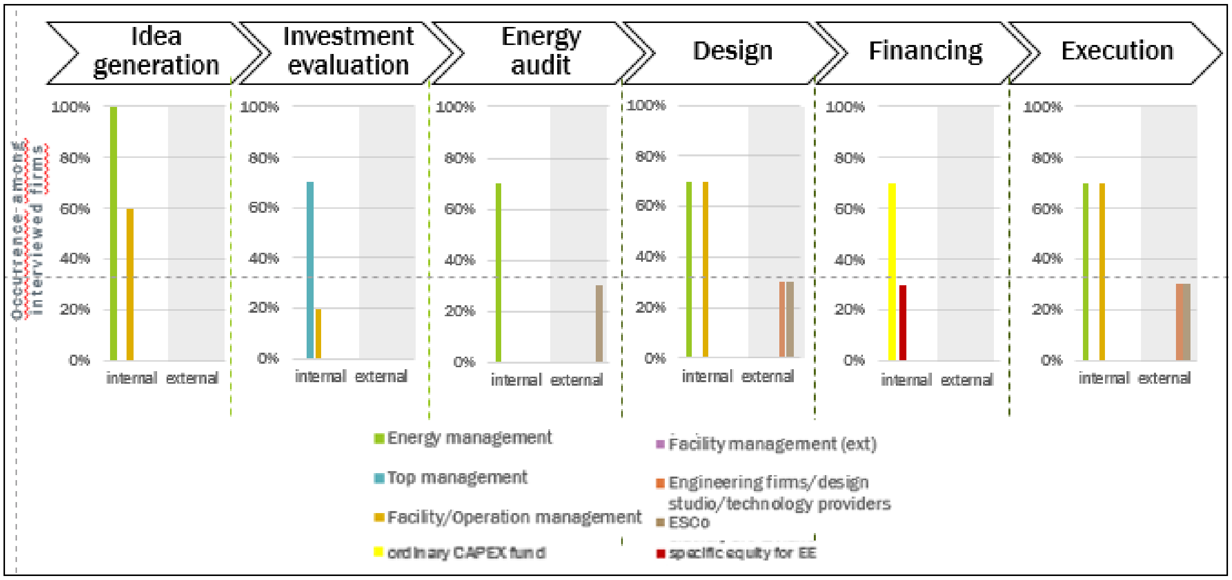
External players
Facility Management firms
Engineering firms
Technology providers
Energy Service Companies
Banks/Financial institutions

Energy efficiency projects are often conducted by relying on internal actors, as shown in Fig. 2. This is particularly true for the first two stages of the decision making process, i.e. idea generation and investment evaluation, where only internal actors are involved. Notably, the Energy Management Department is always involved in the idea generation stage, while the Top Management is typically in charge of the investment evaluation stage (in around 60% of the interviewed firms). We found that Operation or Energy Managers have the final authority over the approval of the project in around 40% of the interview companies.

External players are only occasionally involved, especially when highly specified knowledge is required, such as for CHP plants. Interestingly, the interviewed firms usually have the capability to carry out in-house the first stages of the decision making process, i.e. energy audit, design and execution. The Operation and Energy Managers execute energy efficiency projects in around 70% of the interviewed firms, while Energy Service Companies or other external actors (such as engineering firms, providers of energy efficiency technologies and design studios) are involved in the other cases.

Finally, as for the financial aspect, almost all the interviewed companies have relied exclusively on equity. This is because, on one hand, firms are willing to financially support these investments that require a relative low level of capex and have short Pay-Back time. On the other hand, it should be noted that banks and other financial institutions are usually rather skeptical when it comes to fund energy efficiency projects in Italy (due to a lack of know-how concerning the evaluation of such investments), and therefore equity often remains the only viable route.

Fig. 2. Involvement of different categories of actors in the energy efficiency decision-making process.



Focusing on the evaluation of energy efficiency investments, all respondents use PBT to evaluate the economic viability of adopting energy efficiency technologies. Around 20% of the analyzed companies use IRR together with the PBT to evaluate such investments, while NPV is used quite seldom (16 firms in our sample).

More interestingly, the industrial firms in our sample usually adopt a very strict threshold to evaluate the economic viability of energy efficiency investment when using PBT, between 2 to 3 years. This very short expected PBT is mainly due to the low strategic priority attached to energy efficiency investment by Top Managers, who are in almost all cases the key decision makers in the firms in our sample. Based on the results of our interviews, this aspect represents one of the most important barriers to the diffusion of energy efficiency technologies in the Italian industrial firms.

In particular, the empirical analysis points to a mismatch between the priorities of the actors involved in the decision making process for the adoption of energy efficiency technologies. On the one hand, Energy Managers usually understand the importance and the strategic value of investments in energy efficiency technologies and, consequently, they are inclined to use less strict investment thresholds or to introduce alternative methods to evaluate energy efficiency investments that consider the total economic impact of energy efficiency technologies. On the other hand Top Managers, who in the majority of the cases have the power and responsibility to make the final decision about energy efficiency investments, do not consider energy efficiency as a core priority for their organization, therefore are willing to invest money in it only if very short paybacks are ensured.

As highlighted in our empirical analysis, therefore, it would be important to have an indicator that provides a view of the economic viability of energy efficiency technologies that is more comprehensive, looks at the entire life cycle of the technology and is straightforward to understand for the decision makers with final authority over the energy efficiency investment. The next section introduces a new perspective for the evaluation of energy efficiency technologies that tries to overcome this limitation of the currently employed valuation methods.

4. A new perspective for the evaluation of energy efficiency technologies

The empirical analysis highlights that Italian industrial companies use traditional methods (mainly PBT) in order to evaluate the economic viability of energy efficiency technologies, and most importantly they search for very short-term returns which, in fact, strongly penalize energy efficiency investments. There is a need for evaluation approaches that consider more properly and more clearly the benefits of energy efficiency technologies and provide a more comprehensive view about the factors that should lead to investing in an energy efficiency technology or not. It clearly emerges from our analysis that the application of traditional evaluation methods often prevent firms from adopting energy efficiency technologies that would provide tangible benefits in the medium-long term, along their life cycle, to the final user.

With the aim to fill this gap and taking inspiration from the Life Cycle Assessment (LCA) methodologies (Rebitzer et al, 2004), we introduce a new indicator called Levelized Energy Efficiency Cost (LEEC), which takes into account the total achievable savings accruing from the use of an energy efficiency technology throughout its life cycle. This indicator is also inspired by the life cycle economic assessment methodology for energy production plants – the so-called Levelized Cost Of Electricity (LCOE) (Branker er at, 2011; Said et al, 2015) - even though it is not a discounted method, as shown in Section 4.1.

4.1 The description of LEEC

We suggest the LEEC should be used in a methodology organized around two phases, i.e. LEEC calculation and LEEC comparison.

Concerning the calculation, LEEC represents the overall cost that the investor (i.e. the firm investing in the energy efficiency technology) has to incur in order to achieve a total volume (usually kWh) of energy saved along the life cycle of the technology. In other words, LEEC indicates the cost per kWh of energy saved thanks to the use of an energy efficiency technology in a specific context (e.g., a particular production process) along the life cycle of the technology. Accordingly, the LEEC is calculated as follows:

$$LEEC = \Sigma_{t=0}^{T} ([C_{pa;t} + CapEx_t + OpEx_t] / \text{Total energy saved}_t)$$

Table 6 explains each variable of the formula.

Table 6. Description of LEEC items.

Item	Description
$C_{pa;}$ (Costs of preliminary activities)	It includes the costs (expressed in €) of the activities conducted prior to the implementation of the energy efficiency technology, such as audit, design, planning.
$CapEx_t$ (Capital expenditures)	It considers the cost (expressed in €) required to purchase and install the energy efficiency technology (net of eventual funds obtained through third party financing)
$OpEx_t$ (Operational expenditures)	It considers the annual cost (expressed in €) for the operation and maintenance of the energy efficiency technology (including eventual interest costs due to third party financing and the pay back of the obtained funds)
Total energy $saved_t$	It considers the energy saved each year (expressed in kWh) thanks to the use of the energy efficiency technology
T	Expected useful life of the energy efficiency technology (expressed in years)

Concerning the comparison phase, in order to establish the sustainability of an energy efficiency technology, the indicator calculated in the previous phase has to be compared with a benchmark value. In particular, the suggested approach considers two benchmark values, depending on the type of energy saved through the application of the energy efficiency technology:

- For electricity-saving technologies, the LEEC has to be compared with the cost of purchasing a kWh from the electricity system (i.e. from energy retailers);
- For thermal-energy saving technologies, the LEEC has to be compared with the cost that the customer is currently incurring to produce locally a kWh of thermal energy.

If the LEEC is lower than the benchmark value, this suggests - from a LCA perspective - that the overall costs associated with the installation and use of the energy efficiency technology along the life cycle of such technology are repaid by the overall achievable energy savings during the same period. In other words, the difference between the LEEC and the benchmark value represents the gain that the customer obtains on average for each kWh saved along the life cycle of the technology.

4.2 The application of LEEC

In this section of the paper, we compare the economic viability of different energy efficiency technologies calculated with a traditional methodology (i.e. PBT) and with the LEEC indicator. We start by focusing on the most energy-intensive industries in Italy, i.e. a subset of the industries that have been involved during the empirical analysis, as showed in Table 7.

Table 7. Characteristics of the most energy-intensive industries in Italy.

Industry	**Annual electricity consumption [GWh/year]**	**Share of industrial electricity consumption in Italy**	**Annual thermal energy consumption [GWh/year]**	**Share of industrial thermal energy consumption in Italy**
Metallurgy	20,641	21%	68,698	35%
Mechanical	25,235	23%	24,293	10%
Buildings materials	6,530	6%	41,508	24%
Pulp & Paper	9,597	10%	18,687	8%

By conducting a set of interviews with Energy Managers (or people with similar responsibilities in the firm) working in these industries (see the Section 3 for the details about the empirical sample), we identified the characteristics of the most energy-intensive production processes for each industry (as shown in Table 8).

Table 8. Characteristics of the most energy-intensive production processes.

Industry	**Production process(es)**	**Electricity consumption**	**Thermal energy consumption**
Metallurgy	Production of crude steel (Electric Arc Furnace - EAF)	350 - 800 kWh/ton	-
	Production of crude steel (Integral Cycle - IC)	100 - 200 kWh/ton	4.500 - 5.600 kWh/ton
Mechanical	Subcompact car assembly line	900 - 3.300 kWh/car	500 - 750 kWh/car
Buildings materials	Production of clinker	80 - 150 kWh/ton	800 - 1.200 kWh/ton
Pulp & Paper	Production of paper	500 - 80 kWh/ton	800- 1200 kWh/ton

Considering the production processes indicated in Table 8, we decided to evaluate the economic viability of five different energy efficiency technologies, under the hypothesis of a full-equity investment. The choice of the energy efficiency technologies considered in the study depends on:

- The energy characteristics of the production processes (in terms of, e.g., consumption, intensity, temperature required, presence of both thermal and electrical demand);
- The technical characteristics of the energy efficiency technologies (in terms of, e.g., reliability, modularity).
- The current diffusion of such technologies and the willingness to adopt them by interviewed companies.

Table 9 shows the characteristics of the energy efficiency technologies considered in our application of the LEEC analysis.

Table 9. Characteristics of the energy efficiency technologies considered in the analysis.

Industry	Yearly production	Energy Efficiency Technologies				
		Compressed air	Electric motor	VSD	UPS	CHP plant
Metallurgy	200,000 tons with EAF and 200.000 tons with IC	Power: 0,5 MW	Power: 2,7 MW	Power: 1,6 MW	Power: 20 MVA	n.a.
Mechanical	300,000 cars	Power: 1 MW	Power: 3,5 MW	Power: 2 MW	Power: 200 MVA	Power: 20 MW
Buildings materials	350,000 tons	n.a.	Power: 4,8 MW	Power: 2,9 MW	Power: 6 MVA	n.a.
Pulp & Paper	350,000 tons	Power: 1 MW	Power: 15 MW	Power: 9 MW	Power: 38 MVA	Power: 30 MW

Considering the threshold value of 2-3 years for the PBT indicator (which represents the average value used by the firms in our sample) and the benchmark values for the LEEC indicator of 10 c€/kWh for the electricity and 4.7 c€/kWh for thermal energy generation[4], Table 10 shows the differences between the application of the PBT criterion and the LEEC method in terms of economic viability of the energy efficiency technologies considered in the study.

Table 10. Results from the application of LEEC [c€/kWh] and PBT [Years].

Industry	Energy efficiency technologies									
	Compressed air		Electric motor		VSD		UPS		CHP plant	
	PBT	LEEC[5]	PBT	LEEC[2]	PBT	LEEC[2]	PBT	LEEC[2]	PBT	LEEC[6]
Metallurgy	1-2	1-2	5-6	1.5-2.5	0.5-1	0.5-1	4-6	3-5	n.a.	
Mechanical	1-2.5	2.7-3.5	5.5-7	2.5-3.5	2-3	2-3	5-8	7-9	3-5	0.4-1
Buildings materials	n.a.		5-6.5	2.5-3.5	1-1.5	0.6-1	4-6	3-5.5	n.a.	
Pulp & Paper	1-2	1-2	4-6.5	2.5-3.5	0.5-1	0.5-1	3.5-5	2.5-3.5	3-5	0.3-0.7

[4] The benchmark values represent the average cost of electricity and thermal energy paid by the firms in our sample
[5] Must be compared with the benchmark of electricity savings (10 c€/kWh)
[6] Must be compared with the benchmark of thermal energy savings (4,7 c€/kWh)

The PBT indicator suggests that only in a very limited number of cases energy efficiency technologies would be economically viable. In particular, only compressed air systems and VSD show a PBT lower than the acceptability threshold value of 2-3 years, while the other technologies, i.e. electric motors, UPS and CHP plants, have higher PBT. Overall, only 7 of the 17 analyzed cases of investments in energy efficiency technologies (41%) would be accepted if considering the PBT as the main indicators.

On the other hand, the comparison of the LEEC indicator with the benchmark values points to a different picture and suggests that the economic viability of energy efficiency technologies in industrial processes is far more positive that the PBT suggests. For example, in case of adoption of an efficient electric motor in the metallurgy industry, the LEEC is 1-2 c€/kWh, which is definitely lower than the benchmark value for the LEEC indicator of 10 c€/kWh (savings of electricity). This clearly suggests that energy efficiency technologies are characterized by a relatively high initial investment costs, compared with the annual energy savings that can be achieved through the implementation of such technologies. However, considering the whole life cycle of such technologies, the economic benefits become substantial and their adoption appears as a reasonable choice from an economic point of view. The use of the LEEC indicator would therefore encourage to give a more long-term look at the economic viability of investing in energy efficiency technologies and would make it easier to compare the total savings realized along the life cycle of the technology with an easy to understand benchmark value such as the price a company pays to buy electricity from the grid or the cost it incurs when producing thermal energy locally.

4.3 Discussion about the application of LEEC

The empirical analysis involving 130 Italian industrial firms showed that the conventional approaches for the evaluation of energy efficiency technologies, and in particular the PBT, hinder the adoption of some energy efficiency technologies, especially those characterized by high initial investment costs. This because the PBT does not consider what happens after the time in which the sum of the differential cash inflows earned thanks to the investment is equal to the sum of the differential cash outflows, therefore penalizing energy efficiency technologies that allow to achieve high energy savings along the entire technology lifecycle. Moreover, the very short PBT threshold typically set by the decision makers for energy efficiency investments further penalize those energy efficiency investments with high capex (as discussed in Section 3), for which the energy savings that can be achieved in the first years after adoption do not exceed the initial investment costs.

Therefore, in this paper we introduce a new evaluation perspective for investments in industrial energy efficiency technologies, i.e. the Levelized Energy Efficiency Cost (LEEC).

The main motivation behind the adoption of the LEEC method is related to the need to overcome one of the strongest barriers that hinder the adoption of some energy efficiency technologies, typically evaluated through the PBT. In particular, the main advantage of the LEEC method refers to the introduction of a lifecycle-perspective in the energy efficiency technology evaluation. The LEEC represents the cost per kWh of energy saved thanks to the adoption of an energy efficiency technology, i.e. the overall cost that a subject investing in an energy efficiency technology has to incur in order to achieve a total amount of energy saved along the life cycle of the technology.

On the other hand, the LEEC is simpler compared to the most widespread methods. First, only the differential cash outflows have to be estimated, given that cash inflows are not relevant for this analysis. Second, the discount rate to discount the annual net cash flows is not necessary as well, for which different estimation methods exist, such as using the expected return of other investment choices with a similar level of risk (Xinjing Zhang et al. 2014).

Finally, even though it is a relative indicator to infer about the economic viability of an investment, the LEEC is less subjective compared to other relative methods such as PBR or IRR, because the acceptability threshold does not depend on the decision maker risk propensity.

In summary, the use of LEEC, not only instead of, but in addition to the PBT, may be a good approach in order to properly evaluate the economic viability of an energy efficiency technology, taking into account what happens during its entire lifecycle.

Of course, some potential drawbacks associated with the use of LEEC have to be properly addressed. The main problem refers to the extent at which it is accepted and used by the decision makers of energy efficiency investments. The empirical analysis shows that decision makers (typically top managers) are willing to invest money in energy efficiency technologies only if characterized by very short PBT, because they consider energy efficiency as a non-core priority for their organization. Therefore, a new mind-set is required for a widespread diffusion of the LEEC, in which energy efficiency projects are considered as a priority for an organization, thus evaluated with a long-term perspective, i.e. considering the entire technology life cycle. From this point of view, the LEEC method aims to introduce a lifecycle-perspective in the evaluation of energy efficiency technologies, which is likely to favour the diffusion of such a new mind-set.

A second possible disadvantage of LEEC, linked with its the practical use, refers to the benchmark values that have to be adopted in order to infer about the economic viability of an energy efficiency technology, i.e. the cost of purchasing a kWh from the electricity system (i.e.

from energy retailers) - for electricity-saving technologies - and the cost that the customer is currently incurring to produce locally a kWh of thermal energy - for thermal-energy saving technologies. In particular, such benchmark value may change during the evaluation time horizon, i.e. along the energy efficiency technology lifecycle. For example, the cost of purchasing a kWh from the electricity system for medium industrial companies in the EU-27 countries has increased by 18% in the last ten years (Source: http://ec.europa.eu/eurostat/web/energy/data/main-tables). Therefore, a proper evaluation of energy efficiency technologies following the proposed LEEC methodology implies the estimation of the right benchmark values, as the average cost of electricity taken from the electricity system or of the thermal energy produced on-site during the energy efficiency technology lifecycle (in place of the current cost when the evaluation is run). In fact, such costs have to be estimated also when conventional approaches for the evaluation of energy efficiency technologies are used, in order to measure the differential annual cash inflows related to the investment.

Finally, in its current formulation, which considers the overall average cost that the investor has to incur in order to achieve each unit of energy saving (usually kWh) along the life cycle of the technology, the LEEC does not take into account the possibility to obtain incentives (such as White Certificates in Italy), which may have a positive impact on the economic viability of an energy efficiency technology. Such potential drawback may be overcome quite easily, with the new formulation of the LEEC that follows:

$$LEEC = \Sigma_{t=0}^{T} \left([C_{pa;t} + CapEx_t + OpEx_t - Inc_t] / \text{Total energy saved}_t\right)$$

where Inc_t considers the annual incentive (measured in €) that is earned thanks to the adoption of the energy efficiency technology.

5. Conclusions

Policy makers worldwide increasingly recognize that energy efficiency is an important means for guaranteeing an environmentally sustainable growth, while offsetting climate and environmental threats. Nevertheless, there are still many barriers to be overcome for improving the diffusion of energy efficiency technologies in all sectors, from industry, to services, to households. In particular, the adoption of such technologies is often hindered by the application of economic evaluation methods that are too short-term oriented and do not consider the potential savings resulting from the use of energy efficiency technologies along their life cycle.

The industrial sector has in particular very large opportunities for the adoption of energy efficiency technologies. Empirical research involving 130 Italian industrial firms shows that, even though most of these have already implemented several energy efficiency technologies, many potentially viable projects have been stopped because of strict application of traditional evaluation criteria, such as the PBT with thresholds of 2-3 years. In other words, the PBT does not adopt a lifecycle-perspective in the energy efficiency technology evaluation, i.e. neglecting what happens after the time in which the sum of the differential cash inflows resulting from the investment is equal to the sum of the differential cash outflows,. As a result, this penalizes energy efficiency technologies that allow to achieve high energy savings during the entire technology lifecycle, and especially in its latter stages. This is because industry managers perceive investments in energy efficiency technologies as a non-strategic activity for their companies, for which short payback time thresholds are imposed in order to offset the risk of diverting investment capital away from core business pursuits.

In this paper we argue that an evaluation approach that considers the entire life cycle of the energy efficiency technology, i.e. that takes into proper account all the benefits and costs accruing to the investor over the asset's useful life, may positively impact on the diffusion of energy efficiency technologies, because it can give a more comprehensive evaluation of their benefits and viability. In particular, we propose an indicator, called Levelized Energy Efficiency Cost (LEEC), which measures the overall average cost that the investor has to incur in order to achieve each unit of energy saving (usually kWh), along the life cycle of the technology. In other words, LEEC indicates the cost per kWh of energy saved through the application and use of an energy efficiency technology in a specific context and during its life cycle. An energy efficiency technology can be considered economically viable if the LEEC is lower than the cost typically paid by the same investor to buy or self-produce the same amount of electrical or thermal energy (kWh). Said differently, if the LEEC is lower than these benchmark values, it means that the overall costs of the specific energy efficiency technology (i.e. cost for preparatory activity, capital expenditures and operational expenditures) are lower in total and along the entire life cycle of the technology, compared with the cost of the energy that such technology enables to save along its life cycle.

The application of the LEEC in different Italian energy-intensive industries (i.e. iron & steel, automotive, cement and pulp & paper) clearly shows that all the technologies evaluated in the different application fields are economically viable from the point of view of LEEC, while most of them would be rejected by a typical investor evaluating such investments through the PBT with a 2-year threshold.

The empirical analysis suggests that a decisive shift in the rate at which energy efficiency technologies are adopted in industry implies an important cultural change - from traditional investment evaluation methods, like PBT, to life cycle-oriented indicators as LEEC. Other potential barriers to the LEEC adoption by companies are identified and discussed, such as the definition of the proper benchmark values in order to infer about the economic viability of an energy efficiency technology, i.e. the cost of purchasing a kWh from the electricity system for electricity-saving technologies and the cost that the customer is currently incurring to produce locally a kWh of thermal energy for thermal-energy saving technologies. Nevertheless, the diffusion of such indicator, which has been inspired by the life cycle economic assessment methodology for energy production plants (i.e. the so-called Levelized Cost Of Electricity) represents an opportunity to boost industrial demand for energy efficiency technologies.

The indicator proposed in this paper will hopefully inform future research that could be extended in multiple directions. On one hand, the indicator could be used for the evaluation of other energy efficiency technologies in the industrial sector. On the other hand, the model could also be easily implemented in other sectors (such as residential or services sectors) and even in other countries.

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