Energy Saving and Efficiency Tool
A Sectorial Decision Support Model for Energy Consumption Reduction in Manufacturing SMEs

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Abstract: The problem of Energy Efficiency in industry is a hot topic but companies are not still implementing, on a mass scale, energy efficiency actions. One of the most important barriers is that companies are scarcely aware of their consumptions and consider energy as a fixed cost and not as a resource to be managed. In this paper it is proposed a model, based on self-analysis of consumptions, for facing this barrier. On the base of this model, a software tool, Energy Saving and Efficiency Tool (ESET), was designed as a starting point of an energy diagnosis path for SMEs. ESET was developed for textile/clothing sector but the model is general and, starting from it, similar sectorial tools can be developed. The tool provides different kinds of outputs: best practices, for helping companies to improve its own energy performances; energy efficiency indices, compared with reference values; energy use behaviours. Particularly, best practices are selected using a large set of rules, distilled from the experience of professional energy auditors. The analysis of the accuracy and completeness of ESET results was performed on six companies selected among all those involved in ESET testing and application. The results of this evaluation are very encouraging.

1 INTRODUCTION

The manufacturing sector plays an important role in European economy, since it represents 10% of all enterprises in the non-financial sector and accounts for 80% of European exports (European Commission Factories of the Future, 2013). Its global turnover in Europe is around 7.080.000 million of € and the total amount of energy costs is about 140.000 million of € (EUROSTAT, 2013). Moreover, 99,6% of the 5,1 millions of enterprises operating in the manufacturing and construction European sectors are SMEs (3E, 2013).

The problem of Energy Efficiency (EE) in industry is a hot topic, since the need for reducing the impact of human activities on the environment and for saving resources, as raw material and energy, has become urgent and therefore there is a strong commitment from policy. Policy instruments can be split into four main categories: instruments for planning (like strategies and national programmes of action), institutional organizations (like EE implementation management organizations or cooperation of administrative and municipal management bodies), financial instruments (like public investment programme and EE funds) and communicative instruments (like institutional day of information) (Ekmanis, 2010).

A certain number of studies has been developed about energy efficiency methodologies, going from general energy management methodologies identifying steps for getting energy efficiency (Capobianchi, 2011), to models for assessing energy saving measures (Doukas, 2009; Doukas, 2006). Moreover, further studies were performed focusing on (both general and process specific) techniques and opportunities for energy efficiency, that in the following sections we refer globally as "best practices" (Worrell, 2009). The main references, on these topics, are the Best Available Techniques (BATs) elaborated from the European IPPC Bureau,

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following the request Article 13(1) of the Industrial Emissions Directive (The European Parliament and The Council of the European Union, 2010).

These Best Available Techniques Reference Documents (BREFs) contain, for each industrial sector, the more effective techniques for getting a high level of environment protection and pollution control, including energy consumption issues.

Considering the previous points (policy commitment, availability of energy management standard, methodologies and best practices) why are companies still not implementing, on a mass scale, energy efficiency actions? A good answer is proposed by Dörr (2013), which identifies the following barriers:

- distance between industrial needs and scientific results;
- high costs for the implementation of a company energy management system, measuring devices and additional ICT structures;
- too general and abstract description of energy management systems in ISO 50001, that is the reference standard in this field (ISO, 2011).

The problem of energy efficiency was faced by the authors of this paper through a series of projects funded by the European Commission (ARTISAN, SESEC and SET), focused on Textile and Clothing sector as pilot (turnover around 150.000 million of € in 2012 and total amount of energy costs about 2.600 million of €, with peaks of energy intensity near to 30% for some subsectors like dyeing (EUROSTAT, 2013)).

Moreover a European informative campaign, Energy Made to Measure (EM2M), led by the European industry association (EURATEX), was launched in 2014 with the aim of improving real European companies in their energy efficiency awareness.

From these activities, a further barrier was identified, which precedes, in time and in logic, the previous ones: the companies of the sector (and, more generally, SMEs), have still very scarce awareness of their consumptions. The main reason is that they consider energy as a fixed cost that has to be paid instead than a resource that can be managed and used in a more efficient way.

In order to overcome this barrier, a path was defined based on self-analysis of consumptions, collection of data for improving benchmarks and suggestion of customised best practice lists (unfortunately the Textile/Clothing sector BREF is not so recent, since its date goes back at 2003).

For this purpose, a set of software tools was developed in the last years, in the context of the above quoted projects, for supporting companies in understanding their energy performances, comparing them with sectorial benchmarks and identifying which actions could be implemented for improving their own efficiency.

In this paper the self-analysis standalone tool, called ESET Tool, developed through the activities of SET project, will be analysed.

There exist other self-analysis tools, developed by other initiatives and European projects. Ten tools were analysed (Table 1), eight for industry and two for buildings, and compared with ESET Tool. Among the industry tools, four of them address specific sectors, two are targeted on specific kinds of

Table 1: Outputs provided by the analysed tools and by ESET Tool.

	Audit results	Energy savings	Energy indicators	List of best practices	Payback period	Green house emission / reduction	Cost savings
Plant Energy Profiler	X	X		X			
FanSave		X			X	X	X
PumpSave		X			X	X	X
AMETHIST			X				
LiCEA			X			X	
A2A	X	X	X	X		X	X
SEAS 2.0	X		X				
SENECA			X				
Green Gain				X			
Energy Performance Indicator Tool	X					X	X
ESET	X	X	X	X	X		X

subsystems (pumps and fans) and the others are general.

The inputs required by each of the analysed tools were compared and two possible approaches were identified:

- very detailed set of inputs (bottom-up approach): these kinds of tools have a very affordable output, but filling them is a complex activity and requires a deep knowledge of company processes and of related consumptions;
- macro-level set of inputs (top-down approach): in this case there is a loss of details in the final output, but data analysis is much easier and quicker.

The second approach is more attractive for the companies, but the first one gives more effective results. So, for the ESET Tool a partial and/or progressive filling approach was chosen. Furthermore, even with a not complete filling of the tool, some results are given: the more the input is complete, the more the output is comprehensive and faithful. This strategy is thought for making the tool attractive and for allowing companies to deepen the self-analysis process, after having observed their main energy indicators.

Another important point of view for this comparison is the provided output.

From this point of view, Table 1 shows that the ESET Tool provides the more complete set of outputs, among the analysed tools.

A last important point is that, although ESET Tool is sector specific, it is thought to be easily portable on different sectors, by developing and upgrading the model toward other industrial sectors.

2 THE PROPOSED MODEL

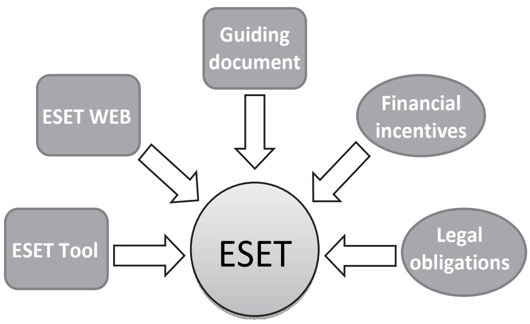


Figure 1: General ESET structure.

The ESET Tool is the starting point of a group of instruments developed under SET project, including (in addition to ESET Tool) a web application (ESET Web), a guiding document and further documents reporting Financial incentives and Legal obligations (Figure 1).

The main scope of this article is to present ESET Tool and the model behind it, with some references to ESET Web.

2.1 Structure and Approach

Thanks to previous experiences (ARTISAN and SESEC) we have learnt that companies which deal with energy efficiency issues, even for the first time, are interested in receiving indications about measures they could implement in the factories in order to reduce energy consumptions and related costs (possibly with a short payback time); they also find useful obtaining a series of indices, calculated on yearly and monthly basis, which give them a view of their behaviours; particularly they would like to know which aspects influence their consumptions or their costs; moreover, they would like to understand how much their performances differ from their peers, nationally or on European scale.

Starting from these learned lessons, the following outputs were defined:

- best practices
- indices and comparison with peers
- behaviours.

It was immediately clear that a certain amount of company data is needed, but companies are often not able to find energy data easily or, if asked for too many data, they prefer to renounce.

To face this point, ESET was designed with a step-by-step approach, involving ESET Tool and ESET Web, asking factories data, organizing them in self-consistent sections and giving back the related outputs progressively (Figure 2).

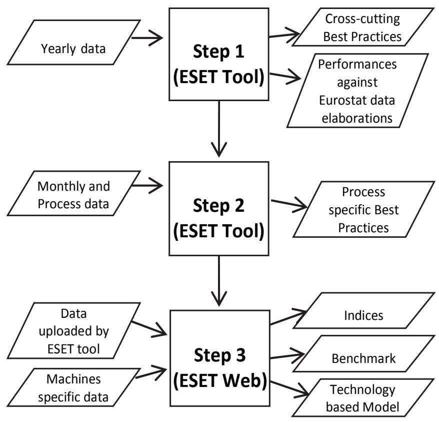


Figure 2: Flow chart of ESET.

In details, in the first step user is asked to insert basic yearly information of the factory (data on business, turnover, production, purchased energy, cogeneration and energy generation when available, energy uses). The results are some global energy indices and a list of recommended best practices, independent from the production processes (cross-cutting), which could be applied in the factory and, consequently, could contribute to reducing energy consumptions associated to auxiliary systems.

In the second step the ESET Tool requires more detailed data related to productive phases and technologies and, on monthly base, production and energy consumptions. The outputs in this case are diagrams which analyse monthly data variations and a list of recommended process specific best practices. The suggested measures, if applied, could lead to a reduction in energy consumptions associated to production processes.

A third step is under test (ESET Web) and aims to extend and deepen the analysis on factories data with new indices, performances comparison against dynamic personalised energy benchmarks; furthermore a section is dedicated to “Technologies based models” for the main textile processes, that allows to calculate the expected theoretical consumption for single machine or department. Companies are allowed to access the web application and its services by anonymously sending their data through ESET Tool, at the end of the second step.

The data required by ESET Tool can be retrieved by companies from the following sources:

- purchased energy (amount and costs) usually available from bills;
- production data retrieved from company’s ERP (Enterprise Resource Planning system);
- information on factory organization, processes and technologies provided by company’s production technician.

The effort to complete the data set needed by ESET Tool depends on the capability of the company in monitoring their production and on their internal organization.

Anyway, the total time necessary to apply effectively ESET Tool to a factory ranges from few hours to a working day.

2.1.1 Best Practices

A list of best practices for improving energy efficiency in an industrial factory was identified on the base of several resources: the performed energy audits, the experience of ENEA experts in the textile sector, the Berkeley Lab document about Energy-Efficiency Improvement Opportunities for the Textile Industry (Hasanbeigi, 2010), the EMS project outcome (EMS-Textile, 2006), the BAT document (IPPC, 2003) and the ENEA document about rational use of energy in textile sector (Paganelli, 1997).

The review of state of art in energy efficient measures allowed to split the identified best practices into the following categories:

- Cross-cutting measures
  - Reduction of peak power
  - Lighting
  - Heating/Air conditioning
  - Electric motors
  - Compressed air
  - Pumping systems
  - Fan systems
  - Steam systems
  - Vacuum systems
- Sector specific measures (e.g. for textile) for
  - yarn production machinery
  - fabric production machinery
  - finishing systems

The rationalization of the best practices list was made in two phases.

At first, the best practices list was enriched with indicative information about:

- investment cost
- energy saving (fuel and/or electricity)
- order of magnitude of payback time.

Then, they were prioritized on the base of the expected cost, benefit and payback time.

Finally a list of 117 cross-cutting best practices and 113 process specific best practices was created (CITEVE, 2014). Each of the identified measures was linked to a process or kind of machinery, organized and classified in a hierarchical classification which covers the most relevant textile processes and the related phases and technologies.

2.1.2 Comparison of Performances

As reported by a study (Asia Pacific Energy Research Centre, 2000), moving down along the pyramid of Figure 3 the faithfulness of energy indices increases, but the data aggregation level falls down, the quantity of data required increases and finding an appropriate benchmark becomes much more difficult.

Taking into account these dynamics, we have built a system to support a twofold level of indices,

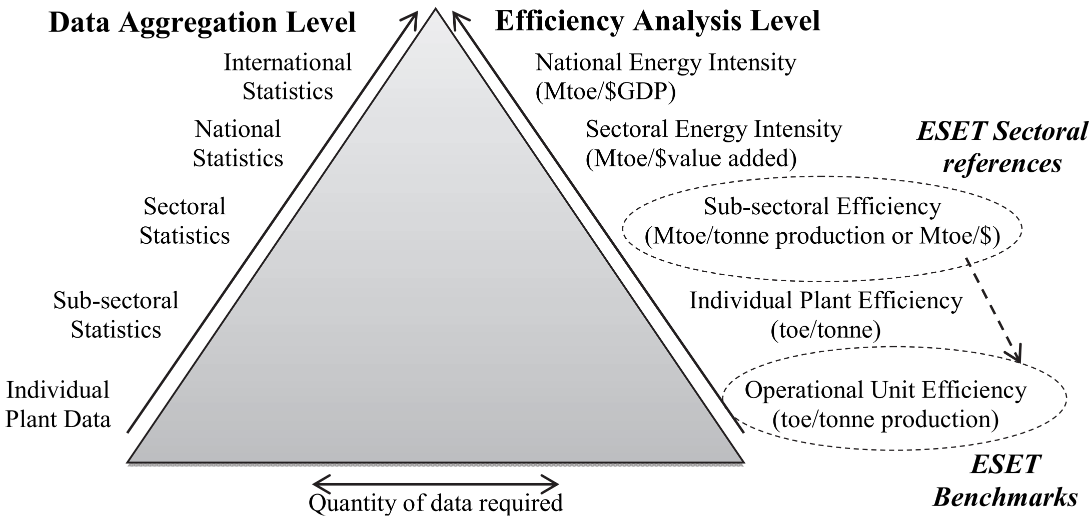


Figure 3: The ESET shifting to Operational Unit Efficiency level on the Energy Efficiency Indicator Pyramid. Elaboration from Asia Pacific Energy Research Centre (2000) and Phylipsen (1998).

in order to enrich the data analysis moving to the "Operational Unit Efficiency" level of the pyramid:

- Step 1 and Step 2 outputs: sectorial reference values built on an elaboration of national Eurostat data based on NACE categories (finishing, yarn and fabric production);
- Step 3 outputs: comparison of internal indices towards energy benchmarks for textile processes, dynamically built around the target company from a centralized database by ESET Web.

The sectorial reference values used in Step 1 and Step 2 are stored inside the ESET Tool and allow companies to perform a first comparison. They consist in four main classes of indices:

- Energy cost / turnover (%)
- Energy consumption / turnover (toe/Euro)
- Energy cost / production (Euro/kg)
- Energy consumption / production (toe/kg).

Nevertheless the Eurostat data refers to NACE categories for the textile industry that are too general and include kinds of factories very different. This has led to consider a different approach. In Step 3, energy benchmarks are built dynamically through a company profiling approach, based on a centralised database which collects companies data from the ESET Tool, and on a web application which calculates the customised energy benchmarks and executes further elaborations.

This is a work in progress within the SET European project, which is involving a number of textile companies (300) in the application of ESET.

The logic and the methodology of the energy benchmarks definition deserves an in-depth analysis and will better explained in an ad hoc paper.

2.1.3 Company Behaviour

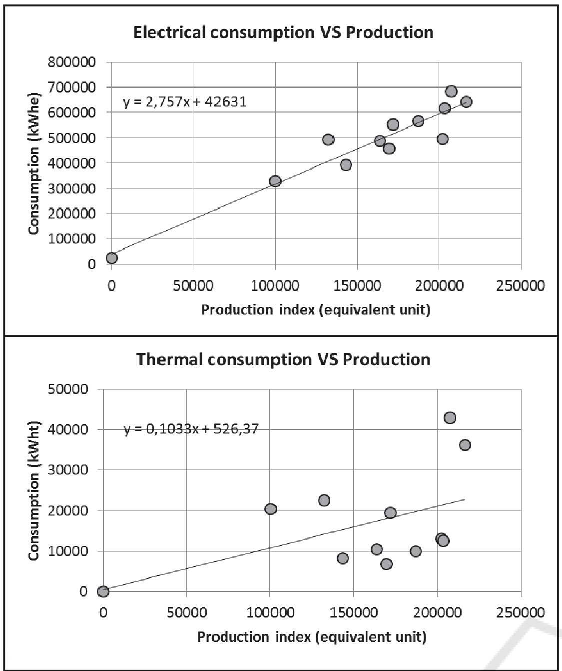
To get information about how companies use energy, it is highly interesting to investigate the relationship between production and energy consumptions: in other words how the energy consumption variation is related to the production.

One of the data analysis performed by ESET Tool is a regression analysis to check the existence of a linear relationship between production (independent variable) and energy consumptions (dependent variables). Specifically, ESET implements a linear regression where the model parameters (slope and interception of the best fit line) are estimated from monthly data (Figure 4).

The extent of linear relationship is evaluated through the R-square, that is the square of Pearson product moment correlation coefficient.

In details, if R-square is close to 1 the model fits well the data, the consumptions appear strongly related to the production and the following indicators can be evaluated:

- consumption when production is zero, which represents those consumptions not directly related to production and includes avoidable and unavoidable consumptions;
- consumption for each additional unit, the energy required to produce each additional unit of product;



	Electrical	Thermal
R-square	0,91	0,26
Consumption when production is zero (kWh)	42.630,5	526,37
Consumption for each additional equivalent unit (kWh/eq. unit)	2,76	0,10
Base energy consumption (%)	8,90	3,12

Figure 4: One of ESET Tool outputs (regression analysis) from a real case. The electric consumption shows a strong relationship with the production, while the thermal consumption appears poorly related (due to winter heating, production changes, other).

- base energy consumption, which is the energy portion not related to production and represents a worthy area for further energy saving investigation to enhance the energy efficiency.

If R-square is close to 0 the model doesn't fits the data and the consumptions could be affected by energy uses not directly linked to the production (e.g. winter heating, air conditioning, etc.), as shown in the second graph of Figure 4.

2.2 Implementation

Each ESET step is composed of two main parts: a data input section and an output section that shows the outcomes. It has been designed according to a user-friendly structure, which leads the user in a path through the different data sections. It allows to run the analysis also with incomplete information, but in this case the outcomes could be partial and less relevant respect to the real case.

ESET Tool is multilingual: presently it is customized in 12 languages and could easily extend his interface to new ones, when requested. Moreover it faces localisation issues like differences in price of energy, differences in values of conversion factors for toe calculation (due to different national mix of electricity generation), comparison against national Eurostat references.

2.2.1 Rules for Best Practices Selection

A list of suggested best practices for the company is selected by the ESET Tool through an evaluation process, which includes two kinds of rules:

- cross-rules, which take into account the value of company energy indices and act on the whole best practices list;
- specific rules, that act on a single best practice (or on a group of them) taking into account the companies features related to market positioning, consumers, technologies, productive phases and plants features.

It is important to underline that, by default, all best practices are considered valid and the ESET Tool discards the ones considered not suitable for the specific case (Table 2). In details, it discards the following types of best practices:

- the ones linked to those consumptions having a low incidence within the company energy uses (based on Pareto's law, also known as the 80-20 rule) or that having a value lower than the sectorial references;

  the ones without a link to specific consumers, processes or technologies implemented by the company or not considered useful on the base of the company features.

This system of rules is integrated within ESET Tool and arises from many years of energy audits performed by experts and from a specific knowledge of textile sector.

2.2.2 Use of MS Excel (Why?)

The ESET Tool was implemented using MS Excel VBA (Visual Basic for Application) language.

The choice of using MS Excel as platform for the tool instead of a Web Application was taken after a lot of discussions with SET partners more used to deal with companies and, particularly, with compa-

Table 2: Simplified scheme of the rules to discard best practices.

Cross rules					**Specific rules (1)**		**Specific rules (2)**
Electrical consumption	Thermal consumption	Electrical index	Thermal index		Process, phase or technology linked to the energy measure		Answers to the question (if any)
≤ 20% of consumptions →Discard electrical measures	≤ 20% of consumptions →Discard thermal measures						
between 20-30% of consumptions →Evaluate electrical index	between 20-30% of consumptions →Evaluate thermal index	≤ sectorial reference →Discard electrical measures	≤ sectorial reference →Discard thermal measures	AND	if absent then →Discard the linked measure (or group of them)	AND	if present then →Evaluate the set of answers linked to the measure (or group of them)
Other cases: No effects							

nies involved in the projects.

The idea is that, if companies are requested to leave on a server their internal data (like turnover, consumption and production data) they would become cautious and could decide to not use the tool because they do not trust on the confidentiality of this data. So, it would be easier to convince companies in using a stand-alone tool. Moreover, Excel is a software about which non-ICT people (who should use the tool) is more confident.

3 PILOT APPLICATION

The pilot factories considered in the following analysis have been selected among about 60 companies already involved in SET project and EM2M campaign activities.

3.1 Pilots Selection

For a deeper analysis of the quality of the outcomes provided by ESET Tool, we selected six SMEs representative of different kinds of companies involved in the usage of ESET, taking into account type of production, size of the company (based on turnover and number of the employees) and incidence of energy costs on the turnover. In detail:

- no. 3 yarn producers
- no. 1 fabric producer
- no. 1 fabric and finishing producer
- no. 1 clothing producer.

The turnover of these companies ranges from 3.000.000 € to 25.000.000 € and the number of employees ranges from 12 to 204, while the weight of energy costs on the turnover ranges from 0,8% (clothing) to 25,37% (yarn production).

These companies were trained by SET experts on the ESET usage, filled the tool and received the suggested best practices. In addition, energy efficiency experts of ENEA visited the factories and provided a further report with energy analysis and proposed actions.

A comparison was done, for each of the six companies, between the ESET outcomes and the results of the visits performed by ENEA experts. After, the experts were asked to evaluate the adequacy of the best practices selected by the tool for each visited factory.

3.2 Results

The accuracy and completeness of ESET results were analysed applying the methods used to evaluate the Information Retrieval (IR) systems (Baeza-Yates, 2011).

The IR is widely used to achieve and find useful information from large amount of data.

The notions of "Precision" and "Recall" (Manning, 2009), which represent respectively a measure of truthfulness and of completeness of results, were used to measure the effectiveness of an IR system.

We applied the notions of "Precision" and "Recall" to the set of rules used to select and discard best practices within ESET Tool, which can be assimilated to an IR system.

In this context, the "Precision" is the fraction of retrieved best practices that are relevant for the specific case:

$$Precision = \frac{\#(retrieved\ relevant\ best\ practices)}{\#(retrieved\ best\ practices)} \quad (1)$$

The "Recall" is the fraction of relevant best practices that are retrieved:

$$Recall = \frac{\#(retrieved\ relevant\ best\ practices)}{\#(relevant\ best\ practices)} \quad (2)$$

3.2.1 ESET Outcomes Analysis

The analysis process of the outcome of ESET Tool involves ENEA experts which visited the factories and follows the steps below:

- the experts evaluate, for each company, the best practices (BPs) retrieved by ESET Tool to indicate the relevant feasible best practices and the unfeasible ones;
- they also identify a "first class" subset, i.e. easily and quickly applicable, within the relevant feasible best practices retrieved by ESET Tool;
- then, the experts identify the "missing" best practices that should have been recommended but were not retrieved by the tool, looking the whole set of ESET best practices (Figure 5).

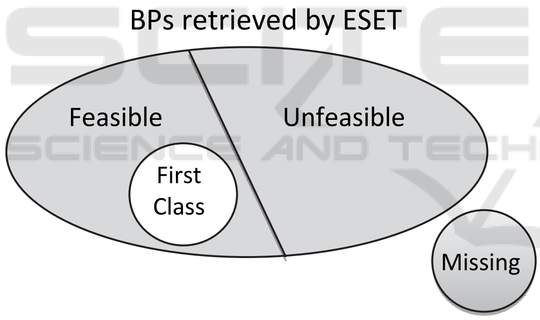


Figure 5: Best practices categories.

Table 3: Results from experts evaluations.

	BPs retrieved by ESET (A)	Feasible (B)	First class (C)	Missing (D)
		Expert evaluation		
Case 1	32	23	7	2
Case 2	57	41	25	3
Case 3	40	28	10	2
Case 4	56	48	18	6
Case 5	58	38	5	2
Case 6	73	57	15	1
Total	316	235	80	16

The results of these steps, reported in Table 3, represent the starting point to analyse the "Precision" and "Recall" indices calculated both for feasible best practices and the subset of "first class" best practices (Table 4).

3.2.2 Results Evaluation

The analysis of "Precision" and "Recall" values for feasible best practices allowed to assess the effectiveness of ESET Tool, with the following considerations:

- ESET Tool is able to retrieve best practises with a high level of precision (74,37%). This result is coherent with the system of rules integrated into the tool, that initially considers all the best practices as valid and then discards only the ones evaluated as not suitable for the specific case;
- the tool is also able to properly select the relevant best practices (93,63%), losing few applicable measures (less than 7%).

Some other observations can be done calculating the values of "Precision" and "Recall" for first class best practices.

Few of these first class best practices are lost (recall 83,33%), even if a lot of applicable but not prior best practices are brought to the attention of the company (precision 25,32%). But this apparently low precision value is coherent with the philosophy of the tool, which does not intend to substitute the analysis of an expert or an energy audit, but aims to make companies aware that energy can be saved and consequently it discards only the really useless best practices.

Table 4: Values of Precision and Recall indices.

	Feasible BPs		First class BPs	
	Precision B/A	Recall B/(B+D)	Precision C/A	Recall C/(C+D)
Case 1	71,88%	92,00%	21,88%	77,78%
Case 2	71,93%	93,18%	43,86%	89,29%
Case 3	70,00%	93,33%	25,00%	83,33%
Case 4	85,71%	88,89%	32,14%	75,00%
Case 5	65,52%	95,00%	8,62%	71,43%
Case 6	78,08%	98,28%	20,55%	93,75%
Total	74,37%	93,63%	25,32%	83,33%

4 CONCLUSIONS

A model has been presented in this paper for helping companies (and in particular SMEs) to become aware of their energy efficiency and to manage energy as a resource and not as a cost.

The main instrument for applying this methodology is a software tool containing intelligence distilled from the experience of professional energy auditors. At the moment, this tool is contextualized for textile and clothing sector, but the model is general and the tool can be extended, with little effort, to other industrial sectors.

The model has been tested comparing its results with the opinion of energy efficiency experts that have really visited the pilot companies. The results were very encouraging. In particular, through these tests, it was possible to verify that the tool is able to select the most part of relevant best practices, losing few of applicable measures.

There are two possible paths for the evolution of the tool after the end of SET project.

The first one is to make it a 'largely used tool' for assessment of company energy efficiency profile and its evolution year-by-year or after the execution of energy efficiency improvement actions (so enabling an objective evaluation of the obtained benefits). In order to be effective, the application model has to be pushed in order to foster self-analysis on large scale. At this aim, the tool is promoted in EM2M campaign, which is achieving interesting results (in 2014, more than 20 public events took place in 8 countries involving around 500 professionals and in 2016 the involvement of more than 300 companies of textile and clothing sector is foreseen).

The second one is the improvement of the tool for supporting the evaluation of the fundability of the proposed best practices. This extension will complete the kind of results offered to the companies, covering the still lacking financial aspects.

Finally the tool and the related methodology is meant to be extended to further industrial sectors, assuring further developments of specific sectorial benchmark.

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