Chapter 3

# Analysing the Adoption of Energy-Saving Technologies in Manufacturing Firms

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Additional information is available at the end of the chapter

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**Abstract**

The present book chapter aims to (i) map the adoption of energy-saving technologies (EST) in manufacturing and (ii) identify structural and operational characteristics that are expected to correlate with EST implementation. The empirical evidence is collected through the European Manufacturing Survey. The analysis presented corresponds to the Spanish subsample 2012 edition. Our main result points to a relatively low implementation of EST, also interpretable as a still unexploited potential these technologies have for manufacturers. Other main findings show (i) a relatively still modest implementation of most EST and (ii) a possible relationship between high implementation of EST and perceived energy efficiency as a consequence of implementation. The chapter draws implications for practice and research.

**Keywords:** energy-saving technology, energy efficiency, manufacturing, European Manufacturing Survey, Spain

## 1. Introduction

Sustainable development, meaning meeting the needs of present generations without jeopardising the ability of the future generations to meet their own needs [1], implicitly calls for an energy- and resource-efficient society, in which all pillars of the quadruple helix—academia, industry, government and citizens—are challenged to move towards energy and resource efficiency. Generating and enriching the current knowledge base by academia, implementing energy-efficient solutions and producing goods/services by companies towards this end, setting goals and promoting policy measures by local, regional, national and supranational bodies, as well as making informed choices by users/consumers are some of the generic musts towards sustainable societies.

Even some progress has already been made; new energy systems are gradually adapting, while the scale of challenge increases. Industrial activity, in particular, is reputedly a primary cause of pollution situating manufacturing firms in the centre of the focus. Nowadays, firms are facing strong pressure from their stakeholders to implement environmental management policies and practices. Moreover, the energy efficiency of the manufacturing processes is gaining importance due to the rising energy costs and the effects of the gas emissions over climate. From the perspective of manufacturers, the challenge is to improve the overall environmental performance of products throughout their life cycle and to boost the demand for better products and production technologies.

In one of the most recent studies on energy efficiency and saving potential in Europe-wide industry [2], the authors make a comprehensive study of the topic, using a sectoral approach as well as detecting barriers and policy measures towards further advances. Global results point towards market competitiveness remaining the strongest driver for energy-efficiency solutions, where the internal barriers to access energy-saving opportunities are not well understood. Another valuable finding is the taxonomy provided by the authors, distinguishing between a series of external and internal aspects that play an important hampering role in implementing energy efficiency and energy-saving potential. The same report calls for innovation as a catalyst towards more energy-efficient manufacturing.

Innovation is a key aspect and possible contributor towards novel solutions' implementation in order to achieve higher energy efficiency. Efforts should be deployed by the targeted promotion and commercialisation of existing solutions, as well as R&D support for emerging alternatives/technologies. The implementation of technologies in the production processes of manufacturing firms falls under process innovation typology.

Defined by the Oslo Manual [3] process, innovation is understood as 'the implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software' (p. 49). According to the same source, the main effects that process innovation might cause are: reduced time to respond to customer needs, improved quality of goods and services, improved flexibility of production or service provision, increased capacity of production or service provision, reduced unit labour costs, reduced consumption of materials and energy, reduced product design costs, reduced production lead times, achievement of industry technical standards, reduced operating costs for service provision, increased efficiency or speed of supplying and/or delivering goods or services, improved IT capabilities, improved communication and interaction among different business activities, increased sharing or transferring of knowledge with other organisations, increase in the ability to adapt to different client demands, development of stronger relationships with customers , improved working conditions, reduced environmental impacts or improved health and safety and meeting regulatory requirements (p. 108).

Monitoring particular, singular and specific energy efficiency technologies ultimately means the disposing of firm-level data in all manufacturing areas and in more than one country.

Regularly conducted large-scale surveys on innovation (see the Community Innovation Survey) are often multipurpose and remain conceptually global. Having argued the importance and possible benefits of energy-saving technologies (EST) as well as the lack of data on detailed and multiple technologies in manufacturing, we detect a possible gap worth filling with our contribution.

Therefore, the objective of this chapter is to map the implementation degree of energy-efficient technologies in manufacturing firms, as well as to identify and understand the structural and operational characteristics that are expected to introduce variations in adoption. The authors also link energy-efficient technologies with perceived saving potential. Using data from the European Manufacturing Survey, we argue the necessity to provide recent data on EST implementation

The chapter is structured as follows. After the introduction, we present the research methodology and methods used to analyse the characteristics of ESTs' adoption and their adopters. The results and findings are presented for the manufacturing firms with the use of descriptive statistics and simple correlation tests. Finally, we discuss our results and present some implications.

## 2. Methodology

Our research is based on data from the European Manufacturing Survey (EMS), 2012 edition [4]. EMS is coordinated by the Fraunhofer Institute for Systems and Innovation Research—ISI, which is the largest European survey in manufacturing activities conducted, to date.

The 2012 edition of the EMS was carried out in 19 countries, mainly the European ones including Russia and Turkey, plus PR of China and Brazil, covering the 70% of firms within the European manufacturing sector with at least 20 employees, NACE codes from 15 to 37 [5].

However, our study will only include data from EMS Spanish subsample, formed by 170 responses (**Table 1**). In this case, no other subsamples from additional countries have been included in order to analyse the major number of different available EST, given that the rest of the subsamples do not contain five of the ESTs kept in the Spanish one for the 2012 edition of the EMS. These five excluded technologies were considered for the 2008 edition of the EMS, but not for the 2012 one in the majority of the involved countries. This fact occurs because, apart from the main body of questions inside the survey, each participant country's partner can include a limited number of particular questions of its interest.

| | |
|---|---|
| Universe | Spanish manufacturing firms with at least 20 employees CNAE 2009; codes from 10 to 32 16.183 companies |
| Target population | 4000 firms |
| Sample | 170 firms |
| Confidence margin | 95% |

| | |
|---|---|
| Variance | Maximum indetermination $p = q = 50\%$ |
| Documentation | Paper (8 pages questionnaire) + Return envelope + Presentation letter |
| Channel | Postal |
| Period conducting the survey | May–September 2012 |
| Reference period | 2009–2011; 2011 |
| Fieldwork | OGEDP Department, University of Girona – Girona (Spain) |
| Data base recording and creation | DAP GmbH—Passau (Germany) |
| Sample distribution | |
| By technological sector | Low technology: 38; medium–low technology: 67; medium–high and high technology: 64 (59 + 5) |
| By relative energy efficiency group | Less efficient: 16; equal efficient: 50; more efficient: 71 |

**Table 1.** Technical details for the Spanish subsample of the European Manufacturing Survey 2012 edition.

In summary, the EMS 2012 Spanish subsample considers nine ESTs, which are as follows:

– T0: Dry process/Minimum lubrication; $N = 162$

– T1: Control system for shutdown of machines in off-peak periods; $N = 164$

– T2: Electrical motors with speed regulation; $N = 162$

– T3: Compressed air contracting; $N = 156$

– T4: Highly efficient pumps; $N = 158$

– T5: Low-temperature joining processes; $N = 157$

– T6: Energy retrieval; $N = 164$

– T7: Bigeneration/Trigeneration; $N = 167$

– T8: Use of waste materials for energy generation; $N = 157$

T0, T1, T6 and T7 are the ESTs included in the main body of the 2012 survey for all the countries, of which T0 was not included in the 2008 EMS edition. T2, T3, T4, T5 and T8 are only considered in EMS 2008 and the Spanish subsample of the EMS 2012.

All these ESTs are evaluated for each firm in terms of use, yes or no, and their extent of use, grouped in three categories: 'low' for initial attempts, 'medium', when partially utilised and 'high' for extensive use. This extent of use is represented with an ordinal variable containing values 1, 2 or 3, for low, medium or high, and it is always relative, comparing the present to the most reasonable potential use.

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In the present study, the EST for this sample of firms will be characterised through descriptive and frequency analyses.

Another descriptive analysis will be presented for the companies inside the sample, including parameters such as number of employees, turnover in 2008 and 2011, firm R&D expenditures, exportation intensity, implementation of environmental management systems, such as ISO 14000 and ISO50001:200, and energy-saving potential according to the several elaborated homogenous groups, based on their technological intensity or their energy efficiency level. Averages for these descriptive parameters mentioned above were directly calculated from variables obtained from the survey.

In particular, the parameter of energy-saving potential becomes a key factor for our study, since it represents a measure of the energy efficiency degree resulting after different implementation levels of EST in manufacturing firms. In this sample, the energy-saving potential is represented by percent, and it corresponds to the relative amount of energy a company could save if it is highly implemented in its production system and in all the available EST nowadays.

Characteristics of EST adopters will be presented according to OECD's taxonomy of industries, classified by their technological intensity [**6**]. In this regard, firms have been classified and also presented in three groups: 'Low technology', for firms from NACE codes 15, 16, 17–19, 20–22, 36–37; 'Medium technology', with medium–low technology firms from NACE codes 23, 25, 26, 351, 27, 28; and 'High technology', with medium–high and high technology firms from NACE codes 24, 31, 34, excluding 2423, 352+359, 29, and 353, 2423, 30, 32, 33.

As shown in **Table 2**, only five firms of this sample have NACE codes 353, 2423, 30, 32 and 33, corresponding to a high technology industry. It is for this reason that medium–high and high technology firms from the OECD's taxonomy have been grouped together in a 'High technology' category ($N = 64$), in order to reduce the number of groups and maintain their significance.

| | **Low technology** | **Medium–low technology** | **Medium–high and high technology** | **Total** |
|---|---|---|---|---|
| N | 38 | 67 | 64 (59 + 5) | 169 |
| % | 22% | 40% | 38% | 100% |
| Number of employees in 2011, $N = 37 + 66 + 63$ | 97 ($\sigma = 107$) | 112 ($\sigma = 165$) | 276 ($\sigma = 820$) | 171 |
| Number of employees in 2009, $N = 36 + 63 + 61$ | 98 ($\sigma = 113$) | 116 ($\sigma = 173$) | 279 ($\sigma = 875$) | 160 |
| Turnover 2011 [M€], $N = 34 + 59 + 57$ | 44 ($\sigma = 70$) | 188 ($\sigma = 893$) | 183 ($\sigma = 747$) | 154 |
| Turnover 2009 [M€], $N = 31 + 57 + 55$ | 35 ($\sigma = 58$) | 341 ($\sigma = 2381$) | 224 ($\sigma = 1099$) | 229 |
| Firms with R&D expenditures, $N = 38 + 67 + 62$ | 53% | 60% | 61% | 59% |
| High exportation intensity firms, $N = 35 + 60 + 57$ | 40% | 48% | 33% | 41% |
| Firms with ISO 14000 implemented, $N = 37 + 61 + 57$ | 38% | 36% | 46% | 40% |
| Firms with ISO50001:2001 implemented, $N = 36 + 63 + 59$ | 3% | 2% | 2% | 2% |

| | Low technology | Medium–low technology | Medium–high and high technology | Total |
|---|---|---|---|---|
| Energy saving potential, $N$ = 29 + 54 + 54 | 15% | 13% | 15% | 14% |
| T0: dry process/minimum lubrication, $N$ = 36 + 65 + 61 | 6% | 15% | 13% | 12% |
| T1: control system for shut down of machines in off-peak periods, $N$ = 36 + 66 + 62 | 14% | 14% | 23% | 17% |
| T2: speed regulation, $N$ = 38 + 64 + 60 | 76% | 63% | 72% | 69% |
| T3: compressed air contracting, $N$ = 37 + 62 + 57 | 38% | 40% | 44% | 41% |
| T4: highly efficient pumps, $N$ = 37 + 63 + 58 | 43% | 30% | 40% | 37% |
| T5: low-temperature joining processes, $N$ = 36 + 62 + 59 | 3% | 15% | 7% | 9% |
| T6: energy retrieval, $N$ = 36 + 66 + 62 | 14% | 5% | 18% | 12% |
| T7: bigeneration/trigeneration, $N$ = 38 + 66 + 63 | 24% | 2% | 10% | 10% |
| T8: waste material for energy, $N$ = 36 + 63 + 58 | 14% | 5% | 14% | 10% |

**Table 2.** Summary of descriptive features of the sample by technological intensity.

A discrete variable 'TechLevel', with value 1 for 'Low technology', value 2 for 'Medium technology' and value 3 for 'High technology', following the previously explained criteria, was calculated from the NACE code data for each firm in the survey. Corresponding dummy variables 'LowTech', 'MedTech' and 'HighTech', with values 0–1, were also elaborated to obtain three subsets of 38, 67 and 64 manufacturing companies, respectively, according to their technological level.

In a similar way, a second classification of firms in the sample, according to their relative energy efficiency level, was performed. To do that, a response in the survey regarding the potential energy saving in the company was utilised. Firms answered to a question on what percent of their current energy consumption could they save if they utilised all the available technical possibilities in the present.

Those percentages are represented by a variable in the survey that was used to elaborate three new dummy variables, 'Low Efficient', 'Equal Efficient' and 'More Efficient', with values 0–1. The purpose was to use these dummy variables to obtain three separated groups according to their relative energy efficiency level, comparing its present situation with a hypothetical stage where the company highly used all the available EST today.

To build these categories and collapse the continuous variable with percentage data into three approximately equal groups, a frequency analysis calculating percentiles at 33.33 and 66.66% was performed [7]. The obtained cut-off points for the percentiles 33.33 and 66.66% were 10 and 20%, respectively. In consequence, firms with a relatively low percent of energy-saving potential from 0 to 10% are considered in the 'More Efficient' group ($N$ = 71). The reference group 'Equal Efficient' ($N$ = 50) includes companies with relative energy-saving potential greater than 10% and lesser than 20%. The rest of the firms with relative energy-saving potential greater than 20% are included in the 'Less Efficient' group ($N$ = 16).

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Finally, in order to explore the possible relationships and their strength and direction (positive or negative) between several continuous and dichotomous variables describing firms' characteristics and the use or extent of use of ESTs, a simple bivariate Pearson correlation analysis has been conducted. When a positive correlation between a pair of variables is significant, it indicates that as one variable increases, so does the other. Analogously, a negative significant correlation indicates that as one variable increases, the other decreases.

Given that the data corresponding to the size of the companies in the survey do not follow a normal distribution, neither in the number of employees, nor in the case of the turnover, a transformation of these variables is required to use parametric statistics [7]. As these data in the histogram appear left-skewed, a recalculation, using the logarithm of the original values, has reset the histogram into a normal bell-shaped distribution.

Other mapping analyses were performed on the EMS 2008 edition Spanish samples, as in the case of [8], and from Spanish and Slovenian samples in [9]. Palcic et al. also mapped EST implementation in manufacturing firms, following a similar methodology.

## 3. Results and findings

### 3.1. Descriptive analysis

Results about the typology of the manufacturing firms in our sample, with regard to their technological intensity according to the OECD's taxonomy, are shown in **Table 2**.

We can observe that companies with higher technological level have, on average, a considerably higher number of employees (276 vs. 112 and 97 in 2011), a strong use of environmental management systems such as ISO 14000 [10], but a lower number of firms with a high exportation intensity (more than 50% of sales abroad).

'Medium–Low Technology' and 'High Technology' groups have higher number of companies with R&D expenditure compared with the low technology ones.

Firms in low technology industrial sectors also had an average turnover in 2009 and 2011, of less than a quarter of each one of the other two technological groups (35 vs. 341 and 224 M€ in 2009, and 44 vs. 188 and 183 M€ in 2011).

No significant differences can be observed with regard to energy-saving potential according to the firms' technological intensity. These averages of energy-saving potential for each technological group are represented by a percentage, with values between 13 and 15%.

With regard to the ESTs, according to each technological intensity group, we can stress that low technology firms have a relatively lower use of T0 but a higher use of T7, compared with other industrial sectors with higher technological intensity. 'Medium–Low technology' firms have a higher percentage of use of T5, and a lower percentage for T2, T4, T6, T7 and T8.

Companies in high technology sectors have a considerably higher percentage of use of T1 and a slightly higher one for T3. Percentage of use of T3 increases homogenously with the technology intensity of the sector.

In the case of MST (T9 and T10), their percentage of use decreases with the technology intensity of the sector.

Results about the typology of the manufacturing firms in our sample and their relative energy efficiency are shown in **Table 3**.

| | **Less efficient** | **Equally efficient** | **More efficient** | **Total** |
|---|---|---|---|---|
| N | 16 | 50 | 71 | 137 |
| % | 12% | 36% | 52% | 100% |
| Number of employees in 2011, $N = 15 + 49 + 71$ | 83 ($\sigma = 75$) | 136 ($\sigma = 289$) | 236 ($\sigma = 755$) | 171 |
| Number of employees in 2009, $N = 14 + 49 + 68$ | 81 ($\sigma = 73$) | 138 ($\sigma = 295$) | 243 ($\sigma = 809$) | 160 |
| Turnover 2011 [M€], $N = 14 + 44 + 65$ | 19 ($\sigma = 21$) | 41 ($\sigma = 55$) | 137 ($\sigma = 519$) | 154 |
| Turnover 2009 [M€], $N = 13 + 44 + 63$ | 17 ($\sigma = 16$) | 36 ($\sigma = 49$) | 73 ($\sigma = 244$) | 229 |
| Firms with R&D expenditures, $N = 16 + 49 + 70$ | 63% | 61% | 58% | 59% |
| High exportation intensity firms, $N = 16 + 45 + 65$ | 25% | 33% | 48% | 41% |
| Firms with ISO 14000 implemented, $N = 16 + 47 + 64$ | 38% | 47% | 38% | 40% |
| Firms with ISO50001:2001 implemented, $N = 16 + 47 + 65$ | 0% | 2% | 2% | 2% |
| Energy saving potential, $N = 16 + 50 + 71$ | 32% | 18% | 7% | 14% |
| Technology level (1–3 from low to high), $N = 16 + 50 + 71$ | 2.25 | 2.10 | 2.23 | 2.15 |
| T0: dry process/minimum lubrication, $N = 15 + 50 + 67$ | 20% | 6% | 16% | 12% |
| T1: control system for shutdown of machines in off-peak periods, $N = 16 + 50 + 67$ | 19% | 22% | 15% | 17% |
| T2: speed regulation, $N = 16 + 49 + 71$ | 81% | 78% | 61% | 69% |
| T3: compressed air contracting, $N = 16 + 47 + 67$ | 50% | 38% | 46% | 41% |
| T4: highly efficient pumps, $N = 16 + 49 + 68$ | 50% | 41% | 38% | 37% |
| T5: low-temperature joining processes, $N = 16 + 49 + 66$ | 19% | 4% | 11% | 9% |
| T6: energy retrieval, $N = 16 + 50 + 68$ | 13% | 20% | 7% | 12% |
| T7: bigeneration/trigeneration, $N = 16 + 50 + 69$ | 6% | 12% | 9% | 10% |
| T8: waste material for energy, $N = 14 + 48 + 69$ | 7% | 10% | 10% | 10% |

**Table 3.** Summary of descriptive features of the sample by relative energy efficiency in production.

As it is observable in **Table 3**, companies with higher relative energy efficiency have, on average, a considerably higher number of employees (236 vs. 136 and 83 in 2011) and a considerably higher average turnover in 2009 and 2011, compared with the other two relative energy efficiency groups (73 vs. 36 and 17 M€ in 2009, and 137 vs. 41 and 19 M€ in 2011). Both, the average number of employees and the average turnover, are directly proportional to the

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relative energy efficiency level. The same effect occurs with the average exportation intensity (more than 50% of sales abroad) being significantly higher in the case of the more efficient group than in the other two groups (48 vs. 33% and 25%, respectively). On the other hand, the average of R&D expenditures is slightly higher in the lower relative energy efficiency groups.

The 'Equally Efficient' group has a higher percentage of firms with ISO14000 environmental management system. A very low percentage of firms have implemented ISO 50001:2001 (2%). The average relative energy saving is 7% for the group of 'More Efficient' firms, 18% for the 'Equally Efficient' group, and a 32% in the case of the 'Less Efficient' ones. On an average, manufacturing companies in Spain could have declared a 14% of relative potential energy saving.

In relation to the implemented ESTs according to each relative energy efficiency group, we can stress that firms in 'More Efficient' group have a relatively lower use of T8 but a higher use of T4, compared with other industrial companies in less relative energy efficiency groups. Firms in the 'Equally Efficient' group have a higher percentage of use of T1 and T7 and a lower percentage for T0, T3 and T5.

Companies in the 'Less Efficient' group have a considerably higher percentage of use of T4 and a slightly lower one for T8. Percentage of use of T4 decreases in groups with higher relative energy efficiency.

### 3.2. EST use and extent of use

In **Figure 1**, we can observe the use of the different analysed EST. In the first place, T2 is the most implemented EST with 69% of the companies in the sample; second comes T3 (with 41% and in the third place T4 with 37%).

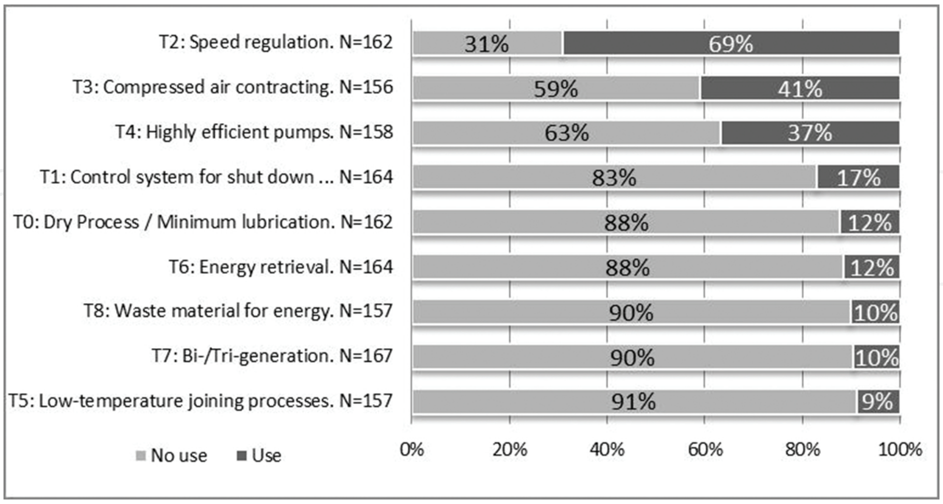


**Figure 1.** Use of EST for all manufacturing sectors.

The rest of the ESTs are implemented by a significantly lower percentage of the firms compared with the top ranked ones.

Furthermore, the most used EST, that is T2, has a considerably higher percentage of use than the rest of the ESTs. This fact could be caused by a wide interpretation of the concept 'electric motors with speed regulation', as almost any system producing movement or rotation powered by an electric motor with a basic speed control could be included in such category. The problem is that, sometimes, this is not an option for this system that could be considered an EST, but a mere intrinsic characteristic of these particular machines.

An exploration of the extent of use of each of these ESTs according to their degree of implementation, ranked from the highest to the lowest percentage for the 'High degree' group, is shown in **Figure 2**. The first effect perceived when studying the extent of use of the ESTs is the radical variation in the ranking for the group of firms that has an extensive use of ESTs and a perceptible reduction of the variance between percentages of high use.

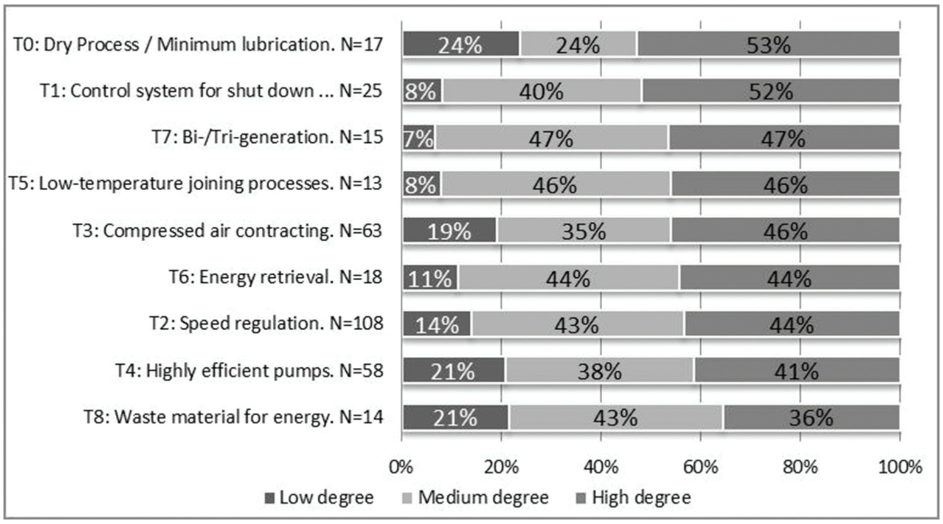


**Figure 2.** Degree of implementation of EST for all manufacturing sectors.

This effect also supports the idea stressed above, regarding a possible wide interpretation of the concept of T2 that now is in seventh position for the group of companies with higher level of implementation of ESTs. Only 14% of the companies declared an intensive use of this technology of the 69% that had declared its use.

T0 is the first EST in the ranking of high implementation with 53% of the firms that use it, followed by T1 with 52% and T7 with 47%.

Only 36% of the companies that use T8 declared an extensive use of it, representing the lowest percentage for the 'High degree' group.

### 3.3. ESTs implementation by firms' technology level

A classification of the companies that have implemented ESTs by technological sector is presented in **Figure 3**. The ESTs are ranked in the graphic, according to percentages in the 'High Tech' group.

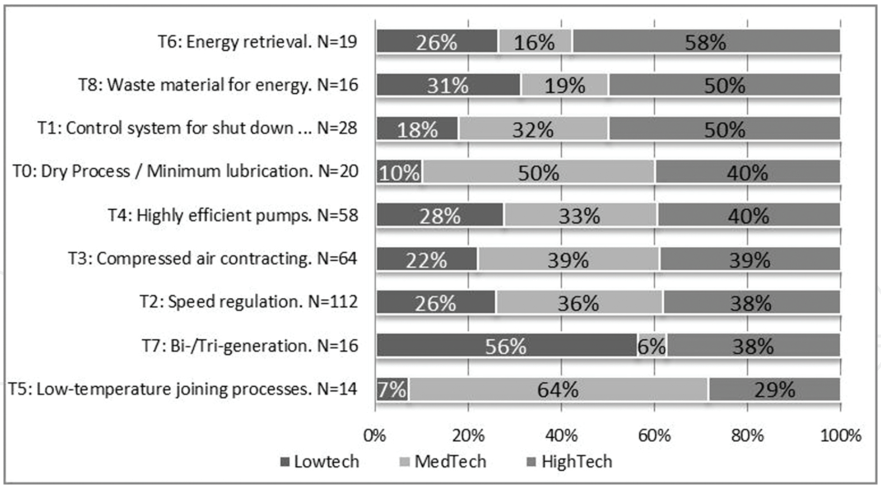


**Figure 3.** Implementation percentage of EST by technological sector.

Companies using T5 are mainly 57.9% of firms within the High Tech group. Moreover, 50% of the companies that have implemented T7 and T1 are the high technological ones.

T6 is implemented by 56.3% companies in the 'Low Tech' group. Only 7.1% and 10% of firms using T4 and T0, respectively, belong to the 'Low Tech' group, while 64% and 50% of the companies in the 'Med Tech' group, respectively, implemented these particular ESTs.

When the same classification is made, considering only an intensive use of the ESTs by technological levels in **Figure 4**, and also ordered according to the percentages in the High Tech' group, a new ranking is established.

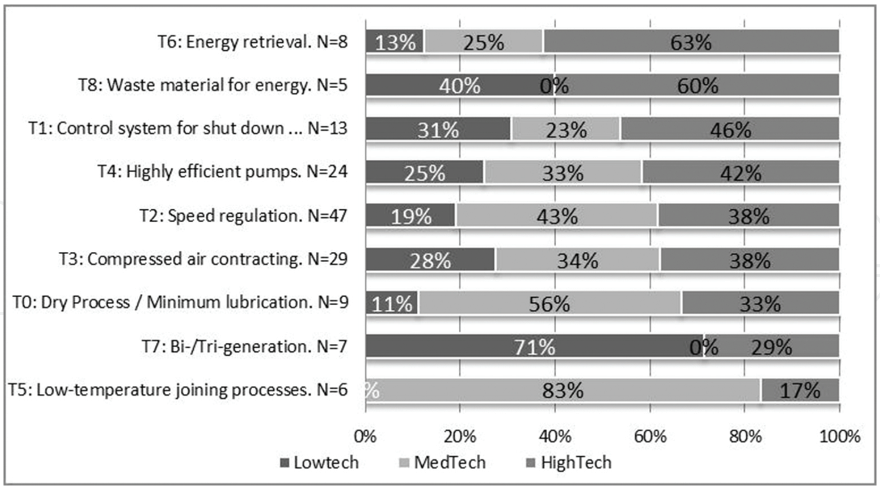


**Figure 4.** High implementation percentage of EST by technological sector.

About 63% and 60% of companies with an intensive use of T6 and T8, respectively, are firms within the 'High Tech' group. On the other hand, only 17% within this group highly implemented T5.

Otherwise, 71% of the companies that have an intensive use of T7 are the low technological ones. However, only 11% of firms using T0 belong to the 'Low Tech' group, and there is not any company in this group with a high implementation of T5.

T5 is implemented by 83% companies in the 'Med Tech' group; 56% of the intensive users of T0 also belong to this group.

### 3.4. ESTs' implementation by firms' relative energy efficiency group

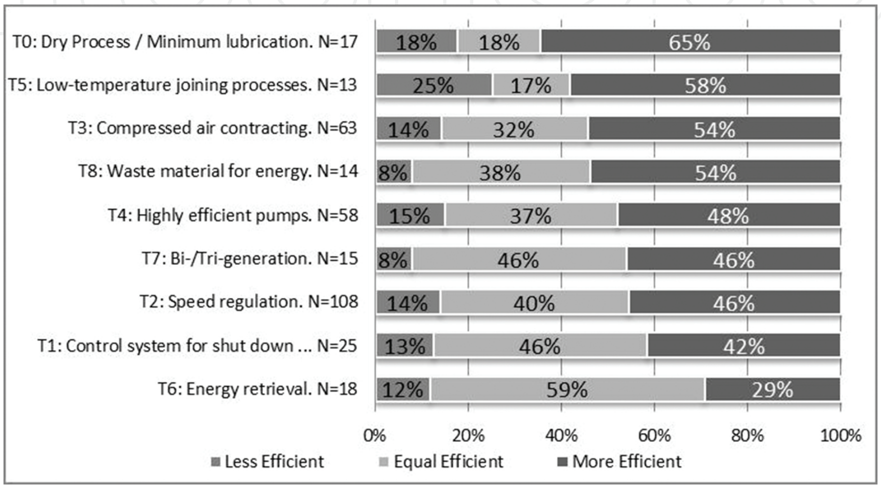


**Figure 5.** Implementation percentage of EST by level of efficiency relative to the energy-saving potential.

Results in **Figure 5** are obtained by classifying companies according to their relative energy efficiency level and ranking the percentages of the ESTs' use from the 'More Efficient' group.

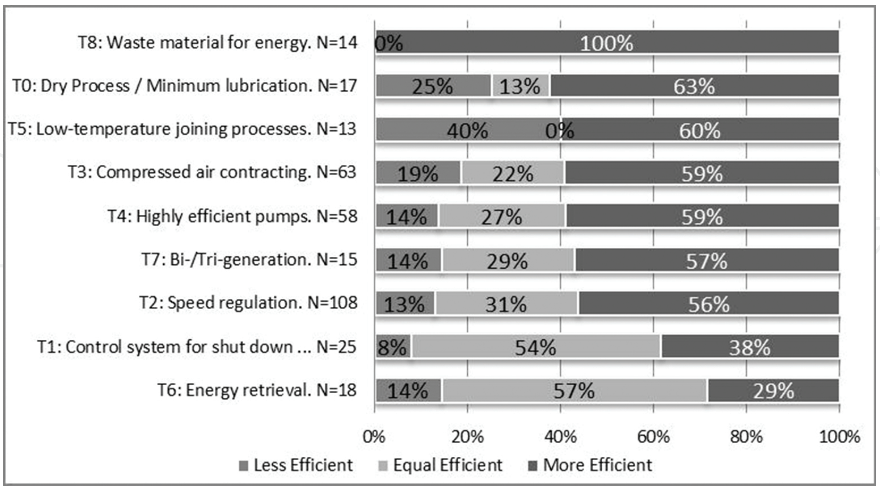


**Figure 6.** High implementation percentage of EST by level of efficiency relative to the energy-saving potential.

More than 50% of the companies implementing T0, T5, T3 and T8 belong to the 'More Efficient' group. Firms in the 'Less Efficient' group do not represent more than 25% of the companies

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using any of the analysed ESTs. These results point to a probable relation between the use of ESTs and the relative energy efficiency of a company.

Results in **Figure 6** are obtained by analysing the same relative energy efficiency groups, considering only an intensive use of the ESTs.

Generally, the average percent in the intensive use of ESTs in the 'More Efficient' group is higher than that when considering only their use, apart from the cases of T0, T1 and T5 that are slightly lower, but quite close. In seven of the nine ESTs studied, the percentage of companies belonging to the 'More Efficient' group that have highly implemented them, represents more than 50% of the firms. Only companies in this group have highly implemented T8.

These facts suggest that a high implementation of the ESTs also contributes to the relative energy efficiency of manufacturing firms.

However, T6 and T1 are highly implemented at 57% and 54%, respectively, by companies in the 'Med Tech' group.

Possible relationships between use or high use of ESTs in manufacturing companies and other parameters such as technological level, size, environmental management systems implemented, export intensity, R&D expenditure and potential energy saving are presented in **Table 4**, by means of a correlation test.

| | | Number of EST implemented | Number of EST highly implemented | Technology level | Firm size log 10 (turnover) | Firm size log 10 (employees) | ISO14031 implemented | ISO50001 implemented | High export intensity (>50% of sales) | R&D expenditure | Potential energy saving |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Number of EST implemented | Pearson correlation | 1 | 0.713 | .013 | 0.210 | 0.157 | 0.131 | 0.178 | 0.073 | 0.027 | 0.098 |
| | Sig. (two-tailed) | | 0.000 | 0.864 | 0.010 | 0.044 | 0.105 | 0.025 | 0.375 | 0.728 | 0.253 |
| | *N* | 169 | 169 | 169 | 150 | 166 | 155 | 158 | 152 | 167 | 137 |
| Number of EST highly implemented | Pearson correlation | | 1 | 0.001 | 0.208 | 0.14 | 0.049 | 0.05 | 0.027 | 0.099 | –0.001 |
| | Sig. (two-tailed) | | | 0.985 | 0.011 | 0.070 | 0.541 | 0.530 | 0.743 | 0.205 | 0.987 |
| | *N* | | 169 | 169 | 150 | 166 | 155 | 158 | 152 | 167 | 137 |
| Technology level | Pearson correlation | | | 1 | 0.12 | 0.160 | 0.069 | –0.027 | –0.070 | 0.015 | 0.019 |
| | Sig. (two-tailed) | | | | 0.151 | 0.039 | 0.396 | 0.740 | 0.394 | 0.851 | 0.825 |
| | *N* | | | 169 | 150 | 166 | 155 | 158 | 152 | 167 | 137 |
| Firm size log 10 (turnover) | Pearson correlation | | | | 1 | 0.632 | 0.344 | 0.14 | 0.005 | 0.113 | –0.171 |
| | Sig. (two-tailed) | | | | | 0.000 | 0.000 | 0.094 | 0.958 | 0.170 | 0.059 |
| | *N* | | | | 150 | 149 | 139 | 142 | 138 | 149 | 123 |
| Firm size log 10 (employees) | Pearson correlation | | | | | 1 | 0.378 | 0.05 | –0.047 | 0.121 | –0.132 |
| | Sig. (two-tailed) | | | | | | 0.000 | 0.540 | 0.568 | 0.124 | 0.127 |
| | *N* | | | | | 166 | 153 | 155 | 150 | 164 | 135 |

| | | Number of EST implemented | Number of EST highly implemented | Technology level | Firm size log 10 (turnover) | Firm size log 10 (employees) | ISO14031 implemented | ISO50001 implemented | High export intensity (>50% of sales) | R&D expenditure | Potential energy saving |
|---|---|---|---|---|---|---|---|---|---|---|---|
| ISO14031 implemented | Pearson correlation | | | | | | 1.000 | 0.180 | –0.061 | 0.100 | –0.001 |
| | Sig. (two-tailed) | | | | | | | 0.027 | 0.474 | 0.215 | 0.994 |
| | *N* | | | | | | 155 | 151 | 142 | 155 | 127 |
| ISO50001 implemented | Pearson correlation | | | | | | | 1 | –0.024 | –0.136 | –0.077 |
| | Sig. (two-tailed) | | | | | | | | 0.780 | 0.089 | 0.387 |
| | *N* | | | | | | | 158 | 143 | 158 | 128 |
| High export intensity (>50% of sales) | Pearson correlation | | | | | | | | 1 | 0.084 | –0.160 |
| | Sig. (two-tailed) | | | | | | | | | 0.307 | 0.074 |
| | *N* | | | | | | | | 152 | 150 | 126 |
| R&D expenditure | Pearson correlation | | | | | | | | | 1 | 0.035 |
| | Sig. (two-tailed) | | | | | | | | | | 0.684 |
| | *N* | | | | | | | | | 167 | 135 |
| Potential energy saving | Pearson correlation | | | | | | | | | | 1 |
| | Sig. (two-tailed) | | | | | | | | | | |
| | *N* | | | | | | | | | | 137 |

**

Correlation is significant at the 0.01 level (two-tailed).

*

Correlation is significant at the 0.05 level (two-tailed).

**Table 4.** Correlation matrix between environmental management systems use, export intensity, R&D expenditure, potential energy saving and the use and high use of EST.

We can find different author criteria for the determination of the strength of relationships from the value of Pearson's correlation coefficient ($r$); however, Cohen [11] suggests the following guidelines that will be used in the present study: small strength for $|r|$ = 0.10–0.29; medium strength for $|r|$ = 0.30–0.49 and large strength for $|r|$ = 0.50–1.

The quantity of EST implemented in a company results in having a positive relationship with the firm size, in terms of turnover as well as number of employees, and with ISO50001:2001 implementation. This relationship is more significant (at 0.01 level; two-tailed) with respect to the company's turnover.

When the extent of use of these ESTs is considered, only a significant relation with its turnover remains at a medium level of strength.

Firms' technology level in our sample has only a light significant relationship with companies' size in terms of number of employees.

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Firms' size, both in terms of turnover and in terms of number of employees, is also interrelated in a medium level of significance.

With regard to the environmental management systems, in the case of ISO14000 implementation, a medium level of strength relationship appears with the company size, both in terms of turnover and number of employees.

For the case of ISO50001:2001, there are small strength relationships with ISO14000 implementation and also with EST use.

High export intensity in companies and the existence of R&D expenditures are not linked with any other studied firms' characteristics according to this test.

Furthermore, and directly related to the main objectives of this study, no significant relationships are revealed between the relative potential energy saving and any other variable in the correlation, especially with the use and high use of ESTs.

In a previous study [12], a relationship was determined between the use, and mainly a high implementation level, of ESTs and energy efficiency in manufacturing firms.

For that reason, an additional Chi-square test is presented in **Table 5**. In this table, a crosstab is shown between the number of ESTs highly implemented in a firm and the relative potential energy saving, scaled according to the three energy efficiency groups: 'More Efficient' (value = 3), 'Equal Efficient' (value = 2) and 'Less Efficient' (value = 3). This test can be done between two categorical variables as is the case, and it allows the exploring of their possible relationship.

| **Crosstab** | | | | | |
|---|---|---|---|---|---|
| | | **Relative potential energy saving (scaled in three groups)** | | | |
| | | **1 (Less efficient)** | **2 (Equal efficient)** | **3 (More efficient)** | **Total** |
| Sum high use EST0 | Count | 7 | 29 | 33 | 69 |
| | Expected count | 8.1 | 25.2 | 35.8 | 69.0 |
| | % within sum high use EST | 10.1 | 42.0 | 47.8 | 100.0 |
| | % within potential saving scale | 43.8 | 58.0 | 46.5 | 50.4 |
| | % of total | 5.1 | 21.2 | 24.1 | 50.4 |
| 1 | Count | 2 | 14 | 15 | 31 |
| | Expected count | 3.6 | 11.3 | 16.1 | 31.0 |
| | % within sum high T0 | 6.5 | 45.2 | 48.4 | 100.0 |
| | % within potential saving scale | 12.5 | 28.0 | 21.1 | 22.6 |
| | % of total | 1.5 | 10.2 | 10.9 | 22.6 |
| 2 | Count | 5 | 2 | 14 | 21 |
| | Expected count | 2.5 | 7.7 | 10.9 | 21.0 |
| | % within sum high use EST | 23.8 | 9.5 | 66.7 | 100.0 |
| | % within potential saving scale | 31.3 | 4.0 | 19.7 | 15.3 |

**Crosstab**

| | | Relative potential energy saving (scaled in three groups) | | | |
|---|---|---|---|---|---|
| | | **1 (Less efficient)** | **2 (Equal efficient)** | **3 (More efficient)** | **Total** |
| | % of total | 3.6 | 1.5 | 10.2 | 15.3 |
| 3 | Count | 0 | 2 | 7 | 9 |
| | Expected count | 1.1 | 3.3 | 4.7 | 9.0 |
| | % within sum high use EST | 0.0 | 22.2 | 77.8 | 100.0 |
| | % within potential saving scale | 0.0% | 4.0% | 9.9% | 6.6% |
| | % of total | 0.0 | 1.5 | 5.1 | 6.6 |
| 4 | Count | 2 | 1 | 0 | 3 |
| | Expected count | 0.4 | 1.1 | 1.6 | 3.0 |
| | % within sum high use EST | 66.7 | 33.3 | 0.0 | 100.0 |
| | % within potential saving scale | 12.5 | 2.0 | 0.0 | 2.2 |
| | % of total | 1.5 | 0.7 | 0.0 | 2.2 |
| 5 | Count | 0 | 2 | 2 | 4 |
| | Expected count | 0.5 | 1.5 | 2.1 | 4.0 |
| | % within sum high use EST | 0.0 | 50.0 | 50.0 | 100.0 |
| | % within potential saving scale | 0.0 | 4.0 | 2.8 | 2.9 |
| | % of total | 0.0 | 1.5 | 1.5 | 2.9 |
| Total | Count | 16 | 50 | 71 | 137 |
| | Expected count | 16.0 | 50.0 | 71.0 | 137.0 |
| | % within sum high use EST | 11.7 | 36.5 | 51.8 | 100.0 |
| | % within potential saving scale | 100.0 | 100.0 | 100.0 | 100.0 |
| | % of total | 11.7 | 36.5 | 51.8 | 100.0 |

**Chi-square tests**

| | **Value** | **df** | **Asymp. sig. (two-sided)** |
|---|---|---|---|
| Pearson Chi-square | 22.812 | 10 | 0.011 |
| Likelihood ratio | 22.850 | 10 | 0.011 |
| Linear-by-linear association | 0.010 | 1 | 0.921 |
| *N* of valid cases | 137 | | |

a.
11 cells (61.1%) have expected count less than 5. The minimum expected count is 0.35.

**Table 5.** Chi-square test crosstab between the number of highly used ESTs and the relative energy-efficiency group.

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However, despite this, there exists a low significance in the relationship between these variables, as the Pearson Chi-square is $0.011 < 0.05$, and the assumption required for this test concerning the minimum expected cell frequency of 5 or more in the 80% of the cases is not respected.

## 4. Conclusions

In the increasingly competitive and changing world, the use of EST has emerged as a strategic imperative for most companies, especially for the manufacturing firms, due to the progressively stricter legislation. Therefore, it is important to have an overall awareness of the current use of those technologies in order to establish future policies for encouraging a higher adoption.

In order to map the current situation of the degree of use of these ESTs in the manufacturing sector, this chapter provides evidences based on data from the 2012 European Manufacturing Survey edition. The case of the Spanish survey is specifically exceptional, since it is a national survey that includes the highest number of ESTs. In total, nine ESTs are included in the analysis. Moreover, the technology intensity variable and the self-elaborated parameter energy efficiency degree are also included in order to contrast their role in the energy-saving performance of the adopters. Finally, some control variables (number of employees, turnover in 2008 and 2011, firm R&D expenditures, high exportation intensity and implementation of environmental management systems such as ISO 14000 and ISO50001:2001) are also included. According to the results, five main conclusions can be formulated.

A general observation on the use of EST shows that their adoption in manufacturing firms is still relatively low. Except for the case of speed regulation (T2, 69.1%), possibly due to a wide interpretation of the term, the technology with the highest percentage of adoption is compressed air contracting (T3, 41%). However, it is interesting to point out how these results vary according to the degree of implantation. Dry process/minimum lubrication (T0) and control system for the shutdown of machines in off-peak periods (T1) are the technologies with the highest degree of implementation, both over 50%.

Second, it has been observed that the more relative energy-efficient companies are, on average, characterised as relatively bigger, both in terms of turnover and number of employees, than the equal and less efficient ones. This group of companies also has a higher average of export intensity (more than 50% of sales abroad). However, R&D expenditures are, on average, higher in the less relative energy-efficient group of firms, and the equal relative energy-efficient group is the one with a higher percentage of environmental management systems implemented.

Third, according to the technology intensity, six out of nine ESTs are implemented higher in low and medium–low technology sectors. Only the control system for shutdown of machines in off-peak periods (T1, 23%), compressed air contracting (T3, 44%) and energy retrieval (T6, 18%) are implemented higher in the group of high technology firms.

Fourth, the results are more significant when the degree of adoption is contrasted with the energy efficiency of the firm, since none of the ESTs are mostly adopted by firms that declare being more efficient than the other firms of the sector. Five ESTs are mostly implemented in less efficient group and four in the equally efficient group.

Fifth, in analysing ESTs, we focused on manufacturing firms that showed high implementation of these technologies. We have analysed these technologies according to their use in different technology-intensive sectors and based on the energy efficiency of the firms. We found that the analysed ESTs are predominately highly implemented in low and medium–low technology groups, except for two technologies, namely, waste material for energy (T8) and energy retrieval (T6). However, we could discard the significance of these ESTs, since the number of adopters is very low. Therefore, we could conclude that most of the highest implemented ESTs are more usual in sectors of low technology, confirming the same conclusion obtained when we generalised for all degrees of implementation. On the other hand, in seven out of nine ESTs studied, a high implementation of these ESTs occurs in the majority of the cases inside the more efficient group of companies. This fact could suggest a possible positive relationship between the high use of ESTs and firms' energy efficiency. However, this potential relationship has not been demonstrated for this sample with the Pearson correlation and Chi-square analysis.

Our research has two main limitations: the statistical analysis applied and the geographical scope of the sample. The first is that only descriptive statistics and correlation tests were used to map the characteristics of EST and their adopters. Therefore, the next step is to use several advanced statistical methods to draw further conclusions. Related to the narrow geographical coverage, the option to focus our analysis on the Spanish survey is explained by the fact of having higher number of technologies. Practical and academic implications of having detailed, single and high number of ESTs convert into a strong argument towards a shared list of such ESTs, which remains further explorable in forthcoming EMS rounds.

In conclusion, this study contributes to disclose to practitioners that Spanish manufacturing companies are recognised to have, on an average, 14% of relative energy-saving potential. It has also been illustrated which ones of these ESTs are the most implemented for each firm typology, in terms of use and extent of use. Moreover, firms have been characterised according to the relative energy efficiency groups to facilitate policy makers to take the right decisions, oriented to improve the energy efficiency in these sectors. Some clues have been pointed at for further researches in order to explore the possible relationships between energy efficiency and the implementation of ESTs, using more powerful statistical tools.

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