Universitat de Girona

FROM ENERGY SAVING TECHNOLOGIES TO GREEN PRODUCT INNOVATION: EVIDENCE FROM THE EUROPEAN MANUFACTURING SURVEY

Marc Pons Pairó

Universitat de Girona

DOCTORAL THESIS

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MARC PONS PAIRÓ

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2019

DOCTORAL PROGRAMME IN LAW, ECONOMICS AND BUSINESS

Supervised by:

Co-Director: Josep Llach Pagès PhD

Co-Director: Andrea Bikfalvi PhD

Presented to obtain the degree of PHD at the University of Girona

Josep Llach Pagès (PhD) i **Andrea Bikfalvi** (PhD) com a co-directors de la present tesi doctoral

DECLAREM:

Que el treball titulat **"FROM Energy Saving Technologies TO Green Product Innovation: Evidence from the European Manufacturing Survey"**, que presenta **Marc Pons Pairó** per a l'obtenció del títol de doctor, s'ha estat realitzat sota la meva direcció.

I, perquè així consti i tingui els efectes oportuns, signem aquest document.

Signat:

Dr. Josep Llach Pagès
Co-director

Signat

Dra. Andrea Bikfalvi
Co-directora

A Girona, 29 de setembre de 2019

La Dra. Andrea Bikfalvi, com a coautora dels articles següents:

- *Exploring the impact of energy efficiency technologies on manufacturing firm performance*
- *Analyzing Energy and Material Saving Technologies' Adoption and Adopters*
- *Analysing the Adoption of Energy-Saving Technologies in Manufacturing Firms*
- *Analysing innovators according to the environmental impact of new products*
- *Clustering product innovators: an exploratory study focused on implementers of new products reducing environmental impact*

Accepto que el Sr. Marc Pons Pairó presenti els articles esmentats com a autor principal i com a part de la seva tesi doctoral, i que aquests articles no puguin, per tant, formar part de cap altra tesi doctoral.

I perquè així consti i tingui els efectes oportuns, signo aquest document

Signat:

Dra. Andrea Bikfalvi

A Girona, 29 de setembre de 2019

Universitat de Girona

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I perquè així consti i tingui els efectes oportuns, signo aquest document

Signat:

Dr. Josep Llach Pagès

A Girona, 29 de setembre de 2019

Universitat de Girona

Dr Iztok Palčič, as co-author of the following articles:

- *Exploring the impact of energy efficiency technologies on manufacturing firm performance*
- *Analyzing Energy and Material Saving Technologies' Adoption and Adopters*

Accepts that Mr Marc Pons presents the cited articles as the principal author and as part of his doctoral thesis and that said articles cannot, therefore, form part of any other doctoral thesis.

And for all intents and purposes, hereby signs this document

Signature:

Dr Iztok Palčič

Maribor (Slovenia), September 29th 2019

Universitat de Girona

Dr Borut Buchmeister, as co-author of the following articles:

- *Analyzing Energy and Material Saving Technologies' Adoption and Adopters*

Accepts that Mr Marc Pons presents the cited articles as the principal author and as part of his doctoral thesis and that said articles cannot, therefore, form part of any other doctoral thesis.

And for all intents and purposes, hereby signs this document

Signature:

Dr Borut Buchmeister

Maribor (Slovenia), September 29th 2019

-«Seràs escultor, però jo pagaré el marbre»-

L'auca del senyor Esteve
Santiago Rusiñol

Per l'Ariadna i la Tanit, perquè sàpiguen que si podem arribar lluny, també és gràcies a la gent que ens estima i que ha lluitat per fer-ho possible.

Agraïments

Ara que puc aturar-me un moment i fer-me conscient de la feina feta als meus 48 anys, permeteu-me que m'esplaï en aquestes línies per expressar la meva satisfacció i agraïments més sincers.

Sempre he tendit a embrancar-me per les vies més complicades en les meus estudis i en la meva vida professional, en general. El fet que se m'hagi permès seguir la meva trajectòria, en tot tipus de moments i situacions, ha representat per mi una sort immensa. Lluny d'obtenir-ne uns beneficis econòmics, m'ha reportat uns coneixements a través de la ciència, la tècnica, però també la docència o l'art mateix, que em permeten apreciar detalls realment importants a la vida i que em proporcionen, sobretot, una llibertat que valoro i necessito enormement.

Vull agrair a la Universitat de Girona l'oportunitat que m'han donat per a poder dur a terme aquests deu anys de docència com a professor associat, que tant m'omplen com a persona i com a professional, així com la subvenció del màster de *Business Innovation and Technology Management*, la tesi del qual va acabar originant aquesta recerca. Tesi, per cert, dirigida per la Dra. Andrea Bikfalvi la qual vull esmentar especialment més endavant.

El dia que em vaig matricular del meu primer màster oficial a la UdG, després del postgrau i el MBA cursats a Barcelona, algú d'administració ja se'n va encarregar de recordar-me que no em donaria dret a fer el doctorat perquè jo provenia del que ell anomenava una "titulació mitjana". Si bé en aquell moment ni m'ho havia plantejat, he de reconèixer que gràcies a aquell comentari se'm va començar a presentar el repte com una possibilitat futura.

Veient la insospitada acceptació dels petits treballs de recerca que havia iniciat, em decideixo a fer el doctorat de mica en mica, aprofitant aquesta feina feta. Una nova dificultat legislativa fa que hagi de cursar un tercer màster de *Tourism Management and Planning*, just per complir l'expedient. Pot ser que sigui la persona amb més màsters de la UdG? Aquí sí que he d'agrair totes les facilitats i acompanyament que em va proporcionar el Dr. Lluís Prats i la directora de la meva Tesi, la Dra. Judit Díaz, que també es va prestar a presentar el meu treball a un congrés internacional a Polònia que jo no em vaig poder permetre en aquell moment.

Molt especialment he d'esmentar els companys de departament d'Organització d'Empreses i Gestió del Producte, amb els que hi he pogut teixir una confiança que ha fet que sigui facilíssim treballar amb ells i als que els he d'agrair totes les oportunitats i acompanyament que m'han proporcionat: en Rudi, la Gerusa, l'Anna, en Josep i l'Andrea. M'és altament gratificant que gent de la seva categoria professional i humana aprecïi una feina complexa que he intentat fer amb tot el rigor i la passió del que he sigut capaç. Si un conspicu company del departament hi trobés a faltar el seu nom en aquesta curta llista, no és perquè me l'hagi oblidat, sinó perquè en faig al·lusió expressa a l'apartat d'amics de tota la vida.

Alhora vull donar les gràcies a la resta de professors associats amb els que he compartit assignatures i amb els que tant generosament hem intercanviat experiències i continguts, especialment amb l'amic Jesús Picornell i de nou l'Andrea amb la que compartim assignatura els darrers anys.

He de fer un esment molt especial als meus co-directors de tesi, el Dr. Josep Llach i la Dra. Andrea Bikfalvi que han sigut capaços d'arrossegar-me en aquesta aventura i els vull agrair molt sincerament la seva implicació, exigència, rigor i paciència, sense els quals no hauria arribat a aquest punt. Han sigut capaços de transmetre d'una manera natural la seva passió i coneixements que valoro molt, de la mateixa manera que em consta que els seus alumnes també ho fan.

Als co-autors d'alguns dels articles, els Drs. Iztok Palčič i Borut Buchmeister de la Universitat de Maribor (Eslovènia) els he de donar les gràcies per haver fet tant fàcil la seva col·laboració, així com per la seva generositat a l'hora de cedir-nos la submostra eslovena de l'EMS pel nostre treball. A l'Iztok li vull agrair l'especial defensa que va fer dels nostres resultats en el congrés d'Amsterdam.

Igualment agrair al Fraunhofer Institute for Systems and innovation Research i a les representants francesa i portuguesa de l'EMS per permetre'ns utilitzar les seves dades en els articles d'aquesta tesi.

També vull agrair al Dr. Lo Kwan Yu Chris de la Polytechnic University de Hong Kong i al Dr. Paul Coughian del Trinity College de Dublin les felicitacions i l'interès que van mostrar pel nostre treball, així com al Dr. Goksel Yalcinkaya de la University of New Hampshire per la seva amable i constructiva crítica de la meva exposició a Reykjavik.

En la part més personal he d'esmentar als amics de tota la vida que, tant si els tinc al costat com si no, són un gran puntal i referent per a mi: en Carles, en Martí, en Xavi, en Yuri, en Jesús, en Jordi i en Joan que recordem tant a prop, en Cesc, els germans Verdaguer o en Lluís Carrillo. Em sap greu deixar-me'n un grapat més.

Finalment, em sento en deute amb la meva família per tot el que m'han proporcionat i permès. Provenim d'una pagesia de secà i de l'una petita menestralia de botiguers i emprenedors, i en sóc deutor del valors que representen i em defineixen.

Vull dedicar aquesta tesi als meus pares que mai m'han escatimant un llibre o una revista especialitzada, a la meva germana que m'ha aguantat coma germà, a la meva àvia Catalina i les seves germanes que em guardaven retalls de diari que parlaven de ciència quan era un nen, a la meva àvia Lola que sense ser-ne conscient era una erudita de la botànica i les herbes remeieres, al meu avi Joan, un home de la terra i un exemple per a mi i a l'avi Ramon, que sense conèixer-lo compartim una atracció per les ones hertzianes.

Per acabar, dedico la meva feina a l'Ariadna i la Tanit que tantes estones els he hagut de robar i a l'Anna per la paciència i l'esforç addicional que ha hagut d'aportar perquè jo pogués enllestir els meus projectes. Us estimo molt a totes.

A Llers , el 29 de setembre de 2019

Abstract

Green manufacturers and an understanding of their differentiating characteristics and environmental and economic performance when applying green practices are at the centre of this doctoral thesis.

The focus is set from two different viewpoints around this particular group of companies. The first is the implementation of energy- and material-saving technologies in production processes and the second is the innovation of new products that have a positive impact on the environment when in use or when disposing of them.

This original dual vision covers two strategic societal issues, namely environment and innovation. The aim is to provide policy makers with new knowledge to promote energy efficiency, green manufacturing and green product innovation in a suitable manner.

The evidence is based on different editions and country subsamples of the European Manufacturing Survey, mainly the Spanish one.

To achieve the research objectives, the results are presented in the form of five studies that have been published in indexed journals or as a book chapter or presented in international conferences.

New recent data describing and differentiating green manufacturing companies have been provided. Evidence has been found indicating that there is no clear significant relationship between the use of energy- and material-saving technologies and economic performance. On the other hand, there is a significant positive relationship between implementing the same technologies and firms' environmental performance.

Keywords

Energy efficiency, manufacturing firm, energy-saving technology, material-saving technology, business performance, environmental performance, European Manufacturing Survey (EMS), product innovation, green product innovation, environmental impact, Spain

Resum (CAT)

Les indústries verdes constitueixen el centre d'aquesta tesi doctoral així com la comprensió de les seves característiques diferenciadores i dels seus rendiments, tant econòmics com ambientals, quan aquestes apliquen pràctiques verdes.

El focus es posa des de dos punts de vista diferents al voltant d'aquest grup especial d'empreses, primerament des del de la implementació de tecnologies per a l'estalvi d'energia i materials en els processos de producció i, en segon lloc, des de la innovació de nous productes que tenen un impacte positiu sobre el medi ambient durant el seu ús o bé a l'hora de la seva eliminació.

Aquesta original doble visió abasta dues qüestions socials estratègiques, com ara són el medi ambient i la innovació. El propòsit és els de proporcionar nous coneixements als responsables polítics perquè puguin promoure l'eficiència energètica, la producció verda, o bé la innovació de nous productes verds d'una manera adequada.

Les evidencies que s'exposen estan basades en diferents edicions i submostres de diferents països, principalment l'espanyola, de la *European Manifacturing Survey*.

Per tal d'assolir els objectius de recerca, els resultats es presenten en forma de cinc estudis que han estat publicats en revistes indexades, un capítol de llibre o presentades en conferències internacionals.

S'han proporcionat dades que descriuen i diferencien les indústries verdes. Alhora, s'han trobat evidències que indiquen que l'ús de tecnologies per a l'estalvi d'energia i materials no tenen una relació clara i significativa amb el rendiment econòmic. D'altra banda, sí que apareix una relació positiva i significativa entre la implementació de les mateixes tecnologies i el rendiment mediambiental de les empreses.

Mots clau

Eficiència energètica, empresa industrial, tecnologia per a l'estalvi energètic, tecnologia per a l'estalvi de materials, rendiment econòmic, rendiment mediambiental, *European Manufacturing Survey* (EMS), innovació en producte, innovació en producte verd, impacte mediambiental, Espanya

Resumen (ES)

Las industrias verdes constituyen el centro de esta tesis doctoral, así como la comprensión de sus características diferenciadoras y de sus rendimientos, tanto económicos como medioambientales, cuando éstas aplican prácticas verdes.

El foco se pone desde dos puntos de vista diferentes alrededor de este grupo especial de empresas, primeramente desde el de la implementación de tecnologías para el ahorro de energía y materiales en los procesos de producción y, en segundo lugar, desde la innovación de nuevos productos que tienen un impacto positivo sobre el medio ambiente durante su uso o bien en el momento de su eliminación.

Esta original doble visión abarca dos cuestiones sociales estratégicas, como son el medio ambiente y la innovación. El propósito es el de proporcionar nuevos conocimientos a los responsables políticos para que puedan promover la eficiencia energética, la producción verde, o la innovación de nuevos productos verdes de una manera adecuada.

Las evidencias que se exponen están basadas en diferentes ediciones y submuestras de diferentes países, principalmente la española, de la European Manifacturing Survey.

Para alcanzar los objetivos de investigación, los resultados se presentan en forma de cinco estudios que han sido publicados en revistas indexadas, un capítulo de libro o presentadas en conferencias internacionales.

Se han proporcionado datos que describen y diferencian las industrias verdes. Asimismo, se han encontrado evidencias que indican que el uso de tecnologías para el ahorro de energía y materiales no tiene una relación clara y significativa con el rendimiento económico. Por otra parte, sí que aparece una relación positiva y significativa entre la implementación de las mismas tecnologías y el rendimiento medioambiental de las empresas.

Palabras clave

Eficiencia energética, empresa industrial, tecnología para el ahorro energético, tecnología para el ahorro de materiales, rendimiento económico, rendimiento medioambiental, *European Manufacturing Survey* (EMS), innovación en producto, innovación en producto verde, impacto medioambiental, España.

List of publications derived from this thesis

In parallel of the development of the thesis, several articles have been published in indexed journals. The list of publications arising from this thesis is presented below:

<table>
<tr><th>Year</th><th>State</th><th>Journal</th><th>Index</th><th>Quartile</th><th>Subject Area</th></tr>
<tr><td colspan="6">❶ Pons, M., Bikfalvi, A., Llach, J., & Palčič, I. (2013). Exploring the impact of energy efficiency technologies on manufacturing firm performance. Journal of Cleaner Production, 52, 134–144. https://doi.org/10.1016/j.jclepro.2013.03.011</td></tr>
<tr><td rowspan="2">2013</td><td rowspan="2">Published</td><td rowspan="2">Journal of Cleaner Production</td><td>JCR</td><td>Q1</td><td>Green and Sustainable Science & Technology
Engineering, Environmental
Environmental Sciences</td></tr>
<tr><td>SCIMAGO</td><td>Q1</td><td>Business, Management and Accounting • Strategy and Management
Energy • Renewable Energy, Sustainability and the Environment
Engineering • Industrial and Manufacturing Engineering
Environmental Science • Environmental Science (miscellaneous)</td></tr>
<tr><td colspan="6">❷ Pons, M., Palčič, I., Bikfalvi, A., Llach, J., & Buchmeister, B. (2013). Analysing energy and material saving technologies' adoption and adopters. Strojniski Vestnik/Journal of Mechanical Engineering, 59(6), 409–417. https://doi.org/10.5545/sv-jme.2012.830</td></tr>
<tr><td rowspan="2">2013</td><td rowspan="2">Published</td><td rowspan="2">Strojniski Vestnik / Journal of Mechanical Engineering</td><td>JCR</td><td>Q3</td><td>Engineering • Mechanical</td></tr>
<tr><td>SCIMAGO</td><td>Q2</td><td>Engineering • Mechanical Engineering, Mechanics of Materials</td></tr>
<tr><td colspan="6">❸ Pons, M., Llach, J., & Bikfalvi, A. (2016). Analysing the Adoption of Energy-Saving Technologies in Manufacturing Firms. In E. Krmac (Ed.), Sustainable Supply Chain Management. https://doi.org/10.5772/62852</td></tr>
<tr><td>2016</td><td>Published</td><td>Intech</td><td colspan="3">International editorial
Double blind review</td></tr>
<tr><td colspan="6">❹ Pons, M., Bikfalvi, A., & Llach, J. (2017). Clustering product innovators: a comparison between conventional and green product innovators. International Journal of Production Management and Engineering.</td></tr>
<tr><td rowspan="2">2018</td><td rowspan="2">Published</td><td rowspan="2">International Journal of Production Management and Engineering</td><td>Emerging Sources Citation Index</td><td>n.a.</td><td>Engineering • Engineering, Multidisciplinary</td></tr>
<tr><td>ERIHPLUS</td><td>n.a.</td><td>Business and Management</td></tr>
</table>

Intermediate contributions

The following table highlights that the present work includes results presented at international conferences mentioned above:

Year	Conference	Presentation
2017	24th Innovation and Product development Management Conference (IPDMC) Reykjavik, Iceland - June 11-13, 2017 European Institute for Advanced Studies in Management (EIASM) http://www.eiasm.org/frontoffice/event_announcement.asp?event_id=1165	Analysing innovators according to the environmental impact of new products
2017	11th International Conference on Industrial Engineering and Industrial Management València, Spain - July, 2017 Asociación para el Desarrollo de la Ingenieria de Organización (ADINGOR) http://www.cigip.upv.es/cio2017/	Clustering product innovators: an exploratory study focused on implementers of new products reducing environmental impact

Abbreviations

CIS	Cominity Innovation Survey
CSR	Corporate Social Responsability
EIASM	European Institute for Advanced Studies in Management
EMS	European Manufacturing Survey
EMS	Environmental Management Systems
EPI	Environmental Performance Index
EST	energy saving technologies
GPI	Green Product Innovation
IEA	International Energy Agency
IMSS	International Manufacturing Strategy Survey
IPDMC	Innovation and Product Development Management Conference
ISI	Franhofer Institute for Systems and Innovation Research
MST	material saving technologies
NACE	European Classification of Economic Activities
NPD	New Product Development
OECD	Organisation for economic Cooperation and Development
R&D	Research & Development
ROA	Return-On-Assets
ROE	Return-On-Equity
ROI	Return-On-Investment
ROS	Return-On-Sales
UdG	Universitat de Girona
UN	United Nations

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Chapter 1 Introduction

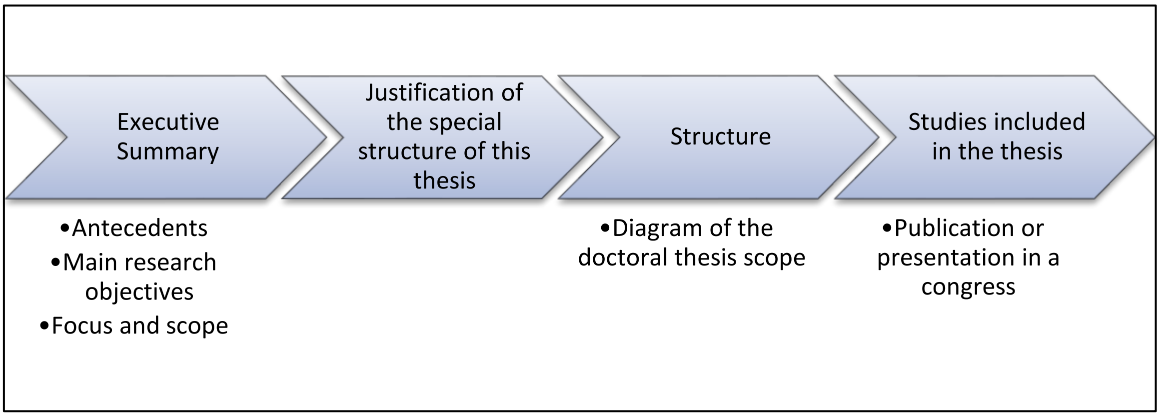
The first chapter is aimed to introduce the special structure of this thesis, its summary and antecedents. It also presents its originality and focus, both, conceptual and geographic, establishing the boundaries of the scope.

The executive summary introduces the antecedents and the general research objectives. Then, the reader can find a justification of the special structure of the thesis and the description of its final structure itself.

Finally, a table of published works or presentations generated by this research, included in following chapters as results, closes this introduction.

Figure 1below presents the structure of this Introduction.

Figure 1: Introduction structure



1.1 Executive Summary

1.1.1 Antecedents

Researchers have previously made significant efforts to empirically test the relationship between environmental management/practices and business performance, without reaching any consensus.

Some studies have found a positive relationship between companies' proactivity in environmental issues and firm performance, but many other studies have not evidenced this relationship.

Conflicting results are also obtained when scholars analyse the implementation of environmental management systems, mainly ISO 14001, in an attempt to find relationships with business performance.

The main difficulties with drawing conclusions on this topic lie not only in the different definitions or measures for both economic and environmental performance, but also in the different research methodologies and the study of very different activity sectors.

Few studies have used variables that include environmental aspects related to production systems as energy- or material-saving technologies.

This divergent body of knowledge is the basis of the first research plan of this thesis. To this effect, the first intended original contribution is the combination of the implementation degree of energy- and material- saving technologies (EST/MST) and environmental and economic performance. In fact, the thesis begins with the study of that we call "cleaner production techniques" and their impact.

A second original contribution of the present research is to obtain evidence from a wide-scale survey carried out in the European manufacturing sector.

The increasing cost of energy and greenhouse gas emissions have made energy efficiency a trending topic. Improving energy efficiency in production processes contributes to directly reducing energy consumption.

The quadruple helix of academia, industry, government and citizens are challenged to move towards energy and resource efficiency. Industrial activity in particular is reputedly a primary cause of pollution, placing manufacturing firms at the center of the focus.

Identifying the barriers to implementing energy efficiency technologies is a key issue if the aim is to contribute to cleaner production. The comparative analysis between the characteristics of greener manufacturing companies (GMC) and conventional manufacturing ones (CMC) is carried out for the purpose of helping policy makers to identify drivers and barriers to implementing these technologies.

There is no consensus on a definition of energy efficiency and there are a range of possibilities to measure and monitor energy efficiency. The survey used provides direct data about energy consumption and the potential for reducing this consumption inside each analysed company. The measure of the extent of use of the ESTs or MSTs indirectly contributes to monitoring these potentials in manufacturing companies.

The dual objective of this thesis is to map the implementation degree of EST in manufacturing firms and to identify and understand the structural and operational characteristics that are expected to cause variations in adoption. The lack of data on detailed and multiple technologies directed at saving energy in manufacturing firms is a gap that the present work contributes to filling.

From the manufacturers' perspective, the dual 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. To this effect, innovation becomes a key aspect and an important and recognised contributor to sustainable production and consumption. The most visible facet of innovation in the supply chain is still product innovation and the aspect on which this research is focused is green product innovation.

Following the definition of green product innovation as the design, production and implementation of new or significantly improved products that have a positive impact on the environment, another objective of this thesis is to characterize these special product innovators, thus setting them apart from the rest of manufacturing firms.

Most of the data used for the analysis corresponds to Spain, a country with a low presence of scientific publications in the sphere of green product innovation.

This thesis responds not only to an academic goal but also to a global institutional priority in the European strategy. Using three countries' data, this research contributes to data-driven approaches and it also combines environmental and innovation policy translated to companies' daily operations.

1.1.2 Main Research objectives

The main research objectives presented in this section are the key drivers of the research work, enabling the research questions in Chapter 3 to be formulated. Based of the previously explained antecedents, the main research objectives were first:

1. To map the adoption of technologies for reducing energy and resource consumption in production.

2. To test the relationship between implementing these technologies and manufacturing firms' performance.

The obtained models are used to explain how significant energy efficiency is and how much of the variability in economic performance and environmental performance this can explain.

Second, following previous studies that have made in-depth analyses of characteristics of the manufacturing companies adopting technologies for reducing energy and resource consumption and combining them according to different perspectives, the objectives were:

3. To contribute to identifying and understanding the characteristics of the manufacturing firms that use energy-/material-saving technologies.

4. To know what the relative energy-saving potential of manufacturing companies is.

5. To understand which of the firms' structural and operational characteristics cause variations in the adoption and implementation degree of energy-saving technologies (EST).

The aim is to contribute to identifying the characteristics of the manufacturing firms that use this kind of innovative technology for the purpose of helping policy makers to promote energy and resource efficiency in a suitable manner.

The present thesis is based on the 2009, 2012 and 2015 editions of the European Manufacturing Survey (EMS), coordinated by the Fraunhofer Institute for Systems and Innovation Research (ISI). The EMS 2015 edition incorporated new data that referred to manufacturing companies innovating with new products that lead to improving their environmental impact in one or more specific ways from six different possibilities. These companies are named 'green product innovators'.

This differentiation drove the research to other new objectives:

6. To characterize green new product innovators as opposed to conventional new product innovators.

7. To identify drivers and factors that boost green product innovations and barriers to their emergence.

1.2 Justification of the structure

The Law, Economy and Business Programme for Doctoral Studies accepts traditional format theses, which incorporate the results in the form of articles. This is the case of the present thesis, which consists of five studies published in journals or presented in the international conferences previously referred to in pages ix and x.

The compilation of these papers, book chapters and conference papers contain the results of a research project of many years' duration, shaping a detailed map of different visions around the concept of green manufacturing companies.

To this effect, these studies were included as specific chapters within the results section as they were published, respecting not only the content, but also the requirements of the specific journal or institution in terms of references, style, table and figure titles, and so on. However, to maintain the structural unity of this thesis, the text adopts fonts and styles and the distribution of the contents in a single column.

The specific bibliography of each study remains in its original format to facilitate the readability of these works. There is also an additional general bibliography chapter that lists and classifies the same references.

The numbering of the tables and figures is different from how they appear in the original papers to enable the continuous numbering system used in the general table of contents.

1.3 Structure of the Thesis

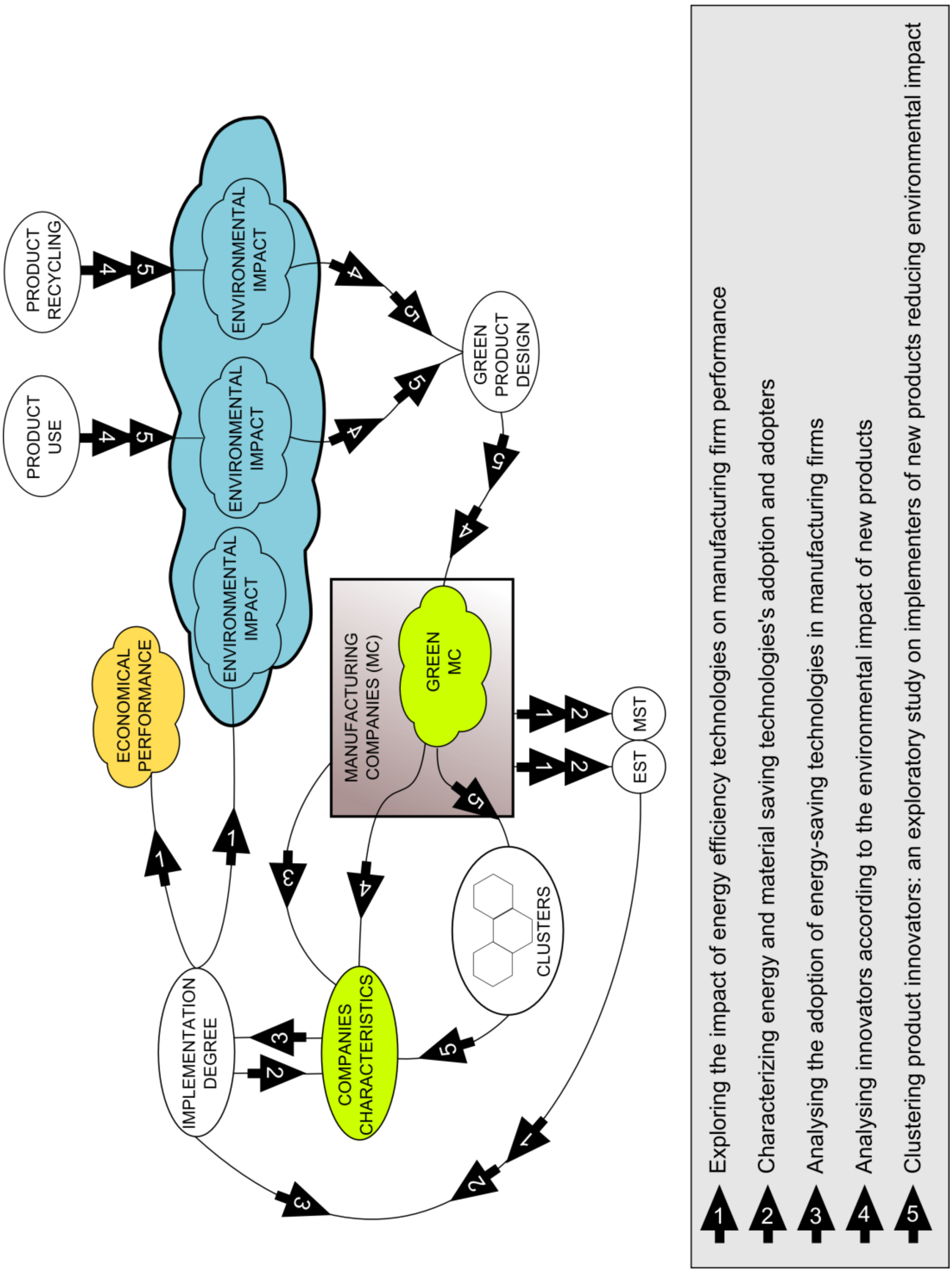
As mentioned in the previous point, this thesis is structured in a traditional monograph format with the results chapter composed of five studies around a common focus on green manufacturing companies. The chart in Table 1 not only provides a vision of the scope of this thesis, but it also shows how each included study contributes to presenting a particular vision from a particular angle such as the characteristics of green manufacturing companies, the drivers and barriers to this greenness or the obtained performance from applying energy- or material-saving technologies. Each arrow includes the number of the corresponding study, indicating the path from each starting point to the observed or measured dimension for each case. A discussion chapter is added at the end of the studies, in addition to the conclusions and the general bibliography.

Table 1, presenting the resulting structure of this thesis and its contents.

Table 1: Structure of the Thesis

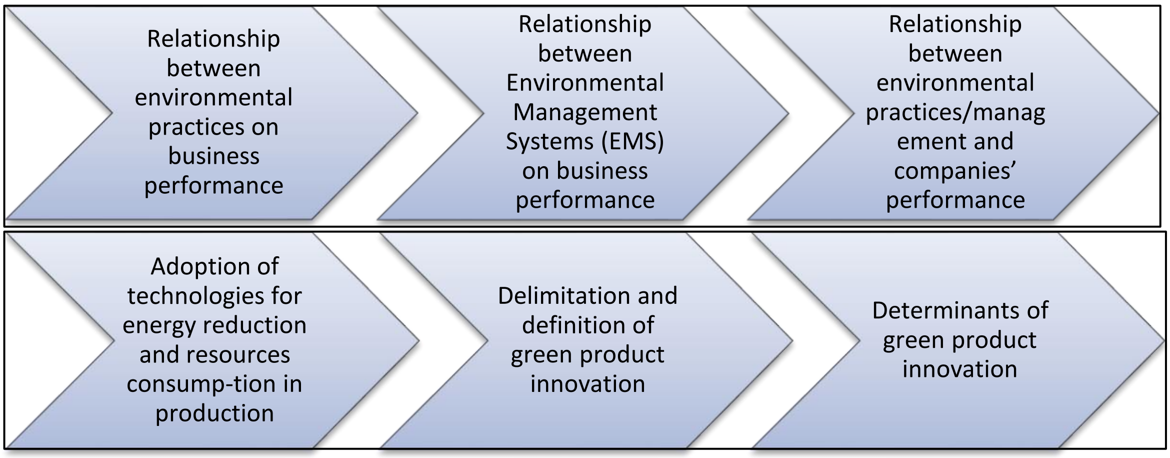
LITERATURE REVIEW	Amalgamates the literature reviews contained in each study included in the chapter of results. This literature is organized in different points and tables depending on the aspect studied or highlighted in each case.
GAPS AND OBJECTIVES	Presents the research questions (RQs) and their relationship with the main research questions of this thesis.
METHODOLOGY	Summarizes the methodology used in the studies presented in the results chapter, in addition to the origin of the data and the variables used.
RESULTS	The results are presented in the form of studies, most of which are published in indexed journals. Five studies are included in total.
DISCUSSION	Interprets the meaning of the obtained results and their relevance. The major findings of this thesis are presented and organized in the form of answers to each research question, and the limitations of the findings are stated in the last section.
CONCLUSIONS	The conclusions restate the important findings of the thesis considering their implication for each aspect of the quadruple helix and future research suggestions are made.

Figure 2: Diagram of the scope of the doctoral thesis.



Chapter 2 Literature Review

Figure 3: Structure of Literature Review



This chapter presents all the reviewed literature included in the document and studies organized into classifications and comparative tables to facilitate its reading and provide a global vision.

Figure 3 below presents the structure of this chapter.

2.1 Relationship between environmental practices and business performance

Significant efforts have been made to empirically test the relationship between environmental management/practices and business performance; however, no consensus has been reached (López-Gamero et al., 2009; Molina-Azorín et al., 2009). Molina-Azorín et al. (2009) and Heras-Saizarbitoria et al. (2011) analyse various studies that test the relationship between environmental practices and business performance, forming two groups: studies that link environmental variables to improved financial performance and studies that link environmental variables to negative financial performance or show no proof of improvement.

A literature review for both groups is presented in the tables below.

Table 2: Summary of the literature evidencing a positive relationship between environmental management/practices and business performance.

Studies that have documented a positive relationship between being proactive in environmental practices and firm performance	
Aragon-Correa and Rubio-Lopez (2007); Galdeano-Gomez et al. (2008)	A positive relationship between being proactive in environmental issues and firm performance is recorded
Nakao et al. (2007)	The tightening of environmental regulations and increased general environmental awareness in recent years has compelled firms to spend large amounts on environmental measures such as obtaining ISO14001 certification, investing in environmental equipment and developing environmentally friendly products. These authors' hypotheses that a firm's environmental performance has a positive impact on its financial performance and vice versa are supported by applying two types of statistical methods to Japanese data. They conclude that this tendency for positive two-way interactions appears to be a relatively recent phenomenon.
Molina-Azorín et al. (2009)	In an analysis of over 300 hotels, these authors conclude that corporations' ability to manage their environmental performance is a strategic issue for many firms worldwide and that proactive environmental strategies should be proposed as urgent, profitable and sustainable ways for firms to handle the natural environment, which is an important variable in the current competitive scenarios.
Bagur-Femenias et al. (2012)	In an analysis of 448 small travel agencies, these authors' conclude that the use of environmental practices such as energy saving, good maintenance of heating installations, water-saving practices and other actions taken to reduce costs have an immediate impact on the company's profit and loss account.
Al-Tuwaijri et al. (2003)	These authors obtain results that suggest that good environmental performance is significantly associated not only with good economic performance, but also with more extensive quantifiable environmental disclosures of specific pollution measures and occurrences.
Nishitani et al. (2011)	These authors find that firms that reduce pollution emissions can increase their economic performance through increased demand and improved productivity.

Table 3: Summary of the literature presenting no evidence of a relationship or a negative relationship between environmental management/practices and business performance.

Studies that have reported no evidence or a negative relationship between being proactive in environmental practices and firm performance	
Link and Naveh, 2006; Wagner, 2005; Watson et al., 2004; Sarkis and Dijkshoorn, 2007; Iraldo et al., 2009	No positive impact of environmental proactivity on financial performance is identified and no relationship is found between environmental management/performance and improved business performance.
Del Rio et al. (2011)	These authors stress a significant positive relationship between environmental technology investment and R&D intensity, human capital and physical capital intensity, and a negative relationship with export intensity.
Aragon-Correa and Sharma (2003)	These authors argue that the proactive environmental strategy and competitive advantage link may not always be positive, depending on the influence of different characteristics of the general business environment such as uncertainty, complexity and munificence. Moreover, the generation of proactive environmental strategies may be facilitated or hindered by the very same dimensions of the general business environment.
Hamilton (1995)	These authors employ an event study using data on US firms with toxic release inventory (TRI) emissions, finding a relationship between TRI announcements and negative abnormal returns.

It is from this rich, divergent body of knowledge that the present study emerges. Existing analysis either focus on exploring the relationship between some techniques and their natural impact on environmental performance or economic facets of the same concept. An overall positive impact of cleaner production on firms' business performance has been described by Zeng et al. (2010), but this positive impact was not perceived for all circumstances. These authors argue that the cleaner production activities of low-cost schemes contribute more to financial performance than high-cost scheme activities, which require significant financial investment that may not result in immediate economic benefits. While low-cost scheme cleaner production activities do not require significant financial input, they may bring immediate financial benefits.

2.2 Relationship between Environmental Management Systems (EMS) and business performance

The studies testing the relationship between Environmental Management Systems (EMS) implementation, most often ISO 14001, and business performance also present conflicting results.

The table below is a summary of the related literature showing contradictory results.

Table 4: Summary of the literature studying the relationship between Environmental Management Systems (mainly ISO 14000) and business performance.

Studies testing the relationship between Environmental Management Systems (mainly ISO 14000) and business performance.	
Naveh's (2006)	No support for the hypothesis that achieving improvement in environmental performance as result of ISO 14001 implementation leads to better business performance was found; however, business performance was shown not to be harmed.
Cañón and Garcés (2006)	These authors also evidence a negative impact of certification on pioneer, middle-polluting and smaller size firms.
Lo et al. (2012)	These authors found that adopting ISO 14001 improves manufacturers' profitability in fashion- and textile-related industries over a three-year period as measured by return-on-assets (ROA), and improves cost efficiency as measured by return-on-sales (ROS).
Wahba (2008)	These authors conclude that ISO 14001 exerts a positive and significant impact on the firm's market value measured by Tobin's q ratio.
Melnyk et al. (2003)	These authors find that EMS have a positive, significant impact on the ten corporate performance measures (e.g. reduced costs, improved quality, reduction of lead times).
Watson et al. (2004)	These authors argue that implementing an EMS strategy does not impact negatively on a firm's financial performance and that EMS adopters do not have a higher financial performance than non-EMS adopters.

2.3 Difficulties drawing conclusions from the literature about the relationship between environmental practices/management and companies' performance

The main difficulties in drawing clear conclusions from previous studies are:

- The mixed results from the different research (Zeng et al., 2010).
- Different definitions/measures for environmental performance (Zeng et al., 2010).
- Different measures for the firms' business performance.
- Different research methodologies.
- Very different economic activity sectors analysed.

Molina-Azorín et al. (2009) and Heras-Saizarbitoria et al. (2011) analyse several studies based on the sample size, environmental variables, performance variables and research methodology. Different environmental variables and indicators have been used in the literature. A comprehensive summary of selected energy efficiency indicators is made by Bunse et al. (2011). Table 5 is a summary showing which authors have used environmental management or environmental performance variables.

Table 5: Authors using environmental management or environmental performance variables

Authors	Use of environmental management variables	Use of environmental performance variables
Gonzalez-Benito and Gonzalez-Benito, 2005	X	-
Wahba, 2008	X	-
Al-Tuwaijri et al., 2004	-	X
Wagner, 2005	-	X
Zhao, 2012	-	X
Judge and Douglas, 1998	X	X
King and Lenox, 2002	X	X
Link and Naveh, 2006	X	X

Table 6 and Table 7 are summaries of the environmental performance variables and environmental management systems (EMS) implementation variables used by scholars.

Table 6: Summary of the environmental performance variables used in the literature.

Authors	Toxic Release Inventory (TRI)	Aggregated measure of environmental commitment	Emission-based and input (water, energy)-based index
Konar and Cohen (2001)	X	-	-
Cohen et al. (1995)	X	-	-
Hart and Ahuja (1996)	X	-	-
Hamilton (1995)	X	-	-
Molina-Azorín et al. (2009)	-	X	-
Wagner et al. (2002)	-	-	X
Wagner (2005)	-	-	X

Table 7: Summary of the EMS implementation variables used in the literature

Authors	Specific EMS adopted	ISO 14001
Sarkis and Dijkshoorn (2007)	X	-
Melnyk et al. (2003)	X	-
Watson et al. (2004)	X	-
Iraldo et al. (2009)	X	-
Link and Naveh (2006)	-	X
Cañón and Garcés (2006)	-	X
Lo et al. (2012)	-	X
Wahba (2008)	-	X

Business performance has been measured using different performance variables and mostly in terms of both financial/accounting ratios and market-based measures. According to Molina-Azorín et al., 2009 and Heras-Saizarbitoria et al., 2011, the most common measures of business performance in environmental studies are:

- Return-on-equity (ROE)
- Return-on-assets (ROA)
- Return-on-investment (ROI)
- Return-on-sales (ROS)
- Stock price
- Market share
- Sales growth
- Profitability

2.4 Adoption of technologies for energy reduction and resources consumption in production

Just a few studies used the use of production activities or energy efficient technologies as environmental variables. Zeng et al. (2010) find an overall positive impact of cleaner production on firms' business performance, but not under all circumstances. Different definitions for both energy efficiency and the ratios used to measure it hinder the study of specific technology adoption aimed at reducing energy or resources consumption in the industry sector. A definition of energy efficiency and a suggestion as to how to measure it found in the literature is given in Table 8.

Table 8: Definitions and indicators for energy efficiency.

Definitions	
(Bunse, Vodicka, Schönsleben, Brülhart, & Ernst, 2011)	"The ratio of energy services output to energy input [meaning] getting the most out of every energy unit you buy"
(Neelis et al., 2007)	Energy efficiency can be monitored by quantifying the ratio of energy input and the useful output of a certain activity over time. This output of an activity can be defined in physical or monetary units

Energy efficiency indicators are usually ratios describing the relationship between an activity and the required energy, resulting in either economic or physical indicators (Phylipsen, Blok, Worrell, & Beer, 2002). Economic indicators are useful at an aggregated level such as for comparing different sectors, but physical indicators are more suitable for gaining insights into particular manufacturing processes.

Table 9: Physical Indicators for energy efficiency

Physical Indicators	
(Phylipsen et al., 2002) (Farla, Blok, & Schipper, 1997) (Duhovnik, Zargi, Kusar, & Starbek, 2009) (International Energy Agency (IEA) /OECD, 2007)	Specific energy consumption
(Irrek, Irrek, & Thomas, 2006)	Final energy efficiency improvement
(Patterson, 1996)	Thermodynamic energy efficiency
(International Energy Agency (IEA) /OECD, 2007)	There is no single energy efficiency indicator that can be applied. The appropriate indicators must be defined depending on the decision to be made or the decision tool to be applied
(Zeng, Meng, Yin, Tam, & Sun, 2010)	Use of production activities or energy efficient technologies

There are few studies exploring the characteristics of manufacturing firms that use EST and MST that provide an understanding of why some companies implement them and others do not. Two of the studies presented in this thesis try to fill this gap, both of which explore the differences between implementers and non-implementers in both direction, starting first from each implementation degree and technology with the aim of determining the differentiating characteristics of implementers (Palčič, Pons, Bikfalvi, Llach, & Buchmeister, 2013), and second starting from different firm characteristics to identify the implementation degree of these technologies (Marc Pons, Llach, & Bikfalvi, 2016).

2.5 Delimitation and definition of green product innovation

Table 10 is a summary of the different definitions of GPI from the literature.

Table 10: Definitions of Green Product Innovation (GPI)

Definitions	
(OECD & Eurostat, 2005)	The Oslo Manual defines product innovation as the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses.
(Commission of the European Communities, 2001)	Products that use less resources, have lower impacts and risks to the environment and prevent waste generation already at the conception stage.
(Dangelico, 2016a) (Gerstlberger, Præst Knudsen, & Stampe, 2014)	A variety of terms for GPI exist based on practice and academic work that also affects its conceptual boundaries: eco, eco-friendly, ecological, green, sustainable, environmental and environmentally friendly.

(Ottman, Stafford, & Hartman, 2006)	These authors define "green product" or "environmental product" as those that strive to protect or enhance the natural environment by conserving energy and/or resources and reducing or eliminating the use of toxic agents, pollution and waste.
(Pujari, 2006)	These authors define GPI as the action to develop and market new products that address environmental issues. An explicit reference to market acceptation is included.
(Gerstlberger et al., 2014)	Product innovations with environmental implications should seek to simultaneously meet two goals, namely improving environmental impact and obtaining commercial performance
(Fraunhofer ISI, 2015)	Green product innovation as the design, production and implementation of new or significantly improved products that have a positive impact on the environment when in use or when they are available

Research into green product innovation is the most recent of the subfields of innovation and especially of product innovation (Keupp, Palmié, & Gassmann, 2012), which has an unquestionable societal impact. Empirical evidence mainly comes from Germany, the UK, the Netherlands, Taiwan and the USA.

Table 10: Definitions of Green Product Innovation (GPI). Table 11 is a list of the reviewed literature related to GPI.

Table 11: Reviewed literature related to green product innovation (GPI)

Literature about GPI	
(Keupp et al., 2012)	These authors systematically review 342 papers on strategic innovation management including GPI.
(Dangelico, 2016a)	Review of 63 studies specially focused on GPI.
(Baumann, Boons, & Bragd, 2002)	Complementary studies partially covering GPI outlining: • Success factors of GPI development. • State-of-the-art in new green products.

2.6 Determinants of green product innovation

Regarding the determinants of GPI, previous research in the field of innovation and new products include (Edison, Bin Ali, & Torkar, 2013) and (Edison et al., 2013). The following challenges arise from these fields of product innovation and after revising the literature when searching for the determinants or drivers of GPI: (i) identifying whether product innovation determinants also apply and to what degree for green product manufacturers, and (ii) measuring the effect of specific drivers on GPI. To this effect, (Dangelico, 2016b) presented some factors clustered into "internal" and "external" determinants, in addition to three groups representing "technological capabilities", "internal integrative capabilities" and "internal integrative capabilities and marketing capabilities". (Pujari, 2006) affirms that most of the sustainable innovation in new product development relates to incremental or evolutionary innovation that comes to replace environmentally harmful products in the marketplace.

Chapter 3 Research questions

Following the literature review, the research questions (RQs) to meet the main research objectives presented in point 1.1.2 are.

The first RQs concern the use and extent of the use of energy efficiency technologies, or in other words energy/material saving technologies (EST/MST) and their possible relationship with firms' performance.

RQ1: What is the degree of adoption of energy efficiency technologies?

RQ2: What is the relationship between the adoption of these technologies and companies' performance?

The third research question is presented to determine what more energy-efficient companies are like and if there are any differentiating factor that characterises the less efficient ones.

RQ3: What are the characteristics of energy-efficient manufacturing companies?

On the other side of the supply chain, the emergence of green innovative products has directed this thesis towards the characterization of green product innovators. The aim, therefore, is to characterise product innovators based on the definition of green product innovation as the design, production and implementation of new or significantly improved products that have a positive impact on the environment. The particular focus is on manufacturing companies that affirm that product innovations implemented in the last three years are also aimed at generating an improved environmental impact through either their use or their availability. Two more research questions are asked with the aim of knowing what aspects of green product innovators are different from conventional innovators:

RQ4: What are the characteristics of green product innovators?

RQ5: Which factors determine more sustainable product innovation in manufacturing companies?

Table 12 below is a summary of the research questions defined in this thesis in relation to the different research objectives and for each included study in the results chapter.

Table 12: Summary of the research questions, objectives and included studies.

Study	Title	Objectives	RQ	
Study 1	**Exploring the impact of energy efficiency technologies on manufacturing firm performance**	1. To map the adoption of energy-/material-saving technologies in production. 2. To test the relationship between the implementation of energy/material-saving technologies and the performance of manufacturing firms.	RQ1	**What is the degree of adoption of energy efficiency technologies?**
			RQ2	**What is the relationship between the adoption of these technologies and companies' performance?**
Study 2	**Characterizing energy- and material-saving technologies' adoption and adopters**	1. To map the adoption of energy-/material-saving technologies in production. 3. To contribute to identifying and understanding the characteristics of the manufacturing firms that use energy/material-saving technologies.	RQ1	**What is the degree of adoption of energy efficiency technologies'?**
			RQ2	**What is the relationship between the adoption of these technologies and companies' performance?**
			RQ3	**What are the characteristics of energy-efficient manufacturing companies?**
Study 3	**Analysing the Adoption of Energy-Saving Technologies in Manufacturing Firms**	4. To know what the relative energy-saving potential of manufacturing companies is. 5. To understand which of firms' structural and operational characteristics cause variations in the adoption and implementation degree of energy-saving technologies (EST).	RQ1	**What is the degree of adoption of energy efficiency technologies'?**
			RQ3	**What are the characteristics of energy-efficient manufacturing companies?**
Study 4	**Analysing innovators according to the environmental impact of new products**	6. To characterize green new product innovators as opposed to conventional new products innovators.	RQ4	**What are the characteristics of greener product innovators?**
			RQ5	**Which factors determine more sustainable product innovation in manufacturing companies?**
Study 5	**Clustering product innovators: an exploratory study focused on implementers of new products reducing environmental impact**	6. To characterize green new product innovators as opposed to conventional new products innovators. 7. To identify drivers and factors that boost green product innovations and barriers to their emergence.	RQ4	**What are the characteristics of greener product innovators?**
			RQ5	**Which factors determine more sustainable product innovation in manufacturing companies?**

Chapter 4 Methodology

The present research is based on several European subsamples of a wider European Manufacturing Survey (EMS), and mainly the Spanish one (EMS 2009, 2012 and 2015 editions). The EMS is coordinated by the Fraunhofer Institute for Systems and Innovation Research (ISI) and it is the largest European survey of manufacturing activities (ISI, 2013). It aims to collect data related to the modernization of manufacturing processes and practices, including environmental aspects. Apart from the EMS Spanish subsample, this thesis includes studies that also incorporate EMS subsamples from Slovenia, France and Portugal, as shown in Figure 5. Amalgamating these different countries' subsamples was possible where the analysed questions and sample selection criteria were identical. These four countries are very close in the Environmental Performance Index (EPI) (2016), developed jointly by Columbia University and Yale University, which ranks 132 countries according to their environmental performance and progress indicators. In Table 13 below, these countries can be seen to obtain high EPI and similar scores (from 88,98 to 88,20) and correlative positions: Slovenia (5th), Spain (6th), Portugal (7th), and very close to France (10th).

Table 13: Environmental Performance Index (EPI) ranking for the 2016 edition.

Country ranking	EPI score	Country ranking	EPI score
1Finland	90.68	**6 Spain**	88.91
2 Iceland	90.51	**7 Portugal**	88.63
3 Sweden	90.43	8 Estonia	88.59
4 Denmark	89.21	9 Malta	88.48
5 Slovenia	88.98	**10 France**	88.2

Based on these results and considering their similarities according to their environmental performance indexes, the Slovenian, Portuguese and French subsamples can be joined to the Spanish one. This fact has enriched the studies presented in this thesis, increasing the analyzed population where possible.

The technical details of the different subsamples used are shown below in Table 14, Table 15 and Table 16.

EMS 2009 (ES-SLO)

Table 14: Technical details of the samples of the European Manufacturing Survey (EMS) 2009 Edition used.

Universe:	**Spanish and Slovenian manufacturing firms with at least 20 employees with NACE codes from 15 to 37.**
Unit of analysis:	Establishment
Sample:	180 firms: (ES) 116; (SLO) 64
Confidence margin:	95%
Variance:	Maximum indetermination p=q=50%
Documentation	Paper (8-page questionnaire) + Return envelope + Introductory letter
Channel	Postal
Fieldwork:	OGEDP department. University of Girona – Girona (Spain) Faculty of Mechanical Engineering, Maribor University – Maribor (Slovenia)
Reference period:	2007-2009; 2009
Database recording and creation:	DAP GmbH – Passau (Germany)
Sample distribution:	By size and sector of activity

EMS 2012 (ES)

Table 15: Technical details of the subsample of the European Manufacturing Survey (EMS) 2012 Edition used

Universe:	**Spanish manufacturing firms with at least 20 employees with NACE codes from 15 to 37.**
Unit of analysis:	Establishment
Target Population	4000 firms
Sample:	170 firms: (ES) 170
Confidence margin:	95%
Variance:	Maximum indetermination p=q=50%
Documentation	Paper (8 pages questionnaire) + Return envelope + Introductory letter
Channel	Postal
Fieldwork:	OGEDP department. University of Girona – Girona (Spain)
Reference period:	2009-2011; 2011 Period conducting the Survey: May-September 2012
Fieldwork institution:	Dept. of Business Administration and Product Design, University of Girona – Girona (Spain)
Database 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

EMS 2015 (ES-FR-PT)

Table 16: Technical details of the subsample of the European Manufacturing Survey (EMS) 2015 Edition used

Universe:	Spanish manufacturing firms with at least 20 employees CNAE 2009; codes from 10 to 33. 13.593 companies.	Spanish, French and Portuguese manufacturing firms with at least 20 employees CNAE 2009; codes from 10 to 33.
Unit of analysis:	Establishment	
Sample:	101 firms	194 firms: (ES) 101; (FR) 62; (PT) 33
Confidence margin:	95%	95%
Variance:	Maximum indetermination p=q=50%	Maximum indetermination p=q=50%
Documentation	Paper (8 pages questionnaire) + Return envelope + Introductory letter	
Channel	Postal	
Fieldwork:	May to September 2015	
Reference period:	2012-2014; 2014	
Fieldwork institution:	OGEDP department. University of Girona – Girona (Spain)	Dept. of Business Administration and Product Design, University of Girona – Girona (Spain) University of Lyon, IAE Lyon, Lyon (France) Dept. of Mechanical and Industrial Engineering, Universidade Nova de Lisboa, Caparica (Portugal)
Database recording and creation:	DAP GmbH – Passau (Germany)	ES: Outsourced to DAP GmbH – Passau (Germany) FR, PT: institution
Sample distribution:	By size and sector of activity	
By 'Green product innovators':	'Conventional product innovators': 25; 'Green product innovators': 56	'Conventional product innovators': 55 (ES) 34; (FR) 15; (PT) 6 'Green product innovators': 60 (ES) 23; (FR) 25; (PT) 12

In recent years, only a few surveys have been carried out worldwide that measure energy efficiency in manufacturing firms and their use of energy-saving technologies (EST) and material-saving technologies (MST). These surveys cover only some industrial sectors, monitor very specific technologies or cover only American and Asian countries. None include the European countries covered by the EMS, which also encompasses all the manufacturing industries. Other widescale surveys such as CIS or IMSS include sections or questions about innovation and its drivers, environmental benefits and performance or competitive strategy. However, due to the way they are built, it is difficult to link environmental benefits with product innovation, and so on.

The European Manufacturing Survey was conducted among manufacturing firms with at least 20 employees. These firms are the ones with NACE codes from 15 to 37 or CNAE 2009 codes from 10 to 33, according to the EMS edition, as shown in Table 14, Table 15 and Table 16. Therefore, the most recent versions of the survey (2009, 2012 and 2015) have included several questions relating to environmental and energy issues. As a methodological reflection, the EMS is nowadays sent to companies by email and it must be answered online. Figure 4 shows the EMS invitation model, which can be filled in with a click.

Figure 4: EMS invitation model received by companies in Spain

ENCUESTA EUROPEA DE INNOVACIÓN EN PRODUCCIÓN

European Manufacturing Survey 2018-2019

¿QUÉ ES EMS?

La *European Manufacturing Survey* es una encuesta que se realiza periódicamente a una muestra de empresas europeas. Diversos centros de investigación y universidades de un total de 15 países estamos coordinados para distribuir esta encuesta bajo la dirección del Fraunhofer Institute for Systems and Innovation (ISI). La encuesta trata la **innovación en producción** desde sus vertientes tecnológica y organizativa. Se estudia una temática ciertamente relevante para la competitividad empresarial.

¿QUÉ ME APORTA EMS?

Su empresa ha sido seleccionada para formar parte de la muestra representativa de la edición española. Con las respuestas al cuestionario, después del tratamiento oportuno, su empresa se podrá comparar con los resultados de los demás países de la red. Los resultados del proyecto a los que usted tendrá acceso se desarrollan en la red europea mediante dos instrumentos: **artículos científicos y de divulgación** y un **sistema de autodiagnóstico** (benchmarking) que se podrá consultar a través de Internet.

¡DESEO PARTICIPAR!

En el caso de que acepte colaborar en este proyecto le agradeciéramos que cumplimente el **cuestionario adjunto** antes del **15 de Julio del 2019**. Rellenarlo requiere un poco de tiempo pero esperamos, sinceramente, que dada la relevancia del tema podamos contar con su colaboración para la edición española de la *European Manufacturing Survey*.

Para acceder a la encuesta por favor, dar click en el siguiente enlace:

https://www.surveygizmo.eu/s3/90147830/EMS-2018-Spain

COORDINADOR

Fraunhofer ISI

ORGANIZADOR

Universitat de Girona

PARTICIPAN

unidemi

VŠE

UNIVERSITY OF GÄVLE

SDU

University of Zagreb

STIIMA

AIT

University of Maribor

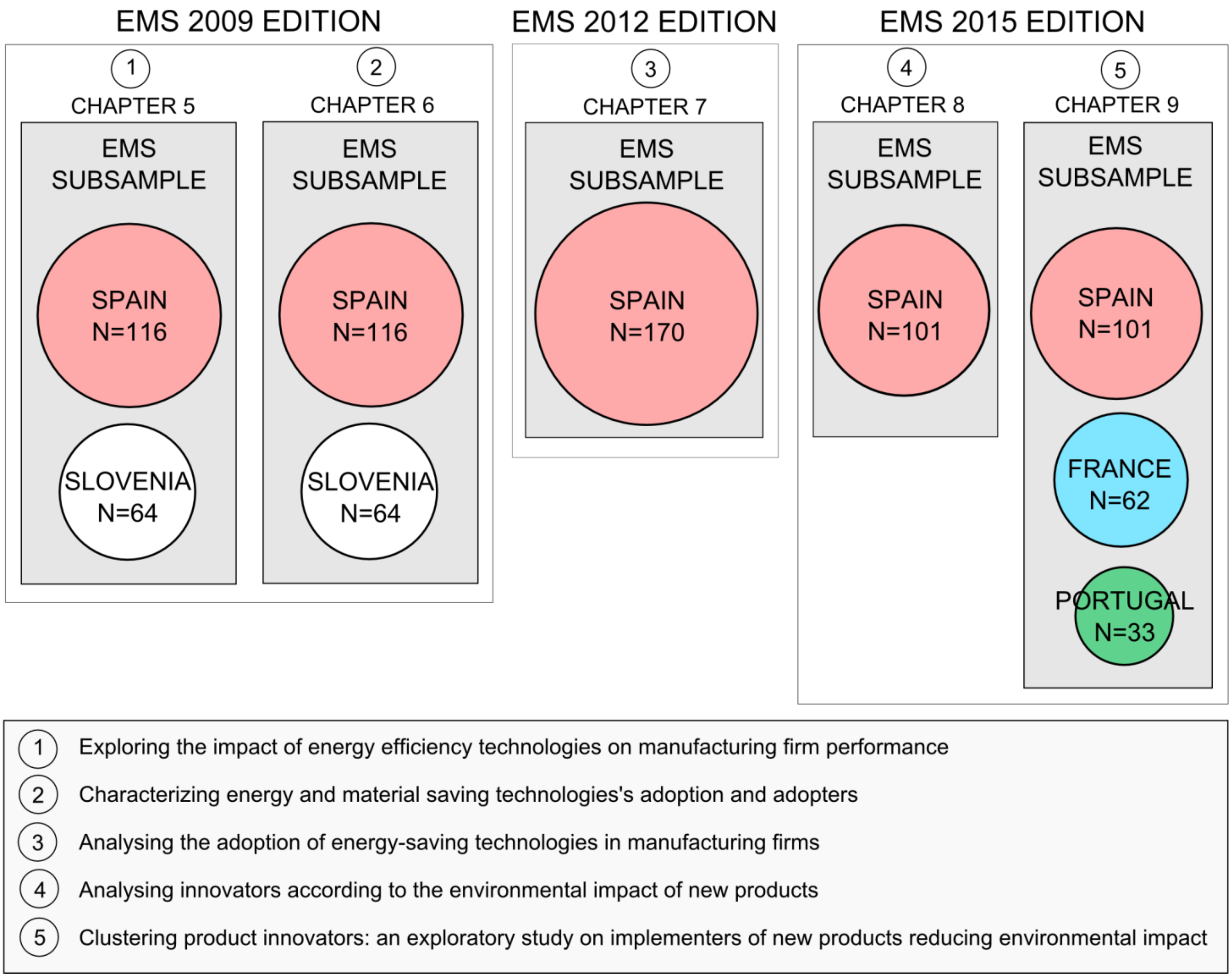
HOCHSCHULE LUZERN

ktu

¡MUCHAS GRACIAS!

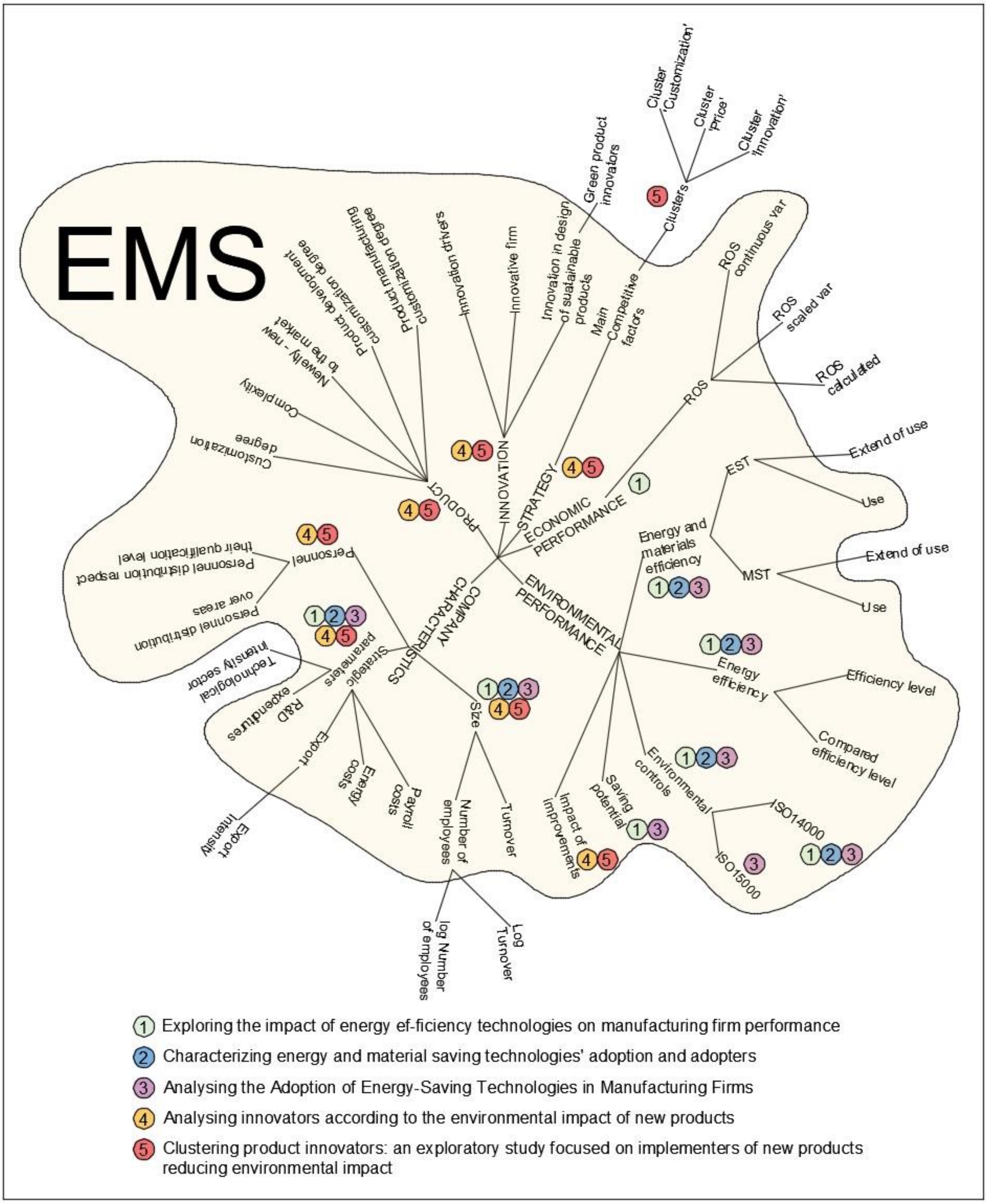
In Figure 5, the EMS subsamples used in this thesis are presented by edition and country.

Figure 5: EMS subsamples used by edition, country and presented study



To help explain the scope of this thesis in terms of the parameters and variables used, Figure 6 presents a general schema organized as a centred tree where each main branch represents a particular typology of data named Company characteristics, Product, Innovation, Strategy, Economic Performance and Environmental Performance. The references of the studies that used each of these parameters appear in several points or branches in this tree of variables. A colour surface encloses the variables directly included in the EMS. The other variables and parameters hat appear outside this surface are the ones compiled or calculated from those in the survey since they were required for use in the presented studies. These external variables, parameters or cluster classifications also represent specific contributions of this work.

Figure 6: General schema of EMS variables used in this thesis and the other obtained variables and parameters presented in the studies by typology.



Regarding the firms' technological intensity sector, different groups were obtained from the Eurostat aggregation of the manufacturing industry, depending on the technological intensity, based on NACE Rev.2 at the 2-digit level as presented in Table 17.

Table 17: Technological intensity sector groups.

Manufacturing Industries	NACE Rev. 2 codes – 2-digit level	
High-technology	21	Manufacture of basic pharmaceutical products and pharmaceutical preparations;
	26	Manufacture of computer, electronic and optical products
Medium-high-technology	20	Manufacture of chemicals and chemical products;
	27 to 30	Manufacture of electrical equipment; Manufacture of machinery and equipment n.e.c. ; Manufacture of motor vehicles, trailers and semi-trailers; Manufacture of other transport equipment
Medium-low-technology	19	Manufacture of coke and refined petroleum products;
	22 to 25	Manufacture of rubber and plastic products; Manufacture of other non-metallic mineral products; Manufacture of basic metals; Manufacture of fabricated metals products, excepts machinery and equipment;
	33	Repair and installation of machinery and equipment
Low technology	10 to 18	Manufacture of food products, beverages, tobacco products, textile, wearing apparel, leather and related products, wood and of products of wood, paper and paper products, printing and reproduction of recorded media;
	31 to 32	Manufacture of furniture; Other manufacturing

Given that this thesis presents results in the form of different studies, the methodology for each of them varies depending on the strategy used to find answers to the research questions. More specific descriptions of the different methodologies are given in each study, while this chapter presents a more global view of them.

Regarding the impact of energy- and material-saving technologies (EST and MST), the first studies included characterize these technologies in terms of both use and levels of usage (extent of use) through descriptive and frequency analyses. This specific dual perspective of firms' adoption of technologies represents a contribution of this thesis. A set of variables from the EMS were used, which covered aspects such as technology use and extent of use, energy and material consumption efficiency in production, potential saving, size, sector, return on sales (ROS) and turnover trend.

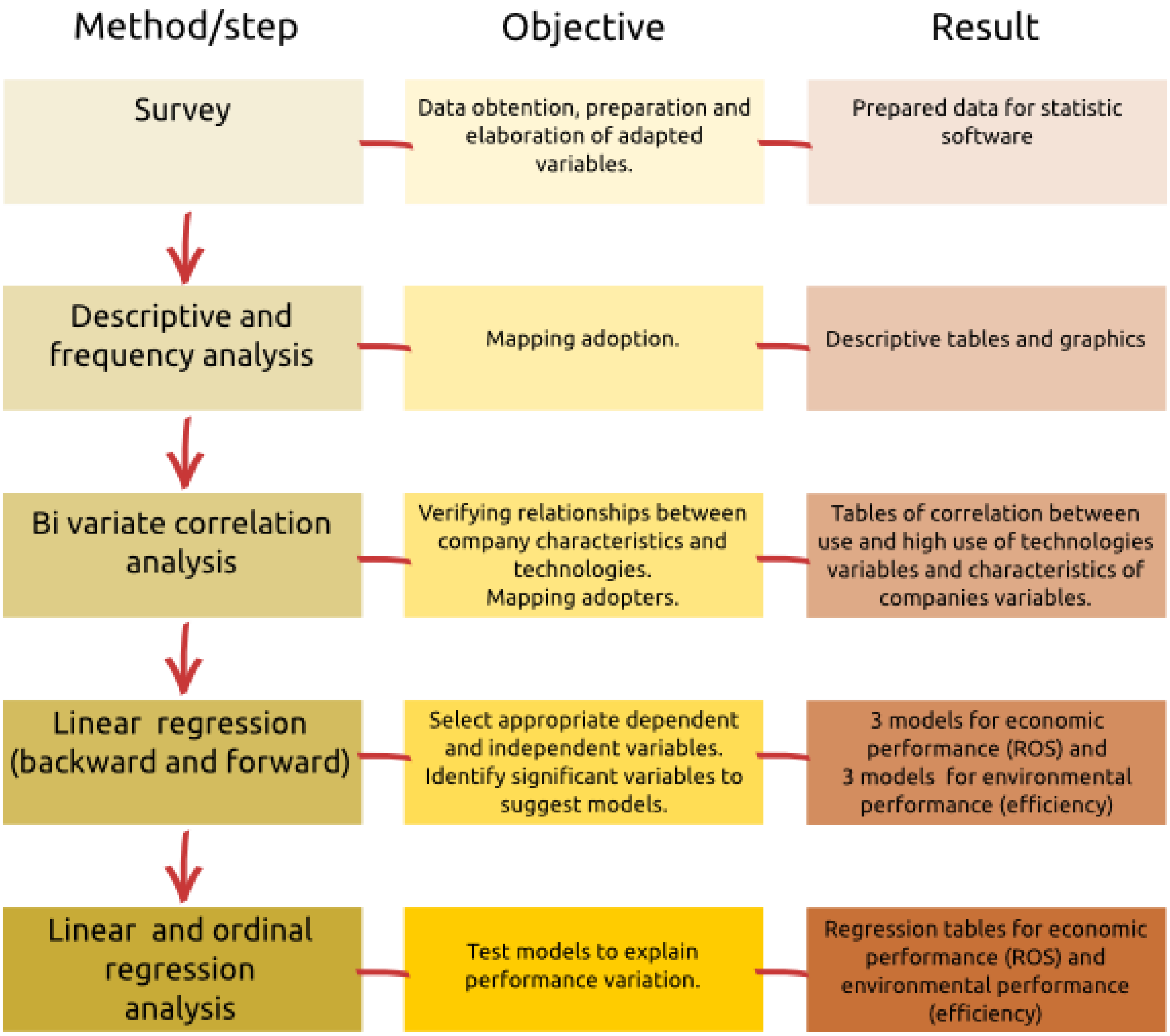
A further statistical analysis used some of the technology adopters' characteristics to search for segmented patterns. For this purpose, a group of chosen variables was processed to obtain the correlation coefficients between them and the different variables describing technology adoption. The purpose was to produce a firms' taxonomy in terms of EST and MST use, and to relate these to the rate of return on sales (ROS), efficiency level, technological level and the environmental control systems implemented. These coefficients describe the interrelationships among all the variables and whether the sense of these interrelationships was positive or negative. The dataset was analysed using linear regression for the quantitative independent variables (Continuous ROS, Calculated ROS or Efficiency Level) and ordinal logistic regression for the categorical independent variables (ROS 2-5%, ROS 5-10%, ROS>10%, Less efficient, Equally efficient and More efficient).

In the case of linear regression, a real R2 parameter was used, while for ordinal regression pseudo R2 parameters were produced following the method proposed by Cox and Snell, Nagelkerke and McFadden. It was expected that the technological variables representing EST had some explanatory power over firm performance represented by ROS and "Energy efficiency". In this regard, two new variables were created to analyse the effect on results of the mere implementation of different technologies following the methodology of Llach et al. (2009). The first variable represented the number of EST implemented in a firm –SUMTEC– and the second variable represented the number of highly implemented EST (technologies that were used at a level close to their full potential) –SUMHIGH–. Complementary variables based on the use and high use of MST were also created and named SUMTEC+ and SUMHIGH+. Figure 7 is a summary of the methodology used for the first study.

The second study presents descriptive and frequency analyses to characterize EST and MST in terms of use and extent of use in manufacturing companies. Extent of use is referred to by comparing the present use of these technologies with the most reasonable potential use according to each industry. There were three levels of extent of utilized potential: "low" for an initial attempt at utilized potential, "medium" for partly utilized and "high" for an extensive use.

This study also classifies the adopters of EST and MST according to their technological intensity from the NACE groups. Three technological levels were established and a discrete variable was constructed from these categories: "low technology", "medium-low technology" and "medium-high and high technology". "Medium-low technology" was taken as a reference variable. The adopters were also classified in three groups representing the relative energy- and material-consumption efficiency. This efficiency was compared with other companies in their industry according to a relative scale variable with 5 possible values. Three groups were created from this variable: "less efficient", "equally efficient" and "more efficient".

Figure 7: Methodology summary for the first study



The EMS 2012 edition of the survey was used in the third study. This was the only Spanish subsample that continued to include five of the eight EST presented in EMS 2009. They were added as part of specific questions that the EMS is allowed to include for each participant depending on their particular interests. This is the reason why the study only includes the Spanish subsample. This third study contains similar descriptive and frequency analyses to the second one, including the differentiation between use and extent of use of EST for each firm, using the same ordinal variable with three levels: low, medium and high use. It also describes firms by their characteristics and particularly by their energy efficiency level, which is the key factor of this study. This degree of energy efficiency is measured by the parameter of energy saving potential, which is represented in the percentage corresponding to the relative amount of energy a firm could save if they highly implemented all the EST available nowadays in their production system. Three new dummy variables were constructed for the analysis, representing "Low efficient", "Medium efficient" and "More efficient". These categories were constructed considering three approximately equal groups coming from a previous frequency analysis in which percentiles were calculated at 33.3% and 66.6%. The characterization of these EST adopters was also presented, classifying them by technological level also using NACE codes.

Last, the intention in this study was to explore the possible interrelationships between several continuous or dichotomous variables representing characteristics of the firms and the use or extent of use of ESTs, and their strength and direction. This was carried out by conducting a simple bivariate Pearson correlation analysis. In the case of the variables not following a normal distribution (size, turnover, number of employees, and so on), some transformations were made to use parametric statistics, rectifying left-skewed histograms using logarithms.

Although the second and third studies may seem to be similar, there is a fundamental difference between them based on the strategy followed to describe adopters and the adoption of EST in manufacturing firms. In the second study, it is each level of use and the extent of use of EST and MST that point us towards the characteristics of the different companies', while in the third study the direction is the reverse, explaining in what way the classification of firms' according to several parameters could be related to their use or extent of use of ESTs.

The fourth and fifth studies are concerned with the other focus of the thesis, which is the point of view of green product innovations and, consequently, manufacturing firms that design products with these special product innovations. Considering companies of this kind as green product innovators, the differentiation from the rest of the innovator companies in the sample was made from the answer to the following question: "Did this new or improved product also lead to an improved environmental impact using or disposing these new products?".

Figure 5 shows the size of the samples used (N). However, it must be considered that the number of companies reduced after the subsample of innovator firms was selected. Hence, the combination of different countries' subsamples helped to enrich the analysis. To build these innovator subsamples, all the companies that did not answer any of the two questions that determine innovators and green innovators were eliminated. This fact again slightly reduced the size of the subsample, making it gain in rigor.

The survey used for these last two studies was the EMS 2015 edition, which was the first time these kinds of questions about green product innovation were included along with six possible impacts of these innovations: reduction of health risks, extended product lifetime, reduction of energy consumption, reduction of environmental pollution, easiness to maintain or retrofit and improved recycling, redemption or disposal properties. It also included variables explaining the main origins of impulses/ideas for product innovation from eight different possibilities: R&D engineering, production, customer service, CEO/management, customer or user, supplier, research institutions or universities and business or organization consultancy. Crosstab analyses showed the percentages of innovator companies for each declared origin of impulses/ideas for green product innovation.

The purpose of these two last studies was to identify and understand the characteristics of green product innovators. To this effect, seven sets of variables grouped by their typology were analysed: general data, companies' economic performance, main product family, firm competitive factors, employees, product innovation drivers and innovation contribution to turnover. Green and conventional product innovators were compared, making descriptive and frequency analyses of all these variables to explore the differences between them. To illustrate these differences as they appear, this study includes bar graphs and normal distribution representations for the continuous or discrete ordinal variables, calculating them by their means and standard deviations.

Regarding the fifth study, an original contribution of this paper consists in analysing the same parameters as in the fourth study, but splitting the sample into three consistent clusters according to their main competitive factors as a firm: product price, product quality, innovative products and customization to customer demands. A K-means cluster analysis produced the final clusters, named “Price”, ”Innovation” and “Customization” as representative of the main competitive factor for the companies in each set. This special perspective complements the descriptive analysis in the previous study and attempts to show the hidden details and differences between green and conventional product innovators that could not be seen when they were analysed together.

Chapter 5 Exploring the impact of energy efficiency technologies on manufacturing firm performance

The objective of this chapter is firstly to map the adoption of the technologies for reduction of energy and resources consumption in production and, second, to verify the relationship between their implementation and the performance of the manufacturing firm. The aim is also to contribute to the identification and understanding of the characteristics of the manufacturing firms that use this kind of innovative technologies in order to help policy makers to promote this strategic field in a suitable manner. Our research is based on the Spanish and Slovenian subsamples of a wider European manufacturing survey. Our suggested models give rise to explain how significant energy efficiency is, and how much of the variability in economic performance and environmental performance indicators it can explain. The results show that the use of energy and material saving technologies does not have a clear significant relationship with economic performance. On the other hand a significant positive relationship appears between energy and material saving technologies and environmental performance.

5.1 Introduction

Firms have recently faced strong pressure to implement environmental management from their stakeholders, especially since events such as the Rio Declaration in 1992 and the Kyoto Protocol in 1997 (Nishitani et al., 2011). This is particularly because through their production activities they are reputedly primary polluters (Dessus and Bussolo, 1998). Climate change, unsecured energy supply, and rising energy prices are topics of increasing importance in today's society (Bunse et al., 2011). In these circumstances, however, there is a trade-off between a firm's environmental and economic performance because private environmental costs lead to higher prices and reduced competitiveness (Porter and van der Linde, 1995).

The relationship between being proactive in environmental issues and firm performance represents a perplexing issue in the literature (López-Gamero et al., 2009). The longer-term relationship between environmental performance and economic performance has been studied for over two decades with a more detailed review of this body of literature provided by Gunther et al. (2004), Wagner (2001), Bunse et al. (2011), Molina-Azorín et al. (2009) and Heras-Saizarbitoria et al. (2011). Significant efforts have been made to empirically test the relationship between environmental management/practices on business performance; however, no consensus has been reached (López-Gamero et al., 2009; Molina-Azorín et al., 2009). The main difficulty in drawing clear conclusions from previous studies lies not only in the mixed results from different research but also the fact that scholars used different definitions/measures for environmental performance (Zeng et al., 2010). The lack of a solid theoretical foundation repeatedly emerges as the main reason why these empirical studies have not led to knowledge convergence (Aragon-Correa and Sharma, 2003; Gonzalez-Benito and Gonzalez-Benito, 2005; Wagner, 2007).

Many scholars argue that there is no single, direct relationship between proactive environmental management and firm performance (Aragón-Correa and Sharma, 2003; González-Benito and González-Benito, 2005; Schaltegger and Synnestvedt, 2002; Wagner, 2007). Rather, this relationship seems to depend on environmental management and environmental performance, the firm resources most directly associated with their proactive environmental management, and the effect that proactive environmental management and environmental performance have on competitive advantage and financial performance (López-Gamero et al., 2009).

This paper is based on an empirical study that tries to build a knowledge base and contribute to world literature in the field of energy efficiency technologies and their impact on environmental and economic performance of the manufacturing firm. The purpose of this study is firstly to map the adoption of the technologies for reduction of energy and resources consumption in production and, second and more important, to verify the relationship between their implementation and the environmental and economic performance of the firm. The aim is also to contribute to the identification and understanding of the characteristics of the manufacturing firms that use this kind of energy efficient technologies.

The paper is organised as follows. After the introductory background, literature about the relationship between environmental management/practices on business performance is recalled. Next, we present our research methodology, selected variables, models and methods to test the relationship between energy efficiency technologies and manufacturing firm performance. Results and findings are presented for the manufacturing firms with the use of descriptive statistics and interpretation of results from linear and logistics regression. Then, we discuss these findings and present some managerial implications.

5.2 Literature review

As already pointed out, significant efforts have been made to empirically test the relationship between environmental management/practices on business performance; however, no consensus has been reached (López-Gamero et al., 2009; Molina-Azorín et al., 2009). Molina-Azorín et al. (2009) and Heras-Saizarbitoria et al. (2011) analysed several studies that tested the relationship between environmental practices and business performance and formed two groups: studies which are linking environmental variables to improved financial performance and studies which are linking environmental variables to negative financial performance or showing no proof of improvement.

Among studies which have documented a positive relationship between being proactive in environmental issues and firm performance are Aragon-Correa and Rubio-Lopez (2007), Galdeano-Gomez et al. (2008) and Nakao et al. (2007). Nakao et al. (2007) argue that with the tightening of environmental regulations and the increase in people’s environmental awareness in recent years, firms are being compelled to spend large amounts on environmental costs through measures such as obtaining

ISO14001 certification, investing in environmental equipment and developing environmentally friendly products. Their hypotheses that a firm's environmental performance has a positive impact on its financial performance and vice versa are supported by applying two types of statistical method to Japanese data. However, they found out, that this tendency for positive two-way interactions appears to be only a relatively recent phenomenon. Some studies indicate that better environmental management/performance is associated with improved business performance (Molina-Azorín et al., 2009; Al-Tuwaijri et al., 2003).

For exalte Molina-Azorín et al. (2009) concluded while analysing over 300 hotels that the ability of corporations to manage their environmental performance is a strategic issue for many firms worldwide and proactive environmental strategies should be proposed as urgent, profitable and sustainable ways for firms to deal with natural environment, which is important variable within the current competitive scenarios. In the same sense, Bagur-Femenias et al. (2012) conclude that, analyzing 448 small travel agencies, the use of environmental practices, such as energy-saving, good maintenance of heating installations, water-saving practices and other actions taken to reduce costs, have an immediate impact on the company's profit and loss statement.

Al-Tuwaijri et al. (2003) obtained results that suggest good environmental performance is significantly associated with good economic performance, and also with more extensive quantifiable environmental disclosures of specific pollution measures and occurrences. Nishitani et al. (2011) found that firms that reduced pollution emissions can increase their economic performance through an increase in demand and an improvement in productivity.

There is also a huge group of studies where scholars do not identify a positive impact of environmental proactivity on financial performance or they find no relationship between environmental management/performance and improved business performance (Link and Naveh, 2006; Wagner, 2005; Watson et al., 2004; Sarkis and Dijkshoorn, 2007; Iraldo et al., 2009). Del Rio et al. (2011) stressed a significant positive relationship between environmental technology investment and R&D intensity, human capital and physical capital intensity, and a negative relationship with export intensity. Aragon-Correa and Sharma (2003) argue that the proactive environmental strategy and competitive advantage link may not always be positive, depending on the influence of different characteristics of the general business environment, such as uncertainty, complexity, and munificence. Moreover, the generation of proactive environmental strategies may be facilitated or hindered by the very same dimensions of the general business environment. Hamilton (1995) employed an event study with data on US firms with toxic release inventory (TRI) emissions, and found a relationship between TRI announcements and negative abnormal returns.

There are also several studies testing the relationship between Environmental Management Systems (EMS), most often ISO 14001, and business performance. The results are again conflicting. Link and Naveh's (2006) study did not reveal any support for the hypothesis that achieving improvement in environmental performance as result of ISO 14001 implementation leads to better business performance; on the other hand, they found that business performance was not harmed. Cañón and Garcés (2006) also prove negative impact of certification on pioneer, middle-polluting and lower size firms. On the other hand Lo et al. (2012) revealed that the adoption of ISO 14001 improves manufacturers' profitability in the fashion and textiles related industries over a three-year period as measured by return-on-assets (ROA) and improves cost efficiency, measured by return-on-sales (ROS). Wahba (2008) also acknowledges that ISO 14001 exerts a positive and significant impact on the firm market value measured by Tobin's q ratio. Melnyk et al. (2003) in their study found positive and significant impact of EMS state on the ten corporate performance measures (e. g. reduced costs, improved quality, reduction of lead times). But Watson et al. (2004) argue that that implementation of an EMS strategy does not negatively impact a firm's financial performance and that EMS adopters do not experience superior financial performance over non-EMS adopters.

The main difficulty in drawing clear conclusions from previous studies lies not only in the mixed results from different research but also the fact that scholars used different definitions/measures for environmental performance (Zeng et al., 2010). At the same time these scholars used different measures for business performance of the firm, different research methodologies, all together in very different economic activity sectors. Molina-Azorín et al. (2009) and Heras-Saizarbitoria et al. (2011) analysed several studies based also on the sample size, environmental variables, performance variables and research methodology.

Firstly, with regard to environmental variables, some studies use only environmental management variables (Gonzalez-Benito and Gonzalez-Benito, 2005; Wahba, 2008), others use only environmental performance variables (Al-Tuwaijri et al., 2004; Wagner, 2005; Zhao, 2012), and a few papers used both environmental management and environmental performance variables jointly (Judge and Douglas, 1998; King and Lenox, 2002; Link and Naveh, 2006). In measuring environmental performance, Konar and Cohen (2001), Cohen et al. (1995), Hart and Ahuja (1996), Hamilton (1995) used TRI; Molina-Azorín et al. (2009) employed an aggregated measure of environmental commitment; Wagner et al. (2002) and Wagner (2005) used emission-based and input (water, energy)-based index; Sarkis and Dijkshoorn (2007), Melnyk et al. (2003), Watson et al. (2004) and Iraldo et al. (2009) adopted specific EMS, and as already mentioned Link and Naveh (2006), Cañón and Garcés (2006), Lo et al. (2012) and Wahba (2008) used ISO 14001 certification. A good summary of selected energy efficiency indicators was made by Bunse et al. (2011).

Different types of efforts for cleaner production may have different implications for business performance. And business performance may also be measured by different performance variables, mostly in terms of both financial/accounting ratios and market-based measures. Most common measures are are return-on-equity (ROE), return-on-assets (ROA), return-on-investment (ROI), return-on-sales (ROS), stock price, market share, sales growth and profitability (Molina-Azorín et al., 2009; Heras-Saizarbitoria et al., 2011).

Only several studies used for environmental variables the use of production activities or energy efficient technologies. One of the most recent is from Zeng et al. (2010), who found out an overall positive impact of cleaner production on firms' business performance, but not under all circumstances. They argue that the cleaner production activities of low-cost scheme (e. g. improve employee environmental consciousness through training, improve working conditions to reduce waste, strictly enforce rules on cleaner production, increase the recyclability of the products and components) have a bigger contribution to financial performance than the high-cost scheme activities (e. g. using energy efficient and clean technologies or using renewable resources as raw materials), which require significant financial investment but may not result in immediate economic benefit. The low-cost scheme cleaner production activities do not require significant financial input but may bring immediate financial benefits.

It is this rich and divergent body of knowledge where we propose the present study. Existing ones either focus on exploring the relationship between some techniques and their natural impact on environmental performance or economic facets of the same concept. Our supposed contribution is the combination of all three pillars of environmental sustainability: implementation, more immediate effect such as environmental performance and finally, firms' ultimate interest, economic performance. Our evidences come from the manufacturing sector. Therefore we argue the appropriateness of the use of the term cleaner production techniques and their impact.

5.3 Methodology

Our research is based on the Spanish and Slovenian sub-samples of a European Manufacturing Survey (EMS) described briefly in the followings. The EMS, coordinated by the Fraunhofer Institute for Systems and Innovation Research – ISI, is the largest European survey on manufacturing activities. In the last EMS edition firms answered questions concerning manufacturing strategies, the application of innovative organisational and technological concepts in production, questions of personnel deployment and qualification, the production off-shoring and back-sourcing strategies. In addition, data on performance indicators such as productivity, flexibility, quality and returns was collected. The main objectives of this research project are to find out more on the use of production and information technologies, new organisational approaches in manufacturing and the best management practices' implementation.

The last (2009) EMS edition has been carried out in 12 countries. The Spanish sub-sample had 116 responses and the Slovenian accounted for 64, all together 180 responses. The survey was performed on manufacturing firms (NACE codes from 15 to 37) having at least 20 employees.

The main arguments in favour of joining the two countries' data are: identical questions, same criteria for sample selection and their position according to the environmental performance index (EPI). Developed jointly by the Columbia University and Yale University, the Environmental Performance Index (EPI) ranks 132 countries on 22 performance indicators spanning ten policy categories, which track performance and progress on two broad objectives: environmental health and ecosystem vitality. According to the latest edition Slovenia ranks 28 with an EPI score of 62.25 and Spain is at position 32 score 60.31 in the ranking of the World's Greenest Countries. Both countries have high EPI performance indicators with an improving trend.

In recent years, only a few surveys have been launched in the world that measure energy efficiency in manufacturing firms and their energy saving technologies (EST) and material saving technologies (MST) use. These existing surveys cover only some industrial sectors monitoring very specific technologies or cover only American and Asian countries. None of them includes the European countries covered by EMS that also encompasses all manufacturing industries. Therefore, the last survey added several questions relating environmental and energy issues. In that sense, EMS defines 10 general groups of technologies, 8 for energy efficiency and 2 for material consumption saving (Table 18).

These wide groups allow classifying any specific technology into one of them obtaining a global map of their use and level of implementation.

Table 18: EST and MST included in EMS 2009

Energy saving technologies (EST)	Material saving technologies (MST)
• Control system for shut down of machines in off-peak periods. • Speed regulation. • Compressed air contracting. • Highly efficient pumps. • Low-temperature joining processes. • Energy retrieval. • Bi-/Tri-generation. • Waste material for energy.	• Recycled material in production. • Product recovery.

EST and MST are characterized in terms of use and also in terms of levels of usage (extent of use) through a descriptive and a frequency analysis. For this study, a set of variables from the survey has been used, regarding aspects as technology use and extent of use, energy and material consumption efficiency in production, potential saving, size, sector, return on sales, turnover trend etc. A further statistical work uses some of the adopters' characteristics in order to search segmented patterns. For this purpose, a group of chosen variables are processed obtaining the correlation coefficients between them and the different technologies adoption variables, obtaining a taxonomy of the firms in terms of EST and MST use relating to rate of return (ROS), efficiency level, technological level and environmental control systems implemented. These coefficients determine the inter-relationships among all of them and its sense.

The dataset has been analysed using linear regression for quantitative independent variables (Continuous ROS, Calculated ROS or Efficiency level) and ordinal logistic regression for categorical independent variables (ROS 2-5%, ROS 5-10%, ROS >10%, Less efficient, Equally efficient and More efficient). In the case of linear regression a real R2 parameter was used while for ordinal regression pseudo R2 parameters according to Cox and Snell, Nagelkerke and McFadden models were used. Technological variables representing EST were expected to have some explanatory power over firm performance represented by ROS and "Energy efficiency". For this purpose two new variables were created to analyse the effect on results of the mere implementation of different technologies following the methodology of Llach et al. (2009): first the variable representing the number of EST implemented in a firm – SUMTEC, and second the variable representing the number of highly implemented (technologies were used at a level close to their full potential) EST – SUMHIGH. Complementary variables including the use and high use of MST added to those related to EST has been also created. They are named SUMTEC+ and SUMHIGH+. All these variables are described in Table 19.

Table 19: SUMTEC and SUMHIGH variables description

Variables	Variable construction	Values
SUMTEC	Sum of technologies used. It represents the number of chosen technologies that the firm had implemented.	From 0 to N (for N = 8 that is the maximum number of technologies analysed)
SUMHIGH	Sum of the technologies having a high level of usage. It represents the number of chosen technologies that have a high level of implementation in the firm.	From 0 to N (for N = 8 that is the maximum number of technologies analysed)
SUMTEC+	Sum of technologies used including MST. It represents the number of chosen technologies that the firm had implemented.	From 0 to N (for N = 10 that is the maximum number of technologies analysed)
SUMHIGH+	Sum of the technologies having a high level of usage including MST. It represents the number of chosen technologies that have a high level of implementation in the firm.	From 0 to N (for N = 10 that is the maximum number of technologies analysed)

The first dependent variable is return on sales (ROS), a ratio widely used to evaluate a firm's business (economic) efficiency. ROS is also known as a firm's "operating profit margin". It is calculated by net income (before interest and tax) divided by sales. This measure is helpful to management, providing an insight into how much profit is being produced for each unit of sales income. As with many ratios, it is best to compare a firm's ROS over time to look for trends and compare it to other firms in the same industry. An increasing ROS indicates that the firm is growing more efficient, while a decreasing ROS could signal looming financial disaster. The questionnaire collected information on the value of ROS before interest and tax in 2008 (less than 2%, up to 5%, up to 10%, and more than 10%), and it reflected the general opinion of the respondent, being a perception rather a result of a computation. For that reason, an additional calculation of ROS from annual turnover, payroll costs and input costs data has been made.

The second dependent variable is energy efficiency. Energy efficiency is measured on a relative scale (values from 1 to 5) requesting that the firm estimate the efficiency of its own production in terms of actual material and energy consumption compared with other firms of their industry. The scale ranges from 1 equalling considerably less efficient (0,5%) to value 5 considerably more efficient (2,2%). The value 2 indicates rather less efficient (6,1%), 3 indicates equally efficient (62,6%) and 4 indicates rather more efficient (28,5%). In the analyses, three groups have been created from this variable: "Less efficient" (including firms rated with values 1 or 2), "Equally efficient" (including firms rated with value 3) and "More efficient" (including firms rated with values 4 or 5).

Table 20: Dependent variables used in multiple regression analysis

Concept	Dependent Variable	Type of variable	Origin of the variable	Contents
ROS	**Continuous**	Quantitative	Elaborated	Quantitative variable elaborated from the range of ROS. Values: not taken in account if ROS is negative, 1 for ROS 0-2 %, 3,5for ROS >2-5 %, 7,5 for ROS >5-10 %, and 50 for ROS >10 %.
	2-5 %	Categorical	Survey	Questionnaire information about the value of ROS before interest and taxes in 2008. Values 0 or 1.
	5-10 %	Categorical	Survey	
	>10 %	Categorical	Survey	
	Calculated	Quantitative	Elaborated	Calculated form annual turnover 2008, inputs 2008 (purchased parts, material, raw materials, operating supplies, services), and payroll costs as % of turnover 2008 (including fringe benefits resp. fringe costs). Data extracted from the questionnaire.
Energy Efficiency	**Efficiency level**	Quantitative	Survey	Questionnaire data about the value of the efficiency of production in terms of material and energy consumption in comparison with other factories of the industry in 2008. Values: 1 if the firm is considerably less efficient, to 5 if the firm is considerably more efficient.
	Less efficient	Categorical	Elaborated	Questionnaire information about the value of the efficiency of production in terms of material and energy consumption in comparison with other factories of the industry in 2008. Data extracted from the questionnaire. Values: 0 or 1.
	Equally efficient	Categorical	Elaborated	
	More efficient	Categorical	Elaborated	

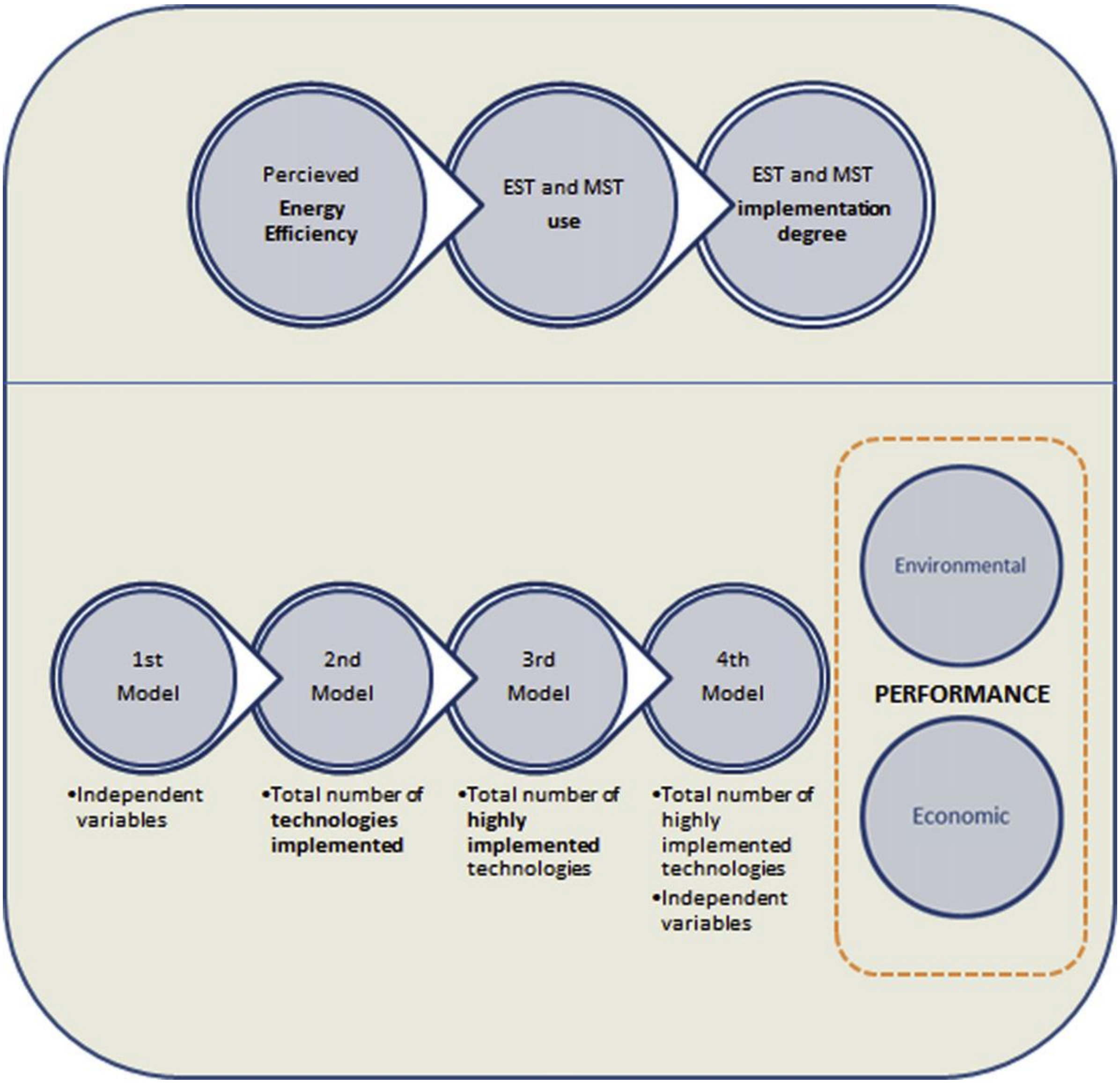
Some control variables were incorporated to isolate the studied relationships in regression analysis. Backward and forward regressions were made to decide which of these predictor variables had the more significant influence over the dependent ones. Taking in account aspects as firm returns, sectorial patterns, size, technological level, product characteristics, competitive factors, environmental control systems or firm objectives, relative efficiency and energy and material saving potential of a firm, the variables are shown in Table 22.

Table 21: Selected control variables for multiple regressions

Dependent variables	Control Variable	Origin of the variable	Contents
ROS: Continuous 2-5 % 5-10 % >10 % Calculated	**Low tech**	Elaborated	From OECD's classification of manufacturing industries and the sector code introduced in the questionnaire. Values: 0 or 1.
	High tech	Elaborated	
	Ln turnover 2008	Calculated	Natural logarithm of questionnaire variables containing absolute turnover and number of employees of the firm.
	Ln employees 2008	Calculated	
	ISO 14000	Survey	Use of a use an environmental controlling system (e.g. ISO 14000, etc.). Values: 0 or 1.
	Less efficient	Elaborated	Questionnaire information about the value of the efficiency of production in terms of actual material and energy consumption in comparison with other factories of the industry in 2008, grouped in three categories (less, equally and more efficient) and taking equally efficient as reference variable. Values: 0 or 1
	More efficient	Elaborated	
Energy efficiency: Effic. level Less effic. Equal. effic. More effic.	**Low tech**	Elaborated	From OECD's classification of manufacturing industries and the sector code introduced in the questionnaire. Values: 0 or 1.
	High tech	Elaborated	
	Ln turnover 2008	Calculated	Natural logarithm of questionnaire variables containing absolute turnover and number of employees of the firm.
	Ln employees 2008	Calculated	
	ISO 14000	Survey	Use of a use an environmental controlling system (e.g. ISO 14000, etc.). Values: 0 or 1
	Saving Potential	Survey	Percentage of the actual energy and material consumption that the firm could economize if they utilized all the technical possibilities available today.

The analytical framework of the present research is depicted in Figure 8. We present the results, described in the following section, following the same sequence. All statistical tests have been performed with the SPSS Statistics 19 software pack. The detailed equations used for the most complex version of modeling economic and environmental performance can be found in Appendix 2.

Figure 8: Analytical framework of the research.



5.4 Results and discussion

5.4.1 Use and implementation of EST and MST

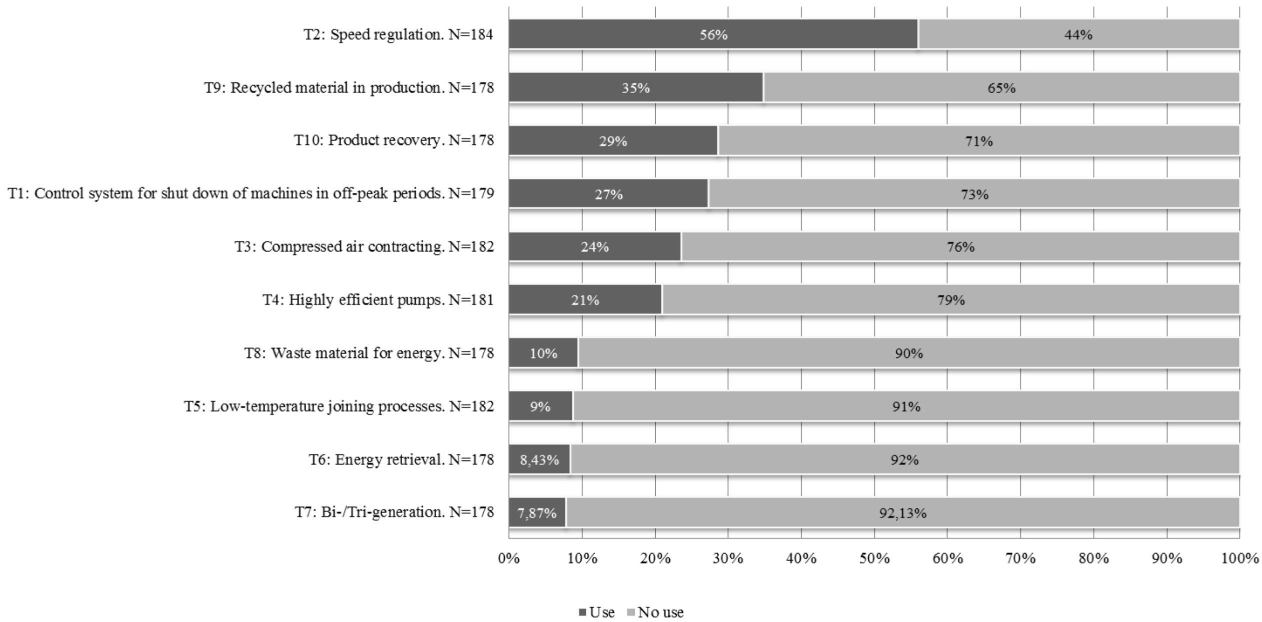
First, we will present some general findings regarding the use and implementation of EST and MST. As previously explained, in our analysis three groups of manufacturing firms have been created regarding the perception of energy efficiency in relation with their industrial sector: “Less efficient”, “Equally efficient” and “More efficient”. Descriptive analysis depicted in Table 22 shows that firms belonging to more relative efficient groups have, in average, higher number of employees. Average firms’ turnover also increases as relative efficiency of these firms increases. However, high exportation intensity (more than 50% of sales abroad) is being reduced in average as the studied group gains relative efficiency. No trend is perceived between these groups of sectors relative to the existence of R&D expenditure or the average use of environmental control systems as ISO 14000.

Table 22: Descriptive statistics by firms' perceived energy efficiency

	Less efficient	**Equal efficient**	**More efficient**	**Total**
Estimation	1=Considerably less efficient 2=Rather less efficient	3=Equally efficient	4=Rather more efficient 5=Considerably more efficient	All from 15 to 37
N	12 (1+11)	112	55 (51+4)	179
Number of employees 2008. N=179	139,92	145,76	376,87	216,04
Turnover 2008. N=164	12,77 M€	22,86 M€	63,54 M€	37,86M€
Firms with R&D expenditures. N=176	58,33 %	61,47 %	60,00 %	60,80 %
High exportation intensity firms (more than a 50% of sales abroad). N=165	63,64 %	41,75 %	37,25 %	41,82 %
Firms with ISO 14031 implemented. N=179	33,33 %	16,96 %	45,45 %	27,81 %
Average of Technological intensity (max. range=3, min. range=1). N=179	2,23	2,13	2,07	2,12

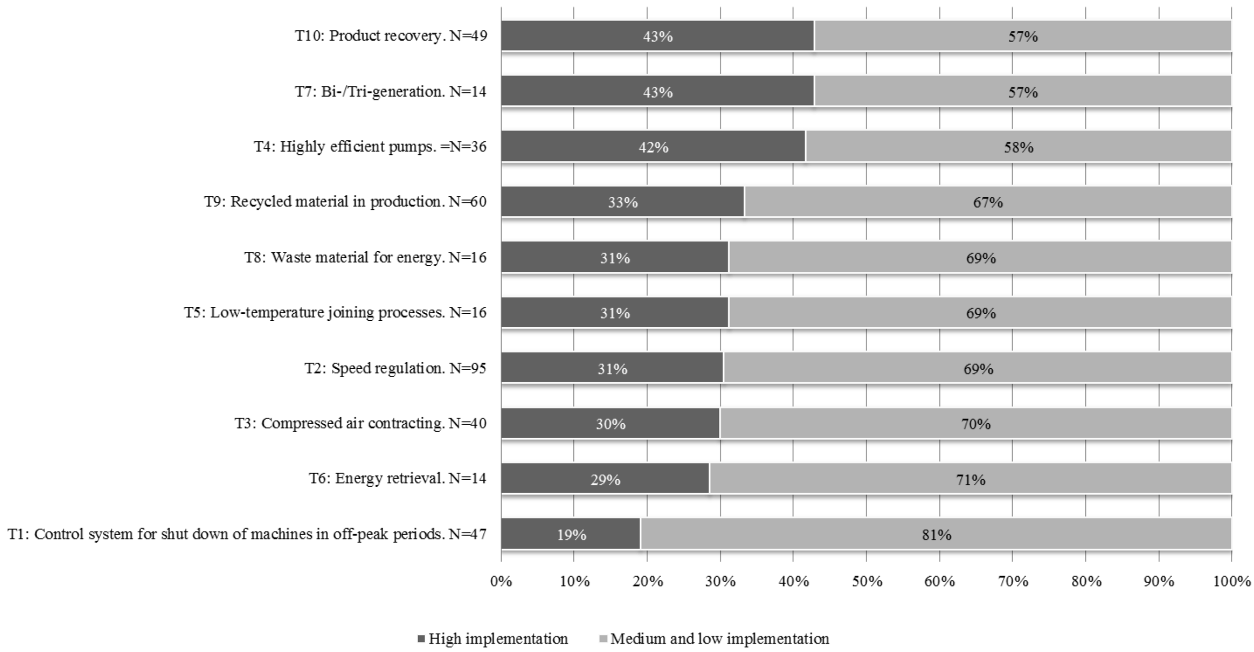
Figure 9 depicts the use of EST and MST for all manufacturing sectors presented. It is shown that "Speed control" is the most used technology with a 56% of affirmative answers, and the second and third technologies in the ranking of use correspond to MST "Recycled material in production" with a 34,83%, and "Product recovery" with a 28,65%, respectively. The second EST is in the fourth position and far from the first one "Control system for shut down of machines in off-peak periods" (27,37%).

Figure 9: Use of EST and MST for all manufacturing sectors



The graph in Figure 10 presents a distribution of technologies used according its implementation degrees (level/extent of use) and ranked by high implementation from top to down.

Figure 10: Implementation degree of EST and MST for all manufacturing sectors



"Bi-/Tri-generation" is the EST with a bigger high implementation per cent (42,86%) with "Product recovery" that is a MST. The second EST in the ranking of per cent of highly implemented ones is

"Highly efficient pumps" (41,67%). The "Speed regulation" technology or system is the fifth EST in terms of high implementation per cent, when in terms of simple use is the first one. A reduction in the dispersion of the presents of the highly implemented technologies is perceived compared with the presents of simple use ones.

5.4.2 Exploring the relationship between energy and material saving technologies and economic performance

In order to test the possible relationship between ROS, material and energy efficiency in production, technological sector, or environmental control systems implementation and the number of EST and MST implemented or the number of these technologies highly implemented, several tests of correlation have been done, using the value of Pearson correlation. Table 23: Correlation matrix between ROS, and use and high use of EST and MST presents a positive and significant correlation between ROS and EST and MST use and high use. However, when we take in account the use and high use of all these technologies including MST, we can notice that the correlation with use is not as significant as the high use one. Relationship between ROS and use or high use is small in all cases. However, this relationship is stronger when considering high use and when MST are not included. In all cases, the relationship strength is small and has positive sign.

Table 23: Correlation matrix between ROS, and use and high use of EST and MST

Correlations

		ROS	Number of energy saving technologies implemented	Number of energy saving technologies Highly implemented	Number of energy saving technologies implemented including T9 and T10	Number of energy saving technologies Highly implemented including T9 and T10
ROS	Pearson Correlation	1	,225**	,243**	,185*	,200**
	Sig. (2-tailed)		,003	,001	,016	,009
	N	169	169	169	169	169
Number of energy saving technologies implemented	Pearson Correlation	,225**	1	,531**	,927**	,480**
	Sig. (2-tailed)	,003		,000	,000	,000
	N	169	187	187	187	187
Number of energy saving technologies Highly implemented	Pearson Correlation	,243**	,531**	1	,509**	,928**
	Sig. (2-tailed)	,001	,000		,000	,000
	N	169	187	187	187	187
Number of energy saving technologies implemented including T9 and T10	Pearson Correlation	,185*	,927**	,509**	1	,519**
	Sig. (2-tailed)	,016	,000	,000		,000
	N	169	187	187	187	187
Number of energy saving technologies Highly implemented including T9 and T10	Pearson Correlation	,200**	,480**	,928**	,519**	1
	Sig. (2-tailed)	,009	,000	,000	,000	
	N	169	187	187	187	187

**. Correlation is significant at the 0.01 level (2-tailed).

*. Correlation is significant at the 0.05 level (2-tailed).

We also detect a positive and statistically significant correlation between material and energy efficiency in production and EST and MST use and high use, as we also expected. Taking in account the use and high use of all these technologies, a stronger relationship was found for all high use variables compared with the only use ones. Inclusion of MST had not noteworthy differences in terms of significance or relationship strength. In all cases, the relationship strength has positive sign and it is small for use and medium for high use.

Three different regression models were proposed to refine the analysis of the relationships: the first one, including the control variables alone as independent variables – Model 1, a second model, considering only the technological variables (SUMTEC and SUMHIGH) – Model 2, and the third model, taking into account all the mentioned variables in previous models together – Model 3.

Table 24: Regression analysis - Economic Performance.

ROS – Model 1	Continuous	2–5%	5–10%	>10%	Calculated
Constant	34.403***	0.548	2.783**	−4.195**	−5.999
Low tech	−7.584*	0.021	0.148	−1.408	7.277
High tech	1.339	0.605	0.007	0.155	−2.969
Ln turnover 2008	4.990**	0.127	−0.378	1.040**	6.059**
Ln employees 2008	−7.545**	−0.322	0.673*	−1.933**	−1.479
ISO 14000	−5.094	0.558	−0.384	−1.430	−0.519
Less efficient	−5.583	−0.408	0.042	−18.879***	−2.293
More efficient	0.058	−0.350	0.723	−0.196	−0.804
Saving potential	0.009	0.037**	−0.017	0.009	0.103
R^2	0.141				0.110
R^2 (Cox&Snell)		0.065	0.059	0.161	
R^2 (Nagelkerke)		0.090	0.083	0.291	
R^2 (McFaden)		0.053	0.049	0.218	

Model 2.1	Continuous	2–5%	5–10%	>10%	Calculated
SUMTEC	11,107***	0.867***	0.867***	1.718***	0.456
Constant	−0.092	0.036	0.036	0.148	2.733**
R^2	0.000				0.051
R^2 (Cox&Snell)		0.001	0.001	0.000	
R^2 (Nagelkerke)		0.001	0.001	0.001	
R^2 (McFaden)		0.001	0.001	0.000	

Model 2.2	Continuous	2–5%	5–10%	>10%	Calculated
SUMHIGH	10.113	0.686**	0.956***	1.875***	2.228
Constant	1.586	−0.251	0.264	0.185	5.584***
R^2	0.010				0.059
R^2 (Cox&Snell)		0.012	0.017	0.005	
R^2 (Nagelkerke)		0.016	0.024	0.010	
R^2 (McFaden)		0.010	0.014	0.007	

Model 3	Continuous	2–5%	5–10%	>10%	Calculated
SUMHIGH	1.742	−0.257	0.275	0.337	4.284**
Constant	33.729***	0.488	2.951**	−4.223**	−6.675
Low tech	−7.531*	0.043	0.167	−1.390	7.785
High tech	1.637	0.582	0.059	0.296	−2.474
Ln turnover 2008	4.430**	0.199	−0.487	0.074**	4.820**
Ln employees 2008	−7.280**	−0.351	0.737**	−1.949**	−1.071
ISO 14000	−4.754	0.536	−0.317	−1.402	0.443
Less efficient	−5.475	−0.436	0.055	−18.882***	−2.343
More efficient	−1.153	−0.218	0.539	−0.648	−3.291
Saving potential	0.016	0.037**	−0.016	0.012	0.112
R^2	0.151				0.138
R^2 (Cox&Snell)		0.073	0.072	0.170	
R^2 (Nagelkerke)		0.102	0.102	0.307	
R^2 (McFaden)		0.060	0.061	0.231	

Significant at * p-value <0.1, ** p-value<0.05, *** p-value ≤0.001.

Model 1 for ROS as performance reveals that the biggest firms in turnover terms have great likelihood of having bigger ROS, mainly when this ROS is over a 10%. However, size in terms of number of employees presents negative influence over the most ROS variables analysed that are significant for the "continuous" one and more significant in the case of ROS over a 10% (">10%" variable). For firms that declare a ROS between 5% and 10% ("5-10%" variable), the influence of the number of employees is positive but not significant. It also shows a negative effect over ROS with a big significance for less efficient firms coefficient when ROS is over a 10%. Regarding to environmental related dimensions, this model reveals that ISO 14000 systems implementation does not produce significant effects over ROS in any of the different natures of the dependent variable. Even a negative but not significant influence of these environmental control systems appears in the results.

Analysing Model 2 for ROS we can observe that signification of SUMHIGH is bigger than the SUMTEC one, for calculated ROS. Furthermore the R2 value increases slightly from Model 2.1 to Model 2.2 considering highly implemented technologies for calculated ROS. In the case of the rest of dependent variables representing ROS, the correlation and consequently R2 also increases in Model 2.2 with variable SUMHIGH.

When technological variables SUMTEC and SUMHIGH are included in Model 3, the coefficients of determination (R2) also increase compared with previous models. This fact indicates that the proportion of the variance in the dependent variable accounted by this model is a little better than in the others. In other words, we can affirm that the model including EST variables in addition to the rest of the control variables is the one that explains better the variability of the ROS. Moreover, a minimal increment of R2 is produced when variable SUMHIGH is added in the model.

However, the difference between the R2 coefficients in Model 1 and in Model 3 is minimal. It means that SUMTEC or SUMHIGH are not able to explain anything different about ROS as performance that control variables do. Results indicate neither EST implementation nor their high use is a good predictor for ROS.

5.4.3 Exploring the relationship between energy and material saving technologies and environmental performance

After ROS models have been tested, the same proceeding is followed for dependent variables representing energy and material efficiency in production as environmental performance. It is expected that EST and MST have a relationship with environmental parameters and with energy and material efficiency in particular. Overall 9 models have been calculated out of which we show 3 that give the best results. These are presented in Table 25.

Table 25: Regression analysis - Environmental Performance

Efficiency	Model 4				Model 5.1				
	Effic. Level	Less effic.	Equally effic.	More effic.		Effic. Level	Less effic.	Equally effic.	More effic.
					SUMTEC+	0.056**	−0.124	−0.122*	0.159**
Constant	3.178***	5.384**	−1.269	0.995	Constant	3.126***	2.375***	−0.806***	1.206***
Low tech	−0.018	0.598	−0.026	−0.080					
High tech	−0.247**	1.766*	0.250	−0.818*					
Ln turnover 2008	0.059	−0.519	−0.094	0.250					
Ln employees 2008	0.009	0.414	0.022	−0.126					
ISO 14000	0.117	0.858	−1.371***	1.295**					
Saving potential	−0.005	0.045**	−0.014	−0.007					
R^2	0.077				R^2	0.042			
R^2 (Cox&Snell)		0.071	0.102	0.108	R^2 (Cox&Snell)		0.004	0.018	0.029
R^2 (Nagelkerke)		0.184	0.140	0.154	R^2 (Nagelkerke)		0.010	0.025	0.041
R^2 (McFaden)		0.151	0.082	0.094	R^2 (McFaden)		0.008	0.014	0.024

Model 5.2					Model 6				
	Effic. Level	Less effic.	Equally effic.	More effic.		Effic. Level	Less effic.	Equally effic.	More effic.
SUMHIGH+	0.178***	−0.890	−0.391**	0.519***	SUMHIGH+	0.178***	−0.852	−0.433**	0.542**
Constant	3.132***	2.315***	−0.796***	1.212***	Constant	3.103***	5.676**	−1.480	1.229
					Low tech	0.015	0.583	−0.109	0.015
					High tech	−0.178	1.684*	0.084	−0.645
					Ln turnover 2008	−0.011	−0.405	0.096	0.001
					Ln employees 2008	0.030	0.502	−0.038	−0.051
					ISO 14000	0.175	0.866	−1.443***	1.419**
					Saving potential	−0.005	0.043**	−0.014	−0.007
R^2	0.127				R^2	0.187			
R^2 (Cox&Snell)		0.021	0.052	0.085	R^2 (Cox&Snell)		0.085	0.149	0.175
R^2 (Nagelkerke)		0.055	0.071	0.120	R^2 (Nagelkerke)		0.219	0.204	0.248
R^2 (McFaden)		0.044	0.040	0.072	R^2 (McFaden)		0.181	0.123	0.157

Significant at * *p*-value <0.1, ***p*-value<0.05, *** *p*-value ≤0.001.

Model 4 examines the relationship between firm characteristics and energy efficiency performance as a relative energy and material efficiency in production – regression without taking in account EST implemented. This model reveals that firms in the "High technology" group present a negative significant relationship with efficiency level and a positive relationship, but less significant, with the "Less efficient" group. It indicates that the "High technological" group has more likelihood to contain firms with less energy and material efficiency. Moreover, the implementation of environmental control systems has a positive significant relationship with energy and material efficiency. This model also shows that less efficient firms have more probability to have a higher saving potential.

Model 5 had four sub-models that deal with relationship between the total number of EST and MST implemented in a firm and energy efficiency performance, regression taking in account only the number of technologies implemented or highly implemented. First two models explain that the use of EST is positively linked to this efficiency as performance. Considering only use of these technologies, less significance is obtained compared with the significance for a high use of them. The coefficients of determination (R2) for this model that take into account only the use or the high use of these technologies are also low. The level of explanation of the dependent variables is consequently low. Hardly any difference regarding the signification is observed when the model also considers MST with the variables SUMTEC+ and SUMHIGH+. However, the per cent of the explained variance of the energy and material efficiency variables increases when model uses the variable SUMHIGH+ including MST.

Finally, Model 6 is presented that encompasses the control variables in addition to use or high use of these technologies variables. In this model the coefficient of determination (R2) improves comparing with the previous models. It means that Model 6 explains a major per cent of the dependent variables representing energy and material efficiency in production. In this case, taking energy and material relative efficiency variables as an indicator of environmental performance, we have a considerable number of significant relationships between these variables and EST and MST as it was expected. These relationships are more significant in the case of considering high implementation (SUMHIGH and SUMHIGH+). In the case of only considering single use (SUMTEC and SUMTEC+), more significant relationships result when considering also MST (SUMTEC+). When considering MST it is observed for the majority of dependent variables that determination coefficient (R2) is lower using SUMTEC+ instead of SUMTEC, and higher using SUMHIGH+ instead of SUMHIGH. It means that MST inclusion helps to improve Model 6 when considering a high use of these technologies.

5.5 Conclusions

5.5.1 Summary and implications

This work has contributed with a quantitative analysis of the use and extent of use of EST and MST in manufacturing firms. Our suggested models give rise to explain how significant energy efficiency is, how much of the variability in economic performance and environmental performance indicators can it explain, which are the more significant relationship between the use and extent of use of these technologies, the economic and environmental indicators and the control variables proposed.

Our results show that EST and MST do not have a clear significant relationship with economic performance represented by ROS. Only low significant relations appear in some models with "calculated ROS", never with respondent reported ROS. The explanation power of the models for economic performance (ROS) that include EST and MST variables do not vary significantly from others only considering the rest of independent variables.

A significant positive relationship appears between EST and MST and environmental performance represented by energy and material relative efficiency. The high use of EST and MST improves the significance and the explanation power of the models explaining economic performance (ROS) and environmental performance (energy and material relative efficiency), compared with those that only contemplate a simple use. Firms in "Less efficient" group have more likelihood to have more saving potential. It indicates that its energy and material inefficiency can be improved implementing EST and MST.

There is a special relevance in the fact that the present study points that EST do not have a clear relationship with economic performance but with environmental performance. In other words, for a manufacturing firm, they are more helpful in order to be greener than to obtain better economic results. Therefore we believe that our main message to the practitioner community is that they do have a more immediate effect on energy efficiency contributing effectively to save energy and material, but they do not have an evident effect over economic performance by themselves.

This finding is also important to be taken in account by policy makers because some conflicts can appear between social requirements for a greener world, institutional interests in energy saving and economic profit firms' orientation that can be addressed with appropriate actions. Regarding implementation levels, there is still place towards either mere promotion towards use or high implementation in manufacturing firms in some of the considered either energy or material saving technologies. Police makers can better plan regulations, recommendations or promotions in order to save energy and materials, knowing this kind of technologies have a real "green" effect over manufacturing firms.

Academia has a new field of research related with such important subject like energy and material efficiency and environmental management. Our quantitative study has started to present numeric results and models for a concrete geographic area. Several relationships between firms' characteristics and economic performance variables, represented by ROS, and also energy efficiency or environmental performance variables, represented by relative energy and material efficiency, have been reported regarding different nature of these concepts. Large scale surveys can contribute with valid and strong field evidences regarding this strategic topic.

5.5.2 Limitations and future research

The main limitations of our study can be summarized under three main points: 1) limited geographical coverage, 2) methodological issues regarding questionnaire items and performance measures and 3) inexistence of previous data using the same source (EMS). These are briefly detailed as follows.

Even two countries' data is presented along the manuscript. Both the absolute number of answers and the relative percentage response rate is relatively low. The inclusion of other countries' data using the same questionnaire would further enrich the analysis.

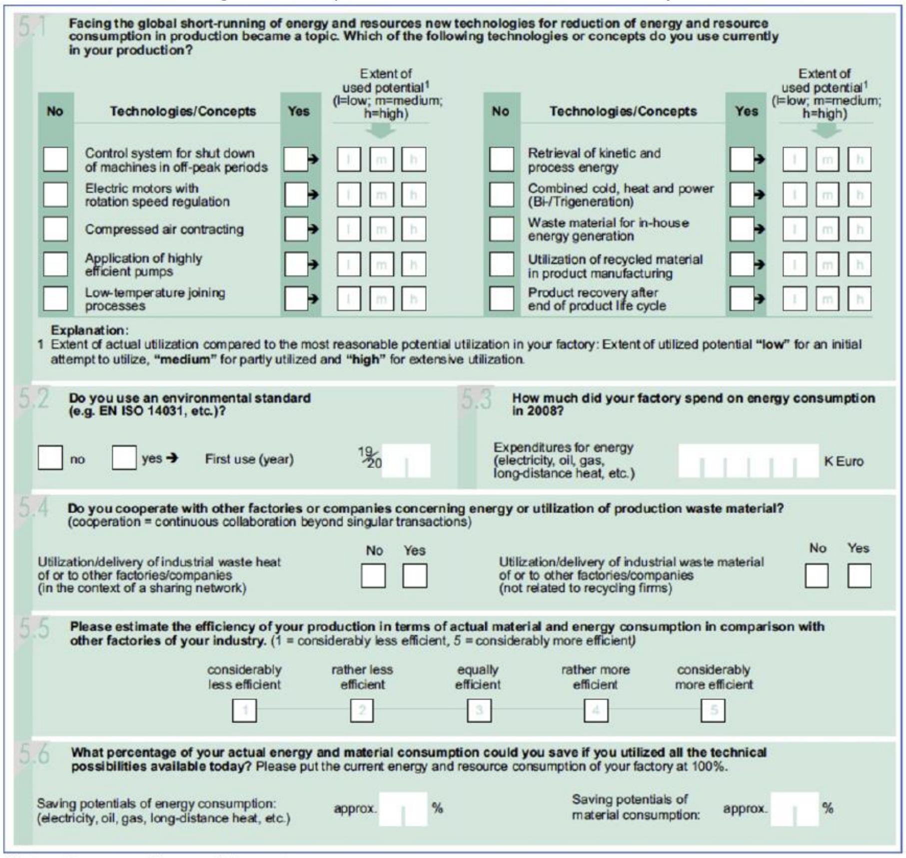
In reference to methodological aspects it should be mentioned that energy and material saving technologies were specified and contrasted with specialized experts in the field. Difficulties arise since firms' economic sector of activity is an important discriminant. Taking into account that target companies belong to the manufacturing sector some general technologies had to be defined and included in the questionnaire. The priority selection criterion was that they were expected to be found in manufacturing firms indifferently of their size or activity. This fact has an immediate consequence: generic technologies often leave space for wide interpretation of respondents. Future rounds of survey conduction should either provide a brief definition of the concept or additional information about the understanding and limits of the concept. Another issue object to respondents' interpretation is performance both economic and energy efficiency. In our analysis we include a calculated variant of ROS in order to mitigate this effect. While energy saving technologies and material saving technologies are differentiated, the perception about efficiency is joint. Further analysis should explore differentiated efficiency trends.

The EMS 2012 round contemplated for the first time the inclusion of energy and material saving technologies into a pan-European harmonized questionnaire targeting the manufacturing sector. The inexistence of previous data using the same source and the divergence of methodological aspects encountered in other studies make difficulties when willing to compare our results with other previous or similar studies.

Despite the mentioned shortcomings our contribution is aimed towards exploring the relationship between use and degree of implementation of energy and material saving technologies on different facets of efficiency, economic and environmental bringing empirical evidences collected through a methodologically sound large scale survey in Europe. Interesting implications for all parties involved in the field of energy saving and efficiency are formulated. However, the topic -still a strategic priority on the worldwide agenda- due to its complexity needs further studies in order to discover unsolved knowledge gaps.

5.6 Appendix 1: Energy and material saving technologies - European Manufacturing Survey 2009

Figure 11: EST/MST inside the EMS 2009 edition layout.



5.1 Facing the global short-running of energy and resources new technologies for reduction of energy and resource consumption in production became a topic. Which of the following technologies or concepts do you use currently in your production?

No	Technologies/Concepts	Yes	Extent of used potential[1] (l=low; m=medium; h=high)	No	Technologies/Concepts	Yes	Extent of used potential[1] (l=low; m=medium; h=high)
☐	Control system for shut down of machines in off-peak periods	☐ →	l m h	☐	Retrieval of kinetic and process energy	☐ →	l m h
☐	Electric motors with rotation speed regulation	☐ →	l m h	☐	Combined cold, heat and power (Bi-/Trigeneration)	☐ →	l m h
☐	Compressed air contracting	☐ →	l m h	☐	Waste material for in-house energy generation	☐ →	l m h
☐	Application of highly efficient pumps	☐ →	l m h	☐	Utilization of recycled material in product manufacturing	☐ →	l m h
☐	Low-temperature joining processes	☐ →	l m h	☐	Product recovery after end of product life cycle	☐ →	l m h

Explanation:
1 Extent of actual utilization compared to the most reasonable potential utilization in your factory: Extent of utilized potential "low" for an initial attempt to utilize, "medium" for partly utilized and "high" for extensive utilization.

5.2 Do you use an environmental standard (e.g. EN ISO 14031, etc.)?

☐ no ☐ yes → First use (year) 19/20

5.3 How much did your factory spend on energy consumption in 2008?

Expenditures for energy (electricity, oil, gas, long-distance heat, etc.) K Euro

5.4 Do you cooperate with other factories or companies concerning energy or utilization of production waste material? (cooperation = continuous collaboration beyond singular transactions)

Utilization/delivery of industrial waste heat of or to other factories/companies (in the context of a sharing network) No ☐ Yes ☐

Utilization/delivery of industrial waste material of or to other factories/companies (not related to recycling firms) No ☐ Yes ☐

5.5 Please estimate the efficiency of your production in terms of actual material and energy consumption in comparison with other factories of your industry. (1 = considerably less efficient, 5 = considerably more efficient)

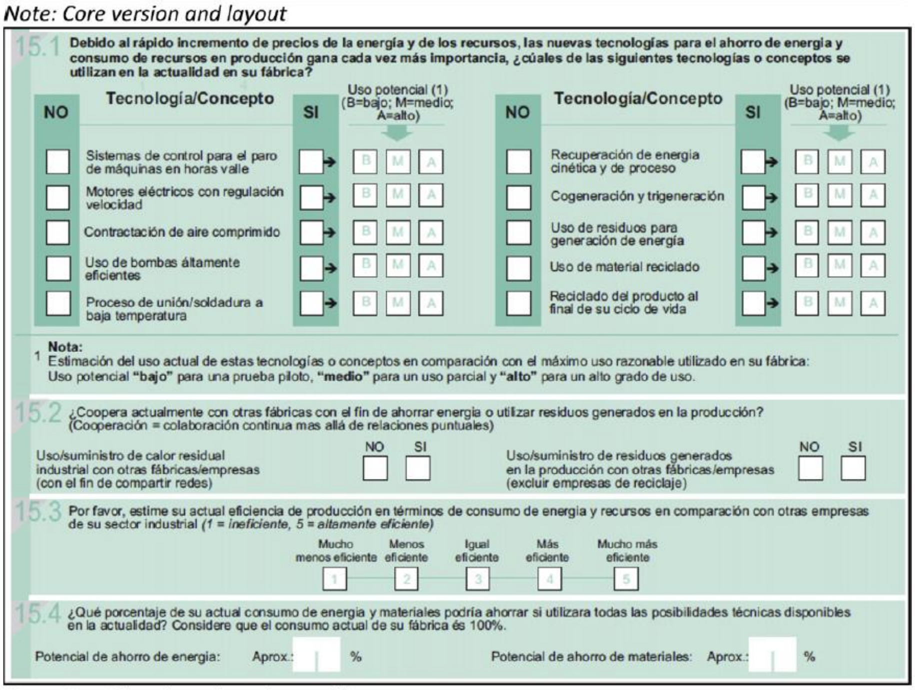
considerably less efficient 1 — rather less efficient 2 — equally efficient 3 — rather more efficient 4 — considerably more efficient 5

5.6 What percentage of your actual energy and material consumption could you save if you utilized all the technical possibilities available today? Please put the current energy and resource consumption of your factory at 100%.

Saving potentials of energy consumption: (electricity, oil, gas, long-distance heat, etc.) approx. %

Saving potentials of material consumption: approx. %

Note: Core version and layout



15.1 Debido al rápido incremento de precios de la energía y de los recursos, las nuevas tecnologías para el ahorro de energía y consumo de recursos en producción gana cada vez más importancia, ¿cúales de las siguientes tecnologías o conceptos se utilizan en la actualidad en su fábrica?

NO	Tecnología/Concepto	SI	Uso potencial (1) (B=bajo; M=medio; A=alto)	NO	Tecnología/Concepto	SI	Uso potencial (1) (B=bajo; M=medio; A=alto)
☐	Sistemas de control para el paro de máquinas en horas valle	☐ →	B M A	☐	Recuperación de energía cinética y de proceso	☐ →	B M A
☐	Motores eléctricos con regulación velocidad	☐ →	B M A	☐	Cogeneración y trigeneración	☐ →	B M A
☐	Contractación de aire comprimido	☐ →	B M A	☐	Uso de residuos para generación de energía	☐ →	B M A
☐	Uso de bombas altamente eficientes	☐ →	B M A	☐	Uso de material reciclado	☐ →	B M A
☐	Proceso de unión/soldadura a baja temperatura	☐ →	B M A	☐	Reciclado del producto al final de su ciclo de vida	☐ →	B M A

Nota:
1 Estimación del uso actual de estas tecnologías o conceptos en comparación con el máximo uso razonable utilizado en su fábrica: Uso potencial "bajo" para una prueba piloto, "medio" para un uso parcial y "alto" para un alto grado de uso.

15.2 ¿Coopera actualmente con otras fábricas con el fin de ahorrar energía o utilizar residuos generados en la producción? (Cooperación = colaboración continua mas allá de relaciones puntuales)

Uso/suministro de calor residual industrial con otras fábricas/empresas (con el fin de compartir redes) NO ☐ SI ☐

Uso/suministro de residuos generados en la producción con otras fábricas/empresas (excluir empresas de reciclaje) NO ☐ SI ☐

15.3 Por favor, estime su actual eficiencia de producción en términos de consumo de energía y recursos en comparación con otras empresas de su sector industrial (1 = ineficiente, 5 = altamente eficiente)

Mucho menos eficiente 1 — Menos eficiente 2 — Igual eficiente 3 — Más eficiente 4 — Mucho más eficiente 5

15.4 ¿Qué porcentaje de su actual consumo de energía y materiales podría ahorrar si utilizara todas las posibilidades técnicas disponibles en la actualidad? Considere que el consumo actual de su fábrica és 100%.

Potencial de ahorro de energía: Aprox.: %

Potencial de ahorro de materiales: Aprox.: %

Note: Spanish adapted version and layout

5.7 Appendix 2: Equations for modelling performance

Equation 1 : Equations for modelling economic and environmental performance

$$
\begin{aligned}
PERF_{economic} = {} & \alpha + \beta 1SUMHIGH + \beta 2TECHINT \\
& + \beta 3TURNOVER + \beta 4EMP + \beta 5ISO_{14001} \\
& + \beta 6ENEFF + \beta 7SAVPOT + \varepsilon
\end{aligned}
$$

$$
\begin{aligned}
PERF_{environmental} = {} & \alpha + \beta 1SUMHIGH + \beta 2TECHINT \\
& + \beta 3TURNOVER + \beta 4EMP + \beta 5ISO_{14001} \\
& + \beta 6SAVPOT + \varepsilon
\end{aligned}
$$

Chapter 6 Characterizing energy and material saving technologies' adoption and adopters

The main objective of this chapter is to map the adoption of technologies for energy reduction and resources consumption in production. The aim is also to contribute to the identification and understanding of the characteristics of the manufacturing firms that use this kind of energy and material saving technologies. Our research is based on the data from the largest European manufacturing survey and it includes data from Spain and Slovenia. The results show that the use of specific energy saving technologies and material saving technologies in manufacturing firms is still modest. Dividing manufacturing firms based on technology intensity sectors and based on the relative energy efficiency we have concluded that firms in high technology industries focus less on energy efficiency than low technology firms. Some other specific relationship between the use of energy efficient technologies and adopters' characteristics (e. g. use of environmental control systems) are presented in the chapter.

6.1 Introduction

Manufacturing is defined as the transformation of materials and information into goods for the satisfaction of human needs. Turning raw materials into consumer products is also a major source of generating environmental pollution. Waste coming out from manufacturing activities is an environmental threat originating from several regions around the world (Marland, Boden, & Andres, 2007). Therefore, in recent years, mostly in response to increasing pressure from environmental regulations, many manufacturing firms have made significant efforts in cleaner production (Tseng, Lin, & Chiu, 2009)(Lovrec & Tič, 2011).

Industrial energy efficiency plays a central role as the manufacturing industry accounts for about 75% of the world's yearly coal consumption, 44% of the world's natural gas consumption, and 20% of global oil consumption. In addition, these manufacturing firms also use 42% of all the electricity generated (Thollander, Danestig, & Rohdin, 2007). Although renewable energy technologies, such as photovoltaic technology, might be a long-term solution, more efficient energy use can make the highest and most economic contribution towards solving these problems in the short run. Using the available energy more efficiently is an effective countermeasure to rising energy needs and unsecure energy supplies (Tanaka, 2008). Bunse et al. (Bunse et al., 2011) argue that examples in the literature and in the world of practice show that although the manufacturing sector has made continuous improvement in energy efficiency, economically beneficial energy efficiency potential is not yet exploited (Bunse et al., 2011)(International Energy Agency (IEA) /OECD & Jollands, 2009).

This paper is based on an empirical study that tries to contribute to world literature in the field of energy and material efficient technologies. The objective of this paper is firstly to map the adoption of the technologies for reduction of energy and resources consumption in production and, second to contribute to the identification and understanding of the characteristics of the manufacturing firms that use this kind of innovative technologies.

The paper is organized as follows. Introductory background and literature review about the energy efficiency in production is recalled. Next, we present our research methodology and methods used to analyse the characteristics of energy and material saving technologies' adoption and their adopters. Results and findings are presented for the manufacturing firms with the use of descriptive statistics and simple correlation tests. In the end we discuss our results and present some implications.

6.2 Theoretical background

Energy efficiency of manufacturing processes has recently been discussed intensively due to the increasing energy cost and the associated greenhouse gas emissions (Li, Winter, Kara, & Herrmann, 2012). Improving energy efficiency is regarded as one of the most important options to reduce the emissions of greenhouse gases and the dependency of countries on energy imports (Neelis et al., 2007). Measuring energy efficiency is the basis for controlling energy consumption in the production processes, for deciding about improvement measures and for tracking changes and improvements in energy efficiency (Bunse et al., 2011). Studies on energy consumption of manufacturing processes have provided fundamental information for improving energy efficiency and build a comprehensive foundation towards reducing the energy consumption of manufacturing processes (Li et al., 2012). There is also an on-going debate on the reasons why profitable investments to reduce energy consumption are not realized in firms (De Groot, Verhoef, & Nijkamp, 2001) (Paton, 2001). There are several barriers to implementing energy efficiency improvement measures in firms, e. g.: payback periods, limited capital, a low priority given to energy efficiency by the management, lack of information, or "difficult-to-measure components" of energy investments (Bunse et al., 2011)(Sancin, Dobravc, & Dolšak, 2010)(Tan & Takakuwa, 2011).

Bunse et al. (Bunse et al., 2011) argue that many industrial firms still lack appropriate methods to effectively address energy efficiency in production management. Current approaches to integrate energy efficiency performance as a relevant criterion in production management seem to have shortcomings in their comprehensiveness and practicality. The authors of this paper argue that there are two reasons for this: the first reason is the fact, that there is no consensus on the definition of energy efficiency. The second reason is the variety of possibilities to measure and monitor energy efficiency.

When discussing energy efficiency in the industrial sector, different definitions are used (Bunse et al., 2011)(Ang, 2006)(Zhao, 2012). Bunse et al. (Bunse et al., 2011)define energy efficiency as "the ratio of energy services out to energy input (meaning) getting the most out of every energy unit you buy". Increased energy efficiency may be accomplished by more efficient technology, energy recovery in the same process or further use of energy waste in different processes, increased energy conversion efficiency or optimized operational practices.

Energy efficiency developments can be monitored by quantifying the ratio of energy input and the useful output of a certain activity over time. The useful output of an activity can be defined in either physical (e.g. litres of beer produced or person kilometres driven) or monetary units (e.g. GDP of a country or value added of a sector) (Neelis et al., 2007).

Usually, energy efficiency indicators are ratios describing the relationship between an activity and the required energy. In the industrial sector, activities such as the production process of a product can be described in either economic or physical terms resulting in either economic or physical indicators. Economic indicators are useful at an aggregated level, such as for comparing different sectors; however, to gain insight into particular manufacturing processes, physical indicators are more suitable (Phylipsen et al., 2002). Examples of physical indicators are specific energy consumption (Phylipsen et al., 2002)(International Energy Agency, 2007), final energy efficiency improvement (Irrek & Thomas, 2006), thermodynamic energy efficiency (Patterson, 1996) etc. There is no single energy efficiency indicator that can be applied in every situation, but the appropriate indicators have to be defined depending on the decision to be made or decision tool to be applied (International Energy Agency, 2007).

Only several studies used for environmental variables the use of production activities or energy efficient technologies. One of the most recent is from Zeng et al. (Zeng et al., 2010) who found out an overall positive impact of cleaner production on firms' business performance, but not under all circumstances. They argue that the cleaner production activities of low-cost scheme (e. g. improve employee environmental consciousness through training, improve working conditions to reduce waste, strictly enforce rules on cleaner production, increase the recyclability of the products and components) have a bigger contribution to financial performance than the high-cost scheme activities (e. g. using energy efficient and clean technologies or using renewable resources as raw materials), which require significant financial investment but may not result in immediate economic benefit. The low-cost scheme cleaner production activities do not require significant financial input but may bring immediate financial benefits.

6.3 Methodology

We used data from European Manufacturing Survey (EMS) for our research. The EMS is the largest European survey on manufacturing activities, coordinated by the Fraunhofer Institute for Systems and Innovation Research – ISI, Germany. The survey collects data on manufacturing strategies, the application of innovative organisational and technological concepts in production, personnel deployment and qualification, the production off-shoring and back-sourcing activities, cooperation patterns etc. In addition, data on firm characteristics and performance indicators (R&D expenses, productivity, returns on sales,) is collected.

The 2009 EMS edition has been carried out in 12 countries. This paper uses data from the Spanish and Slovenian sub-samples. The Spanish sub-sample had 116 responses and the Slovenian accounted for 64, all together 180 responses. The survey was performed in manufacturing firms (NACE codes from 15 to 37) with at least 20 employees.

In recent years, only a few surveys have been launched in the world that analyse energy efficiency in manufacturing firms and their energy saving technologies (EST) and material saving technologies (MST) use. These existing surveys cover only some industrial sectors monitoring very specific technologies or cover only American and Asian countries. None of them include the European countries covered by EMS that also encompasses all manufacturing industries. Therefore, the latest survey added several questions relating environmental and energy issues. In that sense, EMS defines 10 general groups of technologies, 8 for energy efficiency and 2 for material consumption saving. These wide groups allow classifying any specific technology into one of them obtaining a global map of their use and level of implementation.

EST included were:

T1. control system for shut down of machines in off-peak periods;

T2. electric motors with rotation speed regulation;

T3. compressed air contracting;

T4. highly efficient pumps;

T5. low-temperature joining processes;

T6. retrieval of kinetic and process energy;

T7. combined cold, heat and power – Bi-/Tri-generation and

T8. waste material for in-house energy generation.

We included two MST:

T9. utilisation of recycled material in product manufacturing and

T10. product recovery after product life cycle.

EST and MST are characterized in terms of use and also in terms of usage levels (extent of use) through a descriptive and a frequency analysis. Extent of actual use is referred to comparing the actual use of the technology in the firm to the most reasonable potential use. There are three levels: Extent of utilised potential “low” for an initial attempt to utilise, “medium” for partly utilized and “high” for extensive use.

We have analysed the characteristics of EST and MST adopters according to the OECD's taxonomy of manufacturing industries classified by their technological intensity (OECD, 2005). We have formed three groups: “Low technology” with firms from NACE 15-16, 17-19, 20-22, 36-37; “Medium-Low technology” with firms from NACE 23, 25, 26, 351, 27, 28; and “Medium-High and High technology” with firms from NACE 24, 31, 34 excl. 2423, 352+359, 29 and 353, 2423, 30, 32, 33.

Next, we have classified technology adopters in three groups that represent the relative energy and materials consumption efficiency in production. These groups have been created from the responses of the question regarding the perception of their production efficiency in terms of actual material and energy consumption in comparison with other factories in their industry. Energy efficiency is therefore measured on a relative scale with values from 1 to 5. The scale ranges from 1 equalling considerably much less efficient (0,5%) to value 5 considerably much more efficient (2,2%). The value 2 indicates rather less efficient (6,1%), 3 indicates equally efficient (62,6%) and 4 indicates rather more efficient (28,5%). In the analyses, three groups have been created from this variable: “Less efficient” (including firms rated with values 1 or 2), “Equally efficient” (including firms rated with value 3) and “More efficient” (including firms rated with values 4 or 5).

6.4 Results and findings

Table 26 presents the results according to the OECD's taxonomy of manufacturing industries classified by their technological intensity. As we can observe the majority of firms falls within Medium-Low technology group. If we join Medium-Low technology and Medium-High technology this group consists of 131 firms, thus making Medium technology industry the biggest one. Since our High technology industry group (NACE 353, 2423, 30, 32 and 33) involves only 13 firms, this group was merged with the medium-high-technology industry group in order to reduce the number of groups. The results show that adopters in higher technological intensive industries have, on average, a higher number of employees, higher per cent of firms with R&D expenditure, superior exportation intensity (more than 50% of sales abroad) and a major use of environmental control systems, such as ISO14000. Firms in Medium-high and High technology industrial sectors have also an average turnover in 2008 of more than the double of each one of the other two technological groups (61,95 M€ vs. 22,33 M€ and 29,98 M€). Oserving at the average estimation of material and energy efficiency in production (max. range=5, min. range=1), there is hardly any difference between these groups of technological sectors relative to the average of material and energy efficiency in production.

Table 26: Summary of descriptive features of the sample by technological intensity

	Low technology	**Medium-Low technology**	**Medium-High and High technology**	**Total**
N	43 (23%)	82 (44%)	62 (49+13) (33%)	187
Number of employees 2008. N=187	76,40	137,1	401,98	210,94
Turnover 2008. N=169	29,98 M€	22,33 M€	61,95 M€	37,18 M€
Firms with R&D expenditures. N=183	50,00%	53,09%	75,00%	59,56%
High exportation intensity firms. N=172	24,32%	39,47%	52,54%	40,70%
Firms with ISO 14000 implemented. N=187	13,95%	30,49%	33,87%	27,81%
Average energy efficiency in production. N=179	3,25	3,32	3,18	3,26
T1: Control system for machine shut down. N=179	29,27%	24,36%	30,00%	27,37%
T2: Speed regulation. N=184	57,14%	50,62%	62,30%	55,98%
T3: Compressed air contracting. N=182	26,19%	16,46%	31,15%	23,63%
T4: Highly efficient pumps. N=181	26,19%	16,25%	23,73%	20,99%
T5: Low-temperature joining processes. N=182	0,00%	8,75%	15,00%	8,79%
T6: Energy retrieval. N=178	10,00%	7,50%	8,62%	8,43%
T7: Bi-/Tri-generation. N=178	5,00%	6,25%	12,07%	7,87%
T8: Waste material for energy. N=178	10,00%	8,75%	10,34%	9,55%
T9: Recycled material in production. N=178	45,00%	30,00%	34,48%	34,83%
T10: Product recovery. N=178	35,00%	26,25%	27,59%	28,65%

Table 27: Summary of descriptive features of the sample by relative efficiency in production

	Less efficient	Equally efficient	More efficient	Total
N	12 (1+11) (7%)	112 (63%)	55 (51+4) (30%)	179
Number of employees 2008. N=179	139,92	145,76	376,87	216,04
Turnover 2008. N=164	12,77 M€	22,86 M€	63,54 M€	37,86M€
Firms with R&D expenditures. N=176	58,33%	61,47%	60,00%	60,80%
High exportation intensity firms. N=165	63,64%	41,75%	37,25%	41,82%
Firms with ISO 14000 implemented. N=179	33,33%	16,96%	45,45%	27,81%
Average of Technological intensity. N=179	2,23	2,13	2,07	2,12
T1: Control system for machine shut down. N=171	33,33%	21,10%	42,00%	28,07%
T2: Speed regulation. N=176	41,67%	49,55%	75,47%	56,82%
T3: Compressed air contracting. N=174	16,67%	24,77%	24,53%	24,14%
T4: Highly efficient pumps. N=173	8,33%	20,37%	28,30%	21,97%
T5: Low-temperature joining processes. N=174	8,33%	8,26%	11,32%	9,20%
T6: Energy retrieval. N=170	0,00%	6,73%	14,81%	8,82%
T7: Bi-/Tri-generation. N=170	8,33%	6,73%	9,26%	7,65%
T8: Waste material for energy. N=170	0,00%	8,65%	14,81%	10,00%
T9: Recycled material in production. N=170	41,67%	31,73%	38,89%	34,71%
T10: Product recovery. N=170	0,00%	28,85%	37,04%	29,41%

Table 27 presents the results according to three groups representing the relative energy and materials consumption efficiency in production. There are only 12 firms in the "Less efficient" group. The majority of firms are in the "Equally efficient" group. There were only 4 firms that claimed that they are considerably more efficient than firms in their industry. The "More efficient" group has all together 55 firms. Regarding this energy and materials efficiency in groups, descriptive analysis shows that firms belonging to more relative efficient groups have, on average, higher number of employees (much more than equally and less efficient firms – 376,87 vs. 154,76 and 139,92). Average firms' turnover also increases as relative efficiency of these firms increases ("More efficient" group has an average turnover in the amount of 63,54 M€ vs. 22,86 M€ and 12,77 M€). However, high exportation intensity (more than a 50% of sales abroad) is being reduced on average as the studied groups gain relative efficiency. As shown in from the previous analysis, we have classified firms into three groups based on technological intensity. We created a discrete variable to group this classification into three categories: "Low technology" – value 1, "Medium-Low technology" – value 2 and "Medium-High and High technology" – value 3. "Medium-Low technology" was taken as a reference variable. We can observe a slight decrease of the technological intensity values from "Less efficient" group to "More efficient" group. This fact could reveal a possible negative relationship between energy efficiency in production and technological intensity of firms, at least on average. Looking at R&D expenditure and the use of environmental control systems, such as ISO 14000, hardly and trend is perceived. But we have to mention an interesting fact that the average use of environmental control systems in the "Equally efficient" group is much smaller than even in the "Less efficient" group.

Figure 12 depicts the use of EST and MST for all manufacturing sectors presented. It is shown that "Speed control" is the most used technology with a 56% of affirmative responses. The second and third technology in the use ranking MST, namely "Recycled material in production" with a 35%, and "Product recovery" with a 29%. The second EST is in the fourth position and far from the first one "Control system for shut down of machines in off-peak periods" (27%). The high share of "Speed control" technology and its distance to other technologies could be misleading. The understanding of this technology could be misunderstood or widely interpreted. The term "Electric motors with rotation speed regulation" could be understood in the sense that almost each machine that produces any kind of motion or rotation with a common speed regulation system over the engine, have implemented this technology. For most machines this is not an option, but an intrinsic characteristic. A doubt arises to what extent "Speed control", presented as it is, should be considered an EST.

The graph in Figure 13 presents a distribution of technologies used according their implementation degree and ranked by the highest implementation level to the lowest. This ranking compared to the simple use has changed. "Bi-/Tri-generation" is the EST with the largest high implementation per cent (43%), together with "Product recovery" that is a MST. The second EST in the ranking of highly implemented technologies is "Highly efficient pumps" with 42%. The "Speed regulation" technology was the most widely used technology, but only 31% of firms acknowledge high use of this technology – rank 7. This fact could be again related to the possible misunderstanding of the term "Speed regulation". Nevertheless, a reduction in the dispersion of the per cents of the highly implemented technologies is perceived compared with the per cents of the simple use of these technologies. This fact is more evident for EST, less for MST as both MST technologies are more widely used and both have relatively high extensive use share. Only "Energy retrieval" technology and "Control system for shut down of machines in off-peak periods" technology have the smallest usage share in the "high use" group.

Figure 12: Use of EST and MST for all nmanufacturing sectors

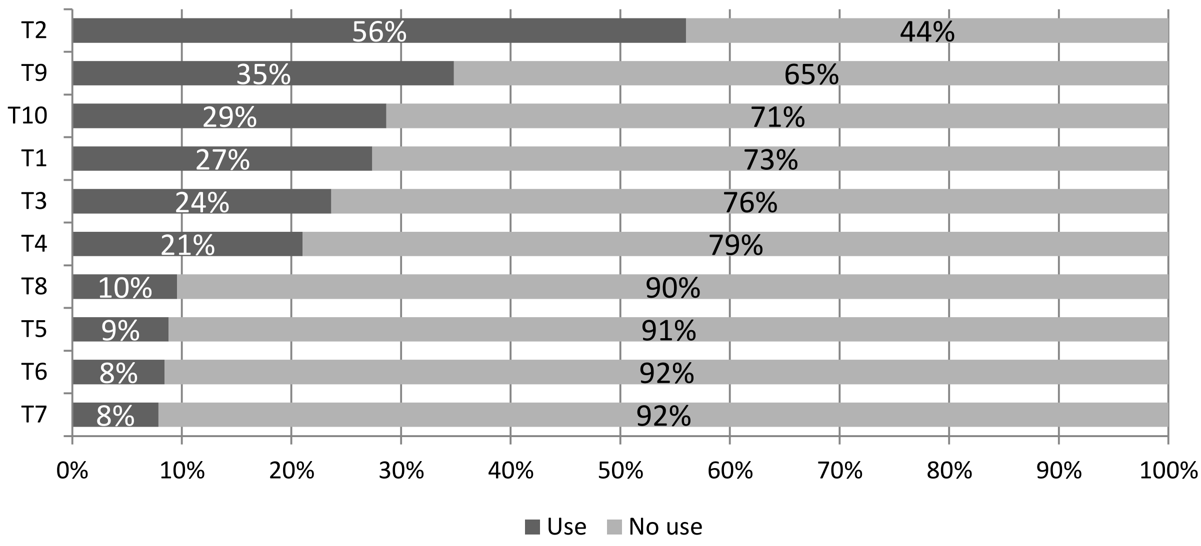


Figure 13: Implementation degree of EST and MST for all manufacturing sector

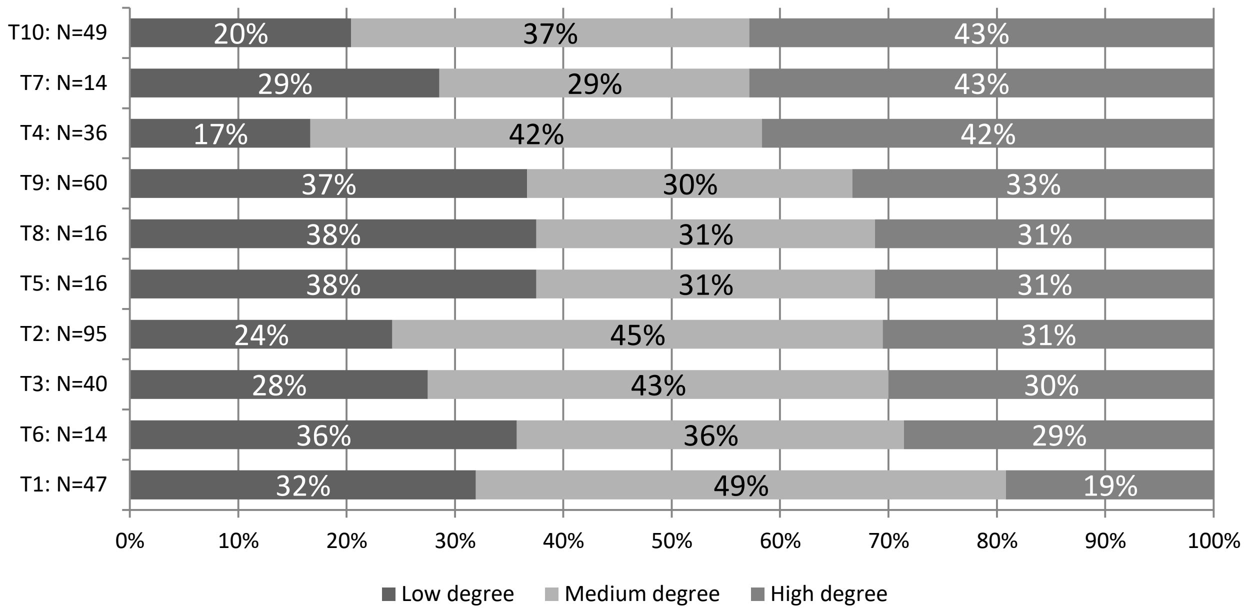


Figure 14: Implementation per cent of EST and MST by tehcnological sector

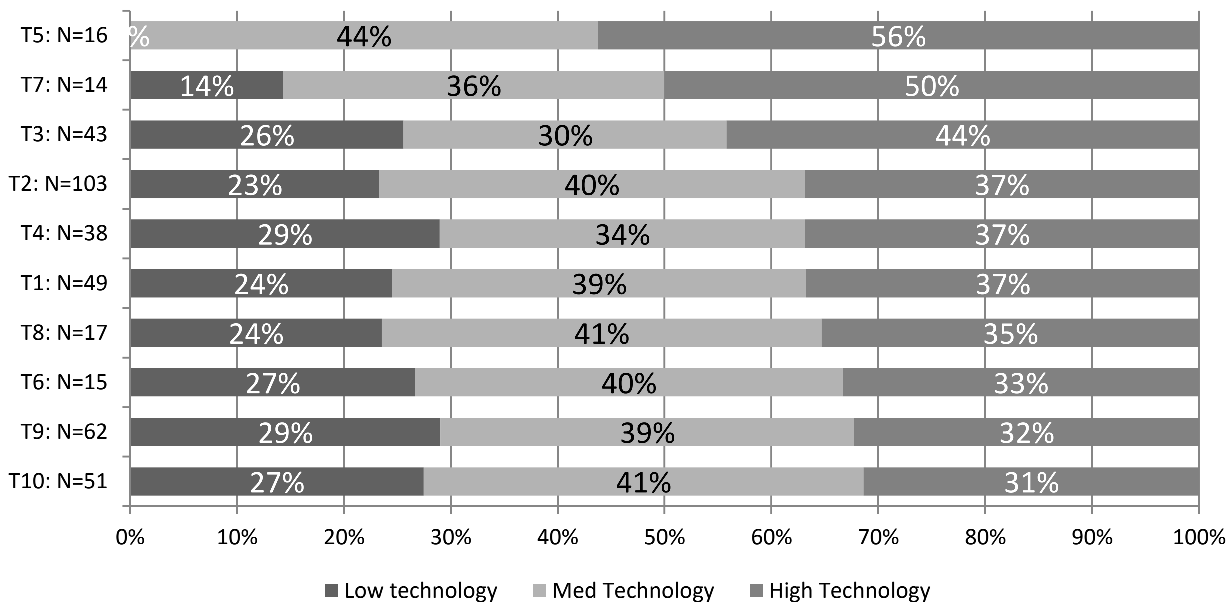


Figure 14 presents EST and MST in accordance to three technological intensity groups. The technologies are ranked based on the share of use in the "Medium-High and High technology" group (from the highest to the lowest share). "Low-temperature joining processes" is the technology with the highest per cent of use in "Medium-High and High technology" with 56%. Not even one firm utilises this technology in the "Low technology" group. "Bi-/Tri-generation" is the only other technology that is predominantly used in "Medium-High and High technology" group with 50%. We can observe that not even one technology is most widely used in "Low technology" group (firms in this group represent a per cent of the total used technologies always below 30%). On the other hand at least 30% of used technologies are within "Medium-High and High technology" group (from 31% to 56%). MST are technologies with lowest use per cent of firms in "Medium-High and High technology" group.

We have also analysed the use of highly implemented technologies according to three technological intensity groups (Figure 15). The highly implemented technologies are ranked based on the share of use in the "Medium-High and High technology" group (from the highest to the lowest share). It is seen that this ranking comparing to general implementation degree has changed. It is interesting to note that the average percentage of highly implemented technologies in "Medium-High and High technology" group is lower than for the implementation of EST and MST in general. This leads to a conclusion that analysed EST and MST are predominately highly implemented in a low and medium-low technology groups.

Figure 15: High implementation per cent of EST and MST by technological sector

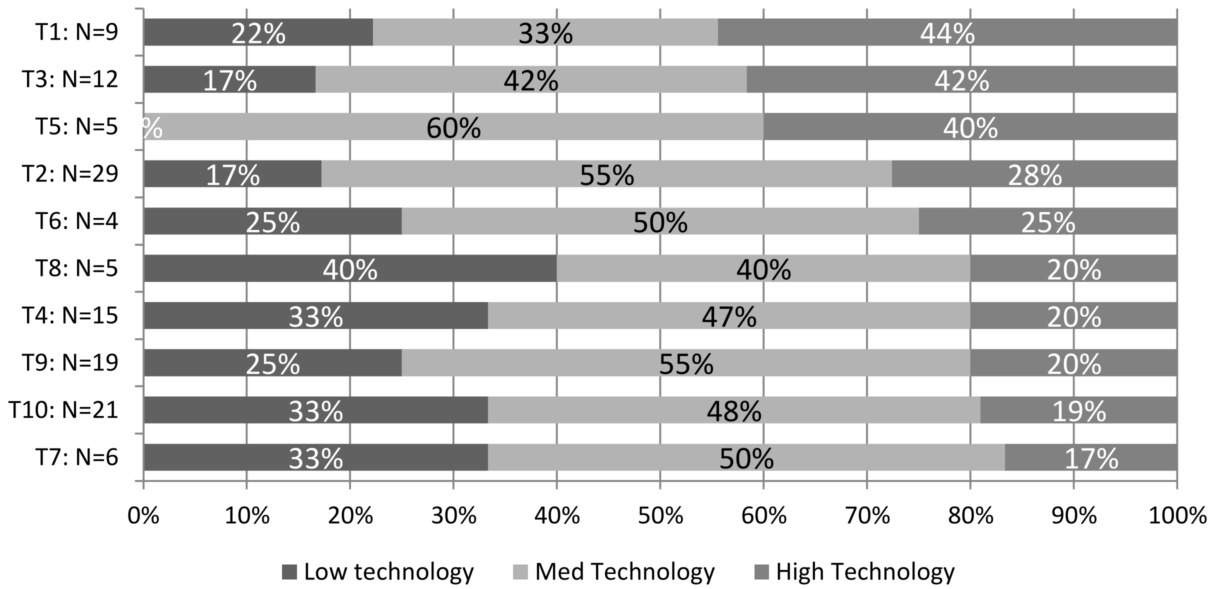
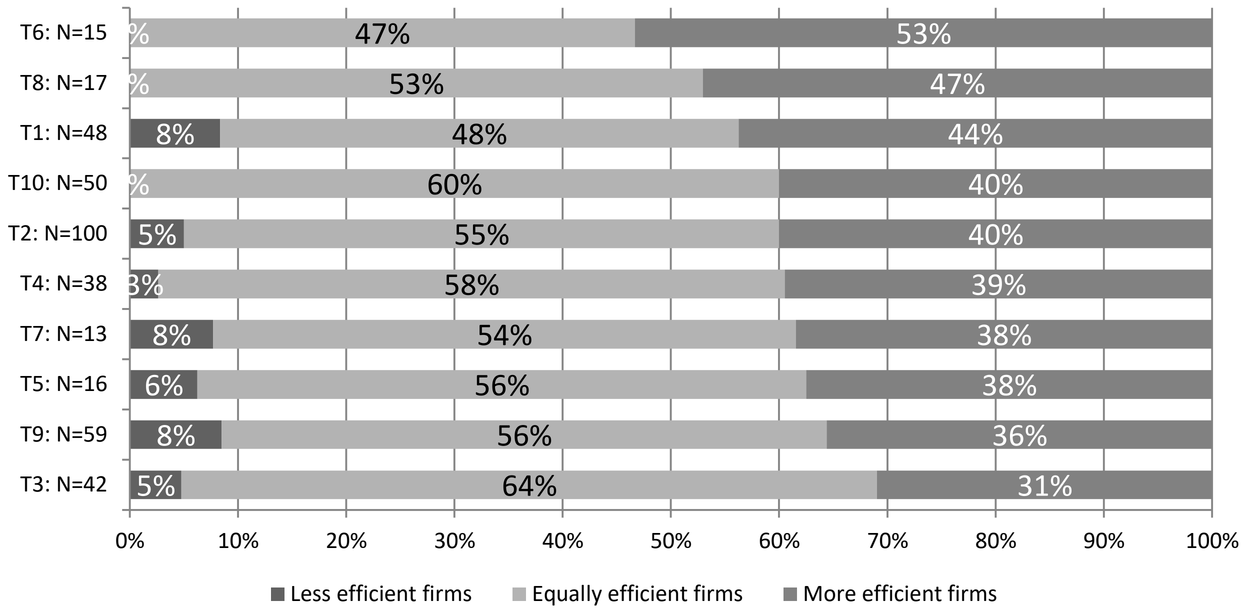


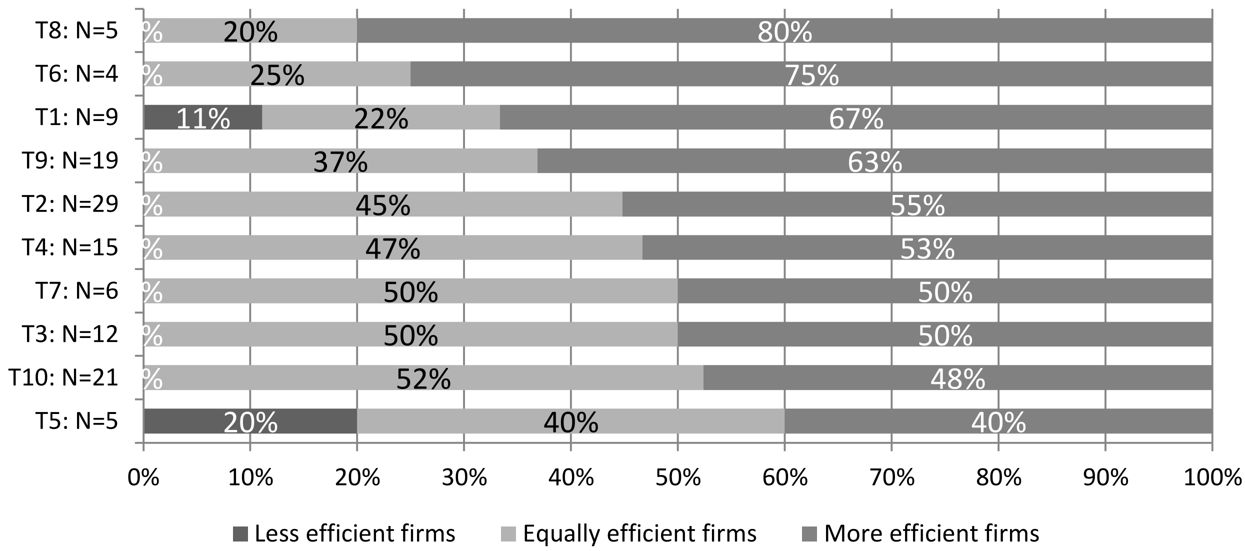
Figure 16 presents EST and MST in accordance to three groups that represent the relative energy and materials consumption efficiency in production. The technologies are ranked based on the share of use in the "More effective" group (from the highest to the lowest share). "Energy retrieval" is the technology with the highest share of "More efficient" group with a 53%. For this technology and for "Waste material for energy" and "Product recovery", no firm (0%) in the "Less efficient" group has answered to use them. "Energy retrieval" is the only technology most widely used in the "More efficient" group. All the other technologies are most widely used in "Equally efficient" group (47-64%). They represent 65% of the total number of firms. It is very obvious that EST and MST are hardly used in "Less efficient" group with the share always lower as 9%. On the other hand at least 30% of the technologies are within "More efficient" group (from 31% to 53%).

Figure 16: Implementation per cent of EST and MST by level of efficiency relative to the sector



We have also analysed the use of highly implemented technologies according three groups that represent the relative energy and materials consumption efficiency in production (Figure 17). The highly implemented technologies are ranked based on the share of use in the "More effective" group (from the highest to the lowest share). It is seen that this ranking comparing to general implementation degree has changed, but not very drastically. More importantly, we can observe that analysed EST and MST are usually highly implemented in firms that claim to be more energy efficient than other firms from their industry.

Figure 17: High implementation per cent of EST and MST by level of efficiency relative to the sector



In order to test the possible relationship between technology level (intensity) and environmental control systems implementation and the number of EST and MST implemented or the number of these technologies highly implemented, several tests of correlation has been done (Table 28 and Table 29). We conducted correlation tests, using the value of a Pearson correlation.

Table 28 presents a correlation matrix between firm technology level and use and high use of EST and MST. The results show that no significant correlation appears between technology level and EST and MST use and high use.

Table 28: Correlation matrix between firm technology level, and use and high use of EST and MST

Correlations

		Technology level	Number of energy saving technologies implemented	Number of energy saving technologies Highly implemented	Number of energy saving technologies implemented including T9 and T10	Number of energy saving technologies Highly implemented including T9 and T10
Technology level	Pearson Correlation	1	,076	-,021	,042	-,063
	Sig. (2-tailed)		,300	,781	,565	,390
	N	187	187	187	187	187
Number of energy saving technologies implemented	Pearson Correlation	,076	1	,531**	,927**	,480**
	Sig. (2-tailed)	,300		,000	,000	,000
	N	187	187	187	187	187
Number of energy saving technologies Highly implemented	Pearson Correlation	-,021	,531**	1	,509**	,928**
	Sig. (2-tailed)	,781	,000		,000	,000
	N	187	187	187	187	187
Number of energy saving technologies implemented including T9 and T10	Pearson Correlation	,042	,927**	,509**	1	,519**
	Sig. (2-tailed)	,565	,000	,000		,000
	N	187	187	187	187	187
Number of energy saving technologies Highly implemented including T9 and T10	Pearson Correlation	-,063	,480**	,928**	,519**	1
	Sig. (2-tailed)	,390	,000	,000	,000	
	N	187	187	187	187	187

**. Correlation is significant at the 0.01 level (2-tailed).

Table 29: Correlation matrix between environmental control systems use and high use of EST and MST

Correlations

		ISO 14.000	Number of energy saving technologies implemented	Number of energy saving technologies Highly implemented	Number of energy saving technologies implemented including T9 and T10	Number of energy saving technologies Highly implemented including T9 and T10
ISO 14.000	Pearson Correlation	1	,238**	,056	,292**	,087
	Sig. (2-tailed)		,001	,445	,000	,237
	N	187	187	187	187	187
Number of energy saving technologies implemented	Pearson Correlation	,238**	1	,531**	,927**	,480**
	Sig. (2-tailed)	,001		,000	,000	,000
	N	187	187	187	187	187
Number of energy saving technologies Highly implemented	Pearson Correlation	,056	,531**	1	,509**	,928**
	Sig. (2-tailed)	,445	,000		,000	,000
	N	187	187	187	187	187
Number of energy saving technologies implemented including T9 and T10	Pearson Correlation	,292**	,927**	,509**	1	,519**
	Sig. (2-tailed)	,000	,000	,000		,000
	N	187	187	187	187	187
Number of energy saving technologies Highly implemented including T9 and T10	Pearson Correlation	,087	,480**	,928**	,519**	1
	Sig. (2-tailed)	,237	,000	,000	,000	
	N	187	187	187	187	187

**. Correlation is significant at the 0.01 level (2-tailed).

We also wanted to explore the relationship between environmental control systems use, and use and high use of EST and MST. As shown in Table 29, only the simple use of EST and MST is significantly correlated with environmental control systems such as ISO 14000, but not with high use of these technologies. In these cases, both Pearson correlation coefficients are significant at 0,01 level (2-tailed), and the one considering also MST is higher than the one considering only EST. Consequently, relationship strength is slightly bigger.

6.5 Conclusions

Based on our analysis several conclusions can be drawn. General observation on the use of EST and MST is that the use of these technologies in manufacturing firms is still relatively low (from 8% to 35%). The only exception is "Speed control" technology with 56%. The first conclusion is the fact that analyzing energy efficiency groups we have observed that there is a slight decrease of the technological intensity values from "Less efficient" group to "More efficient" group . On the other hand, Low Technology group has a slightly higher average of material and energy efficiency in production than Medium-High and High technology group (3,25 vs. 3,18). Both this facts could reveal a possible negative relationship between energy efficiency in production and technological intensity of firms, at least on average. This could lead to a conclusion that firms in high technology industries focus less on energy efficiency than low technology firms.

Both MST are ranked second and third in general use. But it is interesting to see that they are mostly used in low and medium technology sector, not in high technology one. "Product recovery after product life cycle" is even most widely highly utilised technology, being mostly used in low and medium technology sector.

Only 7% of all manufacturing firms claims to be less energy efficient than firms from their sector, 30% believes they are more energy efficient than others. We calculate that MST and EST are on average used 41% in more efficient group, 55% in medium efficient group and 4% in less efficient group of firms. Based on this fact we could affirm that manufacturing firms are more efficient if they use at least one EST or MST.

In analysing EST and MST we have also focused on the manufacturing firms that showed high implementation of these technologies. We have analysed these technologies according to their use in different technology intensity sectors and based on the energy efficiency of the firms. We found out that analysed EST and MST are predominately highly implemented in a low and medium-low technology groups and less in the "Medium-High and High technology" group. This fact could again prove the fact that firms in high technology industries focus less on energy efficiency than low technology firms. We also have to remind that our results show that no significant correlation appears between technology level and the number of EST and MST use and high use.

On the other hand, analysed EST and MST are usually highly implemented in firms that claim to be more energy efficient than other firms from their industry. This leads to a potentially positive relationship between being energy and material efficient and using energy efficient technologies, especially if they are highly implemented.

Our final conclusion deals with the implementation of environmental control systems. Our results proved a positive significant relationship with energy and material efficiency, but only with use (not high use) of these technologies.

Our research has several limitations. The first is that only descriptive statistics and correlation tests were used to map the characteristics of energy efficient technologies and their adopters. To draw further conclusions in the future several advanced statistical methods will be used (e. g. linear regression for quantitative independent variables and ordinal logistic regression). We will further explore the relationship between the implementation of energy efficient technologies and environmental performance of manufacturing firms. Besides that we will also examine the use of these technologies and economic performance of manufacturing firms. Our limitation is also the narrow geographical coverage and the fact that no similar previous data exists to compare our findings. This shortcoming is already considered with the inclusion of energy efficiency questions in the new European Manufacturing Survey 2012.

Despite these shortcomings, our contribution explains the use of energy efficient technologies, the characteristics of their adopters and indicates a possible influence of these technologies on environmental performance of manufacturing firms.

Chapter 7 Analysing the Adoption of Energy-Saving Technologies in Manufacturing Firms

The present 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 sub-sample 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.

7.1 Introduction

Sustainable development, meaning meeting the needs of present generations without jeopardising the ability of the future generations to meet their own needs (European Commission, n.d.), 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 center 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 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 industry Europe-wide (European Commission, n.d.), 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 (European Commission, n.d.) 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 labor 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 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 efficiency 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 efficiency 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 energy saving technologies' 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.

7.2 Methodology

Our research is based on data from the European Manufacturing Survey (EMS), 2012 edition (ISI, 2016). 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 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 (Lerch, 2014).

However, our study will only include data from EMS Spanish subsample, formed by 170 responses. In this case, no other subsamples from additional countries have been included in order to analyse the major number of different available energy saving technologies (EST), given that the rest of the subsamples don't contain 5 of the ESTs kept in the Spanish one for the 2012 edition of the EMS. These 5 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 partner can include a limited number of particular questions of its interest.

In summary, the EMS 2012 Spanish subsample considers 9 ESTs that are:

- T0: Dry Process / Minimum lubrication. N=162
- T1: Control system for shut down 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: Bi-/Tri-generation. 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 not, and their extent of use, grouped in three categories: "low" for initial attempts, "medium", when partially utilised, and "high" for an 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.

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

Another descriptive analysis will be presented for the companies inside the sample including parameters, 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 a percent, and it corresponds to the relative amount of energy a company could save if it 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 (OECD, 2007). 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 31, only 5 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 them significant.

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 value 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, were performed. To do that, a response in the survey regarding the potential energy saving in the company was utilised. Firms answered to a question asking 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 "LowEfficient", "EqualEfficient", and "MoreEfficient", with value 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 (Tabachnick B, 1996). The obtained cut-off points for the percentile 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 a relative energy saving potential greater than 10%, and lesser than 20%. The rest of the firms with a relative energy saving potential greater than 20% are included in the "Less Efficient" group (N=16).

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 data corresponding to size of the companies in the survey don't 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 (Tabachnick B, 1996). As these data in the histogram appears left-skewed, a re-calculation, using the Logarithm of the original values, has reset the histogram into a normal distribution bell shape.

Other mapping analyses were carried on the EMS 2008 edition Spanish samples, as in the case of (Llach, J., Bikfalvi, A., Castro, 2009), and from Spanish and Slovenian Samples in (Palčič et al., 2013). Palcic et al. also mapped EST implementation in manufacturing firms following a similar methodology.

Table 30: Technical details for the Spanish subsample of the European Manufacturing Survey 2012 edition.

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 to 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

7.3 Results and findings

7.3.1 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 31.

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 (ISO Central Secretariat, 2009), 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 regarding 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. T3 percentage of use 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.

Table 31: Summary of descriptive features of the sample by technological intensity

	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 2011. N=37+66+63	97 (σ=107)	112 (σ=165)	276 (σ=820)	171
Number of employees 2009. N=36+63+61	98 (σ=113)	116 (σ=173)	279 (σ=875)	160
Turnover 2011 [M€]. N=34+59+57	44 (σ=70)	188 (σ=893)	183 (σ=747)	154
Turnover 2009 [M€]. N=31+57+55	35 (σ=58)	341 (σ=2381)	224 (σ=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%
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: Bi-/Tri-generation. N=38+66+63	24%	2%	10%	10%
T8: Waste material for energy. N=36+63+58	14%	5%	14%	10%

Table 32: Summary of descriptive features of the sample by relative energy efficiency in production.

	Less Efficient	Equally Efficient	More Efficient	Total
N	16	50	71	137
%	12%	36%	52%	100%
Number of employees 2011. N=15+49+71	83 (σ=75)	136 (σ=289)	236 (σ=755)	171
Number of employees 2009. N=14+49+68	81 (σ=73)	138 (σ=295)	243 (σ=809)	160
Turnover 2011 [M€]. N=14+44+65	19 (σ=21)	41 (σ=55)	137 (σ=519)	154
Turnover 2009 [M€]. N=13+44+63	17 (σ=16)	36 (σ=49)	73 (σ=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 shut down 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: Bi-/Tri-generation. N=16+50+69	6%	12%	9%	10%
T8: Waste material for energy. N=14+48+69	7%	10%	10%	10%

Results about the typology of the manufacturing firms in our sample, and their relative energy efficiency, are shown in Table 32.

As it is observable in Table 32, 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 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 one. 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. T4 percentage of use decreases in groups with higher relative energy efficiency.

7.3.2 ESTs use and extend of use

In Figure 18 we can observe the use of the different analysed EST. In a first place, T2 “electric motors with speed regulation” is the most implemented EST with a 69%; second comes T3 “compressed air contracting” with a 41%, and in the third place T4 “highly efficient pumps” with a 37% of the companies in the sample.

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.

Figure 18: Use of EST for all manufacturing sectors.

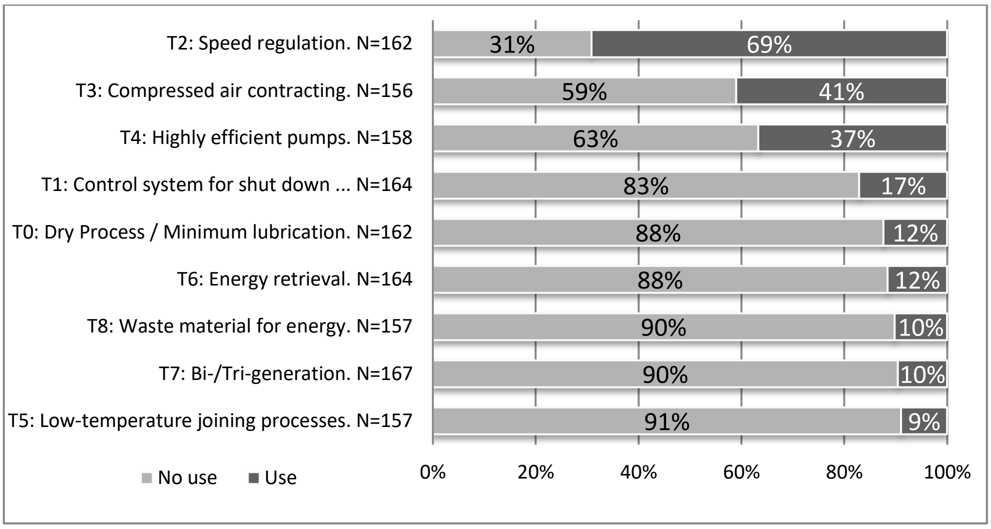
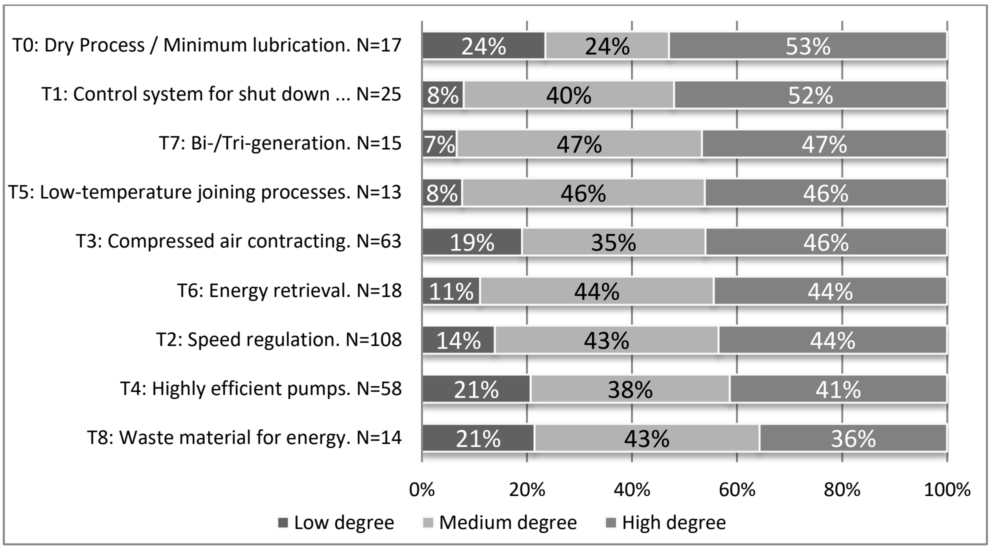


Figure 19: Degree of implementation of EST for all manufacturing sectors.



An exploration of the extent of use of each of these ESTs according to their degree of implementation, ranked from the highest percentage to the lowest one for the "High degree" group, is shown in Figure 19. 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 have an extensive use of ESTs and a perceptible reduction of the variance between percentages of high use.

This effect also supports the idea stressed above, regarding a possible wide interpretation of the concept of T2 "electric motors with speed regulation", 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 “Dry process / Minimum lubrication” is the first EST in the ranking of high implementation with 53% of the firms that use it, followed by T1 “Control system for shut down of machines in off-peak periods” with 52%, and T7 “Bi/Tri-generation” with 47%.

Only 36% of the companies that use T8 “Use of waste material for energy generation” declared an extensive use of it, representing the lowest percentage for the “High degree” group.

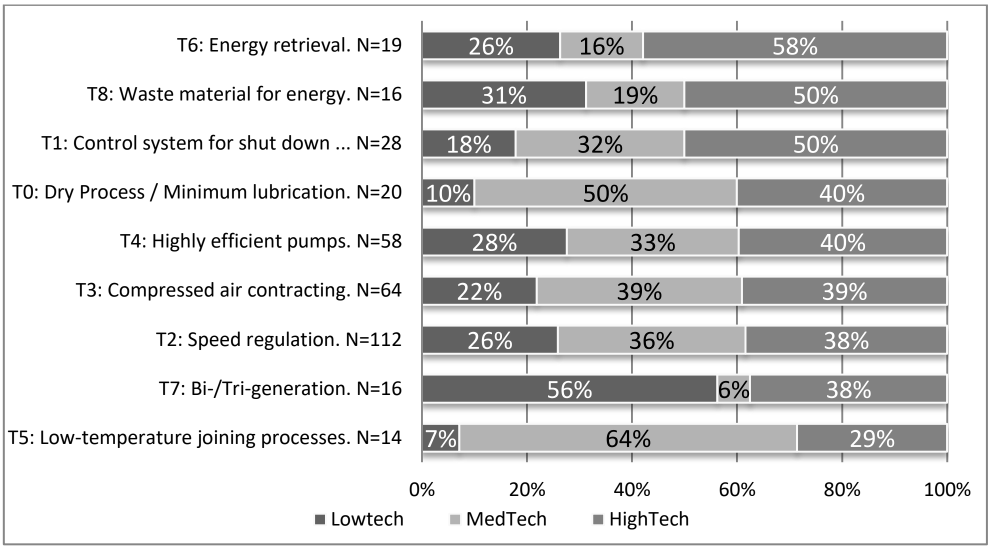
7.3.3 ESTs implementation by firms’ technology level

A classification of the companies that have implemented ESTs by technological sector is presented in Figure 20. The ESTs are ranked in the graphic according to percentages in the “High Tech” group.

Companies using T5 “Low-temperature joining processes” are mainly (57.9%) firms within the “High Tech” group. Moreover, 50% of the companies that have implemented T7 “Bi/tri-generation” and T1 ”Control system for shut down of machines in off-peak period”, are the high technological ones.

T6 “Energy retrieval” is implemented in a 56.3% by companies in the “Low Tech” group. Only 7.1% and 10% of firms using T4 “Highly efficient pumps” and T0 “Dry process/minimum lubrication”, respectively, belong to the “Low Tech” group, while 64% and 50% of the companies in the “Med Tech” group, respectively, implemented these particular ESTs.

Figure 20: Implementation percentage of EST by technological sector.



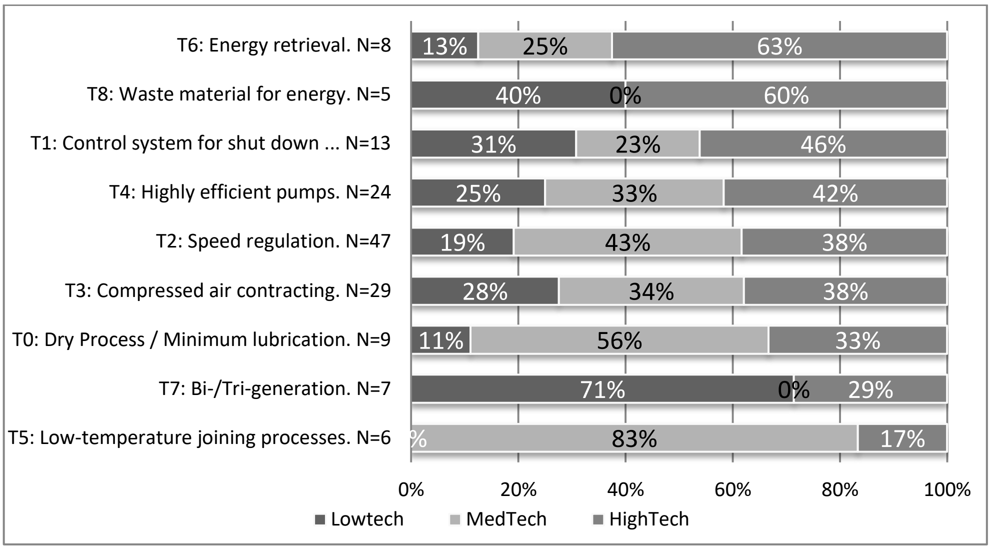
When the same classification is made, considering only an intensive use of the ESTs by technological levels in Figure 21, and also ordered according to the percentages in the “High Tech” group, a new ranking is established.

A 63% and a 60% of companies with an intensive use of T6 “Energy retrieval” and T8 “Use of waste materials for energy generation”, respectively, are firms within the “High Tech” group. On the other hand, only 17% within this group highly implemented T5 “Low-temperature joining processes”.

Otherwise, 71% of the companies that have an intensive use of T7 "Bi/tri-generation" are the low technological ones. However, only 11% of firms using T0 "Dry process/minimum lubrication" belong to the "Low Tech" group, and there isn't any company in this group with a high implementation of T5 "Low-temperature joining processes".

T5 "Low-temperature joining processes" is implemented by 83% companies in the "Med Tech" group; 56% of the intensive users of T0 "Dry process/minimum lubrication" also belong to this group.

Figure 21: High implementation percentage of EST by technological sector.



7.3.4 ESTs implementation by firms' relative energy efficiency group

Results in Figure 22 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.

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

Figure 22: Implementation percentage of EST by level of efficiency relative to the energy saving potential.

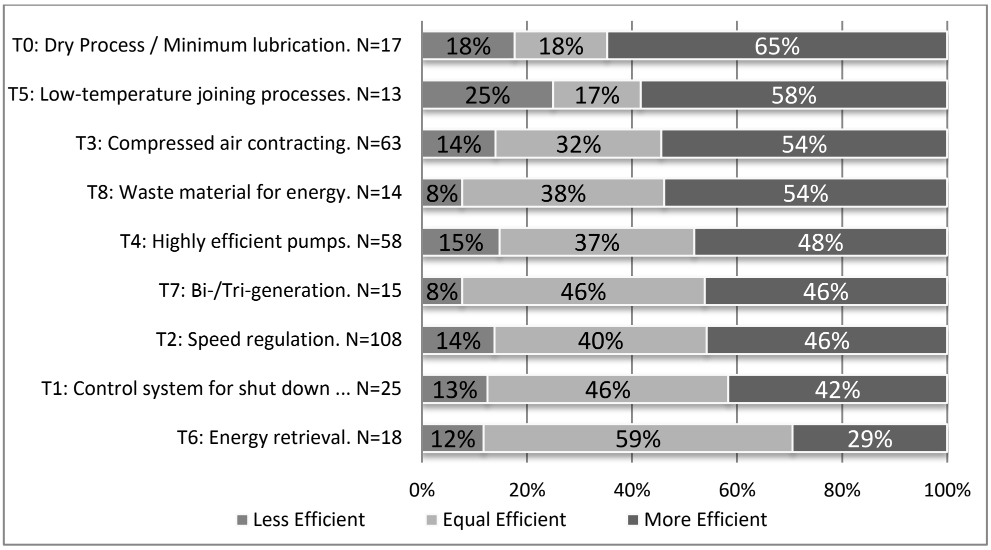
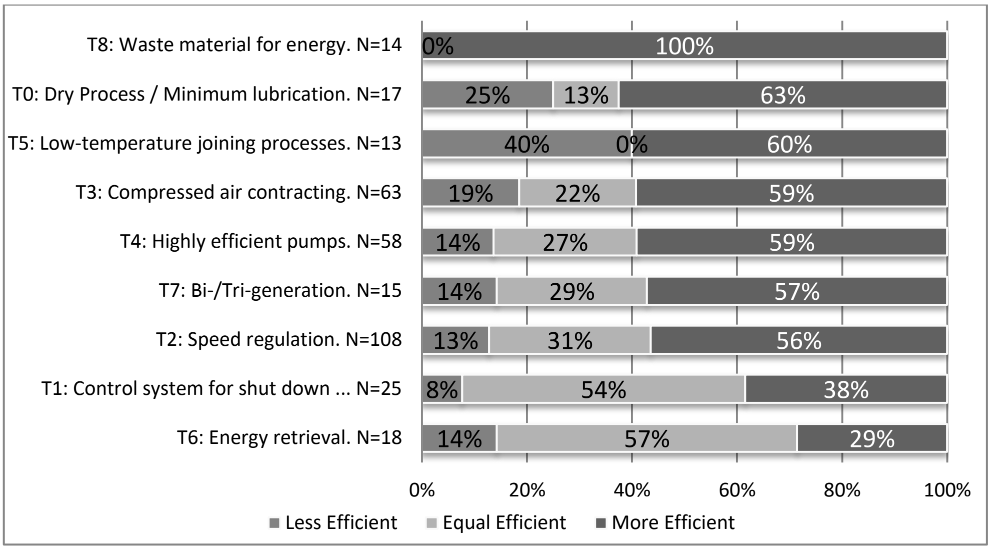


Figure 23: High implementation percentage of EST by level of efficiency relative to the energy saving potential.



Results in Figure 23 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 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 studied ESTs, the percentage of companies belonging to the "More Efficient" group that have highly implemented them, represent more than the 50% of the firms. Only companies in this group have highly implemented T8 "Use of waste materials for energy generation".

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

However, T6 “Energy retrieval” and T1 ”Control system for shut down of machines in off-peak period” 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, a correlation test was presented in Table 33.

We can find different author criteria for the strength determination of relationships from the value of Pearson correlation coefficient (r); however, Cohen (Cohen, 1977) suggest the following guidelines that will be used in the present study: small strength |r|=0.10 to 0.29, medium strength for |r|=0.30 to 0.49, and large strength for |r|=0.50 to 1.

The quantity of EST implemented in a company results in having a positive relationship with the firm size, in turnover as well as in number of employees, and with ISO50001:2001 implementation. This relationship is more significant (at 0.01 level, 2-tailed) in the case of companies’ 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.

Firms’ size, both in terms of turnover, and in terms of number of employees, are also inter-related 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 in 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 use and high use of ESTs.

In a previous study (M Pons, Bikfalvi, Llach, & Palcic, 2013) it was determined a relationship 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 34. In this table, a crosstab is shown between the number of EST 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.

However, despite it, 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 frequencies of 5 or more in the 80% of the cases is not respected.

Table 33: Correlation matrix between environmental management systems use, export intensity, R&D expenditure, potential energy saving, and the use and high use of EST.

Correlations

		Number of EST implemented	Number of EST Highly implemented	Technology Level	Firm Size log10(Turnover)	Firm Size log10(Employees)	ISO14031 implemented	ISO50001 implemented	High Export Intensity (>50% of sales)	R&D expenditure	Potential Energy Saving
Number of EST implemented	Pearson Correlation	1	,713**	,013	,210**	,157*	,131	,178*	,073	,027	,098
	Sig. (2-tailed)		,000	,864	,010	,044	,105	,025	,375	,728	,253
	N	169	169	169	150	166	155	158	152	167	137
Number of EST Highly implemented	Pearson Correlation		1	,001	,208*	0,14	,049	0,05	,027	,099	-,001
	Sig. (2-tailed)			,985	,011	,070	,541	,530	,743	,205	,987
	N		169	169	150	166	155	158	152	167	137
Technology Level	Pearson Correlation			1	0,12	,160*	,069	-,027	-,070	,015	,019
	Sig. (2-tailed)				,151	,039	,396	,740	,394	,851	,825
	N			169	150	166	155	158	152	167	137
Firm Size log10(Turnover)	Pearson Correlation				1	,632**	,344**	0,14	,005	,113	-,171
	Sig. (2-tailed)					,000	,000	,094	,958	,170	,059
	N				150	149	139	142	138	149	123
Firm Size log10(Employees)	Pearson Correlation					1	,378**	0,05	-,047	,121	-,132
	Sig. (2-tailed)						,000	,540	,568	,124	,127
	N					166	153	155	150	164	135
ISO14031 implemented	Pearson Correlation						1,000	,180*	-,061	,100	-,001
	Sig. (2-tailed)							,027	,474	,215	,994
	N						155	151	142	155	127
ISO50001 implemented	Pearson Correlation							1	-,024	-,136	-,077
	Sig. (2-tailed)								,780	,089	,387
	N							158	143	158	128
High Export Intensity (>50% of sales)	Pearson Correlation								1	,084	-,160
	Sig. (2-tailed)									,307	,074
	N								152	150	126
R&D expenditure	Pearson Correlation									1	,035
	Sig. (2-tailed)										,684
	N									167	135
Potential Energy Saving	Pearson Correlation										1
	Sig. (2-tailed)										
	N										137

**. Correlation is significant at the 0,01 level (2-tailed).

*. Correlation is significant at the 0,05 level (2-tailed).

Table 34: Chi-square test crosstab between the number of highly used ESTs and the relative energy efficiency group.

Crosstab

			Relative Potential Energy Saving (Scaled in three groups) 1 Les Efficient	2 Equal Efficient	3 More Efficient	Total
SumHighUseEST	0	Count	7	29	33	69
		Expected Count	8,1	25,2	35,8	69,0
		% within SumHighUseEST	10,1%	42,0%	47,8%	100,0%
		% within PotentialSavingScale	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 SumHighT0	6,5%	45,2%	48,4%	100,0%
		% within PotentialSavingScale	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 SumHighUseEST	23,8%	9,5%	66,7%	100,0%
		% within PotentialSavingScale	31,3%	4,0%	19,7%	15,3%
		% 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 SumHighUseEST	0,0%	22,2%	77,8%	100,0%
		% within PotentialSavingScale	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	,4	1,1	1,6	3,0
		% within SumHighUseEST	66,7%	33,3%	0,0%	100,0%
		% within PotentialSavingScale	12,5%	2,0%	0,0%	2,2%
		% of Total	1,5%	,7%	0,0%	2,2%
	5	Count	0	2	2	4
		Expected Count	,5	1,5	2,1	4,0
		% within SumHighUseEST	0,0%	50,0%	50,0%	100,0%
		% within PotentialSavingScale	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 SumHighUseEST	11,7%	36,5%	51,8%	100,0%
		% within PotentialSavingScale	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. (2-sided)
Pearson Chi-Square	22,812[a]	10	,011
Likelihood Ratio	22,850	10	,011
Linear-by-Linear Association	,010	1	,921
N of Valid Cases	137		

a. 11 cells (61,1%) have expected count less than 5. The minimum expected count is ,35.

7.4 Conclusion

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 EST 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 own-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, 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 the degree of implantation. Dry process / minimum lubrication (T0), and control system for shut down of machines in off-peak periods (T1), are the technologies with the highest degree of implementation, both over 50%.

Secondly, it has been observed that the more relative energy efficient companies are, in average they characterise as relatively bigger, both in terms of turnover and in 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, in 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 on environmental management systems implemented.

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

Fourthly, 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 in firms that declare being more efficient than firms of the sector. Five EST are mostly implemented in less efficient group and four in the equally efficient group.

Fifthly, 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 studied ESTs, 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, a 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 the higher number of technologies. Practical and academic implications of having detailed, single, and high number of ESTs, converts 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 recognise to have, in average, a 14% of relative energy saving potential. It has been also 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 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 possible relationships between energy efficiency and the ESTs implementation, using more powerful statistical tools.

Chapter 8 Analysing innovators according to the environmental impact of new products

Blended approaches of sustainability and innovation orient the attention to the field of green product innovation, an already recognized contributor towards sustainable development. Being of great societal global interest and priority, the body of knowledge around the concept has rapidly grown over the last few years, but still lacks maturity and fine-graining in certain aspects. Using the 2015 European Manufacturing Survey data of the Spanish sub-sample we aim to characterize new product innovations as compared to green new product innovators. The uniqueness of the analysis consists in i) the detailed typologies of green product impact including reduction of health risks, extended product lifetime, reduction of energy consumption, reduction of environmental pollution (in oil, water, air, or noise), easiness to maintain or to retrofit, improved recycling, redemption or disposal properties, ii) the newness of the data, and iii) the comprehensive approach of the methodology used combining innovation, production and sustainability, simultaneous conceptual pillars characteristics to manufacturers' complex reality. Our results show green new product innovators declare higher financial performance in terms of Return On Sales, have lower R&D investments and higher exportation intensity. They produce more customized products and have a workforce with higher qualification than 'non-green product innovators'. This study provides practical implications for companies, policy makers and scholars.

8.1 Introduction

According to the Sustainable Development Goals (UN, 2016) a sustainable consumption and production helps to achieve overall development plans, reduces future economic, environmental and social costs, strengthens economic competitiveness and reduces poverty. One possible action in this direction is by means of innovation, an important and recognised contributor towards this goal. While "greenness" makes sense for product and process innovation, the more visible facet is still product innovation with additional adjectives such as sustainable, environmental, eco, green, environmental-friendly or composite wording used as "product innovation with environmental implications". All in all, green products are defined as products that 'use less resources, have lower impacts and risks to the environment and prevent waste generation already at the conception stage' (Commission of the European Communities, 2001: 3). Consequently green product innovation is the design, production and implementation of new or significantly improved products that have a positive impact on the environment.

Following this definition along the present manuscript it becomes evident that most important stakeholders in terms of policy makers, companies and consumers have a crucial role. While policy makers have to build and promote local, regional, national and supra-national environmental regulations and schemes to promote and incentivize green production and the conservation of the environment, companies have the responsibility to minimize the environmental impact of production, both as an outcome – in terms of products- and as a process. A completely successful new green product, however, has to achieve commercial success which further means that at the end of the supply chain a consumer -being business, administration or end-user- is sensitive to green new products and behaves in a (more) environmentally responsible manner opting for these compared to other available alternatives.

Even their undoubted societal impact and major contribution to a better present and future human life, research maturity in the field of green product innovation is much lower than innovation, in general, and product innovation, in particular, being the latter one of the most researched sub-fields of innovation according to (Keupp et al., 2012) conducting a systematic literature review by analyzing 342 papers in the field of strategic management of innovation. More recently, a review specifically focusing on green product innovation (GPI) published by Dangelico (2016) makes an important contribution by analyzing 63 studies complementing already existing studies, but just partially covering this complex thematic (Baumann et al., 2002), Pereira & Vence (2012), Adams et al. (2012). The review outlines relevant antecedents, outcomes and success factors of GPI development and formulates relevant implications for companies, policy makers and scholars alike. According to the same paper, the present state-of-the-art in the field of green new product needs further extension in terms of fine-graining performance aspects distinguishing between environmental performance and market/financial performance of GPI, broadening research on GPI to other countries while empirical evidence comes predominantly from Germany, UK, the Netherlands, Taiwan and the US. It is also stated that "with regard to capabilities in common with conventional new product development, it would be interesting for future research to investigate whether there is a difference between GPI development and conventional new product development in terms of relative importance of these capabilities and in terms of their extent of use" (Dangelico 2016).

In the current contribution we answer several of the issues raised. Situated at the intersection of two knowledge fields, namely innovation and CSR-oriented practices with special focus on the environmental ingredients of the last mentioned, the objective of this work is to characterize product innovators. In particular the focus is on manufacturing companies which affirm that product innovations implemented in the last three years are also aimed for generating an improvement of the environmental impact by either using or disposing of them. More concretely, the aim is to contribute to the identification and understanding of the characteristics of the manufacturing firms that innovate through the market introduction of sustainable new products by answering the research question "In what aspects -including structural, operational and performance- green new product innovators differ from conventional product innovators?". The data used for the analysis corresponds to Spain, a country with low presence of scientific publications in the panorama of green product innovation.

The paper is organised as follows. After the Introduction (section 1) we proceed by reviewing the academic literature in turn of the topic new product innovation with environmental implications focusing the attention on terminology, possible determinants and expected outcomes constituting Section 2.

Following we proceed with describing the applied methodology (Section 3) and data available representing the empirical evidence used to generate our results presented in Section 4. Finally, the paper concludes in Section 5.

8.2 Literature Review

8.2.1 Delimitation and definition of green product innovation.

The literature offers a quite mature and generally accepted definition of product innovation as the one described in the Oslo Manual (OECD & Eurostat, 2005) namely a product innovation is the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics.

The situation is slightly different when regarding new products with environmental implications. The difference consists in the variety of terms used as well as the conceptual boundaries of the phenomena. Based on both practice and academic work Dangelico (2016b); Gerstlberger et al. (2014) it can be affirmed that synonyms and combinations of eco, eco-friendly, ecological, green, sustainable, environmental and environmental-friendly with innovation, product innovation, new product dominate the terminological landscape.

Authors providing definitions formulate as a piece of example in the following manner. For example, Jacquelyn A Ottman et al. (2006) argue that the terms “green product” and “environmental product” are used commonly to describe those that strive to protect or enhance the natural environment by conserving energy and/or resources and reducing or eliminating use of toxic agents, pollution, and waste.

A different conceptualization appears in more practical terms as the one described by Pujari (2006) which refers to the action to develop and market new products that address environmental issues … most of the sustainable innovation in NPD relates to incremental or evolutionary innovation (e.g. remanufactured products, recycled content, organic cotton-based clothing, water-based paints, to name a few) that comes to replace environmentally harmful products at the marketplace. This definition adds to the previous the process facet as well as making explicit reference to market acceptation.

As requested in Gerstlberger et al. (2014) product innovations with environmental implications should fulfil two goals simultaneously, namely improvement of environmental impact and obtaining commercial performance. One issue remaining undefined is the distinction between traditional, ordinary or conventional new products and the environmental or green products. With this aim in mind and considering possible impact scenarios for the purpose of the present paper we define green product innovation as the design, production and implementation of new or significantly improved products that have a positive impact on the environment when in use or when disposing of them. Our definition regards both the process and the outcome lens covering the funnel from design to implementation as well as internal and external impact aspects.

As obvious from the previous section it is a mission impossible to discuss about green new product management without relating the discussion to other relevant aspects as implications – from the achievement approach- and factors influencing their occurrence – from a determinants approach-. Another systematic literature review available from Thomé et al. (2016) makes a radical contribution in the field by highlighting the importance of the process perspective and the holistic nature in the form of cluster of related themes and their evolution. According to the authors and as a conclusion holistic approaches to model design should prevail, as the ones advocated by the 6Rs (redesigning, reusing, remanufacturing, recovering, recycling, and reducing) and the cradle-to-cradle products with multiple life cycles (Thomé et al., 2016).

Moving the discussion forward the literature focusing on the determinants of GPI is relevant for our purpose. While it is obvious that past research in the field of determinants of innovation, or more specifically NP determinants apply (for existing reviews see Edison et al. (2013); Keupp et al. (2012)), the challenge is double: i) to identify if and up to what degree previously mentioned determinants of product innovation apply to green new product manufacturers, and ii) in the case of specific drivers to measure their effect. A grouping of factors is presented by Dangelico (2016b) who cluster determinant into external and internal ones as well as according to their nature distinguishing between technological capabilities, internal integrative capabilities, internal integrative capabilities and marketing capabilities.

8.3 Methodology

Empirical evidence for the present study comes from the 2015 Spanish sub-sample of the European Manufacturing Survey (EMS). EMS is a cross-country survey that was created and still coordinated by the Fraunhofer Institute for Systems and Innovation Research (ISI, 2016). Considered as the largest European survey in manufacturing activities to date, it complements existing innovation surveys -CIS, for example- (CIS, 2012) including in its content lastly trends in the manufacturing environment.

In the last edition, EMS included several questions related to technological buzzwords like Industry 4.0., business model, servitization or digital factory, among others. Further elaborating in this direction, environmental aspects (energy and material saving technologies and practices, energy consumption, their sources and use) have been considered and updated since 2009 and on-going.

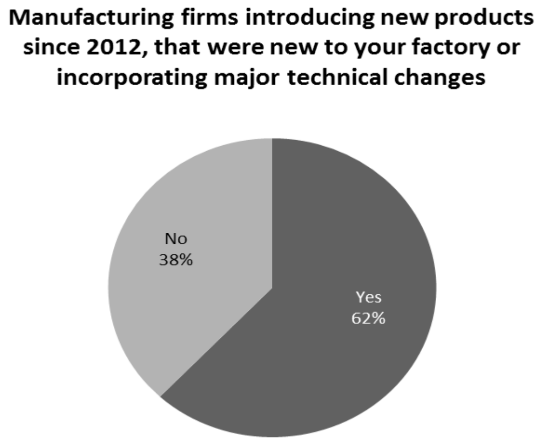
For the purpose of the present paper, the sample consisted of the Spanish firms and was further restricted to manufacturing companies having at least 20 employees. In total, our dataset is composed by 101 firms' responses. Technical details of this EMS 2015 subsample are shown in Table 35.

We consider as product innovators those firms answering 'yes' to the following question in the survey: 'Has your factory introduced products since 2012, that were new to your factory or incorporated major technical changes? (e.g. application of new materials, modifications in product function, modifications in principles of operation, etc.)'. Results obtained are presented in Figure 24.

Table 35: Technical details for the Spanish subsample of the European Manufacturing Survey 2015 edition.

Universe:	Spanish manufacturing firms with at least 20 employees CNAE 2009; codes from 10 to 33. 13.593 companies.
Target population:	4017 firms
Sample:	101 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 to September 2015
Reference period	2012-2014; 2014
Fieldwork:	OGEDP department. University of Girona – Girona (Spain)
Data base recording and creation:	DAP GmbH – Passau (Germany)
Sample distribution:	By size and sector of activity
By ‘Green product innovators’:	‘Conventional product innovators’: 25; ‘Green product innovators’: 56

Figure 24: Product innovators (%) in the sample (N=101)



From these product innovators, we can differentiate those who produce new products improving their environmental impact, answering ‘yes’ to the question: ‘did these new or improved products lead also to improvement of environmental impact using or disposing these new products?’

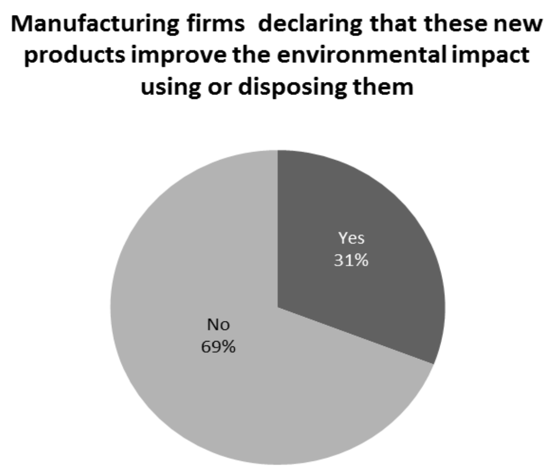
Given that this differentiation will determine the present research, in order to name both subsamples, we name 'green product innovators' to this last group of firms as opposed to conventional product innovators that also innovate in products regardless their product improvements does not lead to an improvement of their environmental impact during their use or disposal, referred in the present work as 'non-green product innovators'.

It has to be taken into account that this study considers the improvement of the environmental impact of new products when they are used or disposed, but not necessarily when they are produced. It is important to clarify this point because the terms 'green' or 'non-green' we use to classify companies in our sample just means these firms consider or not the future impact over the environment of their products when they design or plan to produce them.

However, regardless the greenness of companies' manufacturing processes, they can be considered somehow 'green' when they place product innovations that contribute to improve the sustainability of their use or disposal.

In this specific case, 81 out of 101 companies answered the question, 56 of which are included in the subsample of 'non-green product innovators' and 25 in the 'green products innovators' one as shown in Figure 25.

Figure 25: Non-green and green product innovators (%) (N=81)



Surprisingly, the population for this question is N=81 while only 62 companies have declared they innovate in product when answering the previous query. However, in order to keep the richness of our sample and considering the question in the survey clearly specify that was referred to new or improved products, it will be considered all these 81 firms' answers in this study.

For the first time, EMS 2015 data allows to detect aspects of new products improving their environmental impact when in use, from the green 'product innovators' group. Six aspects are included: (i) reduction of health risks, (ii) extended product lifetime, (iii) reduction of energy consumption, (iv) reduction of environmental pollution (in oil, water, air, or noise), (v) easiness to maintain or to retrofit and (vi) improved recycling, redemption or disposal properties. Respondents can mark the kind of environmental improvement choosing several options from these possibilities.

A descriptive analysis of these environmental improvements in product innovations will show us the degree of their application by 'green product innovators'.

From binary variables (yes/no) representing the main origins of impulses/ideas for product innovation, respondents are asked to mark a maximum of six options from these eight possibilities: (i) R&D engineering, (ii) production, (iii) customer service, (iv) CEO/management, (v) customer or user, (vi) supplier, (vii) research institutions or universities, (viii) business or organisation consultancy.

Crosstab analysis shows the percentages of companies, for each declared origin of the impulses/ideas for product innovation, incorporating a specific environmental improvement in their product innovations. The reverse table is also presented.

Since it is a purpose of this study to identify and understand structural and operational characteristics of the manufacturing firms that innovate with more sustainable new products, several sets (7) of variables have been chosen and grouped by their typology regarding the following subjects shown in Table 36.

Table 36: Resume of analyzed variables sets by typology

Group	Analysed Variables
General data	Size: – Turnover [M€] – Ln of Turnover (normalized turnover) [Ln(M€)]* – Number of employees (excl. temporary agency workers) Relative Costs: – R&D cost relative to incomes 2014 [%] – Total energy costs relative to Turnover 2014 [%] – Payroll cost relative to Turnover 2014 [%] Export index – Products sold abroad [%]
Company's economic performance	– Declared ROS <0% [yes/no] – Declared ROS 0-2% [yes/no] – Declared ROS >2-5% [yes/no] – Declared ROS >5-10% [yes/no] – Declared ROS >10% [yes/no] – Ranked discrete variable from declared return on sales (ROS) 2014 values from 1 for ROS<0%, 2 for ROS 0-2%, 3 for ROS >2-5%, 4 for ROS >5-10% and 5 for ROS >10% [discrete values 1-5]*
Main product family	Product development (only one option) – According to customers' specification [yes/no] – As a standardized basic program into which customer specific options are implemented [yes/no] – For a standard program from which the customer can select [yes/no] – Does not exist in this factory [yes/no] – Ranked discrete variable from Product Development values from 1 for 'Does not exist in this factory' to 4 for 'According to customers' specification' [discrete values 1-4]* Manufacturing (only one option) – Upon receipt of customer's order, i.e. made-to-order [yes/no] – Final assembly of the product is carried out upon receipt of customer's order, i.e. assembly-to-order [yes/no] – To stock [yes/no] – Does not exist in this factory [yes/no] – Ranked discrete variable from Manufacturing values from 1 for 'Does not exist in this factory' to 4 for 'Upon receipt of customer's order, i.e. made-to-order' [discrete values 1-4]* Product complexity (only one option) – Simple products [yes/no] – Products with medium complexity [yes/no] – Complex products [yes/no] – Ranked discrete variable from Product Complexity values from 1 for 'Simple products' to 3 for 'Complex products' [discrete values 1-3]*

Firm competitive factors	– Product price [Rank 1-6 where 1 is the most important] – Product quality [Rank 1-6 where 1 is the most important] – Innovative products [Rank 1-6 where 1 is the most important] – Customization to customers´ demands [Rank 1-6 where 1 is the most important] – Adherence to delivery times/short delivery times[Rank 1-6 where 1 is the most important] – Service [Rank 1-6 where 1 is the most important]
Employees	Qualification level – Graduate degree, graduates [%] – Technicians, skilled workers [%] – Employees with commercial or technical/industrial training [%] – Semiskilled and unskilled workers [%] – Technical/industrial or commercial apprentices [%] – Continuous variable from personnel's qualification level giving the pondered average of these five ranked possibilities for a company, values from 1 for less global qualification to 5 for more global qualification [continuous values 1-5]* Distribution over different areas – Research and Development [%] – Configuration, design [%] – Manufacturing and assembly [%] – Customer service [%] – Other (administration, sales, purchase, maintenance, production planning, etc.) [%]
Product Innovation drivers	Origin of internal impulses/ideas – R&D / engineering [yes/no] – Production [yes/no] – Customer service [yes/no] – CEO / management [yes/no] – Number of checked variables of internal impulses/ideas [1-4]* Origin of external impulses/ideas – Customer or user [yes/no] – Supplier [yes/no] – Research institutions, universities [yes/no] – Business or organisation consultancy [yes/no] – Number of checked variables of external impulses/ideas [1-4]*
Innovation contribution to turnover	– Share of turnover of products that are new to the factory in 2014 [%] – Share of turnover of products that are new to the market in 2014 [%] – Share of turnover of products the company have been offering their customers for more than 10 years in 2014 [%]

(*) Own elaborated or calculated variable from EMS variables

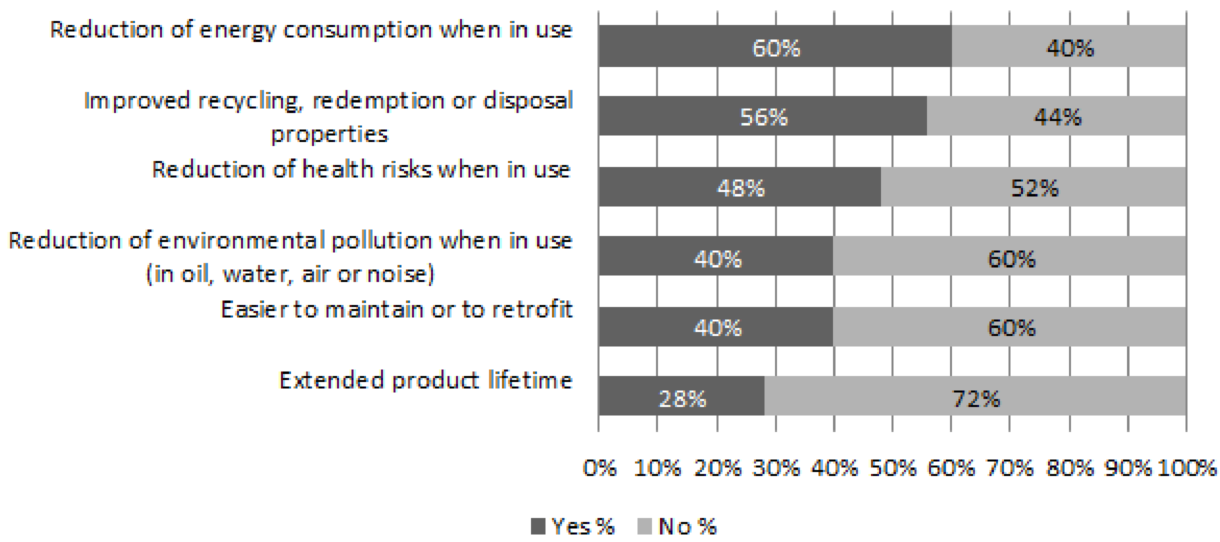
Descriptive and frequency analysis have been performed to characterize the innovative firms of this sample, in terms of more sustainable new products, by parameters shown in Table 36.
For all these analysis, both subsamples of 'non-green product innovators' and 'green product innovators' have been compared to explore differences between them. The objective is to find specific characteristics of 'green product innovators' that could be useful to better know and potentiate them.
Barr graphics help to illustrate these differences when they appear. For the case of continuous or discrete ordinal variables, a normal distribution have been calculated from their means (μ) and standard deviations (σ), and presented as graphs. In the case of descriptive analysis, this kind of

graphs allow to compare means for each subsample and moreover the dispersion of their reported values in a visual way.
To consider these normal distribution graphics with a symmetrical bell shape we have to assume the distribution of scores on these variables is 'normal'. This point has been assessed obtaining skewness and kurtosis values between -2 and +2 (George & Mallery, 2010), and from the tests of normality given by the statistics software.

8.4 Results and findings

Before comparing 'green product innovators' with those 'non-green ones', the nature of these improved environmental impacts can be shown in Figure 26.

Figure 26: Companies (%) declaring specific improved environmental impact of their new products when using or disposing them.



We can observe the most frequent improved environmental impact is, first of all, 'reduction of energy consumption when in use' declared by a 60% of 'green product innovators' and, secondly, 'improved recycling, redemption or disposal properties' with a 56% of these companies. On the other hand, 'extended product lifetime' is the less incorporated product attribute with only a 28% of the 'green product innovators' declaring its implementation in new products. Other attributes are clearly more implemented with results from 40% to 60% in the case of the most frequent one.

Table 37 presents the descriptive analysis of the 'green product innovators' in terms of (i) company dimension (as turnover or number of employees), (ii) significant costs as energy, payroll or R&D costs, and (iii) exportation (as percentage of products produced by the company sold abroad).

Table 37: Resume of green product innovators' descriptive analysis over general parameters classified by achieved environmental improvements from their new products.

		Reduction of health risks	Extended product lifetime	Reduction of energy consumption	Reduction of envi-ronmental pollution (in oil, water, air, or noise)	Easiness to maintain or to retrofit	Improved recycling, redemption or dis-posal properties
Annual turnover 2014 [M€]	N	12	15	9	8	9	16
	Min.	1,5	1,5	1,5	2,5	1,5	1,5
	Max.	500	7110	500	42	500	500
	μ	85,5	536,3	80,8	21,1	116,2	47,6
	σ	139,8	1822,8	160,1	15,2	164,9	121,5
Ln (Annual turnover 2014 [M€])	N	12,0	15,0	9,0	8,0	9,0	16,0
	Min.	0,4	0,4	0,4	0,9	0,4	0,4
	Max.	6,2	8,9	6,2	3,7	6,2	6,2
	μ	3,4	3,6	3,0	2,7	3,6	2,7
	σ	1,6	2,1	1,8	1,1	1,9	1,4
Number of employees 2014	N	12	15	9	8	9	16
	Min.	24	24	24	29	24	24
	Max.	1000	361	361	260	361	329
	μ	240,3	132,5	172,2	130,1	164,7	104,3
	σ	278,8	125,2	142,0	87,4	141,2	104,5
Total energy costs as % of turnover 2014	N	5	9	6	4	7	8
	Min.	0,6	0,3	0,1	0,3	0,1	0,1
	Max.	10	25	10	25	10	10
	μ	3,7	5,1	3,4	7,3	3,0	2,6
	σ	3,9	8,1	3,6	11,8	3,5	3,4
Payroll costs as % of turnover 2014	N	7	10	7	6	7	9
	Min.	2	2	18	14	2	2
	Max.	43	35	43	43	35	43
	μ	24,4	21,9	28,7	25,7	22,9	25,1
	σ	13,3	9,5	8,6	10,2	10,9	11,9
Percent of R&D costs relative to incomes 2014	N	6	6	4	6	3	8
	Min.	2	1	1	1	1	1
	Max.	5	5	5	5	2	5
	μ	3,3	2,0	2,5	2,3	1,7	2,8
	σ	1,4	1,5	1,7	1,5	0,6	1,5
% Products sold abroad	N	12	17	10	7	11	16
	Min.	15	0	15	20	0	15
	Max.	90	89	89	80	89	85
	μ	65,3	52,3	54,9	52,1	47,2	53,0
	σ	25,0	25,5	26,1	19,5	32,1	22,3

It can be observed that companies innovating products reducing their health risks are bigger in number of employees than the rest with a mean of 240.3 employees. They are also the ones presenting the biggest exportation rate with a mean of 65.3% of their manufactured products sold abroad and the biggest percentage of R&D costs relative to incomes with a mean of 3.3%.

Companies extending product lifetime are, in average, the biggest companies in turnover in absolute units of M€ but also applying logarithms to the values in order to compensate dispersion and extreme cases.

Results do not indicate any special influence or relationship between payroll costs and any kind of improved environmental impact.

Factories producing new products that reduce environmental pollution, in average, are the smallest ones in terms of annual turnover and logarithm annual turnover. They are also the ones with higher total energy costs as percentage of turnover with a mean of 7.3%.

Firms that introduce product easiness to maintain or retrofit are, in average, the ones with lowest costs of R&D relative to incomes with a mean of 1.7% and the lowest exportation rate as percentage of products sold abroad with a mean of 47.2%. They are also big considering logarithm of annual turnover.

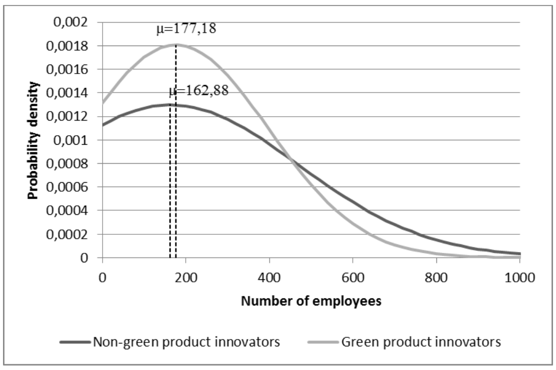
Improved recycling, redemption or disposal properties in new products are incorporated by the smallest companies in number of employees with a mean of 104.3 workers but also in normalized annual turnover. They are the ones with the lower total energy cost as percentage of turnover with a mean of 2.6%.

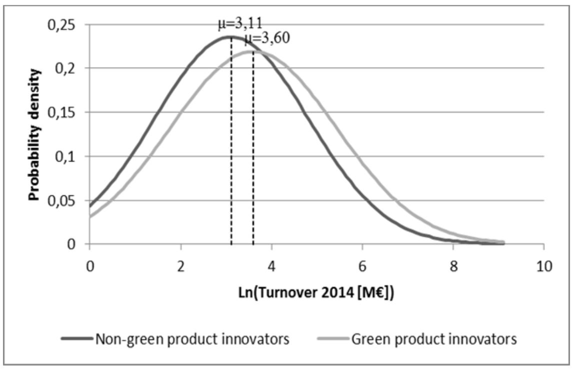
8.4.1 General data

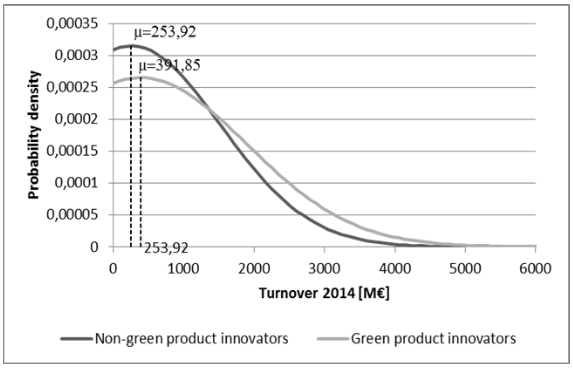
8.4.1.1 Size

As shown in Figure 27, mean for companies' turnover in 2014 is slightly higher for 'green product innovators' in both cases, directly from the variable in M€ with a big dispersion and extreme samples (μ=3.6M€ versus μ=3.11M€), and from the normalized variable applying logarithms.
For the case of number of employees, means are also very close one to each other and slightly higher for 'green product innovators' 177.18 versus 162.88 employees.

Figure 27: Green and non-green product innovators distribution by size





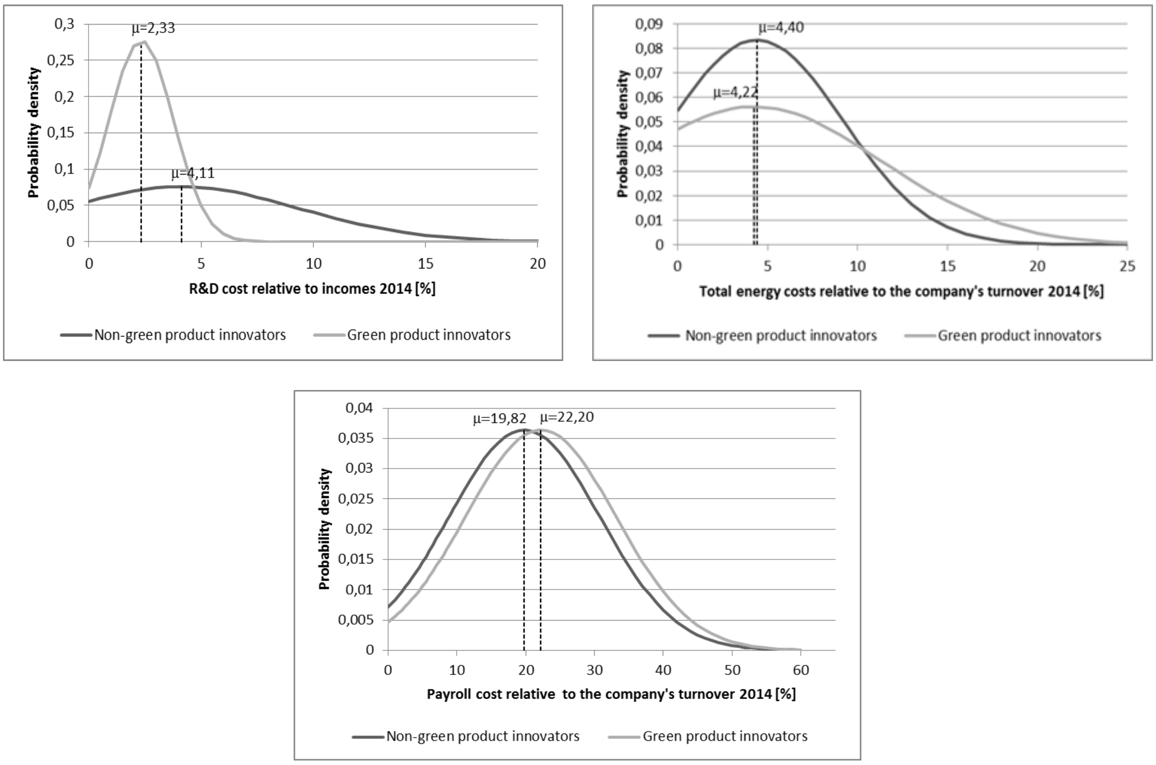


8.4.1.2 Relative Costs

From analysed relevant companies' costs presented in Figure 28, it can be observed total relative energy costs and relative payroll costs do not present big differences between means for each group. Mean is slightly lower in total relative energy costs for 'green product innovators' with 4.22% versus 4.40% of companies' turnover in 2014, and slightly higher in the case of payroll costs with a 22.20% versus 19,82% of companies' turnover in 2014.

However, in the case of R&D relative costs, we can appreciate 'green product innovators' present a mean that is practically a half of the one for 'non-green product innovators', 2.33% versus 4.11% relative to company's incomes in 2014. Furthermore, R&D relative costs distribution for 'non-green product innovators' present a quite bigger dispersion as it is shown in the graph.

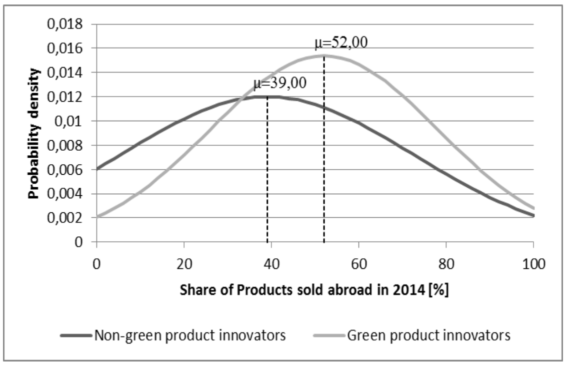
Figure 28: Relative costs distributions of green and non-green product innovators for R&D, total energy consumption and payroll costs



8.4.1.3 Export index

Again, differences appear regarding exportation index between both groups. 'green product innovators' sold in 2014 with a mean of 52% of the products they manufacture while 'non-green ones' only exported a mean of 39%. Dispersion is also bigger for this latest group.

Figure 29: Exportation share distribution for products manufactured in green and non-green product innovators' companies

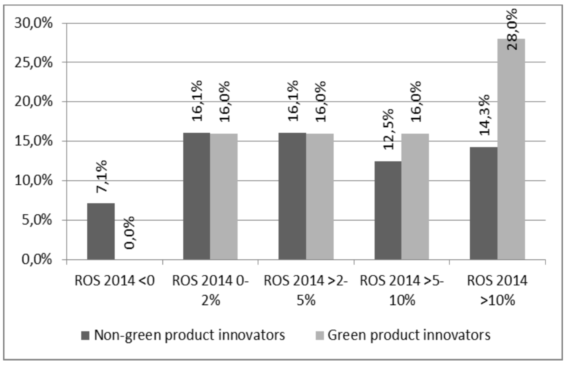


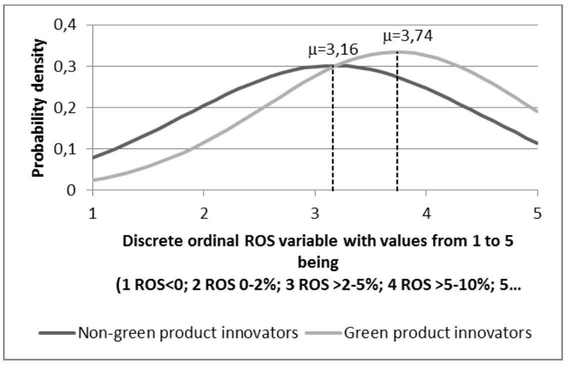
8.4.1.4 Company's economic performance

Considering return on sales (ROS) as an indicator of economic performance for companies, from binary variables of five possible ranges of ROS, graphs from

Figure 30 show that 'green product innovators' group include more percentage of companies declaring higher ranges of ROS in 2014. In the highest range for ROS>10%, the difference is clear with a 28% of companies in the green group against a 14.3% for the non-green one. When these binary variables are integrated in a discrete ordinal variable, a distribution graph is obtained in the same figure, corroborating a higher mean of 3.74 over 5 in the case of 'green product innovators' versus a 3.16 over 5 for the other group.

Figure 30: ROS distributions for green and non-green product innovators' companies



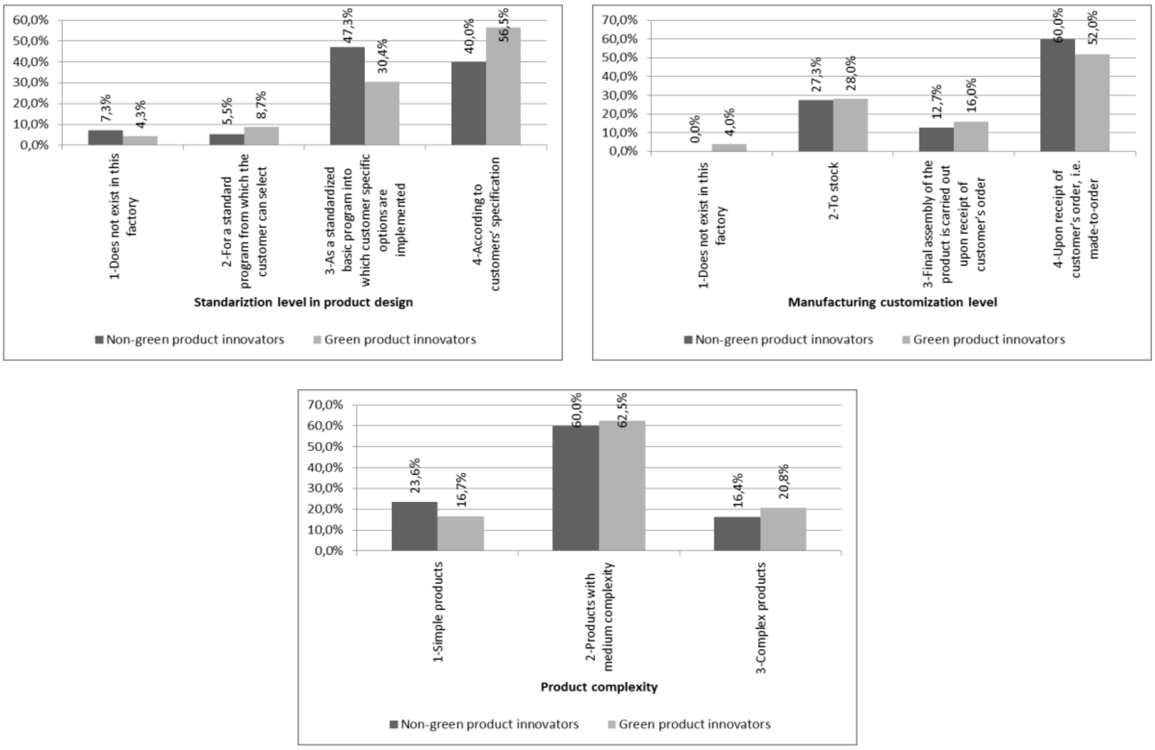


8.4.1.5 Main product family

Describing the main product family according to their standardization level in product design, manufacturing customization level and product complexity for each group, as shown in Figure 31, not much differences in terms of product complexity have been detected and just slight differences in manufacturing customization level.

However, 'green product innovators' group appears to have less standardization level in product design than non-green ones.

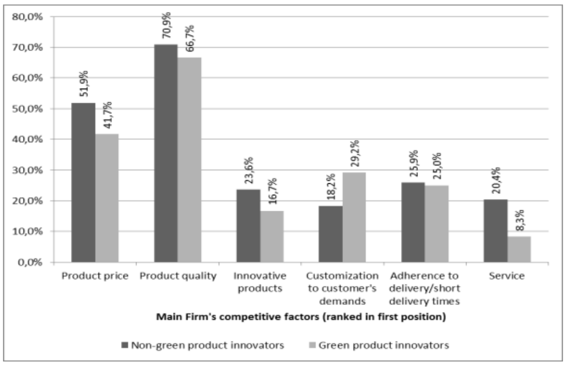
Figure 31: Main product family characteristics for green and non-green product innovators



8.4.1.6 *Firm competitive factors*

As it can be seen in Figure 32, the main competitive factor for both groups is product quality and, secondly, product price, obtaining higher percentage of companies for these factors the 'non-green product' innovators. 'Green product innovators' have higher percentage of companies in customization to customers demand and lower percentage in innovative products and service.

Figure 32: Main firm's competitive factors for green and non-green product innovators

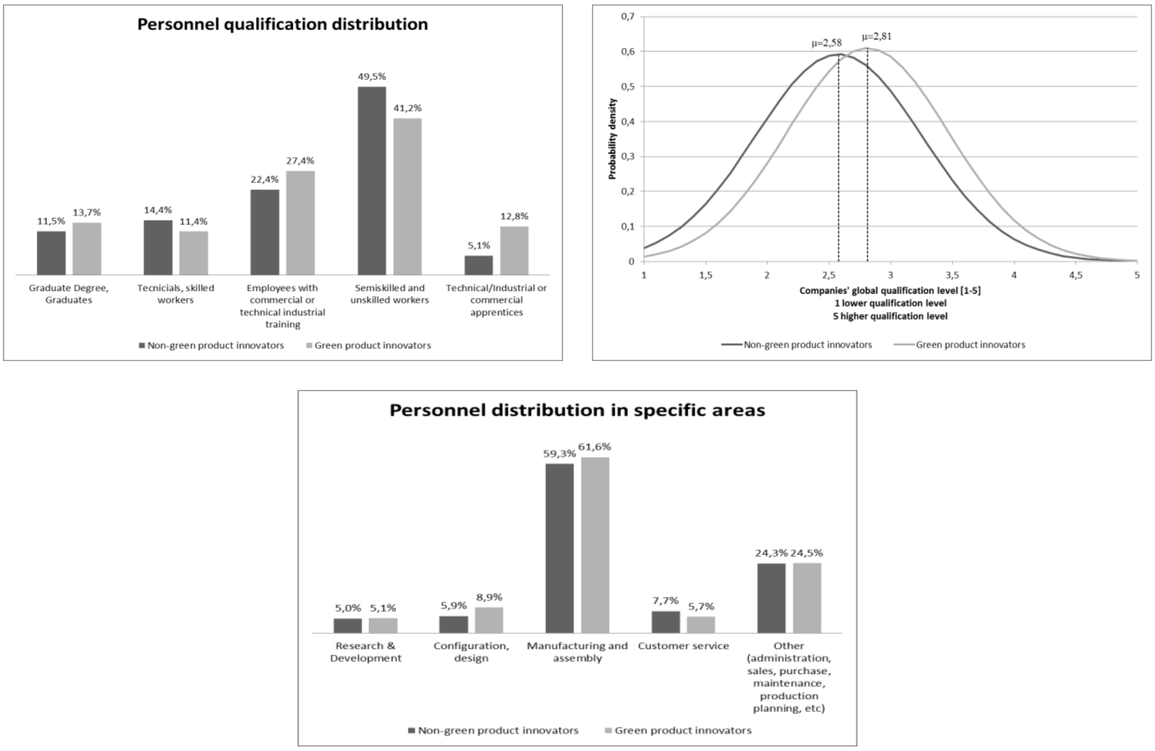


8.4.1.7 Employees

In Figure 33 it is represented the distribution of the employees according both their skills and to their distribution in specific areas of the firm.

As utilized categories for personnel qualifications are ranked from more to less skilled ones, a graphic of distribution can be also presented, in which is perceived that 'green product innovators' obtain a higher mean than the non-green ones with a 2.81 over 5 versus a 2,58 over 5, where 5 corresponds to the maximum level of skilled workers.

Figure 33: Characteristics of companies' personnel for green and non-green product innovators



8.4.1.8 Product innovators drivers

Crosstab analysis in Table 38 shows the percentages of companies, for each declared origin of the impulses/ideas for innovation, incorporating a specific environmental improvement in their product innovations. Impulses for innovation coming from R&D or engineering result mainly in improved recycling, redemption or disposal properties (23.3%) and secondly in a reduction of health risks (19.1%). Low percentages of companies appear when ideas come from production origin, from 5 to 10%.

Customer service impulses for product innovation drive, mainly, to extend product lifetime with a 25.0% of the companies, when other improvements have values from 10 to 17% of the firms. The same occurs with CEO's ideas with a 19%. Management ideas, secondly, impulse reduction of health risk with a 14.9% of the companies.

Customer or user suggestions are oriented to produce, mainly, reduction of health risks and improved recycling of products, both with a 19.7% of the firms. For the same origin of ideas for innovation, an 18.2% of the companies also extend product lifetime.

Impulses originated by suppliers result in a 13.3% of companies declaring improvements in reduction of health risks, extension of product lifetime and reduction of environmental pollution.

When impulses for innovation come from Research institutions and Universities a 20% of the companies improve in easiness to maintain products, while no companies obtain improvements for reduction of health risks, reduction of energy consumption or easiness to maintain or retrofit. For the case of business organization or consultancies, they do not drive to any improvement in reduction of health risks, reduction of energy consumption or easiness to maintain or retrofit.

The complementary crosstab in Table 39 shows the percentage of firms, for each product environmental impact improvement, that declared a specific origin for ideas/impulses of product innovation. An improvement for reduction of product's health risks has been carried by companies obtaining their impulses for innovation from customers in a 92.9% of the cases and with no cases for impulses from business organizations and consultancies.

Products extending their lifetime are produced in a 70.6% of the cases by companies that receive ideas for product innovation from customers or users and only in a 5.9% of the cases by research institutions or business organizations and consultancies.

For reduction of products' energy consumption, main impulses in manufacturing companies come from customers or users in a 90.9% of the cases and in no cases for business organizations or consultancies.

In the case of products' reduction of pollution and the case of products improved recycling, ideas for product innovation are generated by R&D and engineering and in a percentage of 87.5% and 58.8% of the firms, respectively, and in no cases from research institutions or universities for both environmental impact improvements.

Table 38: Companies (%) for each declared origin of the impulses/ideas for innovation, incorporating a specific environmental improvement in their product innovations

Origin of the impulses/ideas for innovation	Type of environmental improvement for product innovation: Reduction of health risks	Extended product lifetime	Reduction of energy consumption	Reduction of environmental pollution (in oil, water, air, or noise)	Easiness to maintain or to retrofit	Improved recycling, redemption or disposal properties
R&D engineering	19,1%	17,0%	12,8%	14,9%	12,8%	21,3%
Production	5,0%	10,0%	5,0%	5,0%	5,0%	5,0%
Customer service	10,7%	25,0%	14,3%	14,3%	17,9%	17,9%
CEO/management	14,9%	19,1%	10,6%	6,4%	6,4%	14,9%
Customer or user	19,7%	18,2%	15,2%	7,6%	13,6%	19,7%
Supplier	13,3%	13,3%	6,7%	13,3%	6,7%	6,7%
Research institutions, universities	10,0%	10,0%	10,0%	0,0%	20,0%	0,0%
Business or organization consultancy	0,0%	16,7%	0,0%	16,7%	0,0%	16,7%

Table 39: Percentage of companies, for each specific environmental improvement in their product innovations, declaring different origins of the impulses/ideas for innovation.

Kind of environmental improvement for product innovation	Origin of the impulses/ideas for innovation: R&D engineering	Production	Customer service	CEO/management	Customer or user	Supplier	Research institutions, universities	Business or organization consultancy
Reduction of health risks	64,3%	7,1%	21,4%	50,0%	92,9%	14,3%	7,1%	0,0%
Extended product lifetime	47,1%	11,8%	41,2%	52,9%	70,6%	11,8%	5,9%	5,9%
Reduction of energy consumption	54,5%	9,1%	36,4%	45,5%	90,9%	9,1%	9,1%	0,0%
Reduction of environmental pollution (in oil, water, air, or noise)	87,5%	12,5%	50,0%	37,5%	62,5%	25,0%	0,0%	12,5%
Easiness to maintain or to retrofit	54,5%	9,1%	45,5%	27,3%	81,8%	9,1%	18,2%	0,0%
Improved recycling, redemption or disposal properties	58,8%	5,9%	29,4%	41,2%	76,5%	5,9%	0,0%	5,9%

Product innovations for easiness to maintain or to retrofit products have been incorporated by companies declaring they receive impulses for innovation from customers in an 81.8% of the cases and in no cases from Business or organization consultancies. In order to present and compare results classified by 'non-green' and 'green product innovators' they are presented separately according different data typology groups defined in Table 36.

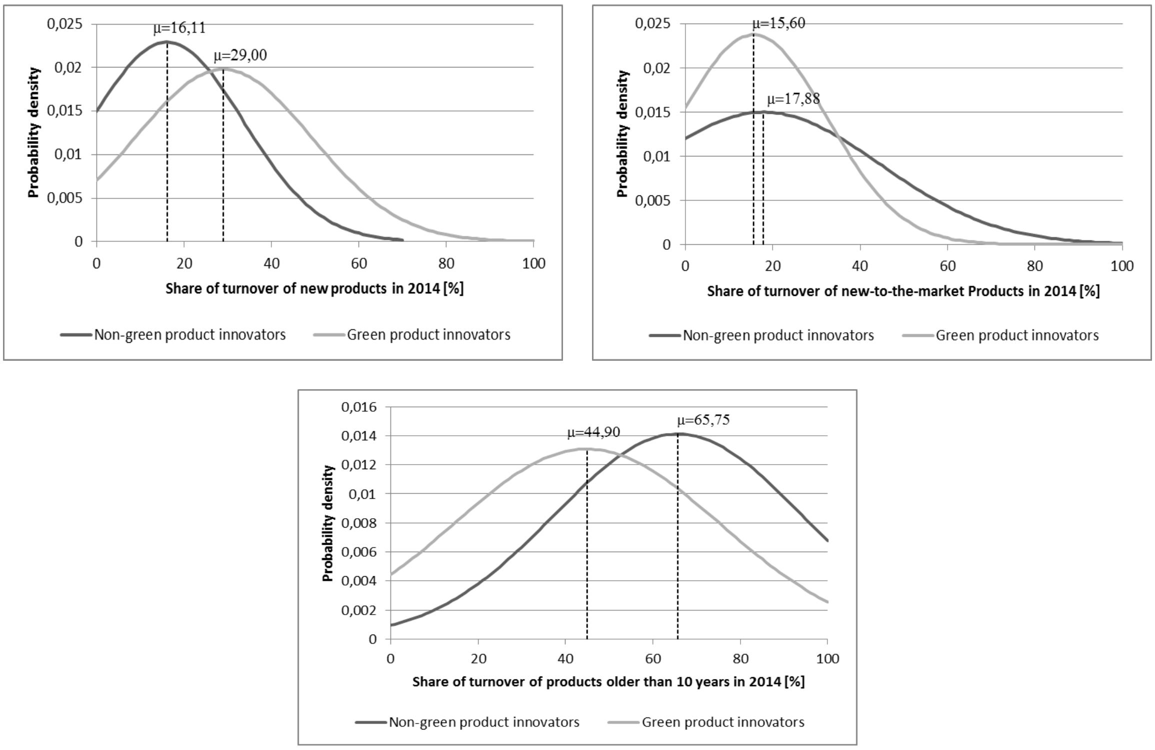
8.4.1.9 Innovation contribution to turnover

Analysing the contribution of new products to firms' turnover in 2014 from the point of view of new products for the company, new-to-market products and other products that are older than ten years, graphical results are presented in Figure 34.

The mean for the share of turnover of new products from 'green product innovators' is higher than in the case of non-green ones, 29% versus 16.11%. When observing new-to-market products, means for both groups are similar and lower and less disperse for 'green product innovators', 15.60% versus17.88%.

On the other hand, the contribution of products older than ten years to the turnover in 2014 is clearly higher in mean for the 'non-green product innovators' group with a 65.75% of share versus a 44.90% for the green group.

Figure 34: Share of turnover of new and old products in 2014 for green and non-green product innovators



8.5 Conclusions

'Green product innovators', in more than 50% of the cases improve the environmental impact of their products reducing their energy consumption when in use or improving recycle, redemption or disposal properties, while less than a 30% of them innovate extending product's lifetime.

When analysing the six possible environmental impact improvements for different firms' characteristics it is detected that some of these parameters appear to be linked with a specific improvement. This is the case, for example, of companies innovating in products to reduce health risks that are the ones with higher relative R&D costs and exportation index, compared with groups of companies introducing other environmental impact improvement for their products.

Trying to incorporate the origin of impulses or ideas for product innovation it can be appreciated that these origins are also associated to the six kinds of considered improvements. It is interesting to see for each origin, which is the kind of improvement that have more percentage of companies, but also the ones with less or zero percentage of companies.

In the other hand, for groups of companies declaring they innovate in their products with a specific kind of environmental impact improvement, some specific sources of impulses or ideas for product innovation appear to be the ones more used by companies. For example, it can be seen that customers is the most selected source of ideas for innovation in the case of firms reducing product's health risks or energy consumption. No companies declared to receive impulses from several origins for specific kinds of innovations. That is the case of research institutions or universities and businesses or organization consultancies.

Based on the results we can affirm there are some differences between defined groups of 'green' and 'non-green product innovators' for our sample of Spanish manufacturing companies. These differences drive to eight conclusions.

First, regarding to companies' economic performance, it has been detected that firms in 'green product innovators' group have declared higher ROS in average and also they present two times more percentage of companies with a ROS greater than 10% compared with the 'non-green' group.

Secondly, share of turnover of new products in 2014 for 'green product innovators' is higher in average and lower comparing the share of products older than 10 years. However, this contribution is also lower in the case of new-to-the-market products compared with firms in 'non-green product innovators' group. The observed results, in this case, are that 'green product innovators' in this sample, in average, are more innovators and produce less old products, but their innovations are more new-to-the-company than new-to-the-market compared with the 'non-green group'.

Thirdly, firm's size, in turnover and in number of employees, results to be, in average, slightly higher for 'green product innovators'. It could explain also part of the differences detected in terms of economic performance.

Fourthly, there is a difference in relative R&D costs, being lower, in average and with less dispersion, in the case of 'green product innovators'. As this cost is not absolute for each firm but relative to turnover, the effect of companies' sizes for each group could also affect to this result.

The fifth conclusion is related to the exportation intensity resulting higher, in average, and less dispersed, in the case of 'green product innovators'. Exportation could be also a driver to innovate improving environmental impact of new products.

The sixth deduction of this study is about the product family of 'green product innovators'. This group have a bigger percentage of companies that produce products according to customer's specifications. In other words, they produce, in average, products with less standardization. However, levels of manufacturing customization are slightly lower for companies of this group, being product complexity similar in both groups.

According to companies' competitive factors, the seventh conclusion for 'green product innovators' is they have a higher percentage of companies competing in customization to customer's demand. In the other hand, they present a lower percentage of companies, compared with the 'non-green product innovators', in the rest of competitive factors, especially in the case of service and product price.

The last conclusion is about companies' personnel, regarding their qualification and distribution in specific areas. In an ordered discrete ranking of personnel qualification, 'green product innovators' appear to demand a higher qualification level mean.

Despite personnel distribution in specific areas is quite similar in both groups, it could be highlighted a higher percentage of employees in the configuration and design area for 'green product innovators' and a lower percentage in customer service.

8.6 Contributions

The main contribution of this work consists in providing recent data regarding product innovation and sustainability in manufacturing firms.

The purpose of differentiating and describing this specific group of manufacturing companies, that innovate in products improving their environmental impact during their use or life, can help policy makers to identify drivers and factors that impulse this kind of desirable innovations and also detect barriers that can difficult their emergence.

For the academic arena, this is just a first exploratory study with recent data from the Spanish subsample of EMS that could be continued comparing results for different or bigger samples, incorporating other countries, trying to detect significant relationships between these factors and the green product innovation or between this kind of sustainable innovation and companies' performance.

Chapter 9 Clustering product innovators: an exploratory study focused on implementers of new products reducing environmental impact

This chapter aims at analysing firms implementing new products. Based on a cluster analysis, three types of manufacturers have been identified representing different types of product innovators according to the competitiveness factors important for their business, environmentally sensitive new products, and a per-formance indicator, such as the share of turnover from new products.

9.1 Introduction

According to the United Nations' approach on sustainable development goals (UN, 2016) a sustainable consumption and production helps to achieve overall development plans, reduces future economic-, environmental- and social costs, strengthens economic competitiveness and reduces poverty. Innovation appears as one possible action in this direction. New products, in general, and new products sensitive towards improving environmental impact, in particular, can make a considerable contribution to the society. Some examples of improved environmental impact refer to: reduction of health risks when in use, extended product lifetime, reduction of energy consumption when in use, reduction of environmental pollution when in use, easier to maintain or to retrofit, and improved recycling, redemption or disposal properties.

Recently, a review specifically focusing on green product innovation published by Dangelico (2016) makes an important contribution by analysing 63 studies in the field. It is affirmed that "with regard to capabilities in common with conventional new product development, it would be interesting for future research to investigate whether there is a difference between GPI development and conventional new product development in terms of relative importance of these capabilities and in terms of their extent of use" Dangelico (2016:574).

The analysis responds not just to an academic goal and a broader scientific call verbalised by Dangelico (2016), but also to a global institutional priority as the Europe 2020 strategy targeting improved environmental impacts and boosted innovation. Moreover, using three countries' data we contribute to other –few- data-driven approaches that combine environmental and innovation policy, translated to companies' daily operations.

9.2 Objectives

The objective of this exploratory work is to characterise patterns of product innovative manufacturing companies distinguishing between green product innovators (GPI) and conventional product innovators (CPI). For this purpose, we proceed with a cluster classification process. More concretely, we focus our analysis on firms that affirm having implemented product innovations in the last three years. We complement this aspect with a further detail, namely product innovators whose new products contemplate an improvement of the environmental impact by either using or disposing of them.

9.3 Literature Review

9.3.1 Conceptual delimitation and definition of green product innovation

A product innovative firm has been defined as the one that has implemented a new or significantly improved product during the period under review according to the Oslo Manual (OECD & Eurostat 2005).

Complementing this definition, and for the purpose of this study, green product innovation is defines as the design, production and implementation of new or significantly improved products that have a positive impact on the environment when in use or when disposing of them.

Different authors use a variety of terms to de-scribe new products with environmental implications that are synonyms and combinations of eco, eco-friendly, ecological, green, sustainable, environmental and environmental-friendly with innovation, product innovation, new product (Dangelico 2016)(Gerstlberger et al. 2014).

“Green product” and “environmental product” are used commonly to describe those that strive to protect or enhance the natural environment by conserving energy and/or resources and reducing or eliminating the use of toxic agents, pollution, and waste (Ottman et al. 2006).

Pujari refers to the action to develop and market new products that address environmental issues. Most of the sustainable innovation in NPD relates to incremental or evolutionary innovation (Pujari 2006).

Product innovations with environmental implications should fulfil two goals simultaneously, namely improvement of environmental impact and obtaining commercial performance (Gerstlberger et al. 2014).

Holistic approaches to model design should pre-vail, as the ones advocated by the 6Rs (redesigning, reusing, remanufacturing, recovering, recy-cling, and reducing) and products with multiple life cycles (Thomé et al. 2016).

9.3.2 Determinants of product innovation

Some authors tried to identify if and up to what degree, determinants of product innovation apply to green new product manufacturers. In the case of specific drivers, they also measured their effect (Edison et al. 2013)(Keupp et al. 2012).

Other, grouped the factors in internal/external or by nature as technological capabilities, internal integrative capabilities, external integrative capabilities or marketing capabilities (Dangelico 2016).

9.4 Methods

Our research is based on data from the European Manufacturing Survey (EMS), 2015 edition. EMS is coordinated by the Fraunhofer Institute for Systems and In-novation Research (ISI, 2017) and it is the largest European survey in manufacturing activities to date. It aims to collect data relative to the modernisation of manufacturing processes and practices. It complements existing innovation surveys by including latest trends among the topics of interest. Further elaborating in this direction, environmental aspects (energy and material saving technologies and practices, energy consumption, their sources and use) have been considered and updated since 2009 and on-going. Our study includes data from EMS Spain, France and Portugal, formed by 194 firms' responses. The survey was performed on manufacturing firms having at least 20 employees.

Developed jointly by Columbia University and Yale University, the Environ-mental Performance Index (EPI) ranks 180 countries on 20 performance indicators, which track performance and progress on two broad objectives: protection of human health and protection of ecosystem (Hsu et al., 2016). According to the latest edition all three countries are part of the top 10 of the 2016 EPI rankings, Spain ranks 6th with an EPI score of 88.91, Portugal is at position 7 with a score of 88.63, while France situates at the 10th position scoring 88.2 in the ranking where Finland has taken the top spot with the maximum possible score of 90.68. All countries included in the present analysis have high EPI performance indicators with a better performance than countries in their region (Europe), globally.

Technical details of the utilized subsamples are shown in Table 40.

Table 40: Technical details for the Spanish, French and Portuguese subsamples of the European Manufacturing Survey 2015 edition.

Universe:	Spanish, French and Portuguese manufacturing firms with at least 20 employees CNAE 2009; codes from 10 to 33.
Unit of analysis:	Establishment
Sample:	194 firms: (ES) 100; (FR) 61; (PT) 33
Confidence margin:	95%
Variance:	Maximum indetermination p=q=50%
Documentation	Paper (8 pages questionnaire) + Return envelope + Presentation letter
Channel	Postal
Fieldwork:	May to September 2015
Reference period:	2012-2014; 2014
Institution:	Dept. of Business Administration and Product Design, University of Girona – Girona (Spain) University of Lyon, IAE Lyon, Lyon (France) Dept. of Mechanical and Industrial Engineering, Universidade Nova de Lisboa, Caparica (Portugal)
Data base recording and creation:	ES: Outsourced to DAP GmbH – Passau (Germany) FR, PT: institution
Sample distribution:	By size and sector of activity
By 'Green product innovators':	'Conventional product innovators': 55 (ES) 34; (FR) 15; (PT) 6 'Green product innovators': 60 (ES) 23; (FR) 25; (PT) 12

From the existing distances in a set of variables, groups of cases have been created by a K-means cluster analysis. Variables were the ones in our sample representing the firm's competitive factors significance ranked from 1 (most important) to 6 (less important): 'product price', 'product quality', 'innovative products' and 'customization to customers' demands'. Other two competitive factors variables, 'Adherence to delivery/short delivery times' and 'Service', were not considered to obtain the clusters because they are not strictly linked with product innovation.

According with the obtained clusters of product innovators, a frequencies analysis for variables representing the technological level of firms and product development and manufacturing aspects and innovation drivers are performed. Other descriptive analysis have been elaborated from variables such as companies' personnel distribution and qualification, company size (normalized with logarithms), exportation index and strategic costs as percentage of the turnover in 2014, like energy, payroll or R&D costs.

The group of companies affirming their new products lead to an improvement of their environmental impact during their use or disposal - differentiating them from the rest of conventional product innovators- is called 'green product innovators'. Both groups are analysed separately to compare results and detect differences among clusters, being this the main objective of the present study.

Figure 35: Clustering methodology for product innovators (Source: Own elaboration)

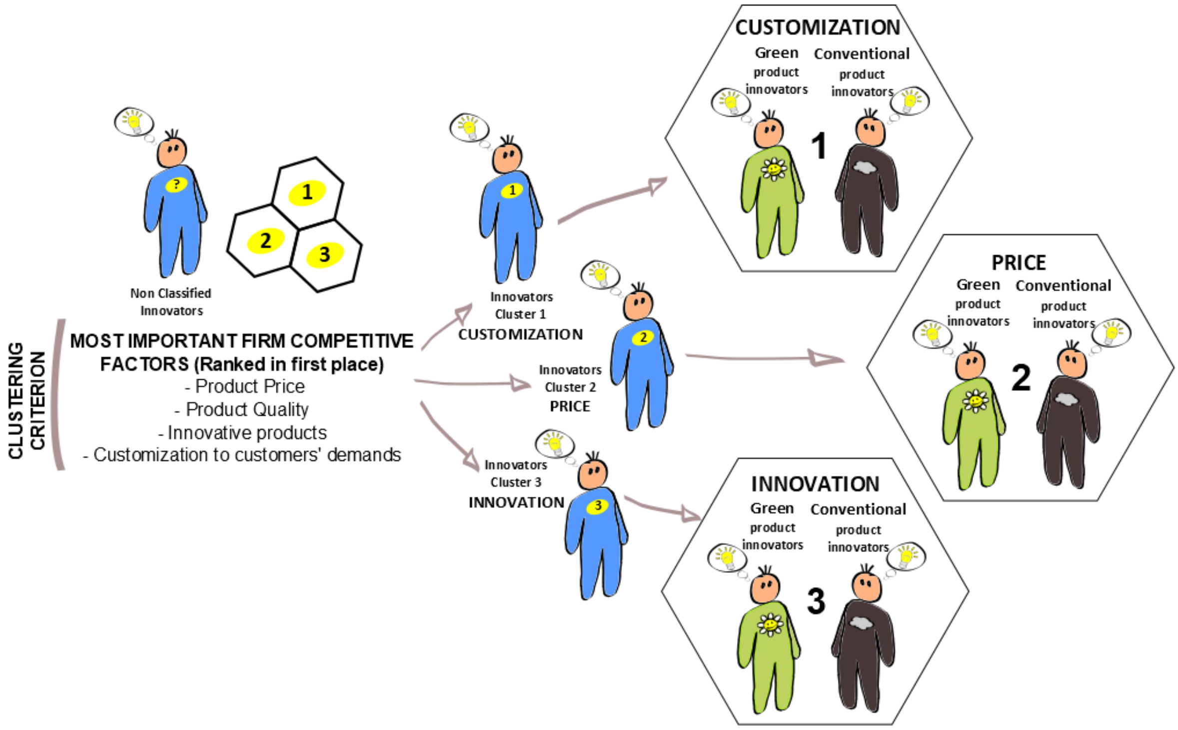


Table 41: Product innovators inside each obained cluster

	Cluster 1 Customization	Cluster 2 Price	Cluster 3 Innovation
	N	N	N
Conventional	22	19	13
Green	23	15	20
Total	45	34	33

9.5 Results

The cluster analysis results in three coherent groups of manufacturing establishments distinguishing between product innovators competing by i) customization, ii) price, and iii) innovation, as shown in Figure 35 and Table 41. In these three cases, companies also compete by quality as well, but we label groups with the most relevant competitiveness factor that differentiates among the groups. The differences are also reported according the presence of firms whose new products improve their environmental impact.

9.5.1 Technological level, product development and product manufacturing

Table 42 presents a frequency analysis of companies' technological level and product development and manufacturing characteristics for the three clusters, differentiating also between green and non-green/conventional product innovators.

Technological level refers to the Eurostat aggregation of the manufacturing industry according to technological intensity based on firm's NACE code Rev.2.

It is observable that the majority of product innovative firms competing by innovation are GPI. Likewise, inside the cluster competing by customization, companies are notably more GPI than CPI except in the case of the low technological intensity ones that are clearly more CPI.

Low technological intensity firms competing by price, are 87.5% CPI, and more equilibrated for both groups in the case of Low-med, Med-high and High technological intensity ones.

Regarding the analysed manufacturing characteristics, we obtain the results for product development customization level, manufacturing customization level, batch or lot sizes, and product complexity level. A summary of the most interesting highlights regarding GPI is presented below..

Table 42: Frequency analysis for firms' technological level, development and manufacturing cus-tomization, lot size and product complexity.

			Cluster 1 Price			Cluster 2 Innovation			Cluster 3 Customization		
			N	[%] Row	[%] Column	N	[%] Row	[%] Column	N	[%] Row	[%] Column
Tech_Level	Low	Non-green	9	40,9%	64,3%	7	31,8%	87,5%	6	27,3%	42,9%
		Green	5	35,7%	35,7%	1	7,1%	12,5%	8	57,1%	57,1%
	Med-low	Non-green	7	41,2%	50,0%	6	35,3%	50,0%	4	23,5%	36,4%
		Green	10	43,5%	50,0%	6	26,1%	50,0%	7	30,4%	63,6%
	Med-high and High	Non-green	6	40,0%	42,9%	6	40,0%	42,9%	3	20,0%	37,5%
		Green	8	38,1%	57,1%	8	38,1%	57,1%	5	23,8%	62,5%
Product develop-ment customization level	Low	Non-green	1	33,3%	100,0%	1	33,3%	50,0%	1	33,3%	50,0%
		Green	0	0,0%	0,0%	1	50,0%	50,0%	1	50,0%	50,0%
	Med	Non-green	8	38,1%	57,1%	9	42,9%	52,9%	4	19,0%	30,8%
		Green	6	26,1%	42,9%	8	34,8%	47,1%	9	39,1%	69,2%
	High	Non-green	13	43,3%	46,4%	9	30,0%	60,0%	8	26,7%	44,4%
		Green	15	48,4%	53,6%	6	19,4%	40,0%	10	32,3%	55,6%
Manufacturing customi-zation level	Make to order	Non-green	1	100,0%	100,0%	0	0,0%	0,0%	0	0,0%	0,0%
		Green	0	0,0%	0,0%	0	0,0%	0,0%	1	100,0%	100,0%
	Assemble to order	Non-green	5	45,5%	45,5%	3	27,3%	50,0%	3	27,3%	33,3%
		Green	6	40,0%	54,5%	3	20,0%	50,0%	6	40,0%	66,7%
	make to stock	Non-green	2	40,0%	40,0%	3	60,0%	42,9%	0	0,0%	0,0%
		Green	3	30,0%	60,0%	4	40,0%	57,1%	3	30,0%	100,0%
	No production	Non-green	12	34,3%	46,2%	13	37,1%	61,9%	10	28,6%	52,6%
		Green	14	45,2%	53,8%	8	25,8%	38,1%	9	29,0%	47,4%
Batch or lot sizes	Unit	Non-green	2	40,0%	22,2%	2	40,0%	50,0%	1	20,0%	12,5%
		Green	7	43,8%	77,8%	2	12,5%	50,0%	7	43,8%	87,5%
	Med size	Non-green	13	41,9%	52,0%	9	29,0%	50,0%	9	29,0%	60,0%
		Green	12	44,4%	48,0%	9	33,3%	50,0%	6	22,2%	40,0%
	Big size	Non-green	7	38,9%	63,6%	8	44,4%	66,7%	3	16,7%	30,0%
		Green	4	26,7%	36,4%	4	26,7%	33,3%	7	46,7%	70,0%
Product complexi-ty level	Low	Non-green	4	50,0%	44,4%	2	25,0%	100,0%	2	25,0%	40,0%
		Green	5	62,5%	55,6%	0	0,0%	0,0%	3	37,5%	60,0%
	Medium	Non-green	14	43,8%	56,0%	11	34,4%	57,9%	7	21,9%	38,9%
		Green	11	36,7%	44,0%	8	26,7%	42,1%	11	36,7%	61,1%
	High	Non-green	4	30,8%	36,4%	5	38,5%	45,5%	4	30,8%	40,0%
		Green	7	36,8%	63,6%	6	31,6%	54,5%	6	31,6%	60,0%

9.5.1.1 Manufacturing characteristics for product innovators in "Customization" cluster

Inside the cluster of innovators competing by Customization, companies with a high product development customization level are more GPI than CPI. No GPI can be found among manufactures that "make to order", that is the highest manufacturing customization level. The share of GPI increases as the lot/batch sizes decrease being a 78% of the firms in the case of manufacturing unit by unit. Mainly in high but also in low product complexity level the percentage of GPI is higher.

9.5.1.2 Manufacturing characteristics for product innovators in "Price" cluster

In high product development customization level, the percentage of GPI competing by price is lower than the CPI one (40% vs. 60%). Re-garding to the manufacturing customization degree, GPI represent a higher percentage in the group of companies that produce with a "make to stock" system. Innovators producing in high lot/batch sizes are, mostly, CPI (66%). The percentage of GPI increases as it increases the product complexity level, being a 55% in the case of companies that produce highly complex products.

9.5.1.3 Manufacturing characteristics for product innovators in "Innovation" cluster

Product innovative firms competing by innovation that offer a medium or high product development customization level are mostly GPI in a 69% and a 55% respectively. In product manufacturing customization level, CPI represent only a 33% of the companies that assemble to order and no one of them make to stock or make to order. GPI represents the majority of innovators producing big size and unitary lot/batch sizes with a 70% and 88% respectively. In all product complexity degrees, GPI represent the majority of firms inside this cluster with a very similar percentages: 60% for high, 61% for medium and 60% for low complexity.

Table 43: Frequency analysis for firms' technological level, development and manufacturing customization, lot size and product complexity

			Cluster 1 **CUSTOMIZATION**		Cluster 2 **PRICE**		Cluster 3 **INNOVATION**	
			N	[%]Column	N	[%]Column	N	[%]Column
Tech_Level (from NACE rev2)	Low	Conventional	9	64,3 %	7	87,5 %	6	42,9 %
		Green	5	35,7 %	1	12,5 %	8	57,1 %
	Med-low	Conventional	7	41,2 %	6	50,0 %	4	36,4 %
		Green	10	58,8 %	6	50,0 %	7	63,6 %
	Med-high and High	Conventional	6	42,9 %	6	42,9 %	3	37,5 %
		Green	8	57,1 %	8	57,1 %	5	62,5 %
Product development customization level	Low	Conventional	1	100,0 %	1	50,0 %	1	50,0 %
		Green	0	0,0 %	1	50,0 %	1	50,0 %
	Med	Conventional	8	57,1 %	9	52,9 %	4	30,8 %
		Green	6	42,9 %	8	47,1 %	9	69,2 %
	High	Conventional	13	46,4 %	9	60,0 %	8	44,4 %
		Green	15	53,6 %	6	40,0 %	10	55,6 %

Manufacturing customization level	Make to order	Conventional	1	100,0 %	0	0,0 %	0	0,0 %
		Green	0	0,0 %	0	0,0 %	1	100,0 %
	Assemble to order	Conventional	5	45,5 %	3	50,0 %	3	33,3 %
		Green	6	54,5%	3	50,0 %	6	66,7 %
	make to stock	Conventional	2	40,0 %	3	42,9 %	0	0,0 %
		Green	3	60,0 %	4	57,1 %	3	100,0 %
	No production	Conventional	12	46,2 %	13	61,9 %	10	52,6 %
		Green	14	53,8 %	8	38,1 %	9	47,4 %
Batch or lot sizes	Unit	Conventional	2	22,2 %	2	50,0 %	1	12,5 %
		Green	7	77,8%	2	50,0 %	7	87,5 %
	Med size	Conventional	13	52,0 %	9	50,0 %	9	60,0 %
		Green	12	48,0 %	9	50,0 %	6	40,0 %
	Big size	Conventional	7	63,6 %	8	66,7 %	3	30,0 %
		Green	4	36,4 %	4	33,3 %	7	70,0 %
Product complexity level	Low	Conventional	4	44,4 %	2	100,0 %	2	40,0 %
		Green	5	55,6 %	0	0,0 %	3	60,0 %
	Medium	Conventional	14	56,0 %	11	57,9 %	7	38,9 %
		Green	11	44,0 %	8	42,1 %	11	61,1 %
	High	Conventional	4	36,4 %	5	45,5 %	4	40,0 %
		Green	7	63,6 %	6	54,5 %	6	60,0 %

9.5.2 Main origins of impulses/ideas for innovation

As it is observed in Table 44 and more easily in Figure 36, some differences between Conventional and Green product innovators appear regarding the origin of impulses/ideas they declared to use for their innovations. These differences are also particular for every cluster and they could not be appreciated in a general, non-clustered analysis.

Green Product innovators competing by customisation find inspiration for new product development in the R&D/engineering department and the customer service section. Complementary, ideas for NPD also come from the customer/user.

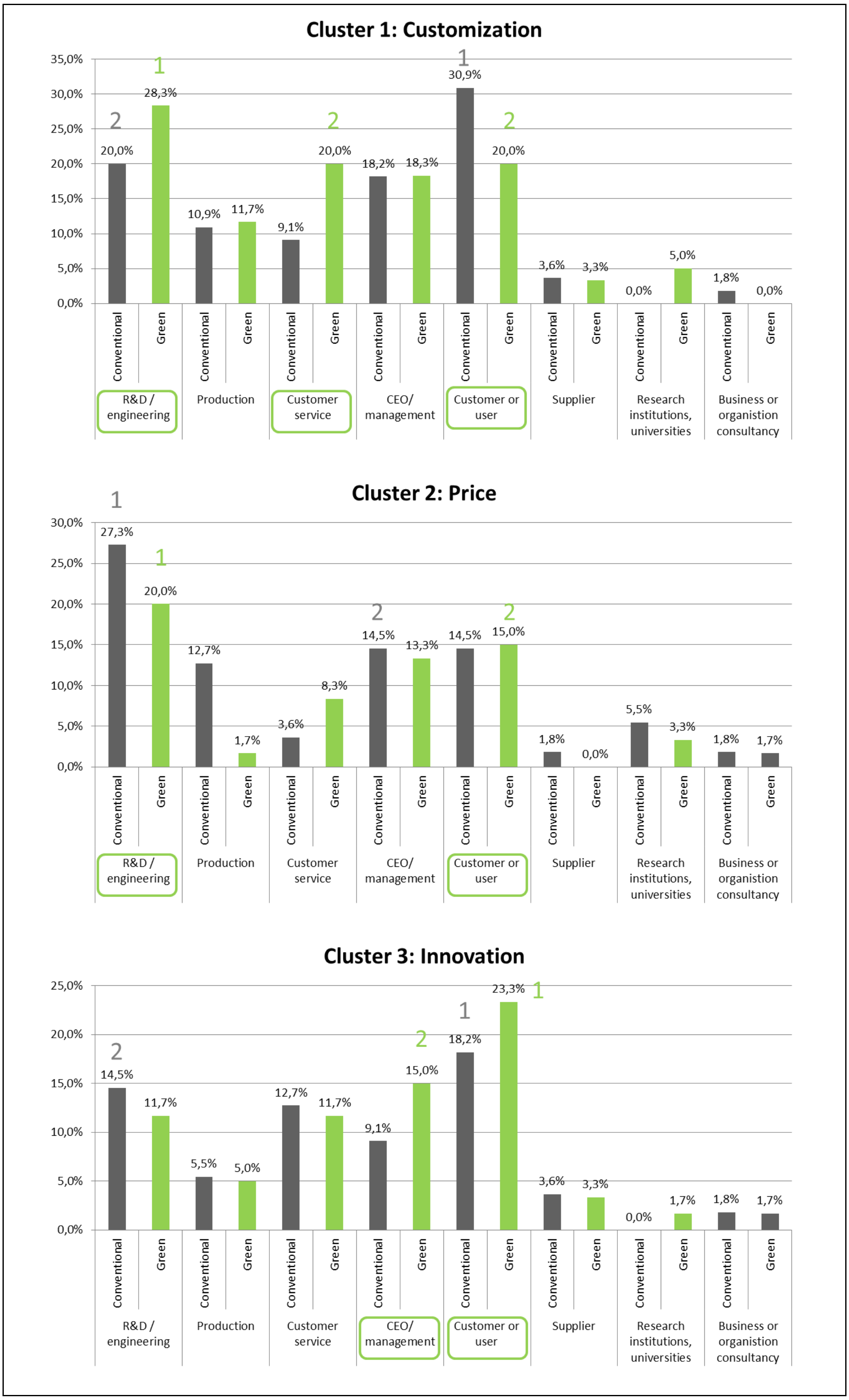
The pattern is partially similar for low cost product innovators who find their main sources of inspiration in the R&D/engineering department, the customer/user and CEO/management (in decreasing order).

Green Product innovators competing by innovation are mainly inspired by the customer/user followed by the CEO/management and third, in the R&D/engineering department.

Table 44: Frequency analysis for main origins of ideas/impulses for innovation by cluster.

		Cluster 1 Customization			Cluster 2 Price			Cluster 3 Innovation		
		N	[%] Share of Companies by cluster	[%] companies by origin of ideas	N	[%] Share of Companies by cluster	[%] companies by origin of ideas	N	[%] Share of Companies by cluster	[%] companies by origin of ideas
R&D / engineering	Non-green	11	32,4%	20,0%	15	44,1%	27,3%	8	23,5%	14,5%
	Green	17	47,2%	28,3%	12	33,3%	20,0%	7	19,4%	11,7%
Production	Non-green	6	37,5%	10,9%	7	43,8%	12,7%	3	18,8%	5,5%
	Green	7	63,6%	11,7%	1	9,1%	1,7%	3	27,3%	5,0%
Customer service	Non-green	5	35,7%	9,1%	2	14,3%	3,6%	7	50,0%	12,7%
	Green	12	50,0%	20,0%	5	20,8%	8,3%	7	29,2%	11,7%
CEO/ management	Non-green	10	43,5%	18,2%	8	34,8%	14,5%	5	21,7%	9,1%
	Green	11	39,3%	18,3%	8	28,6%	13,3%	9	32,1%	15,0%
Customer or user	Non-green	17	48,6%	30,9%	8	22,9%	14,5%	10	28,6%	18,2%
	Green	12	34,3%	20,0%	9	25,7%	15,0%	14	40,0%	23,3%
Supplier	Non-green	2	40,0%	3,6%	1	20,0%	1,8%	2	40,0%	3,6%
	Green	2	50,0%	3,3%	0	0,0%	0,0%	2	50,0%	3,3%
Research institutions, universities	Non-green	0	0,0%	0,0%	3	100,0%	5,5%	0	0,0%	0,0%
	Green	3	50,0%	5,0%	2	33,3%	3,3%	1	16,7%	1,7%
Consultancy	Non-green	1	33,3%	1,8%	1	33,3%	1,8%	1	33,3%	1,8%
	Green	0	0,0%	0,0%	1	50,0%	1,7%	1	50,0%	1,7%

Figure 36: Manufacturing firm's main origin of ideas/impulses for innovation by clusters



9.5.3 Companies' characteristics

Since companies' characteristics are important determinants of innovation, it is interesting to observe the results showed in Table 45, Table 46 and Table 47.

9.5.3.1 Personnel

Closely related to the previous section qualification level of employees is often related to companies' capacity to innovate. The results in Table 45 show that the highest level of qualification is characteristic to cluster of firms following a strategy based on price, followed by those firms differentiating from competitors through innovation, and last the ones focusing on customization. When comparing traditional product innovators to green product innovators, major differences in favour of GPI showing higher or equal values to the other ones, can be observed in the "low cost" category. Differences are minor and do not exceed 0.2 points.

As observed in the previous section both internal to the firm and external sources of ideas/ impulses for innovation can be detected. Focusing the attention on the distribution of employees in the different key functional areas of the firm the analysis shows the following: i) indifferently of the cluster, research & development employees are more numerous in GPIs, ii) Cluster 2 shows differentiated characteristics in the sense that GPIs that belong to this have higher concentration of employees in manufacturing, assembly and other areas, iii) the major difference in percentage points can be observed in Cluster 3, the results showing customer service as the function concentrating more employees in Conventional product innovators than in GPIs (22.3 versus 10.3).

Table 45: Descriptive analysis for the personnel qualification [1-5] by cluster

		Cluster1 CUSTOMIZATION		**Cluster 2 PRICE**		**Cluster 3 INNOVATION**	
		μ	σ	μ	σ	μ	σ
Global Personnel qualification [1-5] 1 for lowest and 5 for highest (PhD and Master)	Conventional	2,6	0,5	3,0	0,6	2,9	0,5
	Green	2,8	0,4	3,1	0,5	2,9	0,6

Table 46: Descriptive analysis for the personnel distribution inside each company areas in % by cluster

		Cluster1 CUSTOMIZATION		Cluster 2 PRICE		Cluster 3 INNOVATION	
		μ	σ	μ	σ	μ	σ
Research & Development	Conventional	3,7	3,9	6,9	6,6	3,8	5,7
	Green	6,3	4,6	7,4	5,3	5,4	7,7
Configuration, design	Conventional	3,8	5,9	7,3	8,1	3,0	3,4
	Green	8,5	8,9	4,2	7,0	4,6	4,9
Manufacturing and assembly	Conventional	69,8	16,9	57,9	22,3	61,6	28,6
	Green	61,0	14,9	65,3	12,0	58,7	19,5
Customer service	Conventional	3,3	4,3	7,8	8,1	22,2	32,2
	Green	6,0	5,0	6,6	4,6	10,3	9,8
Other	Conventional	20,7	14,1	22,3	14,7	15,5	11,5
	Green	19,3	11,7	22,7	23,3	20,6	12,4

Main differences (shaded cells)

9.5.3.2 Size, costs and economic parameters

The results for GPI and CPI regarding different variables representing company size, costs and economic performance are showed in Table 47.

The differential of turnover as a basic financial performance indicator does not show any significant difference between GPI and CPI. The same similarities between green and conventional innovators appear in variables as number of employees, payroll costs or relative percentage of energy costs for all the clusters.

The most outstanding results appear in the cluster of firms following a strategy based on price regarding variables representing relative R&D expenditures and exportation.

In this cluster, we can observe GPI declare, in average, less percentage of R&D expenditures relative to incomes than CPI. On the other hand, GPI declare they sell more percentage of products abroad than CPI.

Table 47: Descriptive analysis for company size, strategic costs and exportation by cluster

		Cluster1 CUSTOMIZATION		Cluster 2 PRICE		Cluster 3 INNOVATION	
		μ	σ	μ	σ	μ	σ
Ln (Annual turnover 2014)	Conventional	3,4	1,4	3,3	1,5	3,1	1,6
	Green	3,1	1,3	3,7	2,2	2,9	1,2
Ln (Number of employees 2014)	Conventional	4,9	1,1	4,4	1,0	4,2	1,8
	Green	4,3	1,0	5,2	1,5	4,5	1,1
% of R&D relative to incomes 2014	Conventional	3,0	4,0	8,8	8,2	3,3	4,9
	Green	2,9	2,6	4,9	5,4	4,0	3,7
Payroll costs as % of turnover 2014	Conventional	20,8	7,7	23,0	12,6	22,9	17,1
	Green	23,1	11,1	25,3	16,0	24,5	12,2
% Products sold abroad	Conventional	44,1	30,7	48,1	37,0	45,2	29,1
	Green	41,4	30,0	63,0	23,2	40,4	32,2
Total energy costs as % of turn-over 2014	Conventional	2,9	4,2	3,2	2,5	6,6	10,8
	Green	4,5	7,8	4,0	3,5	3,8	4,0

Main differences

9.6 Conclusions

The paper provides recent objective data regarding product innovation and sustainability in South-western European manufacturing firms.

Introducing clusters, hidden aspects that differentiate green product innovators from conventional ones it can be observed. These differences cannot be seen in an overall analysis.

Describing and differentiating both groups of GPI and CPI, our findings could be insights for policy makers to identify drivers and factors that impulse this type of desirable innovations or barriers that difficult their emergence.

It could be informative for manufacturing practitioners in terms of characteristics and opportunities of green new product innovation.

9.7 Contribution

The present work aims to complement previous descriptive analysis on product innovation and sustainability in manufacturing firms using the same methodology (Pons et al., 2013; Palčič et al., 2013; Pons et al., 2017), but adding a layer of complexity achieved by the cluster analysis as well as presenting recent data on a topic situated at the intersection of two crucial societal issues, namely environment and innovation.

While manufacturers can find greening opportunities in both process and products, the product option remains one of the most perceived and visible alternative for stakeholders, being that the backbone of the present contribution.

9.8 Future research

The study could be expanded to 10 countries evaluating country effects. It would be interesting to observe if different environmental policies, regulations or green cultures affects to the results.

A more sophisticated analysis of performance (environmental and economic) in relation to these GPI should be made in the future.

In the framework of a wider sample, it could be possible to compute a variable capturing different degrees of greenness considering, for example, the extent of implementation of green product innovations.

Models testing relationships between drivers/barriers, company characteristics and green product innovation and/or performance, have to be further studied.

Chapter 10 Discussion

For the purpose of interpreting the meaning and relevance of the obtained results presented in the form of the included studies, this chapter is structured in different sections which answer each of the research questions.

10.1 What is the degree of adoption of energy efficiency technologies?

Regarding the implementation level of EST/MST, there is still room for greater promotion of their use and implementation. The use of EST/MST in manufacturing firms is still relatively low, ranging from 8% to 35%. Only the use of "speed control", which is a term with a broad margin of interpretation, reaches 56%. Spanish manufacturing companies are recognized to have on average 14% of relative energy-saving potential. This should be seen to be an opportunity to increase the implementation of such technologies. The studied EST/MST are predominately highly implemented in low and medium-low technology groups. In these technological sectors, energy consumption is probably more of a key factor which affects the profitability of the company more than in high technology firms. MST are mostly used in the low and medium technology sector. No significant correlation was detected between the technological level of the company and EST/MST use or high use.

10.2 What is the relationship between the adoption of these technologies and companies' performance?

One of the most relevant findings revealed in the first study is the fact that EST/MST do not have a clear relationship with the economic performance of the studied firms. However, EST/MST do have a significant relationship with environmental performance. In other words, we can affirm that in the case of Spanish and Slovenian manufacturing companies, EST/MST have been more useful in making these firms greener than improving their economic results. This thesis provides numeric results and models for Spain and Slovenia. Several relationships were found between firms' characteristics and economic performance represented by ROS, and energy efficiency or environmental performance variables represented by relative energy and material efficiency.

Companies that have implemented an environmental management system such as ISO 14000 present a significant correlation with the simple use of EST/MST, but not with their high use. These kind of companies seem to be more likely to implement systems and technologies aimed at reducing the environmental impact, but these results show that surprisingly they are not the ones with a high implementation of EST/MST and they are consequently not the most energy efficient ones.

10.3 What are the characteristics of energy-efficient manufacturing companies?

The study reveals a possible negative relationship between energy efficiency in production and technological intensity in firms. It has been observed that high technology industries focus less on energy efficiency than low technology firms. Probably related to this fact, R&D expenditures are higher in the less relatively energy-efficient group of firms.

Firms that claim to be more energy efficient than other firms in the sector are also the ones that implement more EST/MST. This leads to a potentially positive relationship between being energy- and material efficient and using EST/MST, especially if they are highly implemented. However, this potential relationship has not been demonstrated for this sample.

The studied manufacturing firms are more energy-efficient if they use at least one or more EST/MST. The results show that the more relatively energy-efficient companies are on average the biggest in terms of turnover and number of employees, and the ones with a higher average of export intensity, selling more than 50% of their sales abroad. On the other hand, the implementation of environmental management systems such as ISO14000 does not seem to be linked with being a more relatively energy efficient company compared with the rest of firms in the same sector.

10.4 What are the characteristics of greener product innovators?

This thesis provides recent objective data regarding product innovation and sustainability in south-western European manufacturing firms. Describing and differentiating conventional product innovators (CPI) from green product innovators (GPI) helps to characterize both.

The most implemented characteristic of new green products to improve their environmental impact is "Reduction of energy consumption when in use" (50% of the cases) and the least implemented one is "Reduction of environmental pollution when in use" (28% of the cases). This fact could be related to the direct benefits perceived by the final consumer. Reduction in energy consumption produces direct economic savings, while environmental pollution is perhaps not as evident to perceive. If this were the case, it would point to GPI implementing the characteristics demanded by their customers or consumers in their new green products.

There are more GPI in the medium-high technology group, and much fewer in the low technology one. It would seem that high technology and low technology sectors are not as interested in green product innovation as the medium-high group. A possible explanation could be that in these extreme sectors, the main competitive factors are not considered to be the environmental ones. GPI produce more complex products than CPI and they generally implement more energy saving technologies. This last point suggests a relationship between the commitment to energy efficiency and the option to create new green products for the market.

GPI present a balanced distribution in all segments of analyzed return on sales (ROS) (around 25% in each case), while CPI appear to be more concentrated in the >2-5% segment (38%). In the extreme segments of ROS, >10% and 0-2%, GPI present a higher percentage than CPI.

The share of turnover of new-to-the-market products is on average lower for GPI (10.3% and less dispersed) than for CPI (18.2% with more dispersion). Consequently, we can observe that new green products on average do not represent an important contribution to the firm's turnover. For these products, being greener probably does not represent being more profitable.

When clustering green product innovators according to their main competitive factors, we are adding a layer of complexity to previous descriptive studies on product innovation and sustainability. For competitive factor cluster "customization" GPI represent 51.1%, for "Product price" 44.1% and for "Innovation" 60.6%. Companies basing their competition on innovation are mostly GPI, while our innovator firms competing by product price are mostly CPI. It was previously pointed out that green product innovations or introducing EST/MST in the production processes do not represent a direct advantage in terms of economic performance parameters, and supposedly neither in product price.

Regarding technological intensity, firms clustered by customization or price, GPI are in a clear majority in med-high and high technology sectors, while they are in a significant minority for low-technology sectors. This effect does not occur inside the innovation cluster and neither could it be observed in a non-clustered analysis. For companies basing their competitiveness on innovation, the GPI are also in a majority in all technological intensity industries.

GPI in low-technology sectors mainly compete by innovation. Specific results have been obtained and presented in the last study for each cluster of companies, differentiating GPI from CPI according to different parameters and their degrees: product development customization degree, product manufacturing customization degree, product complexity, number of employees, percentage of personnel in each area, size and specific costs. According to the reviewed literature, this represents a contribution to characterize green product innovators. Furthermore, the cluster analysis brings out hidden differences complementing classical descriptive analyses and presenting recent data on a topic located at the intersection of two crucial societal issues, namely environment and innovation.

10.5 Which factors determine more sustainable product innovation in manufacturing companies?

For all the declared origins of impulses/ideas for product innovations in GPI firms, 83% of the companies obtaining ideas from "Research institutions and universities" produced new products improving "easiness to maintain or to retrofit". All the GPI declaring "business or organization consultancy" to be the origin their ideas reported improvements in "reduction of energy consumption" for their new products, but there were no cases of improved "reduction of health risks" or "easiness to maintain or retrofit". This result again suggests that companies are directed towards introducing green improvements in their new products that can be directly perceived by their customers or consumers, and "reduction of health risks" or "easiness to maintain or retrofit" are likely still not as directly perceived, appreciated or demanded by consumers in the countries analyzed. Regarding firms declaring a product improvement in "recycling, redemption or disposal properties", 74% obtained impulses/ideas from customers or users and in no cases from suppliers. This result seems to be comprehensible and it underlines the power of customers and consumers to force changes in companies when considering a greener product innovation.

A total of 70% of GPI declaring that their new products ”extend product lifetime” get ideas from “R&D/engineering”. Slight differences appear between the two groups of product innovators when analyzing drivers for product innovation in the case of external origins or impulses for innovation. However, these become more significant in the case of the internal origins: “Production” (41% for GPI vs. 27% for CPI), and the opposite, “R&D/engineering” (19% for GPI vs. 29% for CPI).

Only some GPI have implemented a certified energy system EN IS 50004 (27%). These kinds of environmental management systems do not seem to be a driver of green product innovation, despite none of the CPI implementing them.

When clustering product innovators according to their main competitive strategy, interesting differences can be detected that remained hidden when analyzing the whole set of companies together. It has been observed than GPI in the cluster “customization” mainly obtain their ideas/impulses from R&D/Engineering and subsequently from customer services or directly from customers or users. Differently, in the case of CPI they receive the impulses first from customers and users and second from R&D or engineering departments.

In the case of product innovators competing by price, both CPI and to a lesser degree GPI first obtain the ideas/impulses from R&D/engineering. However, GPI then obtain the impulse directly from customers or users. This means that customers play an important role in driving companies to produce new greener products.

In companies were innovation is the main competitive factor, the origin of ideas/impulses for innovation is first customers and users and second CEO/management, just for GPI. This reveals the importance of management in driving green product innovation as a desirable option based not only on economic performance.

Chapter 11 Conclusions

This chapter restates the main findings of the thesis in relation to their implication for each aspect of the quadruple helix. A section focusing on each of the stakeholders in this quadruple helix is presented below.

At the end of the chapter, there are also sections for limitations and future research suggestions.

11.1 Implications for Manufacturing Companies

The studied manufacturing companies must know that they can still increase the use or reach a high use of EST/MST. Our society is demanding the implementation of greener practices and greener new products. Social responsibility is increasingly featuring in companies' agendas. However, implementation of these green technologies can involve costs that affect a firm's profit. Since industry is the second most responsible for the world's energy consumption after transportation, this sector has the social duty not only to increase efforts to this effect, but also to pressure policy makers to help when they implement greener solutions in their processes or when they innovate in new greener products.

11.2 Implications for Academia

Manufacturing companies are being pressurised by stakeholders to adopt cleaner, sustainable practices, creating the need to understand how issues like energy efficiency or EST/MST use and extent of use impact on firm's economic and environmental performance. Large-scale manufacturing sector surveys such as the EMS can provide empirical evidence for academia if they include sections asking the pertinent questions in an appropriate way. It is important that these evidences not only include the use of green practices, but they also allow the extent of this use to be observed. The inclusion of the same questions or variables in different survey editions and for the whole group of participating countries would allow cross-country studies to be conducted and the evolution of these practices over time to be observed.

11.3 Implications for policymakers

Some conflict appears to exist between social requirements for a greener world or for energy saving and firms' orientation towards economic profit. Policy makers need to address this conflict with suitable actions. This thesis provides new evidence that actions oriented to improving energy efficiency in manufacturing firms such as implementing EST/MST are directly related to environmental performance. Consequently, helping or conditioning manufacturing firms to move in this direction is a good way to accomplish their environmental agenda due to their immediate effects on energy efficiency improvements.

Regarding green product innovation, policymakers have two clear roles, the first as consumers themselves and the second as regulator and facilitator of best practices implementation. Policymakers are often big consumers and they can be an example for society by demanding greener products, helping to produce changes in increasing numbers of conventional innovators towards green product innovation. As regulators and facilitators, this thesis provides new clues for detecting drivers for GPI and for differentiating characteristics of manufacturing companies producing this special kind of innovations. This new knowledge can help policymakers to plan more efficient actions to expand GPI across the whole industry.

11.4 Implications for society, users and consumers

The present work provides society with an explanation as to why manufacturing companies are not implementing all the available energy- and material-efficiency technologies to the maximum degree, given that no positive relationship was detected between their implementation and firms' economic profit. Citizens cannot generally control the technologies or processes used by manufacturing companies producing the products they will consume. However, users must know that it is commendable that these firms implement desirable green technologies on their own initiative when policymakers are neither facilitating or regulating them.

Regarding GPI, consumers have enormous power to demand increasingly green products. This study provides quantitative data indicating that not all new product innovators are including improvements in environmental impact when using or disposing them. People, as consumers and citizens, play an important role in deciding what kind of products they want to consume and what kind of actions they want policymakers to promote.

11.5 Limitations

The main limitations of this research can be summarized under three main points: 1) limited geographical coverage, 2) methodological issues regarding questionnaire items and performance measures, and 3) the absence of previous data using the same source (EMS).

Even when combining the data for several countries both the absolute number of responses and the percentage response rate is relatively low. The inclusion of other countries' data using the same questionnaire would further enrich the analysis. Furthermore, the study of the evolution of these results over time was complicated by the new editions of the EMS incorporating neither the same technologies nor the same questions, impeding direct comparisons.

With reference to methodological aspects, it should first be mentioned that EST and MST were chosen on the advice of specialized experts in the field. Difficulties arise from the fact that a firm's economic sector of activity is an important determinant. Given that the target companies belong to the manufacturing sector, some general technologies had to be defined and included in the questionnaire. The priority selection criterion was that these technologies were expected to be found in manufacturing firms of any size or sector of activity. This fact has an immediate consequence: generic technologies often leave room for wide interpretation on the part of respondents.

Another issue related to respondents' interpretation is performance, both economic and in terms of energy efficiency. In the suggested analysis a calculated variable for ROS was included to mitigate this effect. While EST and MST can be distinguished, the perception of efficiency tends to blur this distinction. Future analyses should explore differentiated efficiency trends.

For the first time in 2012 the European Manufacturing Survey included energy- and material-saving technologies in a pan-European harmonized questionnaire targeting the manufacturing sector. The lack of previous data using the same source and the divergence of methodological aspects encountered in other studies make it difficult to compare the results with those of previous or similar studies.

11.6 Future developments

Descriptive analyses and correlation tests were used to map characteristics of energy efficient technologies and their adopters, but several advanced statistical methods could be used in the future to draw further conclusions (e.g. linear regression for quantitative independent variables and ordinal logistic regression)

The narrow geographical coverage in this research could be widened through the study of country subsamples of the EMS. Additional cross-country analyses could also provide an interesting perspective, revealing differences between groups of countries or even cultural or political aspects that influence the obtained results. The same study could be expanded to include ten countries, evaluating country effects considering their different environmental policies and green cultures. Within the framework of a wider sample, a variable for the extent of implementation of green product innovations that captures different degrees of greenness and not only green and non-green companies could be computed. Models testing relationships between drivers/barriers, company characteristics and green product innovation and/or performance could also be studies in future works.

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Short biography

Marc Pons is a freelance telecom engineer (UPC & U.Paris X) and a part-time assistant lecturer in the Department of Business Administration and Product Design at the University of Girona (Catalonia). He has a post-graduate diploma in Telecommunications Infrastructures and he holds several masters: MBA (UB-UAB-UPC), Business Innovation and Technology Management (UdG) and Tourism Management and Planning (UdG). As part of his PHD research, he has investigated in the field of green manufacturing, green product innovation and energy efficiency, the results of which have been published in international journals such as Journal of Cleaner Production and in InTech books. He has experience in the private sector in Spain and abroad as an engineer (MATRA-Aerospatiale-EADS). He is also familiar with the public sector not only as a provider of systems and solutions, but also as a board member of public companies (FISERSA) and professional organizations. He is currently the CEO in Global Virtus Energy, SL (LUMINA®), an electrical energy trading company located in Empuriabrava (Catalonia).