STRUCTURAL ANALYSIS OF ELECTRICITY CONSUMPTION BY MANUFACTURING SECTORS. THE SPANISH CASE

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Abstract

The aim of this paper is to identify those sectors that contribute most to electricity consumption in Spain, using a methodology based on input-output tables, and to derive some recommendations aimed at increasing energy efficiency in those sectors. This input-output approach is complemented with a sector-focused study in which we identify the availability of electricity-efficient technologies per sector and the barriers to their uptake. This hybrid approach is deemed very useful to derive policy implications. We thus propose several instruments to remove those barriers

Key words: Electricity consumption, Input-output, energy efficiency.

JEL codes: C0, Q4

1. Introduction

The benefits of increased energy efficiency (EE) are commonly acknowledged and include climate change mitigation, increased productivity and international competitiveness, positive employment effects, creation of business opportunities, reduction in energy dependence and thus improvement in energy security and reduced local and global air pollution. In industry, co-benefits arise through reduced emissions of pollutants and waste production, increased production/product quality, reduced maintenance and operating costs, an improved working environment, improved public image and worker morale and lower capital expenditures (IPCC 2007b, Ürge-Vorsatz and Metz 2009).

These benefits have been acknowledged by several countries. One of the objectives of the EU climate change package, presented by the Commission in 2007 and recently approved, is to realise a 20% EE improvement by 2020[1]. Realising this EE potential requires the introduction of good new EE policies (Harmelink et al 2008).

The aim of this paper is to identify the "key" sectors that contribute most to electricity consumption in Spain, using a methodology based on input-output tables. This input-output approach is complemented with a sector-focused study. For each "key" sector, we identify the availability of electricity-efficient technologies, the barriers to their adoption and policies to increase EE in those key sectors.

Accordingly, the paper is organised as follows. The following section develops the methodology based on an input-output approach and describes the data used in this analysis. The main results of the application of this methodology to the Spanish case are discussed in section 3. Section 4 complements this approach with a sector-focused analysis of electricity-efficient technologies and barriers to their uptake which allows us to infer some policy recommendations (section 5). Section 6 discusses the limitations of this exercise and provides some suggestions for further research.

2. Methodology and data

Since the pioneering work of Leontief (1941), the economic analysis based on input-output has followed two major albeit complementary streams in order to overcome the limitations of the information provided by the input-output. One of the stream has tried to increase the complexity of the basic structure by adding complementary information. The other stream has focused on the manipulation of the central matrix in the model with the aim to highlight already existing information which was not liable to be captured without a specific treatment.

Our methodological approach follows the first approach, i.e., it is based on the input-output analysis of the environmental and energy impacts of economic activities. This is done by adding to the conventional input-output table a matrix or vector which, for each sector and activity branch, picks up the magnitude of the variable which is liable to be impacted[2]. In our case this variable is the final electricity consumption in the production of 118 products. Our input-output approach allows us to link a vector of direct electricity consumptions to a symmetrical input-output table *good by good*. The aim is to show the structural relationship between productive activities and final electricity consumption in order to identify the key sectors regarding electricity consumption in Spain.

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[1] The Commission will assess in 2012 the progress of the Member States towards the 20% target and could, eventually propose measures to accelerate EE improvements.

[2] Leontief himself used this kind of model (Leontief and Ford 1972).

The *good by good* input-output table has been obtained from the 2004 origin-and-destiny tables published by the National Statistical Office (INE) in Spain[3]. The information on electricity consumption stems from OCDE Energy Balances (2008).

In the following paragraphs, vectors will be defined as column-vectors, the transposition will be indicated by (`) and the expression of a vector as a diagonal matrix (diagonalisation) will be represented by (^).

Let **e** be the vector (n x 1) of direct electricity consumption which is necessary for the production of the *n* goods that make up the productive system and let **x** be the vector (n x 1) of production by sectors. The vector of sector intensities in the use of electricity would be calculated as follows:

(1) $$\mathbf{w}' = \mathbf{e}' \hat{\mathbf{x}}^{-1}$$

where **w**′ is the vector (1 x n) of intensities, whose element w_i represents the electricity consumption required for the production of a monetary unit of good *i*.

From equation (1) we can deduce that:

(2) $$\mathbf{e} = \hat{\mathbf{w}}\,\mathbf{x}$$

If **x** is substituted in (2) by its value in the Leontief model, then:

(3) $$\mathbf{e} = \hat{\mathbf{w}}\left(\mathbf{I}-\mathbf{A}\right)^{-1}\mathbf{y}$$

where **y** is the vector (*nx1*) of final production (final demand) and $(\mathbf{I} - \mathbf{A})^{-1}$ is the inverse Leontief matrix (n x n). Note that $\hat{\mathbf{w}}\left(\mathbf{I}-\mathbf{A}\right)^{-1}$ is a lineal operator which transforms final production into electricity consumption. To simplify,

(4) $$\mathbf{W} = \hat{\mathbf{w}}\left(\mathbf{I}-\mathbf{A}\right)^{-1} = (W_{ij})_{\mathrm{n\,x\,n}}$$

The characteristic element in the previous matrix shows the impact of a variation in the final demand of good j on the electricity consumption of good i. Therefore, the sum of any column of matrix **W** (say, j) would give us the total intensity, direct and indirect, per unit of final product of good *j*. And for all goods we would have:

(5) $$\boldsymbol{\varepsilon}'_y = \mathbf{u}'\mathbf{W}$$

where **u** is a vector of the appropriate dimension and ε_y is the vector of total intensities. In reality, this last vector shows the multiplier effect on electricity consumption derived from the final demand for goods (known as *backward linkages* in the literature). This vector expresses the backward-linkage effects which correspond to those of Rasmussen (1956) and Hirschman (1958).

The ε_y multipliers are not scaled-up. In reality, they are multipliers or total potential intensities. From an ex-post analytical perspective, the greater or lower relevance of those multipliers depends on the share of each good in the final demand vector. We thus need to define a new vector of indicators that shows the degree of impact of the consumption of the different goods on electricity consumption at a given moment. Thus, if $\tilde{\mathbf{y}}$ is the vector of the share of the different goods in the total, then $\sum_j \tilde{y}_j = 1$ and the new indicators would be given by:

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[3] See INE's website at: http://www.ine.es.

(6) $\mu'_y = \mathbf{u}'\mathbf{W}\hat{\tilde{\mathbf{y}}}$

Note that, for any good, $\mu_{j,y}$ represents the total electricity consumption of industry *j* per unit of total final demand (GDP). Obviously, the sectoral distribution of this electricity consumption per sector takes place for the goods that are inputs of industry j. Thus,

(7) $\mu_{j,y} = \sum_{i=1}^{n} W_{ij}\tilde{y}_j$

The elements $W_{jj}y_j$ represent the impact of the production of a unit of final demand on the electricity consumption of sector j itself. We can thus decompose the impact of final demand of any good into two effects, the "own backward effect" given by:

(8) $\mu^P_{j,y} = W_{jj}\tilde{y}_j$

and a "pure backward effect":

(9) $\mu^B_{j,y} = \sum_{i \neq j} W_{ij}\tilde{y}_j$

In other words, there are two backward effects.

Similarly, it is possible to obtain the supply multipliers from the inverse matrix defined by Ghosh (1958)[4]. This approach is symmetrical to the demand perspective, although from a supply perspective we use the distribution coefficients and not the Leontief technical coefficients. From the inverse Leontief matrix, the calculation of the Ghosh inverse matrix is immediate (Miller and Blair 1985):

(10) $(\mathbf{I} - \mathbf{D})^{-1} = \hat{\mathbf{x}}^{-1}(\mathbf{I} - \mathbf{A})\hat{\mathbf{x}}$

where **D** is the matrix of distribution coefficients. The characteristic element of this matrix expresses the share of the production of good *i* used in the production of good *j*. The Ghosh model adapted to our energy analysis would be:

(11) $\mathbf{e}' = \mathbf{v}'(\mathbf{I} - \mathbf{D})^{-1}\hat{\mathbf{w}}$

where **v** is the vector of primary inputs for each of the *n* goods.

(12) $\mathbf{Z} = (\mathbf{I} - \mathbf{D})^{-1}\hat{\mathbf{w}} = (Z_{ij})_{\mathrm{n\,x\,n}}$

The matrix **Z** is another lineal operator, although from an output perspective. The characteristic element in the Z_{ij} matrix shows electricity consumption in the production of good *j* per unit of good *i* produced.

The sum of any row *i* of this matrix will give us the total impact (direct and indirect) on electricity consumption due to the production of a unit of good *i*.

For all goods, we can define a vector of multipliers from a supply perspective, as done before from a demand perspective:

(13) $\boldsymbol{\varepsilon}_v = \mathbf{Z}\mathbf{u}$

This set of multipliers is known in the literature as *forward linkages*. However, as with the demand multipliers, these are "potential multipliers". Therefore, from an ex post perspective, these multipliers have to be weighted according to the share of the different goods in the final production. In this case, we define a vector $\tilde{\mathbf{v}}$ which shows the

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[4] The original proposal is by Jones (1976) and has been adapted to the analysis of environmental impacts by Alcántara (1995 and 2007).

proportion of primary inputs that is needed in the different goods, so that $\sum_i \tilde{\mathbf{v}}_i = 1$. Thus, the new indicators of the impact of production on electricity consumption will be:

(14) $\boldsymbol{\mu}_v = \hat{\mathbf{v}}\mathbf{Z}\mathbf{u}$

In a similar vein to the demand model, for any good, the indicator tells us the amount of total electricity (direct and indirect) consumed by the producer sector per unit produced (GDP).

As in the case of demand, we can decompose this impact into two effects. A own effect which would be given by:

(15) $\mu_{i,v}^P = Z_{ii}\tilde{v}_i$

And a pure forward effect which can be calculated as follows:

(16) $\mu_{i,v}^F = \sum_{j \neq i} Z_{ij}\tilde{v}_i$

Key sectors

Once the indicators of the impact on electricity consumption have been determined (both from a supply and demand perspective), the relevance of the different goods in electricity consumption has to be identified. The easiest way to do it is to build an "average indicator", which would be equivalent from both the supply and demand sides, i.e..:

(12)

$$\mu = \frac{\boldsymbol{\mu}_v \mathbf{u}}{n} = \frac{\boldsymbol{\mu}_y \mathbf{u}}{n}$$

The comparison of the different indicators per good, both from a demand and a supply perspective, with respect to the average would lead us to the following classification in table 1.

Table 1. Classification of indicators.

	SUPPLY INDICATORS		
DEMAND INDICATORS		$\boldsymbol{\mu}_{v,i} > \mu$	$\boldsymbol{\mu}_{v,i} < \mu$
	$\boldsymbol{\mu}_{y,j} > \mu$	Key goods	Demand-push goods
	$\boldsymbol{\mu}_{y,j} < \mu$	Supply-push goods	Rest of goods

However, from an energy policy perspective, greater insight on each sector should be obtained, because a given policy will not be equally valid for a sector with a high own effect than for those sectors with low own effects but high pure effects (both backward and forward).

Technically, each effect can be defined as follows.

Table 2. Explaining the backward and forward (own and pure) effects.

	OWN	PURE
BACKWARD	How variations in the final demand for the products of a sector affect electricity	How variations in the final demand for the products of a sector affects electricity

	demand in the sector itself i (demand) → i (EC)	consumption in other sectors. i (EC) ← j (demand)
FORWARD	How variations in the production of a sector affect electricity consumption in the sector itself i (production)→ i (EC).	How variations in the production of a sector affect electricity consumption in other sectors i (production) → j (EC)

EC = Electricity consumption

3. Main results

Expressions (6) and (14) have been computed in order to determine the key goods/sectors, following the criteria in table 2. The results are shown in table 3.

Table 3.- Key sectors or goods.

1	Agricultural products
12	Coke and oil refining
13	Production and distribution of electricity
32	Basic chemical products
34	Pharmaceutical products
35	Other chemical products
42	Metallurgy
43	Metal products
46	Other machinery
65	Trade and repair of motor vehicles.
67	Wholesale trade
68	Retail trade
71	Rail transport services
82	Telecommunication services
86	Real-state services
95	Technical consultancy in architecture and engineering.
100	Public administration
102	Education services.

We thus characterise those goods from both a demand and a supply perspective.

The calculation of (8), (9) and (6) leads to the following information on key goods/sectors from a demand perspective (table 4).

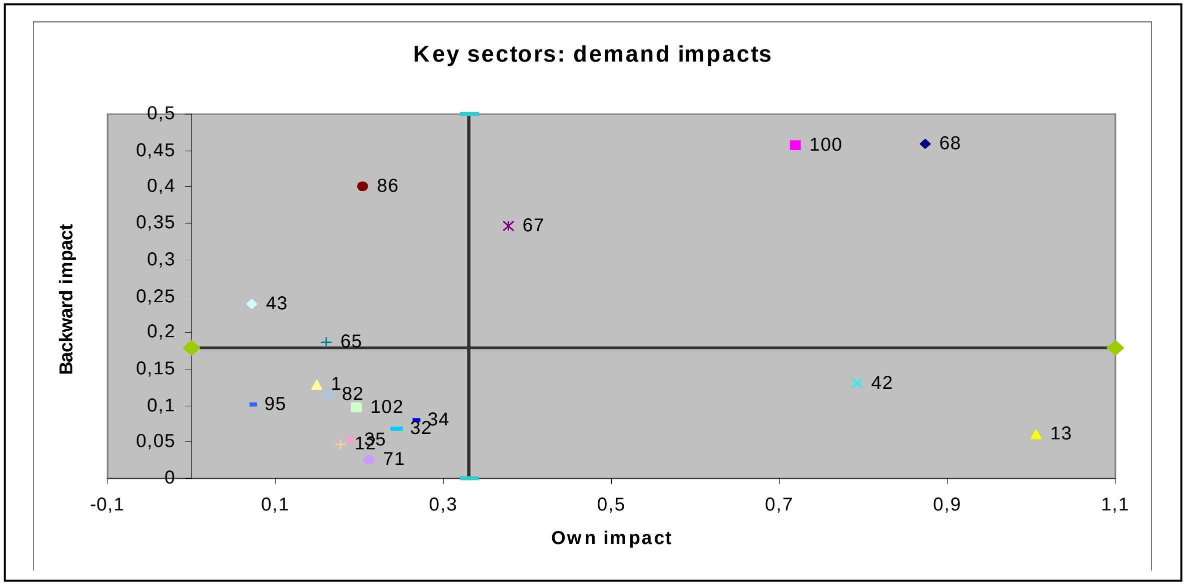
Table 4.-Key sectors from a demand-side perspective.

	Code	**Multipliers**			**Electricity consumption (toe).**			
Goods		**Total**	**Own**	**Pure**	**Direct**	**Total**	**Own**	**Pure**
Retail trade	**68**	1,33167	0,87309	0,45859	914.751,2	1.247.756,5	818.069,0	429.687,5
Public administration	**100**	1,17648	0,71974	0,45674	674.386,4	1.102.343,8	674.386,4	427.957,3
Electricity generation	**13**	1,06663	1,00597	0,06067	3.323.000,0	999.418,2	942.575,7	56.842,5
Metallurgy	**42**	0,92168	0,79204	0,12964	2.475.000,0	863.599,5	742.127,7	121.471,8
Wholesale trade	**67**	0,72263	0,37715	0,34548	646.684,6	677.094,5	353.383,7	323.710,8
Real-state services	**86**	0,60497	0,20418	0,40079	268.953,5	566.847,8	191.311,3	375.536,6
Trade and repair of vehicles	**65**	0,34629	0,15959	0,18670	228.879,6	324.472,3	149.538,1	174.934,2
Pharmaceutical products	**34**	0,34273	0,26332	0,07942	278.489,5	321.137,2	246.723,3	74.413,9

Basic chemical products	**32**	0,31229	0,24357	0,06871	435.952,0	292.609,4	228.225,6	64.383,8
Metal products	**43**	0,31094	0,07184	0,23909	286.483,8	291.343,4	67.317,3	224.026,1
Other machinery	**46**	0,29805	0,07245	0,22560	124.963,8	279.267,4	67.887,5	211.379,9
Education services	**102**	0,29227	0,19548	0,09679	183.158,3	273.849,7	183.158,3	90.691,4
Agricultural products	**1**	0,27768	0,14858	0,12910	267.491,4	260.182,5	139.220,5	120.962,0
Telecommunication services	**82**	0,27692	0,16156	0,11536	360.824,4	259.469,5	151.377,4	108.092,1
Other chemical products	**35**	0,24250	0,18952	0,05297	395.474,8	227.214,9	177.580,1	49.634,8
Rail transport services	**71**	0,23694	0,21125	0,02569	279.393,9	222.013,1	197.941,6	24.071,5
Coke, oil refining.	**12**	0,22471	0,17751	0,04720	289.000,0	210.552,9	166.325,6	44.227,4
Technical consultancy on architecture and engineering.	**95**	0,17270	0,07071	0,10199	118.435,6	161.816,8	66.250,2	95.566,6
Consumption of electricity					11.551.322,7	8.580.989,5	5.563.399,3	3.017.590,2
% share over total electricity consumption in the economy					62,1	46,2	29,9	16,2

Figure 1, which plots the main results in table 4, illustrates the importance of the different sectors with respect to the own and pure backward effects. Four groups of sectors can be distinguished: 1) sectors with high pure backward effects but low own backward effects; 2) high own but low pure backward effects; 3) high pure and own backward effects; 4) low pure and own backward effects.

Figure 1. Plotting key sectors on the demand side (own and pure backward effects).



Similarly, we identify the sectors according to their respective effects on the supply-side (table 5). Figure 2 plots the main results in table 5 and illustrates the degree of importance of the different sectors with respect to the own and pure forward effects.

Table 5.- Key sectors from a supply-side perspective.

	Code	Multiplier			Electricity (TOE)			
		Total	Own	Pure	Direct	Total	Own	Pure
Production of electricity	**13**	2,38198	2,11984	0,26213	3323000,0	2.231.875,5	1.986.259,4	245.616,1
Metallurgy	**42**	1,37563	1,23529	0,14034	2475000,0	1.288.946,4	1.157.449,8	131.496,6

Wholesale trade	**67**	0,90299	0,43734	0,46564	646684,6	846.084,5	409.783,3	436.301,1
Retail trade	**68**	0,69871	0,64348	0,05523	914751,2	654.676,9	602.927,3	51.749,5
Coke and oil refining	**12**	0,69623	0,27038	0,42585	289000,0	652.357,4	253.343,1	399.014,3
Metal products	**43**	0,64890	0,18376	0,46515	286483,8	608.010,5	172.175,9	435.834,6
Real-state services	**86**	0,63805	0,21074	0,42731	268953,5	597.838,7	197.459,1	400.379,6
Public administration	**100**	0,54226	0,54226	0,00000	674386,4	508.087,2	508.087,2	0,0
Basic chemical products	**32**	0,52789	0,31030	0,21759	435952,0	494.621,6	290.746,9	203.874,7
Telecommunication services	**82**	0,50016	0,25809	0,24207	360824,4	468.644,6	241.826,0	226.818,6
Other chemical products	**35**	0,37964	0,28209	0,09755	395474,8	355.719,4	264.316,0	91.403,4
Agricultural products	**1**	0,31268	0,18436	0,12833	267491,4	292.979,4	172.739,4	120.239,9
Other machinery	**46**	0,27368	0,07646	0,19722	124963,8	256.430,4	71.640,2	184.790,2
Trade and repair of vehicles	**65**	0,22170	0,12946	0,09223	228879,6	207.724,8	121.303,7	86.421,1
Rail transport services	**71**	0,20420	0,19167	0,01253	279393,9	191.330,6	179.593,4	11.737,1
Pharmaceutical products	**34**	0,20129	0,19547	0,00582	278489,5	188.602,1	183.149,4	5.452,6
Technical consultancy in architecture and engineering.	**95**	0,18700	0,07737	0,10962	118435,6	175.211,6	72.499,0	102.712,6
Education services	**102**	0,18001	0,18001	0,00000	183158,3	168.666,3	168.666,3	0,0
Total consumption of the above sectors					11.551.322,7	10.187.807,8	7.053.965,7	3.133.842,1
% share over total electricity consumption in the economy					62,1	54,8	37,9	16,9

Figure 2. Plotting key sectors on the supply side (own and pure forward effects).

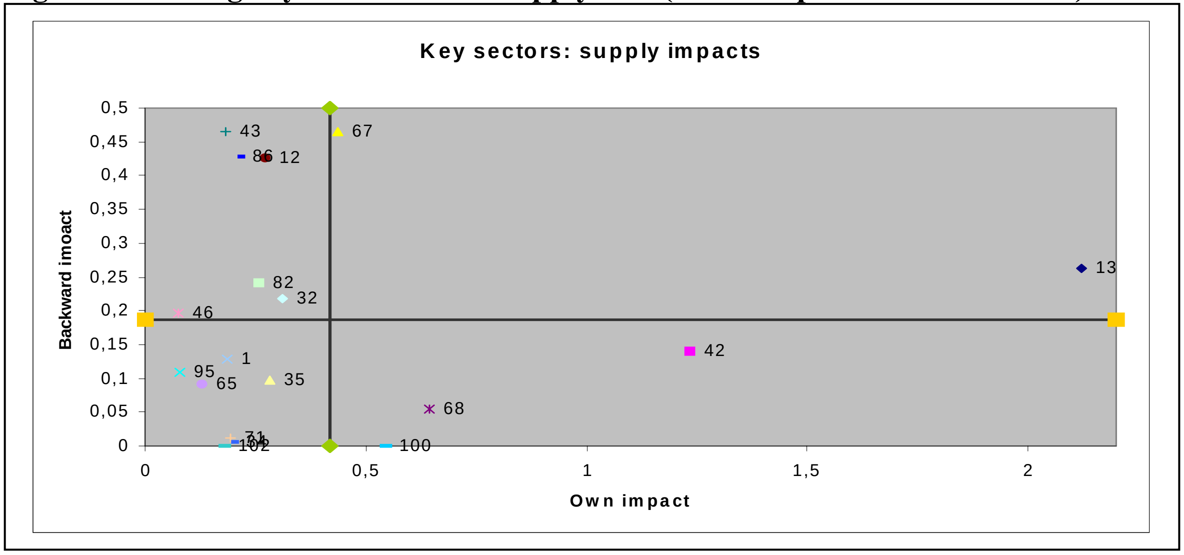


Table 6 classifies the key sectors according to the strength of the different effects.

Table 6. Classifying the backward and forward (own and pure) effects.

	OWN	**PURE**
BACKWARD	Electricity generation, Metallurgy, retail trade, public administration,	Metal products, other machinery, wholesale trade, retail trade, real-state services
FORWARD	Oil refining, Electricity generation, Metallurgy, public administration,	Electricity generation, metal products, wholesale trade, real-state services real-state services

EC = Electricity consumption.

The considered key sectors represent about 62% of direct electricity consumption. The results show the relevance of the electricity generation sector itself, some industrial sectors and the tertiary sector (trade and other services) in electricity consumption. The public administration also plays a relevant role in this regard.

The results of this exercise suggest that policy measures should be adopted in those sectors with either a high own backward, own forward or pure forward effect in order to reduce electricity consumption. In contrast, measures to reduce electricity consumption would not be effective in sectors with a high pure backward effect because these sectors are not directly responsible for electricity demand. In this case, other sectors demand products from these sectors with a high own backward effect and, thus, these other sectors are responsible for electricity demand (i.e., measures should be adopted there to reduce electricity demand).

However, the results of the exercise do not allow us to identify the instruments that should be applied in which sector, i.e., it does not allow us to select a specific measure. This is due to the method chosen, although other methods (CGE models) would be as useful as this one in this regard. Thus, we have complemented the above analysis with an identification of the technologies which could reduce electricity consumption in the key sectors.

Therefore, in sections 4 and 5 we focus on those sectors with high pure backward and forward (own and pure) effects, identifying the available technologies, the barriers to their uptake and the policy measures (if needed) to encourage their development and/or adoption.

4. Complementing the input-output approach: a sector-focused approach on electric efficient technologies and barriers.

For each sector, the main technological alternatives for reduction of electricity demand are identified, with a focus on Spain. The methodology is based on an extensive overview of the (international) literature on technologies which reduce energy use or CO2 emissions in the different sectors[5].

Since the identification of those technologies is very general, we have tried to identify the technologies would be more suitable to reduce electricity consumption in Spain, given its specific socioeconomic and climatic conditions[6]. We rely on secondary sources and, particularly, the background sectoral analysis carried out in the context of the Spanish Energy Efficiency Strategy (E4). This approach has some caveats, which are discussed at length in the concluding section.

The main barriers to the adoption of these technologies are further identified in each sector. The instruments to tackle those barriers are discussed in section 5.

4.1. Availability of electricity efficient technologies in different sectors.

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[5] A filtering exercise has been undertaken, since we are only interested in those cross-sectoral and sector-specific technologies which reduce electricity consumption, and not energy or CO2 emissions generally.

[6] For example, in the building sector, climatic conditions influence the appropriateness of application of certain electricity efficient technologies. In colder climates, the electricity efficiency of air conditioning is hardly an issue, whereas in those countries (like Spain) with warm summers, it is certainly important. The discussion on the most appropriate technologies in this sector in IPCC Fourth Assessment Report (IPCC 2007) is based on two criteria: 1) whether countries have a cold or a warm climate; 2) whether they are developed or developing countries. As a developed country with a warm weather, Spain can be expected to show some special features which are relevant for the discussion of which electricity efficient technologies are more suitable.

4.1.1. Industry

Electricity provides most of the energy for electrochemical, machine drive, and heating, ventilation, and air conditioning (HVAC) services in industry (Edmonds et al 2007). Electricity consumption represents a large share of total energy use[7].

Although industry is relatively efficient compared to other sectors, there is still a significant untapped world-wide potential for EE improvements in industry based on BATs[8].

Electricity-efficient technologies in industry are available at, both, the cross-sectoral and subsector level[9]. Regarding the former, more efficient end-use electrical equipment, power recovery and efficient electric motor driven systems provide a large potential for improvement of industry-wide energy efficiency[10]. Motor-driven systems account for 65% and 63% of electricity consumed by EU-25 and U.S. industry, respectively (IPCC 2007a, De Keulenaer *et al*., (2004), Xenergy (1998), IEA 2008a)[11] and could save up to 202 TWh/yr of energy consumption (30%) and 100 TWh/yr in the EU-25 and U.S., respectively. Efficient high-pressure boilers, optimisation of furnaces and process heaters and energy recovery are other cross-sectoral electricity-efficient alternatives[12]. The following subsections discuss the electricity-efficient technologies available in the "key" sectors.

4.1.1.1. Oil refining.

Oil refining is an energy-intensive industrial activity with an inherent incentive to save energy. However, increases in oil consumption for transport worldwide and the shift towards heavier crude and lower sulphur products will increase refinery energy use.

In Spain, electricity consumption represents a small share of total energy use, between 4 and 15% (excluding cogeneration), whereas thermal uses of energy account for the rest (own

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[7] Electricity represented in 2005 almost 1/5 of energy use in the industrial sector world-wide (IEA 2008a).

[8] According to IEA (2006), the energy intensity of most industrial processes is at least 50% higher than the theoretical minimum determined by the laws of thermodynamics. Manufacturing industry can improve its EE by 18% to 26% based on proven technology (IEA 2008a), although this estimate does not consider the economics of such change. Cross-cutting technologies for motor and steam systems would yield efficiency improvements in all industries, with typical energy savings in the range of 15% to 30%. The payback period can be as short as two years.

[9] In addition to sector-wide approaches and process-specific technologies to reduce electricity consumption in industry, a third alternative is application of housekeeping and general maintenance on older, less-efficient plants. According to Worrell (2009), these can yield energy savings of 10–20%.

[10] The efficiency of motor-driven systems can be increased by reducing losses in the motor windings, using better magnetic steel, improving the aerodynamics of the motor, and improving manufacturing tolerances. However, maximizing efficiency requires properly sizing of all components, improving the efficiency of the end-use devices (pumps, fans, etc.), reducing electrical and mechanical transmission losses, and the use of proper operation and maintenance procedures (Worrell 2009).

[11] According to IEA (2008a), electric motor-driven equipment such as compressors, pumps or fans account for 60% of the electricity consumed in the industrial sector and for more than 30% of all electricity use. Improved motors could save significant amounts of energy on a continual basis. Optimisation of motor systems can typically result in 20% to 25% efficiency gains. It is estimated that up to 7% of global electricity demand could be saved if the EE of motors and their related drive systems were to be cost-optimised. In Europe alone, studies suggest that the implementation of EE options for motors could result in 29% savings. The total investment cost of such a programme would be USD 500 million, while the annual saving would amount to USD 10 billion (Keulenaer, *et al.*, 2004). The electricity demand of industrial motor systems can be reduced by using high-efficiency motors, proper sizing of the motor to the load requirements, using adjustable speed drives (ASDs) to match speed and torque to the load requirements, replacing inefficient throttling devices and/or simplifying (or even avoiding) wasteful mechanical transmissions, optimising systems, proper maintenance and repair, maintaining acceptable levels of power quality. The efficiency of motor-driven systems can be increased by improving the efficiency of the electric motor through reducing losses in the motor windings, using better magnetic steel, improving the aerodynamics of the motor and improving manufacturing tolerances.

[12] Power can be recovered from processes operating at elevated pressures using even small pressure differences to produce electricity through pressure recovery turbines (Worrell 2009).

calculation from MINECO 2003a)[13]. Several technologies to reduce energy use in general and electricity consumption in particular have been identified in background documents for the E4 (MINECO 2003a). Their pay-back period is less than 10 years and they can be grouped into horizontal technologies (applicable across all the oil-refining production processes) and process-specific technologies. In addition, other alternatives are still in the R&D stage (table 7).

Table 7. Electricity-efficient technologies in the oil-refining sector.

Category	Specific technologies
Horizontal	-Steam networks -Cooling systems -Torch networks -Steam management
Productive processes	-Compressors and turbines
Technologies in the R&D stage.	- Better catalysts. - Assessment of optimal operation conditions. - Simulation of operations for their later analysis - Process control - New lubricants - Improvement in the properties of fuels. - New product applications.

Source: Own elaboration from MINECO (2003a).

4.1.1.2. Metallurgy (non-ferrous) metals.

A relevant distinction in this sector is between non-ferrous metals and iron and steel. This subsection focuses on the non-ferrous metals sector[14].

Electricity consumption represents about 2/3 of energy consumption in the non-ferrous metal subsector (70% for aluminium production). Aluminium production, which dominates this sector, is a highly electricity-intensive activity and, thus, producers have a great incentive to search for locations with low electricity prices. Options to reduce the energy-intensity of aluminium production include smelter retrofit, conversion, or replacements, a further penetration of state-of-the-art, point feed, prebake smelter technology and process control plus an increase of recycling rates for old-scrap (IPCC 2007a)[15].

Table 8 lists the technologies that have been identified to reduce electricity consumption in the Spanish non-ferrous sector with a pay-back period of less than 10 years (MINECO 2003b).

Table 8. Electricity-efficient technologies in the non-ferrous sector.

Category	Specific technologies
Horizontal	-Installation of steam meters, compressed air. -Metering and control of consumption of electricity consumption. -Eliminate peak hours. -Improvement in lighting equipment.
Productive processes	-Improvement in the quality of anodes and cathodes.

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[13] Notwithstanding, all production processes which are part of the oil refining business involve electricity consumption (MINECO 2003a).

[14] In Spain, aluminium represents 2/3 of the overall physical production (in tonnes of product) of the non-ferrous metals subsector. It represents half of the world CO2 emissions of the subsector (IPCC 2007a).

[15] The industry plans to retrofit or replace existing smelters in order to reduce electricity consumption to 14 500 kWh per tonne in the short term (from the current world average of 15194), and then to 14 000 kWh to 13 500 kWh per tonne as new smelters are built and older ones are retired. New world-class plants achieve 13 000 kWh per tonne (IEA 2008a). Technologies under development such as drained cells (drained cathodes) and inert anodes offer the promise of further smelter efficiencies (IEA 2008a).

	-There is a large energy saving potential in scrap recovery (aluminium, copper and zinc).

Source: Own elaboration from MINECO (2003b).

4.1.1.3. Metallurgy (iron and steel).

The iron and steel sector is the second-largest industrial consumer of energy in the world. In 2005, it accounted for 20% of world industrial energy use (IEA 2008a).

Steel is produced through a dozen processing steps, which are carried out in various configurations depending on product mixes, available raw materials, energy supply and investment capital. The most EE production route is the scrap/electric arc furnace (EAF) route (IEA 2008a).

Planned EE improvements include greater use of continuous casting and near-net shape casting, injection of pulverized coal, increased heat and energy recovery and improved furnace technology (IPCC 2007a, Worrell 2009).

In Europe, blast furnace improvements constitute the single most important category for EE improvements. The considerable differences in the EE of primary steel production which exist among countries and individual plants can be explained by economies of scale, the level of waste energy recovery, the quality of iron ore, operations know-how and quality control (IEA 2008a).

Two factors facilitate the reduction of electricity consumption in this sector: the significant share of electricity in its cost structure (7% in Spain) and the fact that the EAF is already part of the baseline. However, electricity consumption (ktoe) per tonne of product has remained constant in the last years. The large investments in equipment goods carried out and the slow rate of capital turnover make further improvements costly and difficult to achieve.

Regarding electricity-efficient technologies in this subsector, a relevant distinction is between iron and steel making and iron and steel casting. Concerning the former, the variation in the structure of steel production and the greater weight of the non-integral iron and steel making process are key (non-technological) measures. Table 9 lists the technologies in the iron and steel casting subsector.

Table 9. Electricity-efficient technologies in the iron and steel casting sector.

Category	Specific technologies
Horizontal	1 Improvements in lighting 1.1 Metering and control of electricity consumption per area. 1.2. Improvement in lighting equipment (replacement by energy-efficient lamps, i.e., fluorescent lamps). 2 Regulation and control 2.1. Operation and maintenance: 2.2. Improvement in heating conservation, avoiding leakages when opening furnaces. Appropriate pressure in furnaces and appropriate insulation.
Productive processes	Improvements in furnaces.

Source: Own elaboration from MINECO (2003c).

4.1.1.4. Metal products.

This sector comprises several activities with a common feature: the iron and steel making sector supplies its raw materials[16]. Energy costs represent between 4% and 10% of total costs.

Virtually all energy-saving measures foreseen for this sector in the E4 focus on thermal uses of energy. Only one measure reduces electricity consumption: the substitution of natural-gas furnaces for electric furnaces.

4.1.2. Electricity generation

Electricity production is currently responsible for 32% of total global fossil fuel use (IEA 2008a). Although electricity has a high end-use efficiency compared to direct fuel-fired applications, it often is associated with significant losses in generation (Geller et al 2006). Indeed, the data shows that there is an important potential to increase the efficiency of electricity production in European countries and Spain in particular. The efficiency of electricity production ranges from 43 % (Denmark) to 30 % (Slovakia) for coal, 55 % (Luxembourg) to 34% (Poland and the Czech Republic) for gas and 45% (Belgium) to 23% (Slovakia) for oil (IEA 2008b). The percentages for Spain are, respectively, 38%, 50% and 35%[17].

Improvements in electricity generation efficiency in the Spanish sector will come from two main sources: Modernisation of existing plants (through the substitution of CCGTs for obsolete plants (fuel-gas and coal)) and investments in new generation equipment with better energy efficiency levels (table 10)[18]. In addition to conversion or transmission losses, our analysis in section 3 has shown that electricity production demands electricity (due to "auxiliary consumption")[19].

Table 10. Electricity-efficient technologies in electricity generation.

Category	Specific technologies
Horizontal	Monitoring of combustion, control of turbines and improvements in the efficiency of lighting systems.
Productive processes	**THERMAL PLANTS** • Optimisation of the cooling source. • Installation or modification of pumas. • Use of the heat from vents. • Installation of dry ashtrays • Optimisation of the efficiency of turboalternators **NUCLEAR PLANTS** • Optimisation of the secondary circuit. • Actions in turbines and auxiliary systems. • Optimisation of control and operation. • Reduction of auxiliary devices. **HYDRO PLANTS** • Change of rolls

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[16] The main subsectors included in this sector are: manufacturing of metal products, except machinery and equipment, manufacturing of metal elements for construction, manufacturing of other metal products, manufacturing of steam generators and manufacturing of diverse metal products.

[17] The best practice for new power plants is 48% for coal, 50% for oil and 60% for natural gas.

[18] Note that the former involves "fuel-switching" but, since CCGT have better conversion efficiencies, this fuel switch also involves a general improvement in average conversion efficiencies.

[19] According to MINECO (2003a), consumption of auxiliary services are lower than 2% of total generation in hydro plants, around 6% in nuclear and coal thermal plants, slightly above 6% in gas and fuel plants and around 3% in CCGT plants.

	• Change of power transformer and rewinding.
Technologies at the R&D stage.	Current projects aim at: Improving the use of primary energy contained in the fuel, better behaviour of materials, better management of processes and better maintenance and better energy management The use of the latent heat of combustion and the increase in the burning of fuel in nuclear plants represent two specific R&D efforts in this context.

Source: Own elaboration from MINECO (2003a).

4.1.3. Wholesale and retail trade and real-state services.

In the commercial sector and real-state services, electricity consumption mainly takes place in buildings. Therefore, we focus on electricity consumption in commercial buildings, including office equipment and small appliances.

The building sector plays a very significant role in electricity consumption world-wide. In 2005, buildings consumed 57% of all electricity, whereas electricity accounted for 25% of all energy needs in buildings (IEA 2008a). Electricity use has experienced strong growth in the service sector world-wide, increasing by 50% between 1990 and 2004[20].

Furthermore, the expected world-wide increase in electricity demand in this sector (baseline scenario) is significant, and greater in the service than in the residential sector[21]. Service sector floor area is expected to grow, driven by economic growth, at around 1.4% per year between 2005 and 2050. Space heating and lighting/other electric uses account for 40% of total energy consumption each. Water heating accounts for around 13% and cooling and ventilation for 9%.

Several documents (European Commission 2006, IEA 2008a) show that this sector exhibits the highest relative potential for energy savings of all sectors. reflecting the significant technical potential to reduce space heating and cooling needs and improve the EE of lighting, electric appliances and equipment in both existing and new buildings.

Many end-uses in buildings are already primarily supplied by electricity, including space cooling, lighting, information technology and appliances. Cooling represents a key end-use of electricity in this sector, and, thus, reducing the cooling load is a crucial option to reduce electricity consumption.

In practice, a policy-relevant distinction is between technologies aimed at improving EE in buildings (related to the design of the buildings, including the materials used and its orientation) and those aimed at improving the EE of office equipment and appliances used in commerce and the lighting devices (lamps)(box 1).

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[20] The service sector includes activities related to trade, finance, real estate, public administration, health, education and commercial services.

[21] Electricity demand grows at 2.4% per year, accounting for 41% of the sector's energy consumption in 2050. This reflects the growing demand from electric appliances and other electrical uses. By 2050, 55% of final electricity use is accounted for by the buildings sector (IEA 2008a).

Box 1. Electricity-efficient technologies in the buildings sector (inc. appliances) related to commerce and offices.

1. Thermal envelope and windows. EE depends on the building envelope which, in turn, depends on the insulation levels and thermal properties of walls, ceiling, and ground or basement floor. An important component of EE improvements are windows. Their thermal performance has improved greatly through the use of multiple glazing layers, low-conductivity gases between glazing layers, low-emissivity coatings on one or more glazing surfaces, and the use of very low conductivity framing materials such as extruded fibreglass. Glazings that reflect or absorb a large fraction of the incident solar radiation significantly reduce the need for cooling.

2. Cooling systems. The efficiency of air conditioners available on the market varies substantially[1]. Emerging technologies include solar power for cooling purposes and evaporative coolers. These technologies work particularly well in hot, dry climates, such as the Spanish one. Well-designed passive solar homes reduce the need for air conditioning. Improving the thermal envelope (insulation) and considering building form, orientation and height-to-floor-area ratio, optimizing the glazing area and minimizing the infiltration of outside air would significantly reduce cooling needs.

3. Appliances. The impact of efficiency gains of new appliances has been offset by an increase in the size and range of products. Increasing the efficiency – and where possible reducing the number and size – of appliances, lighting and other equipment within conditioned spaces reduces energy consumption and cooling loads. The biggest savings opportunities in electricity uses in offices are (IPCC 2007b): 1) improved power supply efficiency in both active and low-power modes, 2) redesigned computer chips that reduce electricity use in low-power mode, and 3) repeated reminders to users to turn equipment off during non-working hours.

4. Lighting. Lighting supplied to spaces where no one is present can be reduced through time-scheduled switching, occupancy sensors and daylight-responsive dimming technologies. Efficient lighting systems and devices (ballasts, fluorescent and high-intensity discharge lamps, luminaires) are already fully commercialised technologies which could significantly reduce lighting demand. Appropriate orientation (daylighting) may significantly reduce lighting needs. In the service sector, the use of high-efficiency ballasts, slimmer fluorescent tubes with efficient phosphors, and high-quality luminaires produces significant savings. For street and industrial lighting, energy savings stem from a reduction of the use of inefficient mercury vapour lamps and low-efficiency ballasts, in favour of higher-efficiency alternatives. Future technologies include solid-state lighting.

Source: Own elaboration based on IEA (2008a), IPCC (2007b), Sorrell (2004), Harvey (2009), Schleich (2009).

Electricity consumption represents 86% of energy use in offices and 100% in commerce. Lighting is usually the largest single use of electricity in commercial buildings, except in warmer climates, such as Spain, where air conditioning accounts for the largest share of electricity use (table 11)(IPCC 2007b, MINECO 2003d).

Table 11. Electricity end-uses as a share of total energy consumption.

	Share of electricity end-uses in total energy consumption
Offices building	Climatisation (52%), lighting (33%)
Small commerce	Lighting (46%), heating (28%)
Department stores	Lighting (57%), climatisation (43%)
Malls	Climatisation (47%), other (29%)

Source: MINECO (2003d).

The E4 distinguishes between the energy consumption of fixed installations (buildings), including cooling and lighting, and the energy consumption of office equipment.

The following technologies currently used to reduce the energy consumption of fixed installations are worth mentioning:

1) Office sector: centralised heating and cooling systems are widespread. Fluorescent lamps with electromagnetical reactancies are common.
2) Commercial sector: Wide range of systems, including centralised heating and cooling systems and autonomous systems of heat pumps on top of building roofs.
Regarding the lighting system, the following systems are widespread: fluorescents with electronic or electromagnetical ballast, halogen lamps, incandescent lamps with low energy consumption, etc.

Table 12 shows the measures proposed in the E4 to reduce electricity consumption in buildings.

Table 12. EE measures for buildings in the E4.

New buildings	a) Actions on the thermal envelope. -Increase in the level of insulation of facades and windows. -Greater shadowing of windows. b) Improvements in the energy efficiency of thermal installations: -Renovation of boilers and cooling systems in the commercial, services and public administration subsector. -Substitution of freecooling for air treatment units (ATUs) c) Improving the EE of lighting: -Substitution of energy efficient lamps for incandescent lamps.
Existing buildings	a) Reduction in the energy demand of buildings through: -Increase in the level of insulation of facades and windows. -Greater shadowing of windows. -Reduction of thermal bridges. -Better orientation of buildings. b) Better performance of lighting installations, through: -Integration of energy efficiency as a variable in the design of installations. -Use of efficient lamps. -Use of control systems which adjusts the level of lighting to occupation levels. -Use of natural light (daylighting).

Source: MINECO (2003d).

Regarding office equipment, its level of penetration is very high[22]. Therefore, measures should aim at improving the use of equipment and increasing the share of energy-efficient devices. Furthermore, energy efficient cooling systems should be adopted (for example, cooling systems with absorption technologies or powered by combustion engines).

4.1.4. Public administration,

Finally, the public administrations (central, regional and local) is a significant electricity consumer. Energy consumption of public administrations amounted to about 0.7% of total final energy consumption in Spain. Several measures are envisaged in the E4 to reduce electricity consumption in this sector (table 13)[23].

Table 13. Technologies to reduce electricity consumption in the public administration.

Public lighting	• Substitution of sodium-steam lamps for mercury lamps. • Substitution of high-performance for less efficient lamps.

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[22] Already in 2001 more than 91% of all firms in Spain had computer equipment.
[23] In the E4, electricity consumption within public buildings is not considered.

	• Installation of systems to regulate the level of lighting according to activity levels in streets. • Installation of programmable watches in lighting operation devices in order to better adjust the switch-on/swicth-off modes and to reduce the hours over which the systems are switched on. • Substitution of traffic lights with LED technology for conventional technology.
Water supply and purification and waste water treatment.	Regulation of motors for water supply and purification and waste water treatment.

Source: MINECO (2003e).

4.2. The barriers to electricity-efficient technologies.

A thorough understanding of the nature of general and sector-specific barriers to electricity efficiency is crucial when designing cost-efficient policy measures.

4.2.1. A general discussion on barriers.

General barriers to EE investments can be categorised as follows (table 14).

Table 14. A taxonomy of barriers to EE.

Barrier	**Explanation**
1) Low energy prices	EE investments are unprofitable under low energy prices.
2) Investment costs higher than expected (hidden costs).	Investment costs in EE are sometimes higher than expected due to hidden or transaction costs.
3) Uncertainty and irreversibility of investments	EE investments can not be recovered if they prove unprofitable. Uncertainty on energy prices discourages the realisation of EE investments.
4) Information failures (asymmetric and imperfect information)	Consumers do not have perfect information on future energy prices and characteristics of EE options when assessing EE investments
5) Bounded rationality	Consumers are not able to or not interested in making the necessary complex calculations to take the best decision. The share of energy costs in the total costs of energy end-users is low. Greater relevance is given to upfront costs compared to the life-cycle energy savings due to the EE investment.
6) Slowness of the technological diffusion process	New technologies take time to get adopted.
7) Principal-agent problems.	This problem occurs when the agent which incurs the costs of the investments is not the same than the one who benefits from the investment.
8) Imperfections in capital markets.	Difficulties in accessing capital markets is a barrier to the funding of EE investments.
9) Consumer heterogeneity.	An investment may not be profitable for some end-users (those barely using a given equipment).
10) Discrepancies between private and social discount rates.	This is a common problem in other investments.

Source: Own elaboration from Schleich (2009), Sorrell et al (2004), Linares (2009).

Not all barriers considered above represent market failures. Only information failures, principal-agent problems and imperfections in capital markets are, both, barriers and market failures. In purely economic terms (i.e., orthodox economic theory), only the later would justify a public intervention. However, in line with Sorrell et al (2004) we take a broader perspective and identify how barriers to electricity efficiency investments (whether or not they involve market failures) can be circumvented with the application of instruments.

The relevance of these barriers differs per sector. Therefore, the following subsections provide a discussion of those sectoral barriers for the aforementioned "key sectors" in Spain.

4.2.2. Sectoral barriers to electricity efficiency.

4.2.2.1 Industry

Barriers to EE investments in industry are diverse (table 15).

Table 15. Main barriers to EE investments in industry.

Barriers	Explanation.
Lack of information	Limited ability of companies to access and absorb information on technologies (limited technical resources to interpret the available information).
Large upfront costs and slow capital turnover	The slow rate of capital stock turnover is a main barrier. Excess capacity can further slow capital stock turnover. Companies must also consider the risks of adopting a new technology, the payback period of a technology, the appropriate discount rate and transaction costs. Newer, relatively expensive technologies often have longer payback periods and/or are less reliable than existing technologies.
Lack of management attention,	EE may not be a priority, which results in a lack of internal support.
Insufficient availability of qualified service providers	Lack of technical skills to adapt the technologies to the specific application.
Access to capital	EE technologies tend to increase initial capital costs, which is a barrier in locations where capital is limited.

Source: Worrell (2009), del Río (2005), IPCC (2007b).

The three key industrial sectors (oil refining, metallurgy and metal products) show some similarities regarding barriers to electricity efficiency in Spain: High up-front costs of new equipment, low electricity prices[24] and few alternatives to electricity uses. Other barriers are rather sector-specific: lack of information and a perception of greater risks of EE investments (metallurgy), comparatively low share of electricity consumption in total energy use of the sector (oil refining)[25].

4.2.2.2. Electricity generation

Due to the high up-front costs and long lifetimes of existing plants, improving conversion efficiencies and reducing the electricity consumed by this sector is a difficult task without incurring major costs. In addition, electricity consumption represents a small share in the overall cost structure of utilities (see 4.1.2). BAU trends result in better efficiencies in new plants.

4.2.3. Wholesale and retail trade and real-state services,

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[24] According to European Commission (2008, p. 49), electricity prices for industry in Spain are significantly lower than in the EU-27 (7.19€/100kWh versus 7.81, excise taxes not included).

[25] In contrast, the repercussion of electricity costs in the cost structure of the other key sectors is significant, and reaches a maximum in the case of aluminium (60%).

In the discussion of barriers to EE in buildings a key distinction is between the physical building and the electric appliances used in the buildings (table 16).

Table 16. Main barriers to EE investments in the building sector.

Barrier	**Explanation.**
Limitations of the traditional building design process and fragmentation	Buildings are complex systems. Minimizing energy use requires optimizing the system as a whole- Fragmentation in the building industry (decisions at each stage involve multiple stakeholders) contributes to suboptimal results.
Split incentives (agent-principal barrier).	Agents responsible for investment decisions might be different from those benefiting from the energy savings.
Misplaced incentives	The prevailing selection criteria and fee structures for building designers may emphasize initial costs over life-cycle costs, hindering EE considerations.
Lack of internalisation of negative externalities from energy use and energy subsidies	Energy pricing that does not reflect the full costs of energy hinders the penetration of EE technologies.
Regulatory barriers	These include environmental permitting requirements, variations in metering policies, public procurement regulations which inhibit the involvement of Energy Service Companies (ESCOs).
Small project size and transaction costs.	Many EE projects are too small to attract the attention of investors. High transaction costs (verifying technical information, preparing viable projects and negotiating and executing contracts) prevent some EE investments. Furthermore, the small share of energy expenditures in the disposable incomes of affluent actors, and the opportunity costs involved with spending limited free time to find and implement the efficient solutions, discourage improved efficiency.
Perceived risks	These are due to conservative, asset-based lending practices of financial institutions, a limited understanding of EE technologies, lack of traditions in energy performance contracting, volatile prices for fuel/electricity and non-diversified portfolios of energy projects.
Imperfect information	Information about EE options is often incomplete, unavailable or expensive. Few small enterprises in the building industry have access to sufficient training in new technologies. Lack of knowledge and motivation within the design profession is a key barrier (Harvey 2009).
Limited availability of capital and access to capital markets	High capital costs and limited availability of capital exacerbate the problem of raising capital.

Source: Own elaboration from IPCC (2007a), Schleich (2009), Linares (2009), Sorrell et al (2004) and Harvey (2009).

Several of these barriers have been identified in Spain by the E4 (MINECO 2003c, 2003d). "General" barriers in this sector include few alternatives to electricity uses, low electricity prices, low share of electricity consumption in overall costs, a large penetration of electricity-consuming equipment (electric appliances, lighting and air conditioning), possibly inefficient lighting and office appliances and inappropriate thermal insulation of buildings.

More specific barriers include the low economic return of EE investments (existing buildings) and the fact that companies seldom purchase office equipment according to its EE attributes but rather focus on other aspects, such as storage capacity, processor speed, etc[26].

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[26] In addition, there is an increasing trend towards larger screens in computers.

4.2.4. Public administration,

Few alternatives to electricity uses and low share of electricity consumption in overall costs are perceived as major barriers.

5.- Policy implications and instruments.

The recent literature on policy measures to increase EE has acknowledged the necessary albeit insufficient role of increasing energy costs to encourage the widespread introduction of EE technologies (see Sorrell et al 2004, Scheich 2009), mostly because higher energy costs (for example, induced by higher energy taxes) would be suitable to address the environmental externality, but would not be able to tackle most other barriers in table 14.

We thus identify the most appropriate measures to tackle the aforementioned barriers (see section 4) and facilitate the uptake of EE technologies in each sector in Spain as well as those measures already proposed/identified by the E4.

5.1. Industry.

Table 17 identifies the instruments to improve EE in industry, the main barriers addressed by the instruments and the typical circumstances in which to apply them. Given the multifaceted character of barriers to EE, instruments should be applied in combination.

Table 17. Policy instruments to enhance EE in the industrial sector.

Instruments	Description/barriers addressed/Typical circumstances in which to apply this instrument
Voluntary programs/agreements	They are formal agreements between government and industry that include negotiated targets with time schedules and commitments by all participating parties. Particularly appropriate when dealing with a small number of actors or a strongly organised sector and when there are is much cheap saving potential exists.
Financial and fiscal instruments.	Generally suitable when there is a financial barrier and when an informative instrument needs financial incentives to attract the target group.
Taxes	Taxes applied to electricity use in industry (UK Climate Change Levy), eco-taxes on electricity consumption (Germany). Particularly appropriate when dealing with large target groups and when aiming at internalization of external costs.
Subsidies	They include grants, favourable loans and fiscal incentives (tax deductions for low-energy capital equipment investments, lease credits for EE investments, accelerated depreciation, income tax credits for EE investments and exemptions of customs taxes for imported EE technologies. Suitable as a demand-pull for EE technologies in case taxes prove ineffective. They mitigate the up-front cost barrier.
Access to capital	Low-interest loans can ease this barrier. A stable policy regime can reduce capital costs.
Regulation and labelling	For example, mandating the labelling of mass-produced motor systems and training/certification requirements for technicians/planners. Appropriate when other instruments proved ineffective and with information problems.
Information provision (inc. energy audits), education, training	Energy companies might provide information and promote energy saving campaigns in industry. Particularly suitable when there is a knowledge barrier and when dealing with large target groups.
Obligation of having an energy manager	The idea is to ensure that large energy-consuming companies employ an expert who analyses energy flows, promotes EE etc….
Technology research, development, deployment, and diffusion (RDD&D)	Appropriate for immature and/or expensive technologies with large cost-reduction potentials.

Public provision	Provides a demand-pull in a niche. Appropriate with large potentials for further development and market transformation of new technologies.

Source: del Río (2002, 2005), Carrillo et al (2009), IPCC (2007b), Sorrell (2004), Schleich (2009), Worrell et al (2009), Harmelink et al (2009).

The instruments in the E4 for industry are mostly informative. Their aim is to improve the knowledge of firms about EE technologies in the EU through specialised centres (industrial associations) and technical workshops and to raise the awareness of company managers on the existence of profitable energy-saving technologies.

5.2. Electricity generation.

A price signal resulting from a market-based instrument (taxes or allowance prices, such as the one provided by the EU ETS) would be preferable to other instruments from a cost-effectiveness perspective. The increasing gas prices may provide a similar incentive for EE, suggesting that significant EE incentives already occur under a BAU scenario. A price signal should be complemented with R&D support for the immature technologies mentioned in 4.1.2.

5.3. Wholesale and retail trade and real-state services,

Policies should foster new technologies both in buildings themselves and in the energy-using equipment inside of them.

Improvements in the envelope (existing buildings) generally entail high up-front costs, usually offset by energy savings (with different lengths of pay-back periods). This may require financial support and also efficiency standards.

EE can be achieved in this sector through a mix of existing and new technologies. This suggests a policy mix to tackle the wide array of barriers in this sector (table 18) and support technologies with different maturity levels, i.e., some already fully commercialised, others recently developed (*e.g.* high-performance windows) and yet others under development (*e.g.* integrated intelligent building control systems). Whereas demand-pull measures (such as information, labels, taxes and subsidies) are needed to encourage widespread deployment of existing technologies, supply-push measures (i.e., RD&D) are required to encourage the development of new technologies and the technical improvement of the yet immature ones.

Table 18. Instruments to improve electricity efficiency in the commercial sector (buildings and appliances).

Instruments	**Brief description**	**Barriers addressed/Typical circumstances in which to apply this instrument**
Policies and programmes aimed at building construction, retrofits, and installed equipment and systems		
Building codes (regulatory)	They include: 1) Overall performance-based codes that require compliance with an annual energy consumption level. 2) Prescriptive codes that set separate performance levels for major envelope and equipment components. Codes addressing electricity demand: maximum installed electric loads for lighting ventilation and cooling in new commercial buildings.	The cost of achieving a given energy performance is lower in new buildings. Thus, failure to rapidly implement better building performance requirements represents a lost opportunity. Suitable when dealing with a target group which is unwilling to act and difficult to address with other instruments.
Building certification and	An energy performance certificate includes key	Appropriate to overcome barriers relating

labelling systems (regulatory/voluntary)	data on energy consumption for tenants and clients.	to the lack of information, the high transaction costs, the long lifetime of buildings and split incentives. Energy performance certificates lower the transaction costs for assessing the energy performance of properties.
Education, training and energy audit programmes	Extensive training programs in the integrated design process and in the techniques for reducing cooling, ventilation, and lighting loads in buildings for all actors involved in building construction (Harvey 2009).	When there is a knowledge barrier and lack of awareness about EE opportunities by end-users and other actors.
Policies and programmes aimed at appliances, lighting and office/consumer plug loads		
Product standards (regulatory)	They cover all end-uses and fuel types, with a focus on appliances, information and communications devices, lighting and cooling equipment.	When dealing with a target group which is unwilling to act and difficult to address with other instruments. When aiming at removing the worst energy-consuming products from the market
Mandatory or voluntary labelling (regulatory/informative)	Comparison labels induce manufacturers to improve EE and inform consumers of the product's performance.	Information barriers, when dealing with large consumer or service sector groups and when there are large differences in energy performance between similar units.
Voluntary agreements to save energy (services sector) or improve EE (appliances).	The government and manufacturers agree to a mutually acceptable level of energy use per product.	When dealing with a small number of actors or a strongly organised sector and when cheap saving potential exists.
Awareness raising, education / information Campaigns / metering devices / energy management systems	Information dissemination can take many forms: brochures, TV commercials, internet-based approaches…	Information barriers. Appropriate when dealing with large target groups.
Training and certification of installers of energy-efficient equipment		Inappropriate training.
Cross-cutting policies and programmes that support EE in buildings		
Utility demand-side management programmes (regulatory).	Utilities facilitate energy savings by end-users.	Information barriers
Taxes and ETS	Electricity, energy and carbon taxes, auctioned permits.	Lack of internalisation of the negative externality from energy use and financial barriers.
Tax exemption/deductions	Tax-exemptions/deductions when adopting EE technologies.	When financial barriers exist and when an informative instrument needs financial incentives to attract the target group.
Capital subsidies, grants, subsidized loans,		When there is a financial barrier (High up-front costs and difficult access to capital.
Removal of subsidies.		Subsidised energy prices reduce the incentive to use energy more efficiently.
Public sector leadership programmes and public procurement policies	They create demand for EE products and serve as an example for others.	They facilitate demand- pull in a niche. Suitable with large potentials for further development of new technologies.
Promotion of ESCOs and energy performance contracting (EPC)	ESCOs are companies that offer energy services (energy analysis and audits, energy management etc...). They take responsibility for EE investments and improved maintenance and operation of the facility.	ESCOs facilitate the access of building owners and operators to technical expertise and innovative project financing.
Obligation of having an	To ensure that large energy consumers employ	Information barriers/lack of awareness.

energy manager	an expert who promotes EE.	
Energy adviser	Enable every municipality to have an energy adviser to give advice on energy savings to local companies.	Information barriers/lack of awareness.
EE obligations and tradable EE certificates (regulatory/economic)	An obligation on economic actors to meet specified energy savings, potentially coupled with a trading system of white certificates.	When aiming at energy savings in the service sector, i.e., large target groups being difficult to address by EE services. When knowledge, financial and institutional barriers are important.
Technology research, development, demonstration and deployment (RD&D)		Suitable for still immature and/or expensive technologies with a large cost-reduction potential

* Economic instruments include financial instruments and incentives
Source: Own elaboration from Linares et al (2009), IPCC (2007a), IEA (2008a).

According to the E4, the most suitable measures are those introduced in the building design stage by setting (though building standards) minimum EE requirements and informing the purchaser/user on the EE of its building (in line with Directive 2002/91/EC on the EE in buildings). Additional measures include energy certification of buildings, greater insulation requirements and regulation of air conditioning in public and commercial buildings (MINECO 2003c).

Several policy measures have already been implemented as a result of compliance (and internal transposition of) Directive 2002/91/CE, including the implementation of minimum EE requirements in new buildings (and existing buildings undergoing significant reform)[27], energy certification of buildings and the periodic inspection of air conditioning devices.

Given the significant investments involved, the E4 suggests that financial support to adapt existing buildings to new EE regulations is appropriate.

5.4. Public administration.

Some of the measures in this sector are common to the building sector. However, public provision is particularly suitable and can play two major roles: 1) an "exemplary" role for the rest of society and; 2) a "demand-pull" for EE measures, contributing to the creation of a market for these technologies.

5.5. Discussion. General policy implications.

Several policy implications are derived from the above exercise.

i) The intensity of the backward and forward (own and pure) effects suggests that some measures might be more appropriate than others. In those sectors with a high own effect sector-specific measures are more appropriate, whereas those with a high pure effect cross-sectoral measures are more appropriate (table 19).

Table 19. Identifying the most appropriate measures according to relevant effects.

	OWN	**PURE**
BACKWARD	Internal measures, i.e., to increase the own electricity efficiency of the sector (sector-specific measures).	Measures should aim at reducing the electricity demand of the "j" sector.

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[27] They include measures on the thermal envelope and lighting.

	Electricity generation, Metallurgy, retail trade, public administration,	Metal products, other machinery, wholesale trade, retail trade, real-state services
FORWARD	Internal measures, i.e., to increase the own electricity efficiency of the sector (sector-specific measures). Oil refining, Electricity generation, Metallurgy, public administration,	Measures to reduce electricity consumption associated with the supply of sector "i". Electricity generation, metal products, wholesale trade, real-state services real-state services

ii) Electricity consumption is as important as electricity generation.

There is a need to focus on end-use electricity sectors in addition to the power generation sector, which has been the focus of the literature. Indeed, improvements in the thermal efficiencies of electricity-generation plants are (partly) offset by the increase in electricity consumption in Spain. We need to combine instruments which reduce end-use electricity consumption (scale factor) with other measures aimed at improving the specific electricity-efficiency (kWh/ton of product) of end-user sectors (technological factor).

iii) Instruments need to be combined according to a dynamic efficiency perspective.

It has been shown that EE technologies are at different maturity levels. Some are currently expensive but have a significant cost-reduction potential with further deployment. Diffusion would allow them to advance along their learning curve. This, together with R&D investments, would facilitate cost-reductions. Therefore, instruments to promote EE technologies need to be adapted to their maturity level, which involves a combination of technology-pull and demand-pull measures. The former would be aimed at supporting the emergence of new EE technologoies and at improving the quality and reducing the costs of the existing ones through RD&D support. The later include several instruments, such as regulation, economic incentives and others. As shown in section 5, some of these instruments are cross-sectoral, while others are sector-specific[28].

iv**) Need to apply sector-specific measures.**

Instruments need to be implemented in order to increase EE in the power generation sector and in the key sectors. These are highly diverse sectors and, thus, the adoption of measures should take their technoeconomic particularities into account. A one-size-fits-all solution is at odds with the inherent technoeconomic complexity of each sector.

v) Cost pass-through onto electricity prices should be favoured.

The price signal is important to encourage EE investments. Climate policies and higher fuel demand would lead to higher energy prices[29]. Ensuring that such price increases are passed on to consumers is important to promote the uptake of EE technologies. However, as shown by the partial cost pass-through into electricity prices in the EU ETS, instruments may face barriers that would not lead to an increase in final (retail) electricity prices. Regulations preventing such cost pass-through and maintaining artificially low electricity prices are one of those barriers. Some governments may have an incentive to

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[28] Of course, instruments combinations are likely to result in interactions between instruments (synergies and conflicts) which should be analysed and, if possible, mitigated or fostered. But this should be a topic for further research.

[29] See IEA (2008a). Nevertheless, the current economic crisis is pushing down fuel demand and, thus, fuel prices.

avoid such cost pass-through for political reasons. For example, in Spain, the maximum increase in retail prices is set by the government every year for the following year. Electricity prices do not fully reflect electricity-generation costs. Therefore, governments should remove regulations which do not allow variations in wholesale electricity prices to be reflected in retail prices in order to encourage electricity-efficient investments.

6. Conclusions, limitations of the analysis and suggestions for further research.

The results in this paper show the relevance of certain "key" sectors in electricity consumption and suggest that policy instruments should be applied in order to increase both EE in the electricity generation sector as well as electricity efficiency in end-use electricity sectors. Those measures should take the technoeconomic particularities of each sector into account. The combination of the input-output and the sector-focused approaches in this paper has allowed us to derive some policy recommendations to encourage electricity efficiency in those key sectors. A major lesson is that we need to combine instruments aimed at different technologies (maturity level) and different sectors. Furthermore, a price signal is essential and, thus, regulations impeding cost-pass through into prices should be avoided or removed.

Some of the limitations of this analysis are inherent to the methods chosen. Although our input-output approach allows us to identify key sectors to be tackled in order to reduce electricity demand, a well-known caveat of input-output techniques is that the costs of reducing electricity consumption are disregarded and, thus, we are unable to say anything about the economic feasibility of reducing electricity demand in a given sector. Cost-effectiveness is a crucial variable for designing policies since electricity demand reductions should be encouraged where they are cheapest.

Although we have provided a complementary qualitative analysis that gives some orientation on the technologies, barriers and instruments that should be considered, there is missing information, which can only be provided by an additional bottom-up analysis. EE policies in the future should be based on this in-depth analysis of sector-level data, including whether the identified technologies are really cost-effective (although, according to the E4, they are), whether sectors are able to pass the extra costs of EE technologies into the price of their products without a significant competitiveness loss, what are the barriers to the uptake of EE technologies, whether those barriers should really be overcome because they inhibit economic efficiency, i.e., whether public policy is justified because market failures are involved[30] and the extent to which EE technologies have already been adopted in the key sectors. Our preliminary efforts suggest that bottom-up data should be collected, preferably through consultation with individual firms, the sectors' associations and sectoral experts.

Notwithstanding, one of the lessons of the combination of approaches followed in this paper is that, given the pros and cons of different economic approaches and methods to the analysis of electricity efficiency (see Sorrell 2004), including input-output tables, transaction cost, neoclassical and evolutionary economics. their combination would be preferable to the use of individual approaches.

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[30] For example, from the perspective of neoclassical economics, the inability to access capital may well constitute a barrier, but it need not imply a failure in capital markets that should be corrected. If small companies are considered high-risk borrowers, potential lenders may demand a high risk-adjusted rate of return. In this case, the market outcome is efficient and policy interventions are not justified (Schleich 2009).

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