Effects from carbon pricing and anti-leakage policies in selected industrial sectors in Spain - Cement, Steel and Oil refining

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1 Introduction

The impact of the European Emission Trading System (ETS) on competitiveness is a worrying issue for industrial sectors in Europe. The price for carbon emissions created by the ETS will clearly affect their cost structure, and therefore their competitiveness with foreign imports. This in turn might result in emissions leakage, hence reducing the effectiveness and efficiency of the system; and also in delocalization of industries, with the corresponding impact on jobs and domestic production. These risks have made the European Commission think about possible schemes to reduce them, with a final decision still to be made for the third phase of the ETS in this regard.

Steel, cement and oil refining are the biggest industries included in the ETS, and including the aluminium sector, they are the industries most exposed to risk. Some studies have already addressed the impact of the ETS on the cement industry (Demailly & Quirion, 2006), iron and steel industry (Hidalgo, Szabo, Ciscar, & Soria, 2005), and a general scope for Europe (Monjon & Quirion, 2009; Reinaud, 2004), but there are not many studies about the possible consequences of ETS in industrial sectors in Spain. Spain is an interesting country for an analysis of the risks of leakage, given that the technologies used in cement, steel and oil refining sectors are sometimes different than in other countries in Europe, and also, the exposure to imports is higher than for other countries.

In this study, three specific bottom-up models for each of the sectors covered are presented. The models, based on previous literature but adapted to the specificities of the Spanish industry, are basically engineering models in which we represent to a large level of detail the different production technologies, the alternatives available, and we allow for changes in investment and operation to adapt to different carbon prices or anti-leakage policies, assuming a cost minimization objective. Compared to other models such as CASE II, these models follow a more engineering-oriented approach, which allows us to represent better the possible non-linearities in substitutions within industries. The models are not plant-specific but aggregated per technology. They are characterized by the different technologies in terms of costs, raw materials and fuel requirements, and carbon emissions. Finally, imports are modeled exogenously, with a fixed price, and an infinite elasticity of substitution.

The result of each model is an estimation of how the different carbon price levels affect national production, how will carbon emissions from these sectors evolve, and also how production may be displaced to other countries where emissions leakage may occur.

The present study is divided into 4 parts. First of all, section 2 gives an overview of the Spanish carbon emissions. Then, in the following section, a brief description of each sector in Spain is provided and the sectoral models are explained. In section 4, the results obtained will be displayed and discussed. Finally, some conclusions will be presented.

2 Carbon emissions in Spain

Power generation and road transport are the most relevant emitting sectors in Spain, followed by the rest of the industry. Together, they cover almost 80% of the total GHG emissions in Spain. Other important sources, showed in Figure 1, are agriculture and residential sectors.

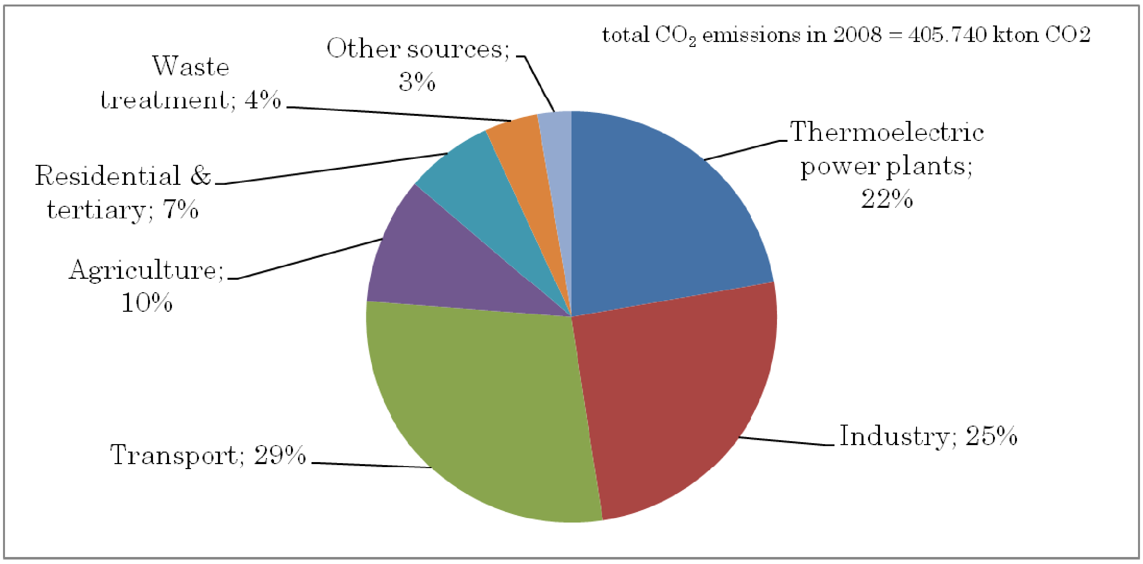

Figure 1. Sources of emissions of Spain in 2008 (Ministry of Environment, 2010)

Regarding the industrial sector, it can be observed in Figure 2 that 45% of the emissions come from the cement sector, refineries and the iron and steel industry. These are the sectors which will be analyzed in this paper.

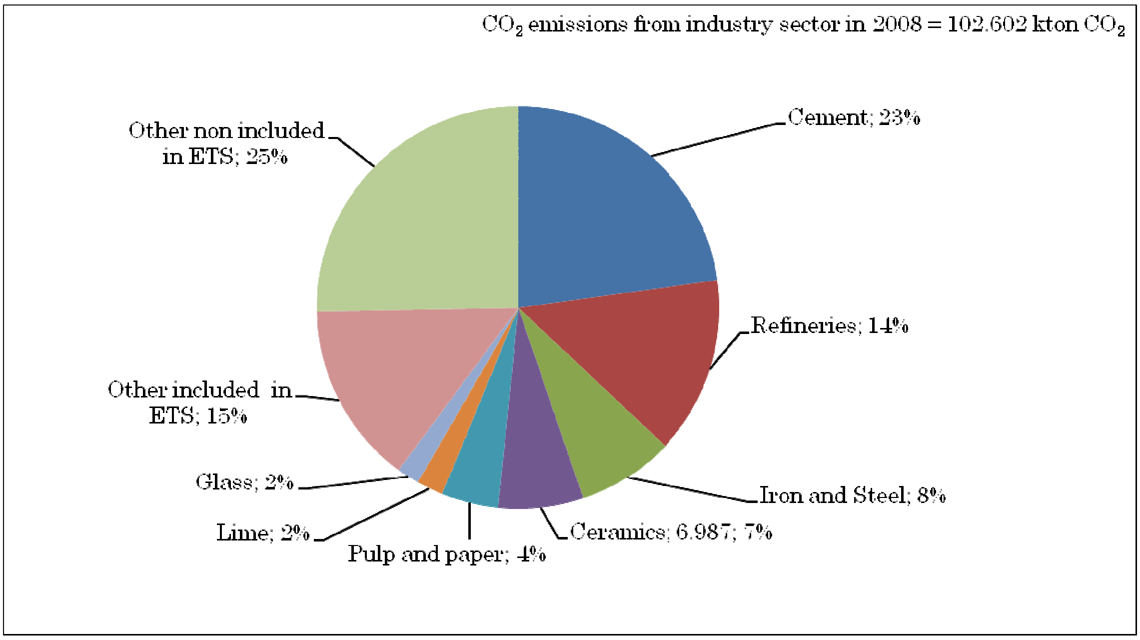

Figure 2. CO2 emissions in the industry sector in Spain in 2008 (Ministry of Environment, 2010)

These sectors have also experienced a significant increase in their emissions since 1990, mostly driven by the growth that took place until the economic crisis struck in 2008, as shown in Figure 3.

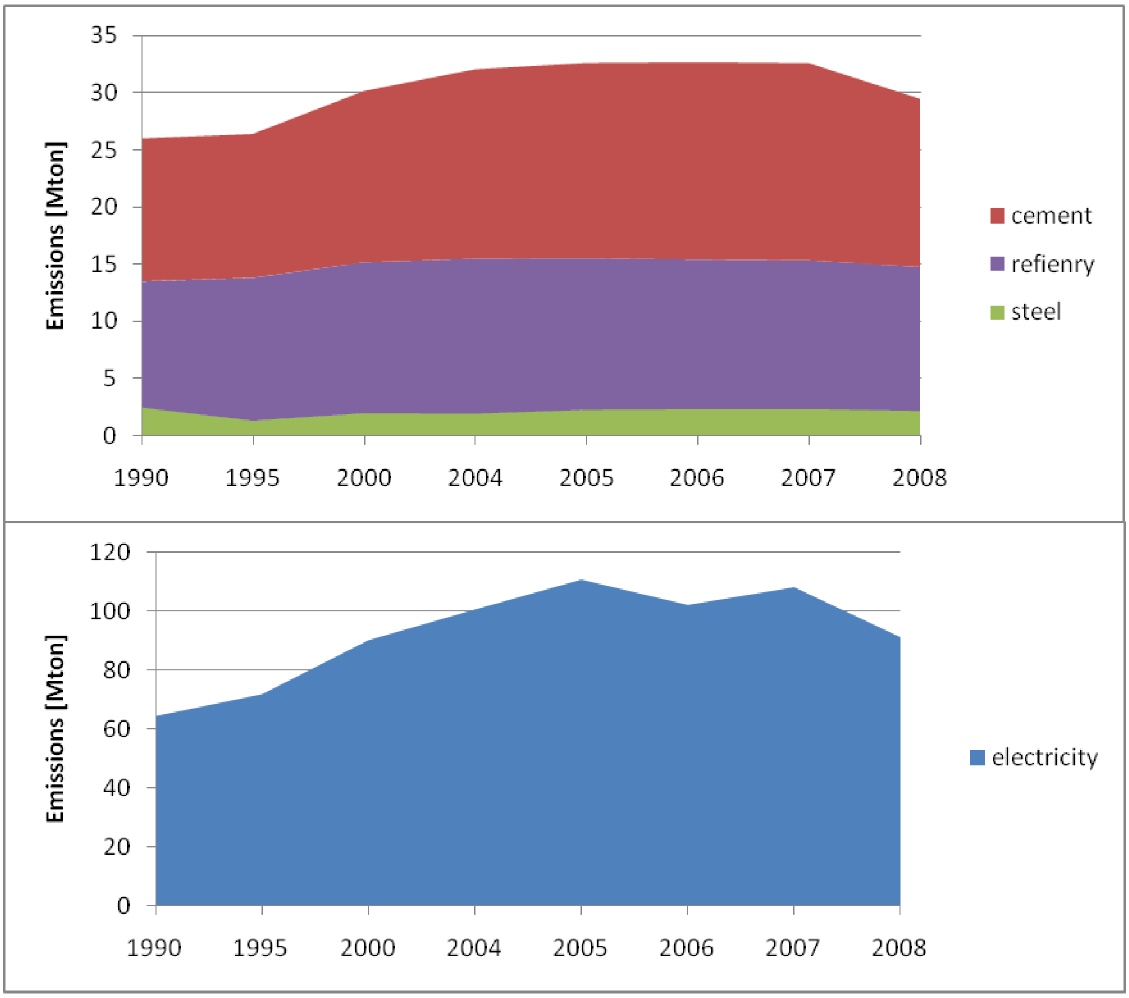

Figure 3. Historical emissions from relevant sectors - steel, cement, oil refining, electricity - in Spain (Ministry of Environment, 2010)

Although during the last few years a reduction in energy use and carbon emissions has taken place, the perspective for the near future is not very encouraging. As shown e.g. in Economics for Energy (2010), most of these reductions are explained by the collapse of the housing bubble, the economic crisis, and also other factors. Therefore, if economic growth resumes, emissions might increase again. Therefore, it seems sensible to study the possibilities for emissions reductions in these sectors in the medium term, and the cost of these reductions. This is attempted by the use of sector-specific models, which are described in the following section.

3 Sectoral models

This section is focused in describing the assumptions and the technical considerations followed to model each sector. Also, a description of the Spanish situation for these sectors is provided.

The three models presented, steel, cement and oil refining, simulate the behavior of each sector in different emission scenarios, assuming as an objective the minimization of costs, and allowing for changes in production technologies, raw materials and fuels, as well as investment in low-carbon technologies.

3.1 Steel

3.1.1 The Spanish steel industry

The steel industry in Spain has some unusual characteristics different from most countries in Europe. There are two ways of producing crude steel: from iron ore, usually melted in blast furnaces and basic oxygen furnaces (BOF), and from scrap, which is mostly used in electric arc furnaces (EAF). As can be seen in Figure 1, most European countries produce steel with BOF facilities, except Italy and Spain, where EAF facilities are the most usual (Greece, Portugal, Luxembourg and Slovenia only have electric arc furnaces but they have a very small industry which together amounts for 3% of the European production).

64% of European steel is produced in Germany (23%), Italy (15%), Spain (10%), France (9%) and UK (7%) (EUROFER, 2011), and the reason why Spain and Italy show a different trend in steel production is the availability of scrap and the easy access to the sea, which is the main way of importing this raw material. EAF facilities are able to use other raw materials such as direct reduced iron (DRI) but this is not as profitable as using scrap.

Spanish steel production in 2010 was 16.4 Mton. This was 14% higher than in 2009, driven not by domestic demand but by exports, mainly to Germany.

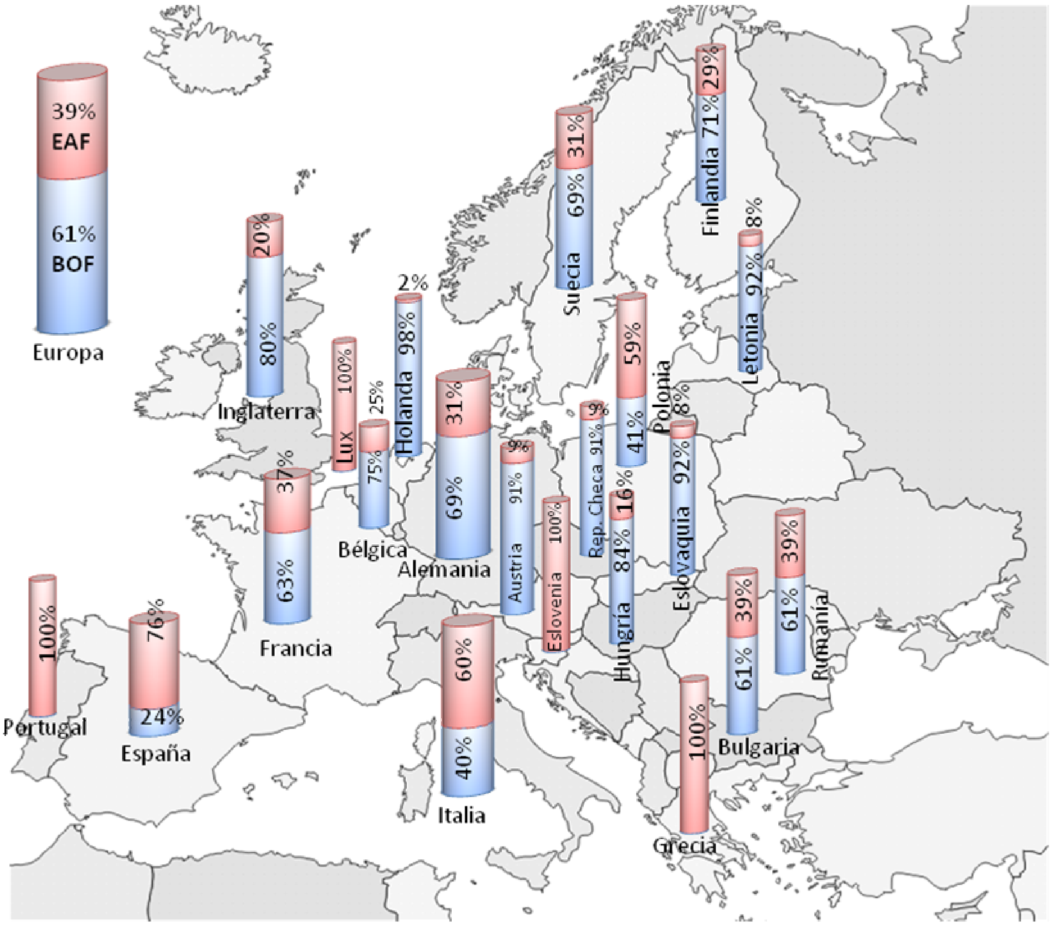

Figure 1. European steel production map

3.1.2 The steelmaking model

The steel sector in Spain has been modeled taking into account the two types of existing furnaces: basic oxygen furnaces (BOF) and electric arc furnaces (EAF). Unlike the rest of Europe, electric arc technology is widely used in Spain, which involves an important reduction in the direct emissions compared with the blast furnace procedure. However, the electricity consumption of EAF is much higher.

Regarding the technologies considered, as can be seen in Figure 2, both methods can use pig iron and scrap, but each technology was designed to produce crude steel from different raw materials and the use of them involves limits in the efficiency of the process. That is the reason why some constraints of mixing raw materials to feed the furnace have also been included.

It is important to mention that pig iron can be considered as a raw material for producing steel, but it comes from iron ore, and the process to produce it has to be taken into account since it is the most energy intensive process in steelmaking. Pig iron is made up of sinter and pellets (both are products from iron ore), and coke from coal. All these elements are put together into a blast furnace to make pig iron.

Moreover, iron ore can be also used to produce an alternative raw material used mainly in electric furnaces. This material is called DRI, direct reduced iron, and it is presented as an alternative to scrap.

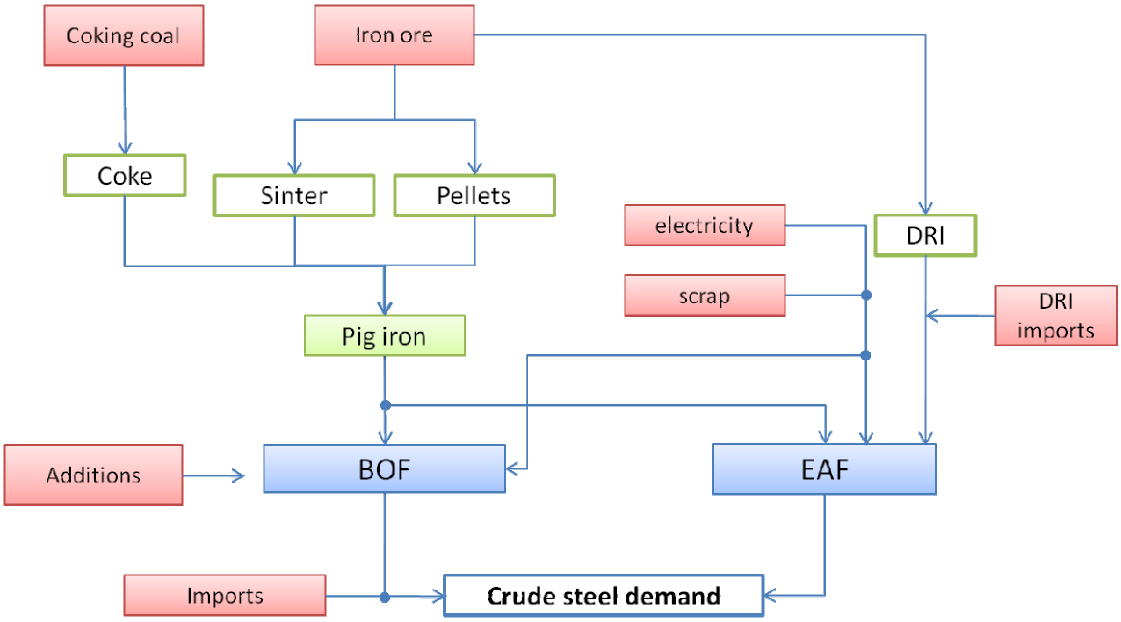

Figure 2. Steel production scheme

Electricity demand in steelmaking depends on the technology used. BOF steel consumes an average of 0.128 MWh per ton of crude steel while EAF technology requires 0.544 MWh of electricity per ton of crude steel.

We have assumed a constant demand for steel. If this demand cannot be met with domestic production, imports are allowed.

Regarding emissions, the model takes into account the main sources of direct emissions, which are pig iron, coke, sinter and pellets production processes. On the other hand, the main indirect source of emissions, electricity consumption, is also considered.

3.2 Cement

3.2.1 The Spanish cement industry

Clinker and cement production is a mature process whose main steps are similar around the world: raw materials management, grinding of crude, heating the mixture to produce clinker, cooling the product and finally grinding the clinker and other components. There are mainly three technologies worldwide: wet, semi-dry and dry. The use of these technologies depends on the moisture content of raw materials. Countries where raw materials, specially limestone and clay, have high moisture can only use wet technology. It is important to mention that the drier raw materials are, the more efficient the process is.

In Europe, 75% of the total production is based on dry technology, but in Spain, this figure is even higher, reaching 93% of the total installed capacity. Spain has 47 dry cement kilns, 5 semi-dry ones, and 5 more that that use wet technology (Ministry of Environment, 2003). In Spain the availability of low-moisture raw materials is very high, and only in the north of the country wet kilns are required to produce cement.

Regarding emissions, the chemical reactions that take place in the furnace are responsible for the 60% of the total emissions of the process, and the remaining 40% is produced due to combustion. Nowadays, it is difficult to reduce the emissions caused by the chemical reaction because a substitute for clinker is not known yet. Then, efforts are mainly concentrated on the fuel mix that heats the furnace. Wastes from other industries and biomass seem to be a good solution. Nevertheless, although Spain is increasing the use of wastes and biomass in the fuel mix up to 6.4% in 2011 (Oficemen, 2011), it has still not reached the European average (18%).

3.2.2 The cement model

The cement sector in Spain, as shown in Figure 3, has been represented with two types of facilities. On the one hand, the integral cement plants, where clinker and cement are manufactured. On the other hand, the cement mills, where only cement is produced from imported clinker.

Integral cement plants are facilities that use raw materials such as limestone and clay and convert them into clinker in the furnaces. In order to achieve this process, different fuels can be used. The model considers petroleum coke, coal, natural gas, used oils and tires. Also, an important electricity consumption is required. As was explained in the previous section, there are different ways of producing clinker. From the point of view of the model, the only difference among all these technologies is the energy requirements to produce clinker. The model considers wet, semi-dry and three variants of dry technology, which are the most used in Spain. These are long dry, dry with pre-heater and dry with pre-heater and pre-calciner.

The model considers white clinker and grey clinker, and the energy requirements are different for both types.

Once clinker is produced or imported, the process followed in integral plants and in cement mills is similar and the only difference is the cost structure.

Cement production has zero direct emissions because this process just consists of grinding clinker and other additions, such as slag and flying ashes, but it is always produced in electric mills. All the emissions of this process are indirect, and are considered through an emission factor which is the average for the power sector in Spain.

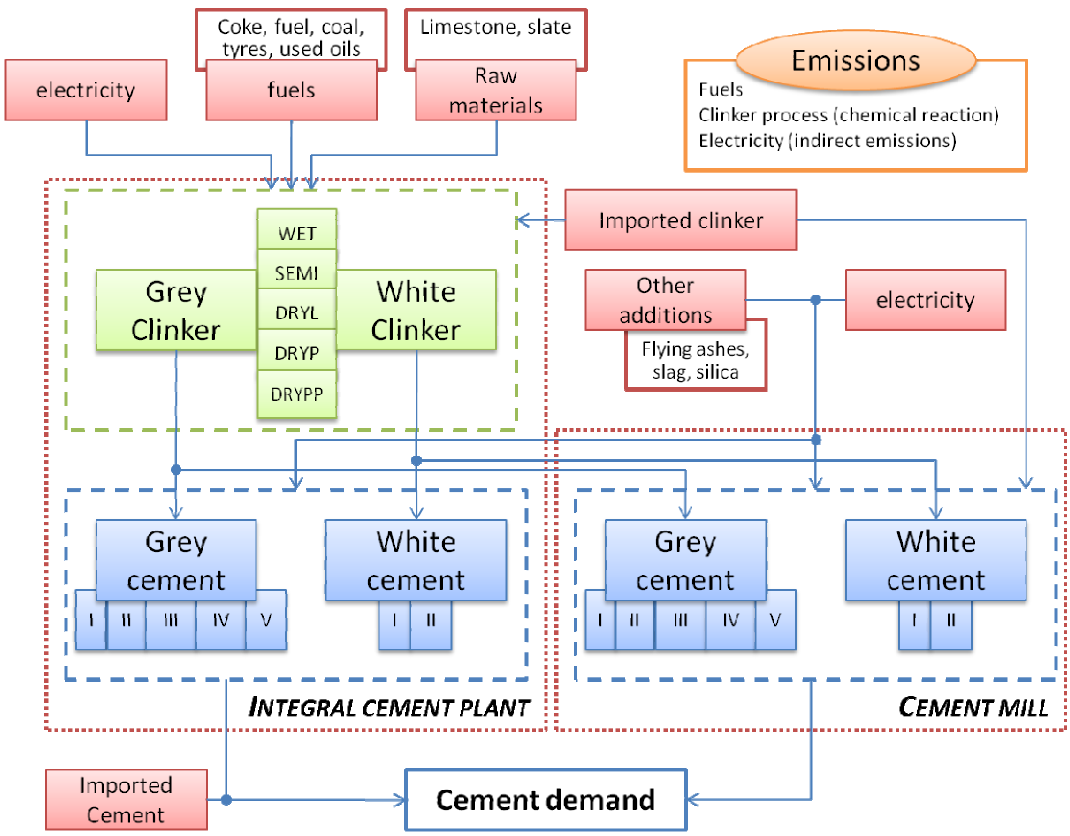

Figure 3. Cement production scheme

The cement model minimizes the cost of producing seven types of cement, divided into two groups, grey cements and white cements. They differ mainly in the content of clinker per ton of cement.

3.3 Oil refining

3.3.1 The Spanish oil refining industry

The Spanish oil refining sector is composed by ten refineries around the national territory. They belong to three companies: BP owns the Castellon refinery, and the rest are distributed among CEPSA and REPSOL.

Refineries can be classified according to their level of complexity. Although it is difficult to find two equal refineries, there exists a consensus about a gross classification which is: topping, hydroskimming, conversion and deep conversion schemes. Today, most refineries in the world belong to the conversion and deep conversion schemes, they present similar features, and although there are differences in buildings, they have the same modules and systems.

Conversion schemes in refineries refer to those refineries that have some cracking unit. The cracking units are the fluid catalytic cracking system (FCC), the hydrocracker (HC) and the coker. Those refineries that have a FCC module belong to the conversion scheme. If they have a HC or a coker they are included in the deep conversion classification. In Spain, most refineries follow a conversion scheme and only 30% include a HC or a coker.

In complex refineries the average emission factor is 0.25 ton of CO2 per ton of crude oil refined.

Regarding refined products, it is important to notice that Spain is a net importer of diesel with more than 40% of consumption mainly coming from Italy, Russia, Holland, United States and India. Nevertheless, Spain exports gasoline to the United States and Mexico.

3.3.2 The refinery model

The model used to assess the Spanish oil refining sector is a big refinery which includes all the modules that a real refinery might have. The way all these modules work together can be observed in Figure 4.

First of all, the module shared by all refineries in the world is the atmospheric distillation tower. The crude oil enters in this module to suffer a first division in the main fractions of the crude: fuel gas, propane, butane, naphtha and some heavier extractions. Then, subsequent systems use these fractions to refine final products. As shown in Figure 4, the catalytic reforming module converts naphtha into the main component of commercial gasoline. This module is aimed to increase the octane index of the crude, which is typically lower than required. Moreover, there are other important modules devoted to extracting sulfur from medium distilled fractions (HDS). Regarding diesel production, these modules have to extract enough sulfur from crude oil fractions to reach the levels allowed in the European normative.

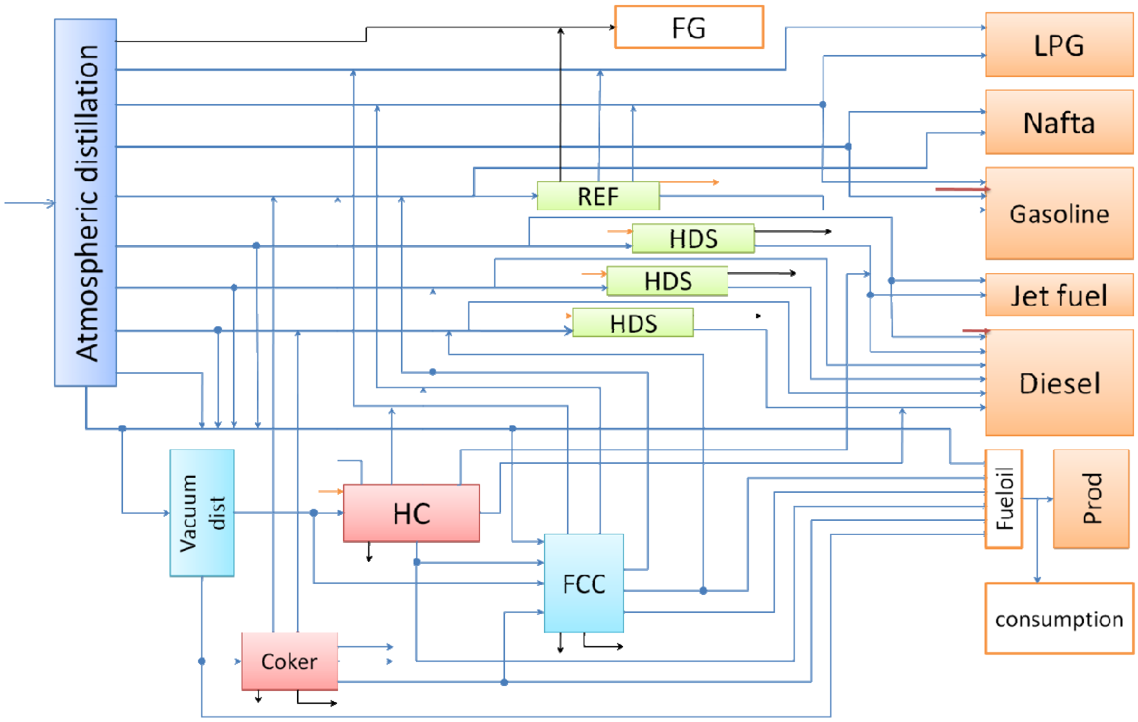

Figure 4. Refinery scheme

The next four modules (vacuum distillation tower, FCC, HC and coker) are complex modules designed to increase the performance of the refineries. These modules are devoted to break the big molecules present in the heaviest fraction of the crude oil to increase diesel and gasoline production.

The vacuum distillation tower is similar to the atmospheric one. It takes the fuel oil coming from the first distillation in the atmospheric tower, and it increases the production of the lighter fraction and gases. The FCC module can be fed with many flows and its objective is to increase the naphtha proportion to increase mainly gasoline production. On the other hand, the hydro cracker (HC) is usually the alternative of the FCC in a refinery. HC is aimed to increase mainly diesel production. Finally, the coker is used to avoid fuel oil production and increase the refinery performance as much as possible.

The model has the objective of meeting a determined demand of diesel, gasoline and jet fuel, which are the most valuable products. Requirements of sulfur content, density and octane level are considered but some linear approximations and simplifications have been taken.

4 Results

In this section, the most representative variables of each sector will be assessed from the point of view of the risk of leakage. The evolution of these parameters when the carbon price increases is shown in this section. In addition, we also present the impact of leakage-reduction policies. The policies considered have been:

- Full auctioning scenario (FA). In this scenario no anti-leakage policy is assumed. The cost of buying allowances for direct and indirect emissions has to be incorporated in the cost structure of each sector.

- Output based scenario (OB). In this scenario we assume that allowances are given for free to industry so that the impact of carbon pricing is reduced. The amount of free allowances received will depend on the production (output) level. We assume a certain carbon price, and then calculate the amount of free allowances (as a share of the total output) that would be required to avoid leakage.

- Border adjustment scenario (BA). In this scenario the full carbon cost is included in the cost structure of each industry as in the FA scenario, but now the cost of imports is adjusted with a border tax. This border tax for imports, in € per ton of imported product, incorporates into the price of imports the equivalent cost of carbon emissions. Again, for a given carbon price we calculate the level of the border tax required to avoid leakage.

First, we start by defining the major parameters used in our study.

4.1 Input parameters

The total demand for the steel sector has been fixed at 14.36 Mton of steel per year (UNESID, 2011). Purchase prices of steel and scrap are assumed to be 420 €/ton of steel and 220 €/ton of scrap respectively (UNESID, 2011). As far as power consumption is concerned, BOF technology is assumed to consume an average of

0,128 MWh per ton of steel produced while EAF technology consumes 0,544 MWh per ton of steel (Meyers & Buen, 1993). Fuel consumption is considered necessary only in BOF production and has been included as a variable cost in the cost structure of this technology.

The emission factors involved in the different processes carried out to produce steel, extracted from the guide of best available techniques (European Commission, 2001), are collected in Table 1.

Process	Factor	Unit
Sinter	0,2	[ton CO_2 / ton produced]
Pellet	0,03	[ton CO_2 / ton produced]
DRI	0,7	[ton CO_2 / ton produced]
Coke	0,56	[ton CO_2 / ton produced]
Pig Iron	1,35	[ton CO_2 / ton produced]
Scrap	0,1	[ton CO_2 / ton produced]
Electricity	0,394	[ton CO_2 / MWh consumed]

Table 1. Emission factors used in steel model.

As can be seen in Table 1, DRI (direct reduced iron) can be obtained as a result of a process with the corresponding carbon emissions, but also it can be imported at 260 €/ton and no direct emission factor is associated. As DRI, pellets and sinter are sub products obtained from iron ore. The costs for the rest of raw materials (UNESID, 2011; SOTN, 2011) are 65€/ton for iron ore and 160€/ton for coking coal.

Demand in the cement sector is classified by cement type, 35.4 Mton of grey cement and 1.08 Mton of white cement (Oficemen, 2011), and it is considered as a constant input for the model.

Since demand has to be met, imports might be necessary. The prices considered for imported clinker and cement are shown in Table 2. These prices have been adjusted and computed according to the content of clinker in each type.

		Clinker	Cement				
			I	II	III	IV	V
Price [€/ton]	Grey	45	59	51	42	45	37
	White	55	72	69	-	-	-

Table 2. Purchase price of clinker and cement.

The maximum capacity of producing clinker and cement in Spanish facilities can be seen in Table 3. Because of the low moisture of raw materials in Spain, wet technology is almost in disuse.

Technology		Clinker WET	SEMI	DRYL	DRYP	DRYPP	Cement Cement plant	Cement mill
Capacity [Mton]	Grey	0,9	0,9	7	10	10	30	10
	White	0,1	0,1	0,5	2	2	1	1

Table 3. Production capacities for clinker and cement in the Spanish industry

Regarding the oil refining industry, the demand considered is presented in Table 4.

Gasoline	9	[Mton / year]
Jet fuel	6	[Mton / year]
Diesel	23	[Mton / year]
Fuel oil	9	[Mton / year]

Table 4. Demand of refined products

This is the demand of the main refined products in Spain in 2009 (CORES, 2011). The capacity of the refining sector is 67.8 Mton of crude oil (Ministry of Environment, 2004) including: atmospheric distillation, vacuum distillation, catalytic reforming, hydro desulfurizators, FCC, HC and coker. Prices for imported goods are considered fixed and their values are shown in Table 5.

Gasoline	696	[€/ton]
Jet fuel	625	[€/ton]
Diesel	662	[€/ton]

Table 5. Price of importing refined products (CORES, 2011)

The net margin assumed is 4.25$/bbl (AOP, 2011).

4.2 Risk of leakage

This section presents the results obtained in industrial sectors under different scenarios. Each sector is individually assessed.

4.2.1 Steel

The steel industry is characterized by two types of facilities: BOF plants with higher fixed and variable costs and high energy intensity; and on the other hand EAF facilities, where costs are lower and the energy consumption, mainly electricity, does not involve high levels of emissions.

Assuming a “full auctioning” scenario, Figure 5 shows how the CO2 price affects the production from both technologies. It can be seen how BOF production stops being profitable when CO2 price reaches 85 €/ton of CO2. EAF production, according to its low level of emissions, continues being a suitable and profitable alternative even with CO2 prices over 200€/ton of CO2.

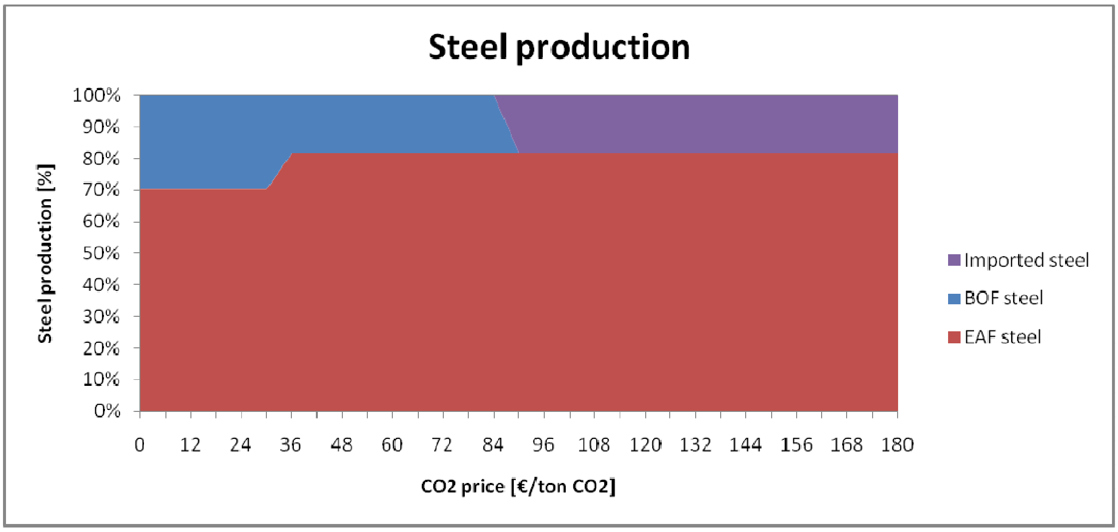

Figure 5. Steelmaking evolution under FA.

However, some assumptions made for the steel sector and which might explain these results must be explained in more detail. There are many products obtained from crude steel such as hot and cold rolled steel, steel wire rod, medium steel sections, etc. This study considers crude steel as a homogeneous product. Processes afterwards increase significantly the value of the product, and also the risk of leakage in this sector due to the reduction of the margin between production costs and price in the market and the increase in emissions because of forward processes. However, although the leakage ratio would increase (leakage would occur at a lower cost of CO2), to take into account this fact would involve including new and more complex modules in the model.

Other fact that makes the steel sector to be so resilient to carbon prices is the existing margin of benefits, mainly in the EAF industry. The price of scrap represents 65% of the total cost in the EAF technology and changes in its price involve important changes in the production chain. Furthermore, scrap price is very volatile which makes it difficult to extract conclusions for this sector.

Figure 6 shows how scrap consumption evolves. It is important to notice that with low prices of CO2, pig iron is the cheapest alternative and it is used in BOF production and even in small quantities in the electric furnaces, but when CO2 price increases, the tendency to use scrap also increases. Prices over 28 €/ton produce a reduction in pig iron consumption, which is compensated by an increment in the proportion of scrap used in both routes, BOF and EAF. Moreover, the reduction of pig iron production involves a reduction in steel production from BOF due to the technical constraints in the use of scrap in this route.

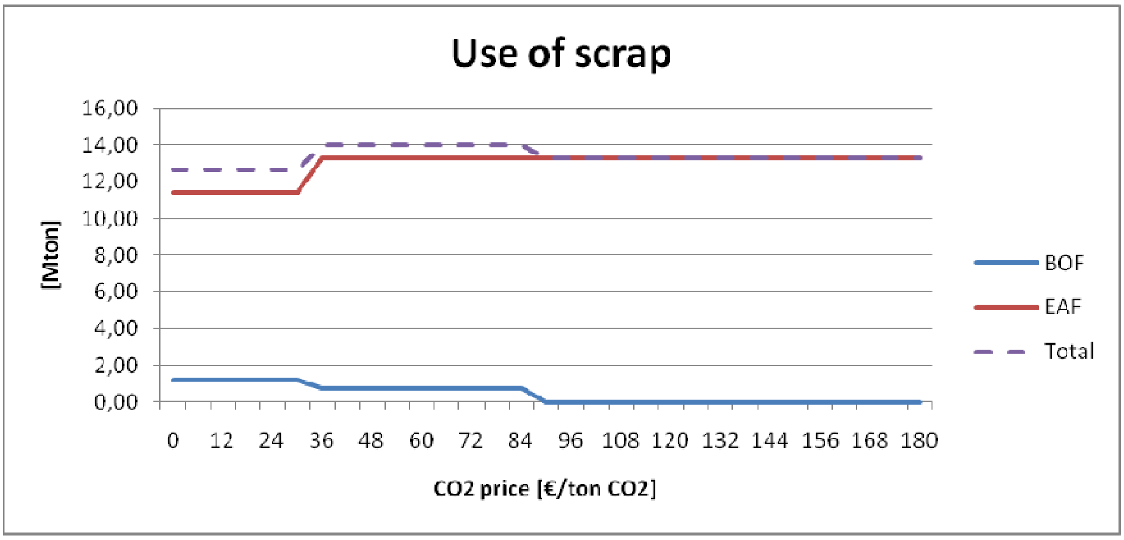

Figure 6. Use of scrap in the steel industry

The cost of electricity represents only 2% of the total cost of BOF steel production, while in the EAF route this value rises up to 11%. Indirect emissions in steelmaking due to electricity consumption are very small in BOF technology, and although the EAF approach involves a big amount of electricity, the low average emission ratio for the Spanish electricity sector (0.394 ton CO2/MWh) makes that this effect affects only with very high prices of CO2. This is the reason why making distinctions between free allowances only for direct emissions and free allowances for direct and indirect emissions does not show big differences.

Regarding the different anti-leakage policies and scenarios that are being assessed in this study, it is shown in Figure 5 that the risk of leakage would occur at very high CO2 prices. That is the reason why implementing anti-leakage policies does not make much sense for this industry, under the assumptions considered..

4.2.2 Cement

Cement is a finished product whose process of production consumes only a small amount of electricity. The main problem in this industry is the production of the raw materials of the cement. These are mainly clinker and other materials, such as flying ashes, slag, silica, etc. which usually come from wastes from other industries. The key element of cement industry is the production of clinker. This is the most energy intensive process of this industry and the element that makes this sector subject to leakage risk. Figure 7 shows the level of leakage that could take place in the cement sector if the CO2 costs, direct and indirect, are included into the cost structure of the sector (full auctioning scenario) at different carbon prices.

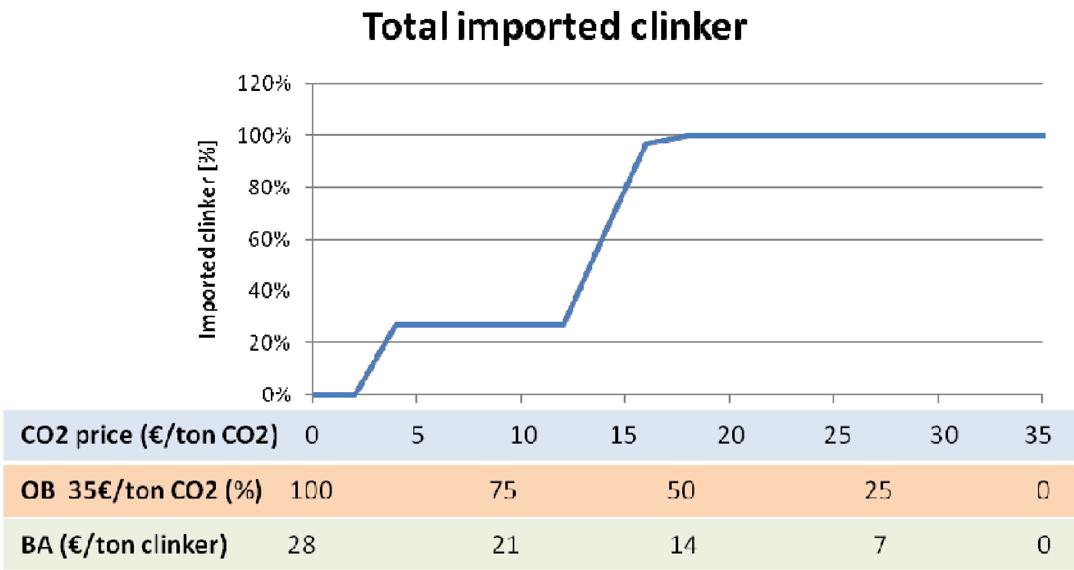

Figure 7. Imports of clinker

In Figure 7 it can be seen how CO2 prices over 17 €/ton of CO2 would involve that the total need of clinker to meet the demand of cement in Spain would be imported. The cement sector presents therefore a clear risk of leakage mainly caused by the need of clinker. It can be seen in Figure 7 that at a CO2 price of 35€/ton, leakage occurs. In an output based scenario more than 50% of the total emissions should be allocated for free in order to start reducing the leakage effect, and almost 85% of allowances should be given for free to keep the whole production with DRYP and DRYPP facilities.

Assessing the emissions in the BA scenario, it is important to mention that it has been assumed an average ratio of emissions of 0,8 tons of CO2 per ton of clinker. This factor is an estimation taking into account the average emission factors for grey and white clinker published by the European Commission and a representative share of demand of these two products in the Spanish industry. Figure 7 shows that border taxes between 14€/ton of clinker and 28€/ton of clinker would be required to reduce the risk of leakage in the Spanish cement industry.

Finally, Figure 8 shows how the different cement technologies in Spain are affected by CO2 prices.

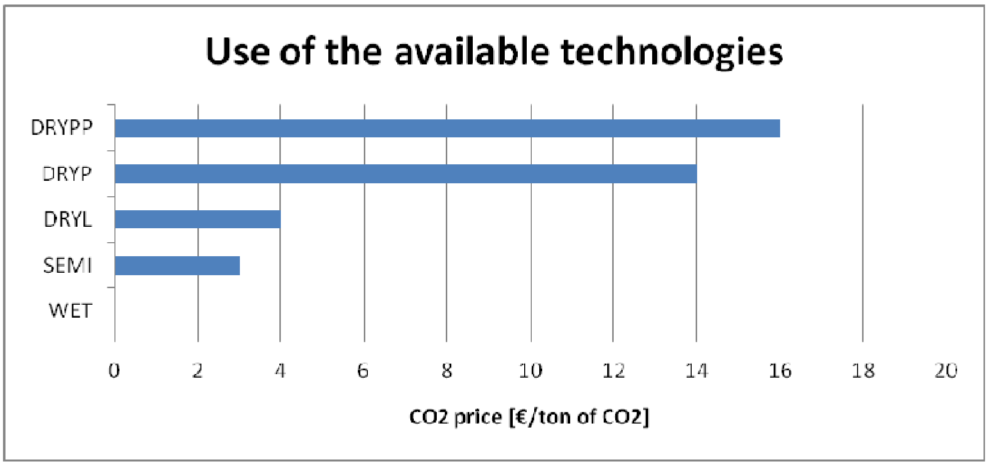

Figure 8. Effects from leakage in available technologies

It is observed that wet technology is fully abandoned even with a zero price of CO2 because of its low efficiency. Semi-dry and dry long technologies keep their competitiveness only with very low CO2 prices, while the most efficient technologies are profitable with prices of emissions around 15€ per ton of CO2.

It is important to mention that the availability of dry raw materials in Spain makes it possible to produce clinker and cement from the most efficient technologies. However, there are more alternatives to improve the efficiency of the process: one has to do with the fuel mix used to feed the kilns; the other has to do with the improvements that could be applied to the existing facilities to increase their performance.

Regarding technology improvements, there are two alternatives that would increase the performance of the Spanish cement industry up to the levels defined in the guide of best available techniques. These are changing the traditional cooler present in some facilities in Spain by a most efficient cooler (19 facilities in Spain in 2011)(Oficemen, 2011), and installing pre calciners in those facilities that only have pre heaters (29 facilities in Spain in 2011)(Oficemen, 2011). This measure is a big investment for the sector that only would be profitable if the price of CO2 were over 107 €/ton of CO2.

Finally, the other key point that should be analyzed in the cement industry from the emissions point of view is the fuel mix. One feature of the clinker production process is that almost everything can be burned in their kilns. It usual to burn used oils, plastics, tires, etc. and also biomass. Biomass used in Spain to produce clinker represents only 6.4% of the fuel mix, while the European average is three times higher. The investments required to achieve a fuel mix with 24% of biomass (which is the objective presented in the Spanish Plan of Renewable Energies for 2020) would be profitable at a CO2 price over 14€/ton.

4.2.3 Oil refining

The approach followed to analyze this sector is different from the others presented in this study, firstly because of the complexity of the sector, and secondly because there are different products that have to be considered, at least gasoline, jet fuel, diesel and fuel oil. Moreover, all the refined products considered cannot be analyzed separately due to the features of a refinery. When one ton of crude oil enters in a refinery, the proportion of products that can be obtained is limited by several technical constraints.

Taking all these elements into account, we thought it more illustrative to represent the impact of carbon prices on the competitiveness of refineries by means of the net margin, that is, the price of the refined product minus the cost of the crude, the costs of production and the costs of emissions. Figure 9 shows the evolution of net margin when the CO2 price increases.

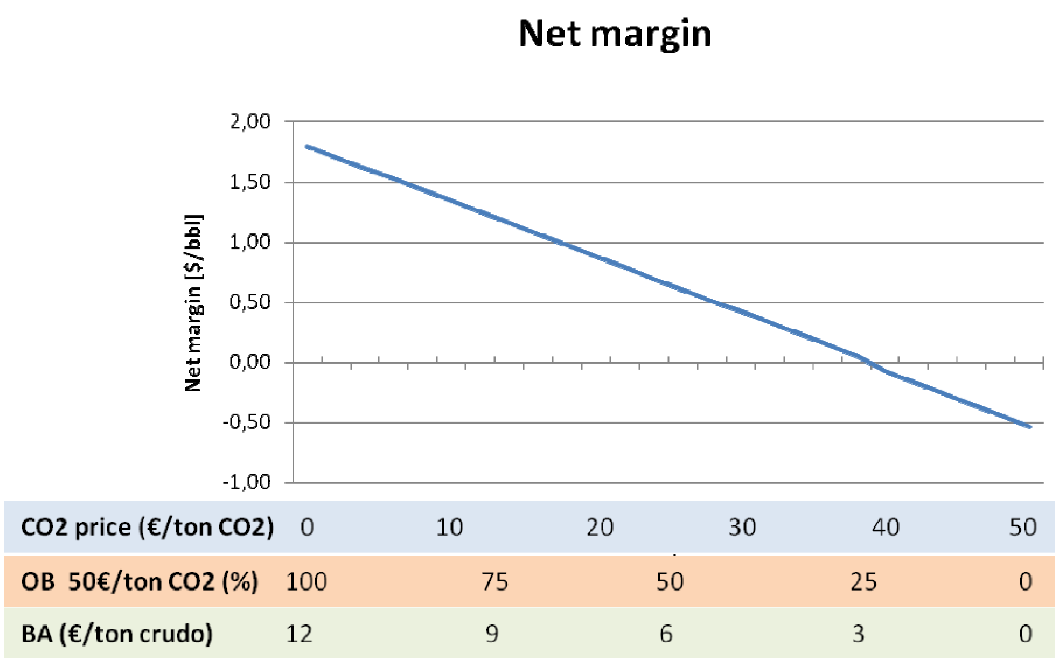

Figure 9. Net margin in the refinery sector

Prices of CO_2 over 40 €/ton CO_2 produces negative net margins, which would involve a risk of leakage for this industry. Actually, net margins under 1$/bbl cannot be supported for a long time, so CO_2 prices over 19 € per ton could even change the production trends.

The oil refining industry has a peculiar feature uncommon to other industries. This is that the prices of the main raw material and the refined products are almost completely determined by international markets, and it is very usual that changes in raw material prices (crude oil) are not proportionally followed at the same time by the refined product prices (gasoline, diesel, jet fuel, etc.). This fact increases the uncertainty in the refinery margin, makes more difficult to take investment decisions, and also increases the risk of leakage if the net margin decreases dramatically for a determined period of time.

Figure 9 shows that the oil refining sector is an industry clearly exposed to the risk of leakage, and consequences could be even stronger than in cement sector due to the uncertainty and rapid changes in product and raw material prices. In this context, under an OB scenario of 50€ per ton of CO_2, refineries should receive around 25% of their emissions for free to keep the net margin of benefits at zero. This would be an unstable situation and the industry would probably require more free allowances. If the option is to set border taxes, we have assumed an average emission factor of 0,24 tons of CO_2 per ton of processed crude oil (AOP, 2011). This factor depends on the complexity and the grade of conversion of each refinery. The simplest refineries have an average emission factor of 0,21 ton CO_2/ton crude oil, while the most complex ones (those who include cokers and hydrocrackers) can reach 0,28 ton of CO_2/ton of crude oil. At the emission factor assumed, the frontier at which the net margin is zero is placed at a border tax of 3€/ton of imported crude oil.

Regarding the refined products, the simulation shows that gasoline would not be imported due to the wide margin between the cost of production and the market price selected.

Jet fuel is a peculiar product and it is used by refineries as an element to adjust the benefits. Jet fuel usually does not have a very high price in the international market nor in the domestic market, and its chemical properties allow to use it as a component of diesel with no need of forward processes. That is the reason why it is usual to use the jet fuel produced to increase diesel production, and meet the demand of jet fuel from imports. Although simulations show high import ratios of jet fuel, this product cannot be considered as a good indicator of leakage.

Finally, diesel is probably the most critical product in the Spanish refining industry. Spain imports more than 40% of the diesel demand but this is an historic trend that could not be associated with the leakage in this sector. However, the demand used in these simulations is already computed taking into account this fact and the products really obtained in domestic refineries. Results from the model show that prices over 38€/ton of CO_2 produce an increase in diesel imports of 7.3%.

It is important to be careful with the conclusions for this sector. As was previously said, prices of refined products are so volatile and the margin of benefits is so thin that it is very difficult to predict trends for this industry.

5 Conclusions

This section explains, by sectors, the main conclusions extracted from the results presented in this study.

5.1 Steel

Steel industry is made up of two types of technologies. The BOF route is clearly exposed to leakage because all the processes behind are intensive in emissions. When CO_2 prices reach 28 €/ton of CO_2, pig iron production, which is the most energy intensive process, decreases. This decrease is firstly supplied by increasing the proportion of scrap used in BOF furnaces, but there is a technical limit for the scrap used in this route and the amount of steel produced from this alternative is reduced. Then, to meet the demand it is necessary to increase the share of EAF steel. While CO_2 price is below 85 €/ton of CO_2, around 15% of the total demand is supplied by BOF production and the rest is produced by EAF, but when CO_2 price increases, pig iron production stops being profitable and the BOF alternative has to be dismissed. Thereon there are two alternatives to meet the demand: imports or investments in new capacity of EAF. The steel industry has high investment costs and the current situation makes the investment decisions a very sensitive issue. Actually, nowadays the Spanish steel production is growing mainly because of the increase of exports, not because an increase in domestic demand. This fact reinforces the decision of not investing in new capacity but importing.

Regarding EAF technology, it is important to mention that this industry is not strongly affected by different anti-leakage policies because direct emissions from this route are quite small. Emissions from EAF technology are indirect and come from the electricity consumption, but the low emission factor for the Spanish electricity sector makes that the risk of leakage in EAF steelmaking is small. Nevertheless, it is important to notice that in spite of being a low-emission industry, EAF technology strongly depends on the availability and cost of scrap. From this point of view, Spain has a good geographical situation due to the easy access to the sea, which makes the transport cheaper.

In conclusion, the Spanish steel industry seems not to be so exposed to risk of leakage as other industries do.

5.2 Cement

Nowadays, the Spanish cement sector is one of the most efficient in Europe, in part, due to the low moisture of the raw materials. In clinker production it is necessary to dry the feeder elements before introducing them into the kiln. This is a costly procedure that can be avoided if the materials are already dry. The low moisture of raw materials in Spain enables the use of the two most efficient existent technologies, dry with pre-heater (DRYP) and dry with pre-heater and pre-calciner (DRYPP), which represent more than 90% of the total capacity installed in Spain. However, in spite of the high efficiency of the Spanish industry, this is a sector where the risk of leakage is stronger than in the steel industry.

Clinker production, the main component of cement, is a very energy intensive process. At very low prices of CO2 the industry is able to keep its competitiveness but when CO2 prices increase over 4€/ton, around 28% of the clinker demand is imported. When CO2 prices are around 15€/ton the share of imported clinker increases and prices over 18€/ton of CO2 make the total demand of clinker to be imported. These values can be slightly altered due to differences in the cement demand. There are many kinds of cement in the market and not all of them require the same proportion of clinker.

It is important to notice that the cement industry has two sources of emissions: emissions from fuel combustion and emissions from the chemical reaction that takes place. Today, there is not a clear substitute for clinker in cement production, and the European normative on the requirements of clinker in each type of cement is strict, so reducing emissions from changing raw materials seems not to be a suitable alternative yet. This fact results in that the alternatives for reducing emissions from the cement sector are basically changing the fuel mix and improving the efficiency of the existing facilities. In the case of Spain, improvements to increase efficiency require investments that would only be profitable at CO2 prices over 107 €/tonCO2. However, the investments required to increase the proportion of biomass in the fuel mix are around 14€/ton of CO2. This value shows that it seems to be profitable for the industry to increase the share of biomass used, but in this case, industries are finding difficulties in obtaining the permits necessary to build facilities to manage the biomass. In this case, the Spanish industry is facing more a political problem than a technical one.

The cement industry is the sector most exposed to leakage presented in this study. At relatively low CO2 prices leakage occurs and the required measures to prevent the industry from importing the whole demand of clinker are strong. Around 75% of total emissions should be allocated for free in an output based scenario or border taxes around 22€/ton of imported clinker should be established.

Finally, it is important to mention a key issue for the cement industry: transport costs could play an important role and could act as a barrier for leakage in this sector. Results presented in this study do not take into account transport costs, but several studies (Szabo et al., 2006) explain that transport by road of clinker is only profitable for distances shorter than 200 km. Although Spain has good access to sea, costs in clinker transport could reduce the risk of leakage for this sector.

5.3 Oil refining

The oil refining sector is the most difficult sector to analyze from the leakage point of view due to its complexity. Prices of crude oils and refined products change every day and there are so many factors responsible for these changes that it is almost impossible to find a correlation or a good approach to estimate their behavior.

In this study it has been assessed how the net margin of refined products changes when CO2 price increases. The oil refining industry is a sector with a low unitary benefit margin and results from the analysis show that prices over 19 €/ton of CO2 would make that margin decrease dramatically and a CO2 price over 40 €/ton would involve net losses. Therefore, the risk of leakage seems to be a problem in this sector. According to this fact, in an output based scenario more than 25% of the emissions should be freely allocated while in a border adjustment framework, a border tax between 3€ and 12€ per ton of imported crude oil would be required for avoiding that problem.

In Spain, and probably also in the rest of Europe, the high diesel demand and the difficulties in supplying such amount from domestic production result in that more than 40% of demand is covered from imports. This is the "business as usual" scenario. However, an extra increase in imports of diesel is observed when CO2 price reach 36€/ton.

In spite of the fact that most conclusions extracted for the oil refining sector show that risk of leakage exists due to the thin benefit margin and the direct effect of emissions in the production processes, the huge investment costs involved in this industry and the volatility of prices make it difficult to move production from one country to another, even for the international companies of the sector. On the other hand, it is important to mention that the increasing demand of medium distillates (mainly diesel) is increasing the grade of conversion, or complexity, of most refineries in Europe. This means that the performance of refineries from the diesel point of view is increasing, but at the same time, the efficiency of the plant and the emissions ratios also increase. This fact makes the oil refining industry to be more and more exposed to leakage.

The current trend for this sector in Spain is that new investments are taking place, even under the economic crisis, in order to increase the proportion of diesel produced. This means that new investments are focused on increasing the capacity of hydrocracker and cokers, which are the most complex and advanced modules that allow squeezing the performance of a refinery a bit more. This fact increases CO2 emissions from refineries and also the risk of leakage for this sector.

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