:vivideconomics

Case Studies

Report prepared for DECC

Final report
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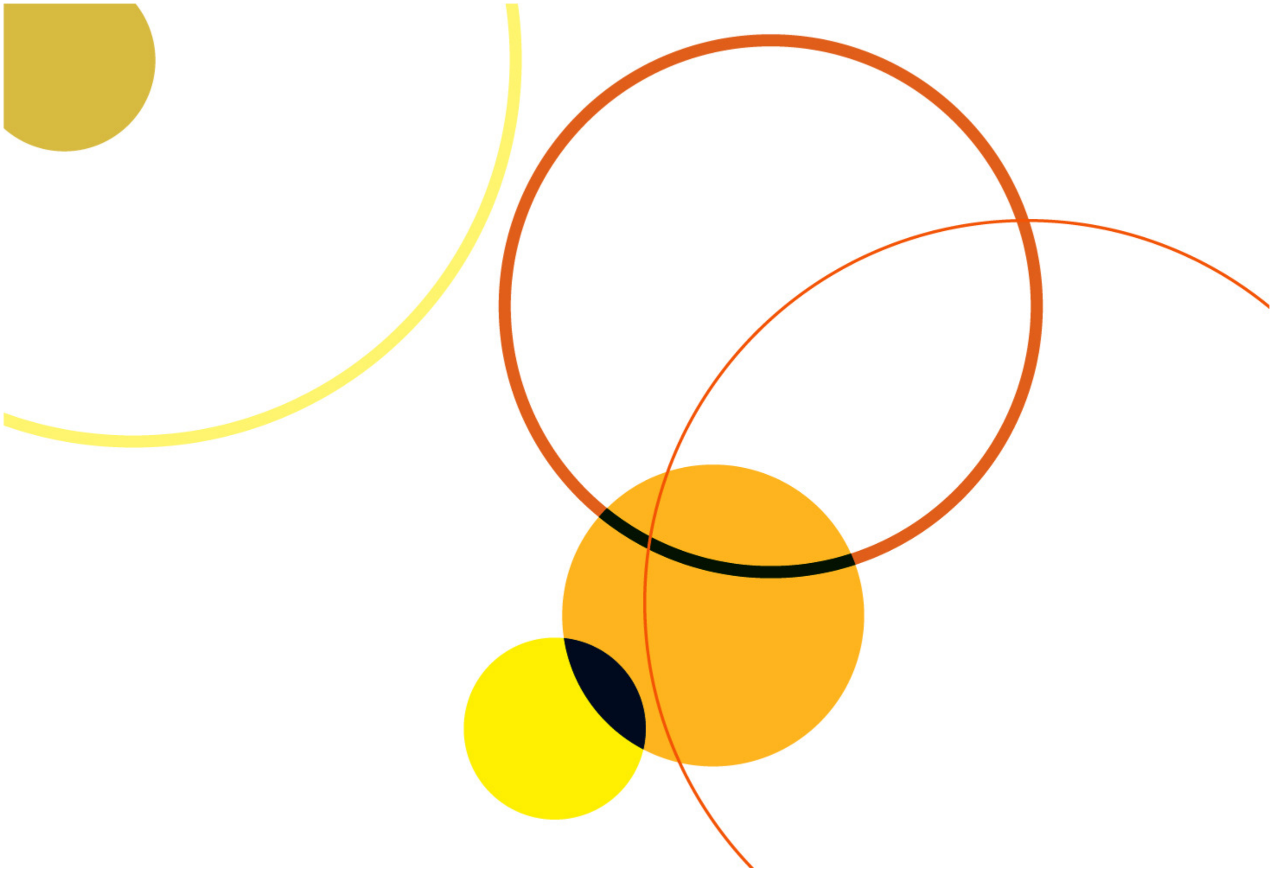

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1 Content of the case studies and glossary

Case studies provide detail on the state of the sectors and modelling results

1.1 Aim and structure of case studies

Case studies were produced for each of the sectors investigated in detail using FIMM. These case studies provide additional context and understanding of the market environment of sector, and space for the presentation of sector model results. Inevitably, the discussion involves usage of some economic jargon, which is defined for reference in Section 1.2.

Neither the case studies nor this section describe the mechanics of the IMMs, which can be found instead in Section 3 of the main report. The reader may find it useful to read over Section 3, and the summary modelling results in Section 4, and particularly the discussion of cost pass-through in Box 1 of the main report, before tackling the case studies.

In addition to a brief opening summary, the structure of each case study is along the following lines:

Characteristics of production:
- *production process:* details of the production process, explaining the sources of carbon emissions and providing context for the discussion of abatement;
- *emissions- and energy-intensity of production*: estimates of sector energy use and carbon emissions, providing a sense of the increase in production costs under carbon pricing. A general discussion covering the outlook for energy- and carbon-abatement.

Sector composition and features:
- *market composition:* market segmentation and major producers, and their share of the market;
- *trade patterns:* discussion of whether modelling is performed at the UK, EU, or global level, informed by patterns of trade. Sources of imports are of interest when determining estimates of output and carbon leakage;
- *profitability* and *pricing, elasticity and substitutes:* the FIMM requires estimates of several other variables describing characteristics of the sector, which are discussed in this section.

Modelling:
- *model inputs:* any inputs not explicitly identified in previous sections are discussed, and all major inputs are summarised;
- *UK and EU production:* focusing on production quantities rather than carbon emissions, the impact of carbon prices on UK and EU producers is discussed;
- *output and carbon leakage:* the extent to which production losses and declines in emissions are offset by increases in imports and associated embedded emissions;

- *additional notes:* any final thoughts, issues, or particular provisos concerning the inputs and outputs for the sector under investigation.

While the case studies provide an overview of the abatement options in each sector, no adjustment is made for carbon-abatement (or electricity decarbonisation) in the modelling.

1.2 Glossary

Allowances: EU Allowances issued under the EU ETS.

Border carbon adjustment: Applying financial instruments to traded goods in line with their calculated embodied carbon content with the intention of equalising the playing field faced by domestic and foreign producers.

Carbon leakage rate: The *c*arbon leakage rate is commonly measured as the ratio between increases of emissions in unregulated regions and decreases of emissions in regulated regions. The carbon leakage rate is frequently expressed as a percentage of emissions reductions in regulated regions. For instance, if, as a consequence of particular policy, total carbon emissions in the EU declined by 200 tonnes but foreign emissions increased by 60 tonnes, the leakage rate would be reported as 30 per cent, 60 divided by 200.

Competitiveness: Within the industrial market models, a competitive firm has low costs of production relative to its rivals. This contrasts with 'strength of competition', which is a market property, where strong competition results in low profit margins and results from a combination of a large number of rivals or aggressive behaviour or both.

Cost pass-through rate: The absolute change in the sale price of a product divided by the absolute change in per-unit production costs which drove the price change.

Leakage estimate: An estimate of the extent of carbon or output leakage under a hypothetical policy, based on a theoretical economic model concerning the behaviour of producers with key parameters calibrated to real-world data.

Empirical leakage estimate: An estimate of the extent of carbon or output leakage under a hypothetical policy, based on empirical analysis of statistical time series.

Full Industrial Market Model, or FIMM : see Industrial Market Model.

Gross Value Added, or GVA: The sum of profits and labour costs which can, broadly speaking, be considered a sector's 'contribution' to the national economy.

Industrial Market Model: A proprietary model developed by Vivid Economics, described in detail in Section 3. The model focuses on the microeconomics of specific product markets, allowing for examination of the impact of changes in the competitive environment, such as changes in production costs or firm entry and exit. The model comes in 'full' or 'reduced' forms, which are abbreviated to FIMM and RIMM respectively. In brief, the main distinction between the different versions is that the FIMM can include detail down to the production decisions of specific installations, while the RIMM is focused on the distinctions between aggregated regulated and non-regulated regions.

Output leakage rate: output leakage is defined similarly to carbon leakage, but refers to changes in industrial production in different regions.

Price elasticity of demand: the responsiveness of consumers to changes in product prices, defined as the percentage change in quantity demanded divided by the percentage change in price. For instance, an elasticity of -0.5 would imply that a 1 per cent increase in price would result in a 0.5 per cent decrease in the quantity demanded.

Reduced Industrial Market Model, or RIMM: see Industrial Market Model

2 Aluminium production

2.1 Characteristics of production

2.1.1 Production process

In primary production, aluminium is produced from alumina. Alumina itself is refined from bauxite and is sometimes referred to using its chemical name, aluminium oxide. Two tonnes of alumina are required to produce one tonne of aluminium. The production process follows several steps (Ecofys, 2009):

- alumina is reduced in a fluorinated bath of cryolite under high intensity electrical current (the energy-intensive stage);
- molten aluminium is tapped from the electrolysis cells and alloyed with some combination of manganese, magnesium, silicon, zinc and copper;
- aluminium is cast and extruded or rolled to form semi-finished products.

In the secondary production process, aluminium is produced from scrap, machine turnings and dross (scum formed on the surface of molten metal). Again, there are several steps within the process:

- the aluminium inputs are prepared, for instance by milling and grading for dross, or by paint-stripping for scrap;
- rotary drum or hearth furnaces are used to melt down aluminium scrap and materials, at temperatures of around 750 degrees Celsius;
- molten aluminium is then alloyed and cast, as in primary production.

2.1.2 Emissions- and energy-intensity of production

Primary production of aluminium is much more energy intensive than secondary production. In the EU, the total direct emissions from the primary smelting and casting of one tonne of aluminium are between 1.5 and 2.7 tCO_2 (Ecofys, 2009a). The electricity intensity ranges from 14 to 16 MWh per tonne which, at the average Western European emissions intensity of 0.34tCO_2 per MWh, is equivalent to around 5 tCO_2 (Ecofys, 2009a). Recycling aluminium emits around 0.2 tCO_2 per tonne of product; see Table 1 below. Note this excludes additional emissions from alumina and cathode production and also excludes the energy used in the mining and transport of bauxite and alumina, as well as the release of perfluoro compounds.

Table 1. **Estimated direct emissions and electricity intensity of various stages in aluminium production**

Activity	Direct emissions (kg CO_2/t product)	Electricity consumption (kWh/t product)
Primary smelting	1,500 – 2,550	14,000 – 16,000
Primary casting	70 - 200	50 – 200
Secondary remelting	150 - 350	120 – 340
Secondary refining	250 - 390	---
Rolling operations	20 - 235	70 - 900
Extrusion operations	50 - 250	300 - 1200

Source: Ecofys, 2009

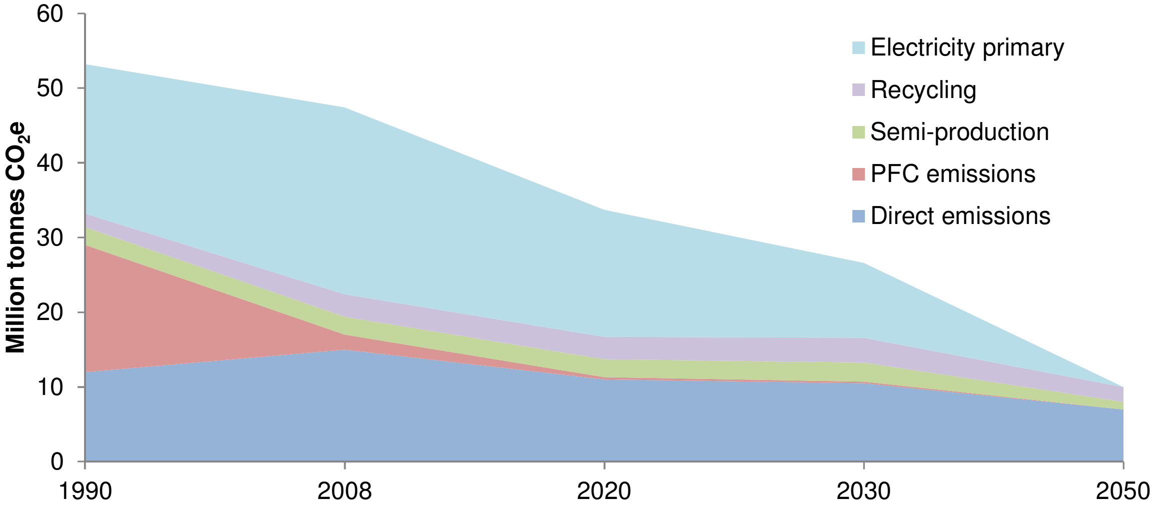
The electrical efficiency of primary aluminium making has gradually improved over time. The specific electricity consumption in Europe for primary aluminium, for instance, declined from 16.7 to 15.7 MWh per tonne over the period 1980 to 2013 (Nappi, 2013). The proportion of recycled aluminium greatly affects electricity consumption because secondary aluminium production, using recycled materials, has an energy intensity which is about 20 times lower.

Another option for carbon abatement is the use of Combined Heat and Power (CHP), which about half of Europe's primary plants currently employ (Ecofys, 2009a). The combination of high electricity use and steam for refining and calcination make the sector suitable for CHP. However, a sizeable share of the sector is located in the vicinity of hydro power plants, which makes the use of CHP less appropriate: the EU aluminium sector uses about 60 per cent hydroelectric power (The Carbon Trust, 2011a). The only aluminium smelter in the UK uses hydro power, limiting the scope for this abatement strategy within the UK.

Over the past two decades, the aluminium sector has drastically reduced emissions from perfluoro compounds (PFC) which arise during the electrolytic smelting process. In Europe, there remains 800,000 tCO_2e per year PFC emissions from aluminium production. Globally, there is an effort to reduce PFC emissions by 50 per cent from 2006 levels by the year 2020 (International Aluminium Institute, 2011). The European Aluminium Association (EEA) has produced a briefing that is in line with this global ambition, proposing to deliver a 70 per cent reduction in the sector's direct emissions by 2050 (European Aluminium Association, 2013).

If this reduction is combined with the European Commission's scenario on reductions of emissions from electricity generation, this proposal has the potential to deliver a 79 per cent reduction in the aluminium sector's direct and indirect emissions. New technologies that eliminate direct emissions from carbon anode consumption are anticipated by the EEA by 2030, as seen in Figure 1. However, approximately 62 per cent of the reductions in emissions are due to the reduced consumption and carbon intensity of electricity.

Figure 1. **Decomposition of 79 per cent carbon emissions reduction by the aluminium sector by 2050**



Source: Based on European Aluminium Association, 2013, Vivid Economics

2.2 Sector composition and features

2.2.1 Market composition

There is only one primary smelter still operational in the UK: the Lochaber smelter owned by Rio Tinto Alcan. Two primary smelters closed in 2009 and 2012, located in Anglesey and Lynemouth, Northumberland, respectively. The Anglesey smelter lost its access to low cost electricity from the Wyfla nuclear power plant and could not negotiate a new commercially viable electricity contract despite offers from the government of electricity subsidies (Anglesey Aluminium Metal, 2013). Reasons cited for the closure of the Lynemouth plant were tough market conditions and increased costs of compliance with environmental regulation (Rio Tinto Alcan, 2011). The Lynemouth smelter produced 178,000 tonnes of aluminium a year, which is more than three times the size of the smelter in Lochaber.

Primary production in Western Europe has stagnated since 2000, while global production has almost doubled. This led the EU's market share of global primary aluminium production to slip from 20 per cent in 2000 to 11 per cent in 2012 (International Primary Aluminium Institute, 2013). Britain's production of aluminium is following broadly the same trends as Europe as a whole, with declining primary production contrasting with growing secondary production. EU primary production is concentrated in Germany, Spain, France, The Netherlands and Romania, with Germany having the largest share at around 432,000 tonnes in 2011. The joint production of these nations in 2011 was around 1.7 million tonnes, over 40 times the UK's current productive capacity.

On the other hand, a large number of secondary aluminium production facilities remain operational. There are currently almost 40 separate operational secondary production assets within the UK (Light Metal Age, 2013). Secondary facilities generally have smaller capacities than primary smelters. In the EU in 2011, there were 283 plants producing recycled aluminium, accounting for a third of total EU aluminium supply (European Aluminium Association, 2011). Secondary production of aluminium in the EU occurs mainly in

Germany, Italy, Spain and the UK, which together account for more than three-quarters of total output. With 600,000 tonnes, Italy was the largest secondary producer in 2000. However, secondary production in Europe has also been hit by the recession. Italy's secondary production accounted for more than three quarters of its total production before 2008, but fell by 44 per cent in 2009. Germany's secondary production was also heavily affected by the recession, falling 33 per cent between 2007 and 2009.

2.2.2 Trade Patterns

In 2011, Germany was the largest importer of aluminium globally with a market share of 12 per cent. It is considered one of the largest exporters of aluminium due to its large semi-finished aluminium product market. The USA was close behind with 9.9 per cent. France is the second largest importer in the EU and is the fifth largest globally. In 2012, France and Germany supplied almost 50 per cent of the UK's aluminium imports. The destinations of 82 per cent of the UK's aluminium export were within the EU (Eurostat, 2013). However, only 35 per cent of aluminium consumed in Europe is produced within the EU ETS zone (The Carbon Trust, 2011a).

In the secondary aluminium market, aluminium scrap is a vital input in the production process. The EU has gone from being a net importer ten years ago to an net exporter now (Schrynmakers, 2012). Producers in the Middle East and China are now processing aluminium scrap that is exported from the EU.

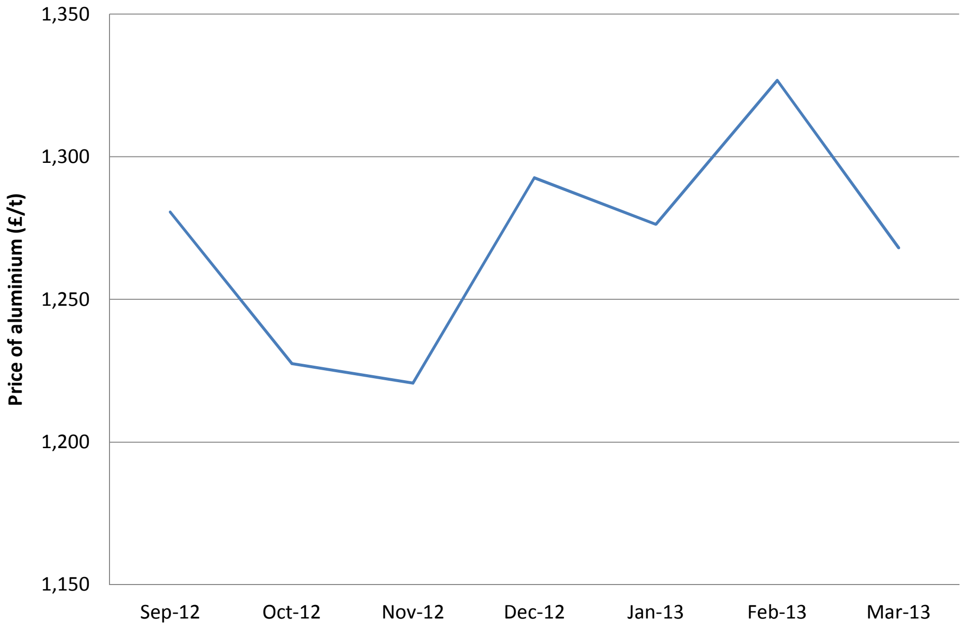
2.2.3 Employment and GVA

In the UK, aluminium sector employment has fallen by 60 per cent since 1998, and there are now around 5,000 workers in the sector (ONS, 2012a). GVA has also declined by about 60 per cent over the same period. In the EU as a whole, the sector directly employs 250,000 workers (Schrynmakers, 2012).

2.2.4 Pricing and elasticity

Aluminium is a globally traded commodity, with prices across the world indexed to the price at the London Metals Exchange. Prices are procyclical, largely driven by fluctuations in demand from the construction, transport and packaging industries. The price used in the modelling is £1,289 per tonne, taken as the average over the 2012 period (IndexMundi, 2013a).

Figure 2. **Aluminium prices have shown some volatility, but remain around £1,200-£1,300 in the 2012-early 2013 period**



Note: *Aluminium, 99.5% minimum purity, LME spot price, CIF UK ports, pound sterling per metric ton*

Source: *Vivid Economics*

2.2.5 Profitability and costs

Profit margins on primary production have been reduced by rising electricity costs and falling prices. Average gross margins for primary smelters across the sector in UK are around 11 per cent (IBISWorld, 2013a). UK profit margins within the sector are volatile in part due to firms' limited ability to pass on costs. Large firms have not been immune to competitive pressures, as shown by the closure of Rio Tinto's Lynemouth smelter.

Capital, alumina and energy costs account for about equal shares of total aluminium production costs. However, energy costs are a key driver of differences in profitability between countries. A firm's investment decision is therefore largely predicated on a cheap and reliable energy source. About 70 per cent of the variability in aluminium's total cost is linked to energy cost (Nappi, 2013). Recent statistics suggest purchased materials, services and utilities jointly are equivalent to almost 75 per cent of total sector revenues (IBIS World, 2013). Depreciation also accounts for a significant share of revenue.

2.2.6 Elasticity and substitutes

Composites, magnesium, steel and titanium all compete with aluminium for some transport and construction uses, while glass, paper and plastic all offer alternatives within packaging. As a result, demand for aluminium production as a whole is more price elastic than some other energy intensive goods, with estimates within the literature suggesting a price elasticity of around -0.8 (Federal Environment Agency, 2008).

2.3 Model simulation

2.3.1 Modelling aluminium

Aluminium is a global market and thus non-EU producers encompass all primary aluminium smelters world-wide. The sector is the only one modelled at a global level.

The modelling is focused on the more energy-intensive primary production, due to poor data availability on secondary production.

A striking feature of the aluminium sector is the difference between the average EU carbon intensity measure, 5.2 tCO_2/t, and the non-EU average carbon intensity measure, 10.7 tCO_2/t. These measures represent weighted averages by tonnes of production. They were calculated using a combination of data from sector associations, the World Development Survey, fuel mix estimates on a national level published by the Aluminium Trade Association, and measures of carbon intensity for electricity generation published by the International Energy Association. Although the only aluminium smelter in the UK is hydro powered, nation-wide electricity emissions-intensity numbers are applied across all countries, due to an assumption of substitutability of energy sources in the long-run. The non-EU figure is weighted towards Chinese carbon intensity measures as a third of world primary aluminium production is based in China, where electricity generation is approximately 80 per cent coal powered.

Model inputs for the aluminium sector are summarised in Table 2.

Table 2. **Inputs to modelling aluminium**

Variable	Value	Source
Initial market price	£1,289/t	IndexMundi (2013)
Demand elasticity	-0.8	Sinden, Peters, Minx, & Weber (2011)
UK production (2011 calendar year)	29,000t	USGS (2011)
EU production (2011 calendar year)	4,000,000t	USGS (2011)
UK emissions intensities	5.7 tCO_2e/t	
EU emissions intensities	5.2tCO_2e/t	
non-EU emissions intensities	10.71 tCO_2e/t	
Gross UK profit margins	3%	Cote (2009)

Notes: *To determine emissions intensities: minor contributors are added according to International Aluminium Institute (IAI) (2007) global average; electricity use is taken from International Primary Aluminium Institute, (2013) and combined with data on emissions intensity. IPCC (2006) estimation methods are used regarding technology types and associated emissions, along with data on regional technology mixes from the JRC. This provides a weighted average emissions intensity of production within a region (Anode effect: Luo & Soria (2007)).*

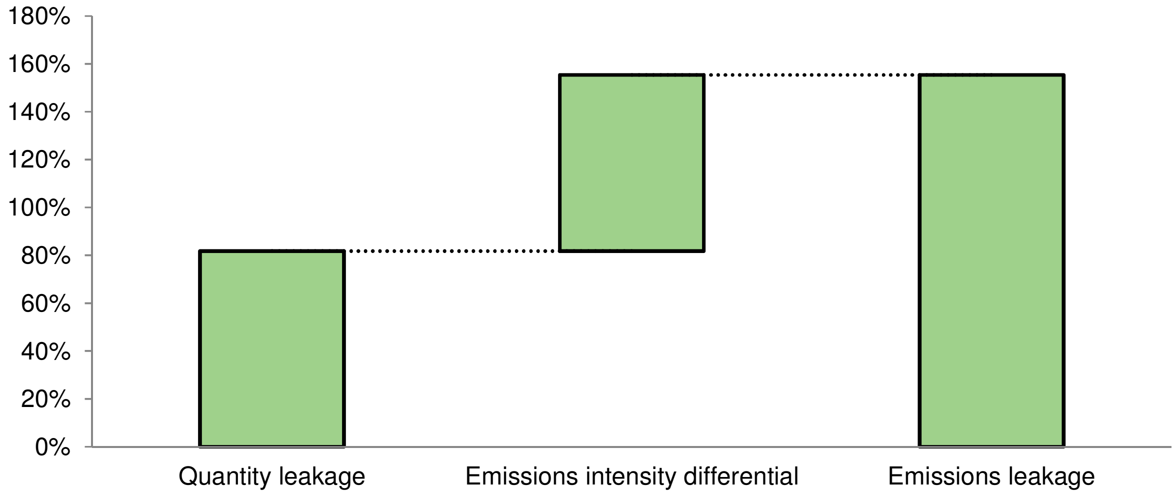
Source: *Vivid Economics*

2.3.2 Output and carbon leakage

Aluminium is an energy-intensive sector in which the carbon cost is between 2 and 17 per cent of the product price (2020 core scenario). It also features relatively high long-run sensitivity of demand to product prices, which combine to give output leakage of 82 per cent. That is, every 100 units of output lost in the EU are replaced by 82 units outside it.

Carbon leakage increases with both output leakage and the differential in emissions intensity between regulated and unregulated producers. In the case of the aluminium sector, non-EU producers are, on average, almost twice as emissions-intensive as those in the EU, thus carbon leakage is almost double output leakage, at approximately 150 per cent (Figure 3). That is, for every 100 units of emissions reduced in the EU, emissions elsewhere increase by 150 units.

Figure 3. **High quantity leakage and a large emissions intensity differential creates high emissions leakage**



Note: *Shows decomposition of leakage for a €30 carbon price in 2020*

Source: *Vivid Economics*

2.3.3 Sector notes

Only primary smelters are considered in the modelling, due to data limitations. The impact of including secondary smelters is not clear, but the overall narrative, that primary aluminium producers in the EU will struggle to pass on costs and face large output reductions under carbon pricing, would remain robust.

Table 3. **The EU aluminium sector faces a relatively strong leakage risk**

Counter-factual	Price of carbon (€)		EU production (t)	EU Market share	EU emissions (tCO$_2$)	Non-EU emissions (tCO$_2$)				
2012	0		3,700,000	10.0%	20,000,000	360,000,000				
2020	0		3,400,000	7.0%	18,000,000	490,000,000				
2030	0		3,300,000	5.0%	25,000,000	649,000,000				
Year	**Change in price of carbon (€)**	**Cost shock as a fraction of price (%)**	**Change in EU production**	**Change in EU and UK) market share**	**Change in EU emissions**	**Change in non-EU emissions**	**Output Leakage rate**	**Carbon leakage rate**	**Cost pass-through rate**	**Change in price**
2012	5	2%	-1%	-2%	-15%	2%	85%	162%	15%	0.3%
2012	15	5%	-38%	-4%	-39%	4%	85%	162%	15%	0.8%
2012	30	10%	-65%	-8%	-66%	7%	85%	162%	14%	1.4%
2020	5	2%	-16%	-1%	-16%	1%	82%	155%	15%	0.3%
2020	15	5%	-42%	-3%	-42%	3%	82%	155%	15%	0.8%
2020	30	10%	-70%	-6%	-69%	5%	82%	155%	13%	1.3%
2020	50	17%	-86%	-7%	-86%	6%	82%	156%	10%	1.6%
2030	5	2%	-17%	-1%	-17%	0.8%	78%	147%	14%	0.3%
2030	15	5%	-43%	-3%	-45%	2%	78%	147%	14%	0.8%
2030	30	10%	-71%	-4%	-72%	3%	78%	148%	12%	1.2%
2030	50	17%	-87%	-5%	-87%	4%	78%	149%	9%	1.5%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

3 Cement

3.1 Characteristics of production

3.1.1 Production process and emissions efficiency

‘White’ and ‘grey’ cement are distinct: white cement is made from raw materials that are extremely low in impurities, resulting in a lighter coloured product often used for decorative work. White cement is not produced in Great Britain due to a lack of suitable limestone. The UK does, however, produce calcium aluminate cement; otherwise, within the grey cement market, there is little product differentiation, although compressive strength and heat of hydration can vary. The Office of Fair Trading and the EU Commission (Ecofys, 2009b) found that grey cement of all grades comprise a single relevant product market and can be used interchangeably.

Portland cement is the most commonly used cement, and is produced by grinding and heating limestone. The manufacturing process has four steps:
- limestone is quarried in a location in close proximity to the cement works;
- limestone rock is pulverized, along with some sand and clay;
- powder is heated to 1,450 degrees C, to form a glass-like clinker;
- clinker is mixed and ground with additional materials, such as gypsum, to produce cement.

3.1.2 Emissions- and energy-intensity of production

Over the two decades 1990 to 2010, cement producers in the EU reduced gross emissions intensity by 9 per cent (Mineral Products Association, 2012). Total emissions fell from 163 million to 123 million gross tonnes of CO_2 due to increased carbon efficiency and a fall in production.

The majority – typically around 60 per cent – of carbon dioxide emissions arise from calcination and heating, and are a product of the chemical process (Mineral Products Association, 2013a). The remainder is due to fossil fuel combustion or electricity use, as the process itself is also energy intensive:
- energy is around 40 per cent of cost of production in EU (Ecofys, 2009b);
- in 2007, 12 per cent of energy use in the UK was electricity (Mineral Products Association, 2013a);
- electricity intensity on average in OECD Europe is 100 to 110 kWh/tonne cement (Ecofys, 2009b).

The most efficient EU cement kilns are dry process cement kilns with pre-calciners and pre-heaters. The thermal energy consumption associated with Best Available Techniques (BAT), under idealised conditions – that is, without start ups and shut downs to production – is about 2.9 GJ/tonne of clinker. In practice, European production currently averages about 3.5 GJ/tonne clinker (Ecofys, 2009b). The principal energy efficiency measures are:
- conversion of so-called *wet* to the more energy efficient *dry* clinker production, applicable to around 20 per cent of production in Europe;
- addition of pre-calciners and/or pre-heaters to the clinker kilns to dry kilns, applicable to around 25 per cent of the dry kilns in Europe;
- improved heat recovery.

The Minerals Product Association (MPA) in February 2013 published a roadmap to reduce carbon emissions in the cement sector (Mineral Products Association, 2013a). It identifies two possible scenarios. The optimistic case concerns UK and EU targets of reducing emissions by 81 per cent by 2050 from 1990 levels. In this scenario, Carbon Capture and Storage (CCS) is deployed, preventing the release of around 3 million metric tonnes of CO_2 per annum by 2050. In the second scenario, which has a reduction in emissions of 62 per cent, technological or economic reasons rule out carbon capture. The two scenarios are otherwise identical, with equivalent levels of production, clinker content, transport emissions, plant efficiency and fuel switching.

In the long-term, the cement sector may be a relatively appealing area for Carbon Capture and Storage to be applied. Cement plants are large point sources of CO_2, their flue gas has a higher CO_2 concentration than coal fired power plants, and over 60 per cent of emissions come from mineral decomposition which cannot otherwise be avoided.

Changes in the fuel mix can reduce emissions. Most cement kilns still use coal as a principal fuel, but alternative fuels are also employed: Ecofys (2009) found that the top 10 per cent most carbon efficient producers all had a biomass usage significantly higher than the average.

Another option to reduce the amount of emissions in cement making is the use of clinker replacements, namely fly ash or blast furnace slag. Ordinary Portland cement typically contains 95 per cent clinker whereas blast furnace cement can contain as little as 5 per cent clinker. The extent to which this is possible depends on the local availability of such alternatives and to what extent end-use requirements allow clinker replacement. The reduction in emissions over the past twenty years is in part due to the decrease in the average clinker content of cement from 78 to 73 per cent; the UK is at least as advanced in clinker replacement as the rest of the EU (Mineral Products Association, 2013a).

3.2 Sector composition and characteristics

3.2.1 Market composition

The UK cement sector consists of Lafarge Tarmac, Cemex, Hanson and Hope Construction Materials. Hope Construction Materials is a new entrant and was a remedy required by the Competition Commission for forming of a joint-venture between Lafarge and Anglo American-owned Tarmac in 2013. Hope Construction Materials bought €353 million worth of plants and quarries including one of the UK's largest cement plants in Hope, Derbyshire. Following the merger, Lafarge Tarmac, Cemex and Hanson controlled over 90 per cent of production (Global Cement Magazine, 2013).

The capital cost of a new cement plant can typically come in at around the equivalent of three years of turnover, which ranks the cement sector among the most capital intensive industries. Total net capital expenditure in the UK in 2010 was £30 million (ONS, 2011).

3.2.2 Trade patterns

Around 15 per cent of the cement consumed in the UK is imported (Mineral Products Association, 2012). While production in the UK fell during the recent recession, the import share remained fairly stable at above

13 per cent (Mineral Products Association, 2013b). To enable further imports, there has been an increase in the number of ports that can accept cement. Furthermore, there is a growing international market in clinker, the intermediate energy-intensive component of cement (The Carbon Trust, 2008). The low volumes of international trade can be attributed to the ubiquity of limestone and the high cost of its transport relative to the cost of extraction.

3.2.3 Employment and GVA

In the EU, the production of cement provides an estimated 45,000 direct skilled jobs, with 2,500 of those jobs located in the UK. A modern plant is typically run by about 150 people. GVA in the UK in 2010 was £279 million (ONS, 2011). In the EU, total value added by the cement sector in 2010 was estimated at approximately €7.6 billion (BCG, 2013).

3.2.4 Profitability

As demand for cement is strongly procyclical, the cement sector has suffered during the recent financial crisis. The average return on capital employed (ROCE) during the 2009-2012 period was 3.1 per cent. Furthermore, according to Boston Consulting Group, the ROCE in Europe has been between 3 to 5 per cent *lower* than the average cost of capital. The current analysis uses a longer time-series to arrive at an average profit margin of 5.3 per cent (BCG, 2013).

3.2.5 Pricing and elasticity

Although produced from natural raw materials which vary from plant to plant, cement is a relatively homogenous product. With little room for quality premiums, competition on price is the most important differential for a producer. Furthermore, the geographic structure of localised markets means that the cement prices are specific to regional submarkets.

Demand for cement is relatively inelastic compared to the other sectors analysed. Concrete, a common use for cement, faces substitutes in the form of aluminium, bricks, timber and steel. La Cour & Møllgaard (2002) estimate the demand elasticity of cement at -0.27. This is similar to the estimates obtained for steel products and heavy clay ceramics, that is, other construction oriented sectors modelled here.

3.3 Model simulation

3.3.1 Model inputs

Due to limited trade between EU countries, especially between the EU and the UK, cement was modelled at the UK level. Domestic UK production accounts for approximately 85 per cent of domestic consumption and the majority of imported cement comes from within the EU. The EU (including UK) producer market share of the UK market was 96 per cent in 2012.

The average EU carbon intensity is 0.70 tCO_2/t. The average non-EU carbon intensity is 0.81 tCO_2/t. To overcome shortcomings in COMEXT data, due to certain information being withheld for commercial disclosure reasons, official trade statistics were combined with MPA data (Mineral Products Association, 2013b) on the UK's trading partners to allow estimation of the source of imports.

Table 4. **Inputs into modelling the UK cement sector**

Variable	**Value**	**Source**
Initial market price	£70/t	Mineral Products Association, (2013b)
Demand elasticity	-0.27	(La Cour & Møllgaard (2002)
UK production	8,400,000 t	Mineral Products Association, (2013b) (for calendar year 2012)
Non-UK production (imports into UK)	1,700,000 t	European Commission, (2013) (for calendar year 2012)
UK emissions intensities - direct	0.47 tCO_2e/t	IEA (2007)
UK emissions intensities - indirect	0.25 tCO_2e/t	IEA (2007)
non-UK emissions intensities - direct	0.46 tCO_2e/t	IEA (2007)
non-UK emissions intensities (including non-EU) - indirect	0.33 tCO_2e/t	IEA (2007)
Gross UK profit margins	5.3%	BCG (2013)

Source: *Vivid Economics*

3.3.2 Changes in UK and EU output

The cement sector is characterised by competition, both intra-EU and between EU and non-EU firms. Thus cost pass-through rates are high, in the neighbourhood of 90 per cent.

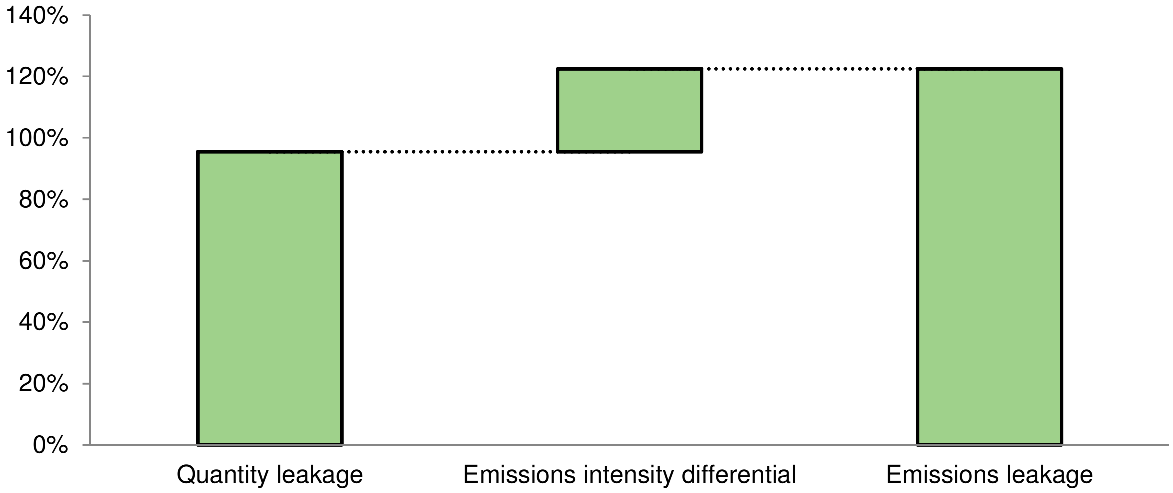
UK producers are carbon intensive compared to the EU average, so are less resilient to increases in carbon prices than their EU competitors. With carbon costs being between 5 and 45 per cent of product prices, both UK and EU output contracts significantly as carbon prices rise: indeed, as carbon prices rise to €30/tCO_2 and beyond, UK output drops to zero, and at prices of €50/tCO_2, EU imports into the UK cease in favour of non-EU import sources.

3.3.3 Output and carbon leakage

Being a low-margin product where carbon prices constitute a significant fraction of product prices and demand elasticity is lower, output leakage is expected to be large: in the 2020 core scenario, over 90 per cent for carbon prices over €5/tCO_2. This suggests that for every 100 units of output lost in the UK or from EU importers into the UK, imports into the UK from non-EU sources increase by more than 90 units.

Carbon leakage is determined by output leakage as well as the difference in emissions intensity between regulated and unregulated producers. In the case of cement, non-EU producers are significantly more emissions-intensive than their EU competitors, and thus carbon leakage in the model is high: in the 2020 core scenario, over 116 per cent for carbon prices at €15/tCO_2, and higher for higher carbon prices. This suggests that incomplete environmental regulation in this sector is associated with an increase in net global emissions associated with this sector.

Figure 4. **Output relocates from the EU to more emissions-intensive non-EU producers**



Note: *Shows decomposition of leakage for a €30 carbon price in 2020*

Source: *Vivid Economics*

Table 5. **At high carbon prices the UK cement sector struggles to compete with non-EU firms**

Counter-factual	Price of Carbon (€)	Cost shock as a fraction of price	UK Production (t)	UK imports from EU (t)	UK and EU imports market share	UK profits (€)	UK emissions (tCO_2)	EU import emissions (tCO_2)	Non-EU emissions (tCO_2)
2012	0		8,400,000	1,300,000	96%	25,200,000	6,000,000	900,000	350,000
2020	0		7,700,000	1,200,000	95%	23,000,000	5,600,000	800,000	440,000
2030	0		7,700,000	1,200,000	94%	23,000,000	5,500,000	830,000	500,000

Year	Change in price of carbon(€)	Cost shock as a fraction of price (%)	Change in UK production	Change in EU imports	Change EU and UK market share	Change in UK profits	Change in UK emissions	Change in EU import emissions	Change in non-EU Emissions (tCO_2)	Carbon Leakage Rate	Cost pass-through rate	Change in price
2012	5	5%	-4%	-9%	-4%	-8%	-4%	-20%	349,000	68%	94%	5%
2012	15	14%	-52%	-47%	-50%	-70%	-52%	-70%	4,700,000	116%	83%	11%
2012	30	27%	-100%	-71%	-96%	-100%	-100%	-88%	8,970,000	122%	64%	17%
2020	5	5%	-6%	-11%	-5%	-9%	-6%	-22%	441,000	78%	93%	5%
2020	15	14%	-53%	-48%	-51%	-71%	-53%	-71%	4,500,000	116%	82%	11%
2020	30	27%	-100%	-72%	-96%	-100%	-100%	-88%	8,400,000	123%	63%	17%
2020	50	45%	-100%	-100%	-100%	-100%	-100%	-100%	8,700,000	125%	40%	18%
2030	5	5%	-6%	-13%	-6%	-10%	-6%	-24%	513,000	83%	93%	5%
2030	15	14%	-53%	-49%	-51%	-71%	-53%	-71%	4,500,000	116%	82%	11%
2030	30	27%	-100%	-72%	-96%	-100%	-100%	-89%	8,400,000	123%	64%	17%
2030	50	45%	-100%	-100%	-100%	-100%	-100%	-100%	8,800,000	125%	40%	18%

Note: *The figures quoted here are to two significant figures.*

Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.

Source: *Vivid Economics*

4 Ceramics

4.1 Overview and key findings

Ceramics is a diverse sector, encompassing many separate markets. The focus of the analysis here is the heavy clay (or structural clay) subsector which is composed of bricks, roof tiles and clay drainage pipes. Heavy clay is the largest major ceramic subsector by production value and is responsible for the largest single proportion of overall ceramic sector emissions. Within heavy clay products, brick manufacture accounts for the largest tonnage, in excess of 90 per cent of the total subsector output, so the results in this section mainly relate to brick production.

Heavy clay product manufacture is emissions intensive relative to the value of the product. Ecofys report that emissions typically vary between 0.12 and 0.32 tCO_2 per tonne of product produced (Ecofys, 2009c), while 2011 BCC data specific to the UK heavy clay subsector show total emissions ranging between 0.13 to 0.99 tCO_2 per tonne of product. Natural gas makes up the bulk of total delivered energy used in the sector (approximately 90 per cent), with electricity a relatively small proportion (approximately 8 per cent).

Due to low trade intensity, heavy clay ceramics are modelled as a UK market, with most imports coming from the EU. Analysis suggests that the UK sector faces output decline under high carbon prices, though the associated carbon leakage *rate* is more moderate due to reallocation of output from more emissions-intensive to less emissions-intensive sites. Given the high share of bricks in heavy clay production, the model results represent the brick sector and not the other heavy clay subsectors. For instance, higher rates of imports in roof tiles in particular suggest that both the reduction in output, and the rate of carbon leakage, may be higher in such non-brick subsectors.

4.2 Characteristics of production

4.2.1 Production process

‘Brick clay’ describes the clays and shales used in the manufacture of heavy clay ceramics. A range of brick clays are used, with a range of mineral contents producing various colours.

The production process consists of several different stages: clay extraction, clay preparation, shaping, drying, firing, packaging and dispatch:

- clay extraction, where brick clays are extracted from quarries entirely by open pit methods;
- clay preparation, consisting of a range of processes that homogenise and grind the raw materials and add water to form a workable consistency;
- shaping. Extrusion is the most common method for shaping clay construction products. In this process, clay is continuously extruded through a die at high pressure and subsequently cut by means of a wire. In the UK, the majority of bricks, most clay roof tile and drainage pipes are made by this method. More complex shaped clay products such as roof tiles are produced by pressing the clay between the two halves of a mould;
- the shaped products are then dried, removing moisture prior to firing;
- firing, the most energy- and emissions-intensive step. Clay is heated to a temperature to instigate chemical and physical changes that develop the final properties of the product, including bonding to form

a rigid matrix. Most bricks and roof tiles are fired in continuous tunnel kilns where the product is loaded onto kiln cars which pass through a stationary firing zone near the centre of the kiln, with firing generally requiring between one and three days to complete. Firing of pipes generally occurs in continuous roller hearth tunnel kilns. Intermittent (batch) kilns are also used for all products, most notably Hoffman kilns used to make Fletton or 'London' bricks.

- the finished products are then packaged and dispatched.

The decomposition of carbonates and the oxidation of organic matter within the clays give rise to process emissions. The production of paler coloured bricks requires the presence of carbonate minerals which results in higher process emissions. Lower Oxford clay (used to make Fletton bricks) contains a high carbon content which results in a lower firing temperature but higher process emissions.

4.2.2 Emissions- and energy-intensity of production

All direct emissions come from the firing stage and include fuel-related and process-related emissions. Firing in the heavy clay sector generally requires a temperature of 1,000°C or more. Natural gas and to a lesser extent LPG, gas oil and coal are the most common sources of energy. Electricity is around 8 per cent of total delivered energy (European Commission, 2007; BCC, 2013).

Ecofys (2009) found that across the EU, emissions vary between 0.12 and 0.32 tCO_2 per tonne of product. This compares with 2011 BCC data for the heavy clay subsector across the UK which shows a variation between 0.13 and 0.99 tCO_2 per tonne of product. The share of energy costs in total production costs generally varies between 17 per cent and 30 per cent, with maximum values up to 40 per cent (European Commission, 2007a). There are large variations of energy costs within the UK.

In the past two decades, energy efficiency measures have included conversion from intermittent (batch) to continuous technology, recovery of kiln cooling air (subsequently used in the dryer and preheat sections of the kiln) and better insulation of kilns and dryers (European Commission, 2007a). The deployment of CHP is, in principle, effective due to the simultaneous constant demand for power and heat. A European Commission report advocates CHP use in new kilns. Gas-fired CHP is widely used in some other ceramics manufacturing operations (such as spray drying in the floor and wall tile subsector) but uptake in the heavy clay subsector is low since, in many plants, there is limited use for the derived heat as all the heat required for drying is provided by heat recovered from the kiln; the British Ceramic Confederation also suggests that the UK taxation system provides limited incentives to switch compared to other countries (BCC, 2013).

The heavy clay ceramics sector is capital intensive and mature. Plants typically have a life of 40 years or more, so it is unlikely that many new plants will be built in the near term. However, existing plants do need to be rebuilt from time to time while many older plants were closed during the recession. There is some potential for new investment and capacity increases to meet growing housing demand, assuming companies can demonstrate an adequate rate of return.

In the long term, the ceramics roadmap considers electrification of kilns as an option, but this is not currently economically viable (Cerame-Unie, 2012). CCS is unlikely to be economically viable until well-established; other industrial sectors such as cement and steel would be higher-priority targets for CCS since heavy clay installations have a more dilute carbon dioxide exhaust stream and the production sites are smaller and more widely dispersed.

In the UK, substitution of fuel oils and solid fuels by lower emission fuels (such as natural gas) is not always possible as most sites already employ natural gas; many of the remaining non-natural gas-fired processes are located in locations remote from the gas grid. In the long term, the use of biogas (from anaerobically digested feedstock) or syngas (from gasified waste or biomass) could decrease the emissions intensity of the fuel mix if successfully developed.

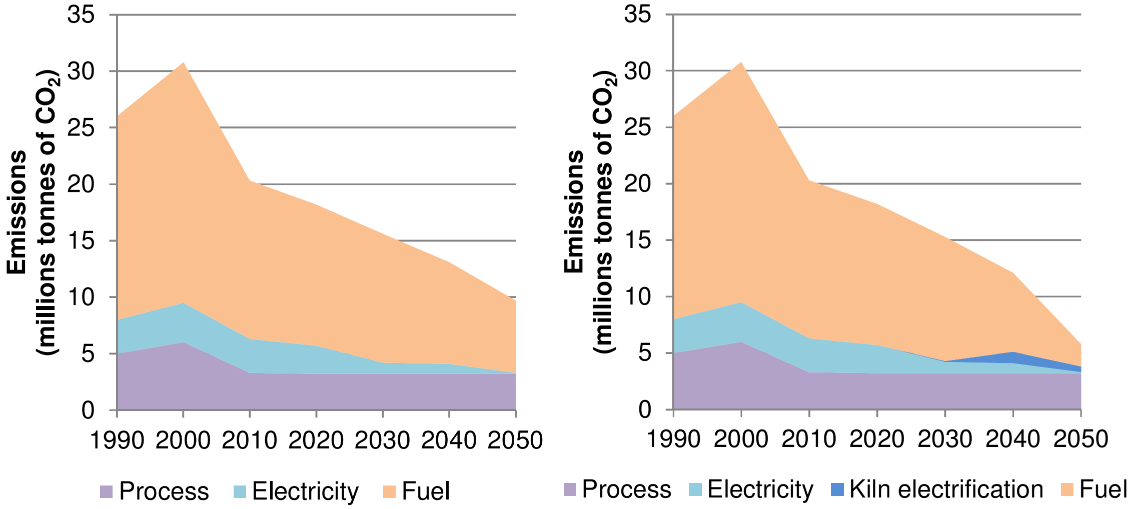
Process emissions arise from the decomposition of carbonates in the raw materials, as well as oxidation of organic content. The magnitude of these emissions accounts for approximately 16 per cent of emissions on average for the whole European ceramics sector (Cerame-Unie, 2012) but is approximately 20 per cent in the UK heavy clay subsector (BCC, 2013). Emissions due to electricity consumption account for 18 per cent of emissions for the whole European ceramic sector (CU, 2012) but are approximately 14 per cent in the UK heavy clay subsector (BCC data). On average, two thirds of emissions are due to fuel use in the production process (Cerame-Unie and BCC, 2012).

Cerame-Unie, in November 2012, published a 2050 roadmap which included options to reduce sector emissions (Cerame-Unie, 2012). The assessment covered brick, roof tiles, wall and floor tiles and refractory subsectors. Figure 5 shows two paths emissions reductions in the sector could take. The assumptions are:

- constant production from 2010 to 2050;
- near-full kilns;
- 95 per cent decarbonisation of electricity supply by 2050 from 1990;
- checked against specific energy consumption in trends in ceramic Best Available Technologies reference document.

According to these models, the EU could only achieve the targets outlined by the European Commission if breakthrough technologies are developed and become economically viable. In Figure 5, the chart on the left illustrates a reduction in emissions by up to 65 per cent between 1990 and 2050. It assumes that all barriers to the usage of alternative fuels which are co-fired with natural gas can be overcome (availability, sustainability, cost) and that regulators will treat syngas and biogas as producing net zero emissions. Moreover, the co-firing technology would need to be proven and viable by 2020. The chart on the right illustrates a reduction of 78 per cent between 1990 and 2050 under the assumption that half of the EU's kilns can be electrified using breakthrough technologies, with the remaining plants being co-fired with gas and alternative fuels. The authors estimate that the scenario with the larger reductions would cost the sector €90 billion in capital costs in building new plants (Cerame-Unie, 2012), and that €40 billion would be written off through early plant closure and plant interruption. CCS (or other equivalent breakthrough technology) would need to be viable after 2040 – at least for some installations.

Figure 5. **Sharp declines in emissions result if various assumptions hold regarding the usage of alternative fuels, electrification, and decarbonisation of the electricity supply**



Note: *The left chart does not allow for kiln electrification.*

Source: *Vivid Economics, based on Cerame-Unie, 2012*

4.3 Sector composition and features

4.3.1 Market composition

Ceramics is a heterogeneous sector, encompassing many subsectors and products. The European Commission distinguishes nine subsectors (European Commission, 2007a):

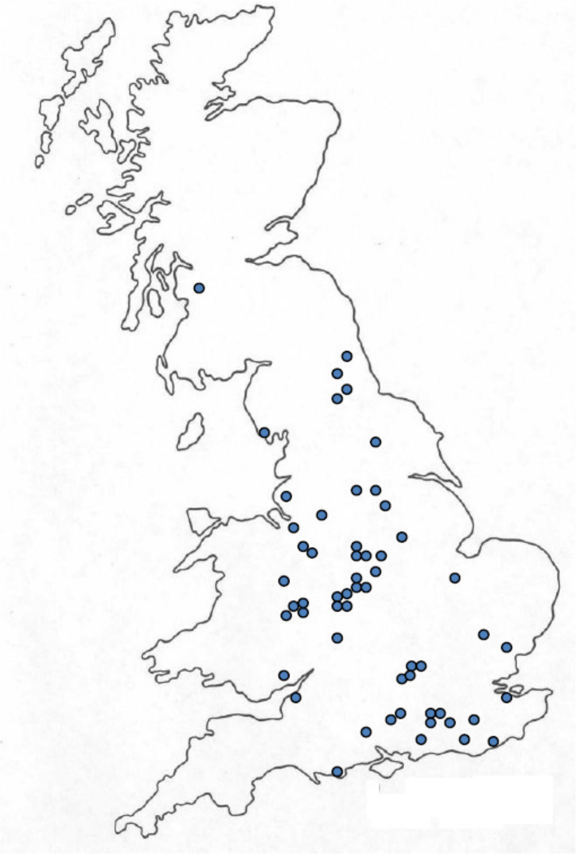
- wall and floor tiles;
- heavy clay construction products (bricks and roof tiles);
- vitrified clay pipes;
- table- and ornamental-ware;
- refractory products;
- sanitaryware;
- technical ceramics;
- expanded clay aggregates;
- inorganic bonded abrasives.

This analysis focuses on the heavy clay (bricks and roof tiles) and vitrified clay pipe subsectors and is not representative of the impact on other subsectors. Ideally, even the subsectors considered together here would be treated separately, but data limitations make this difficult. Brick sales revenue in the UK is around 5.5 times tile revenue; hence, the modelling results largely reflect the brick subsector.

The location of heavy clay manufacturing largely reflects the distribution of clay resources (Figure 6). The industry has undergone major rationalisation over the last two decades through mergers, acquisitions and plant closures. Indeed, between 2006 and 2009 the number of operating installations fell from around 100 to

78, declining further to 65 by 2012. England now accounts for all heavy clay production, with the exception of one brick site in Scotland. There are no longer any operational sites in Wales. There are three large multinational brick manufacturers in the UK, three main producers of clay roof tiles, and two companies that account for almost all clay drainage pipe manufacture.

Figure 6. **Brickworks follow clay availability across the UK**



Source: *Smith, 2013*

4.3.2 Trade Patterns

International trade in heavy clay ceramics overall is limited, due to relatively high transport costs. Around 7 per cent of recent domestic demand has been served by imports, with 0.3 per cent of domestic demand coming from outside the EU (European Commission, 2013a). Imports have increased substantially in 2013; with the share of imports in domestic consumption between January and August 2013 rising to 15 or 16 per cent. Only one per cent of UK production, by value, was exported (European Commission, 2013a).

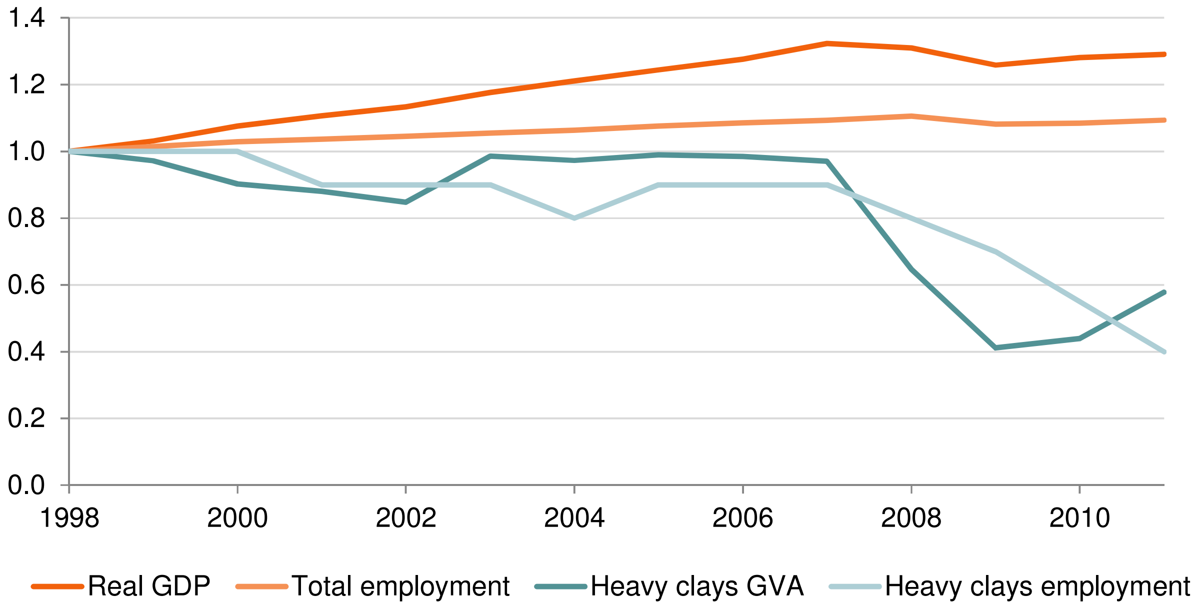
The roof tile and clay pipe sectors are more strongly traded. Both have greater exposure to non-EU trade than bricks, in the case of clay pipes dramatically so:

- for clay roof tiles, 17 per cent of total sales by weight were imports (15.8 per cent from the EU, 1.3 per cent from non-EU). Of these imports, around 30 per cent were from Poland and 5 per cent from Turkey;

– for clay drainage pipes, the United States made up around 86 per cent of imports by weight (UK Trade Info); further detail is difficult to provide due to confidentiality concerns.

Bricks and roof tiles contribute over one quarter of ceramics GVA, which totalled approximately £990 million in 2011 (ONS, 2011). Employment in the brick and roof tile subsector declined significantly during the recent economic downturn, due to dependence on the construction industry. Real GVA fell by around 60 per cent between 2007 and 2009, though it has recovered somewhat since (Figure 7).

Figure 7. **Real GDP and employment growth in the UK economy has not been reflected in the heavy clay sector (index, 1998=1.0)**



Source: ONS, 2011, *Vivid Economics*

4.3.3 Profitability

Accounting information for Ibstock and Baggeridge, released during an acquisition, allows the estimation of historic sector profit margins (Competition Commission, 2007). Five years of accounting data are available for Ibstock, six for Baggeridge, over which time gross profit margins were between 6 and 11 per cent, with an average of 8.4 per cent for Ibstock, and 7.8 per cent for Baggeridge (Competition Commission, 2007). As far as possible, 'fixed costs' are excluded from our calculations, so that the profit margin captures only the variables relevant to production decisions.

Due to its reliance on the construction industry, alongside energy price increases, ceramics sector margins have reduced in size during the economic downturn. The UK industry association estimates that average gross profit margins are now approximately three per cent (British Ceramic Confederation, 2013). This figure was used in the modelling to show the effects of carbon prices in a conservative scenario.

4.3.4 Pricing and elasticity

Price per brick is a function of distance from production site, volume and brick type (Competition Commission, 2007). Firms do not always post listed prices and where they do, may offer discounts. An average price per kg can be estimated using the PRODCOM database, which includes weight and revenue measures aggregated across all bricks sold in the UK (European Commission, 2013a). PRODCOM lists brick prices per cubic metre. The price of bricks appears to be between £170 and £220 per m^3. Using the density of Fletton bricks, which is around 1,795 kg per m^3, the price per tonne is between £90 and £120. The estimates for the prices in the years 2009, 2010 and 2011 are £96, £100 and £121 respectively. The industry trade association suggested a price of £97/tonne to be used for the sector (British Ceramic Confederation, 2013).

From what literature is available, the demand for bricks appears to be inelastic. Cambridge Econometrics has previously attempted to estimate the price elasticity of domestic demand for bricks and tiles (DECC, 2010). It found the overwhelming determinant of domestic consumption to be construction output, which alone explained almost all variation in demand. Attempts to estimate price elasticity of demand were unable to return an effect significantly different from zero. The European Commission (1994) found that price elasticities in this sector are low, but did not publish a quantitative estimate. It argues that demand for bricks represent ‘only two to three per cent of the cost of a building’ and that consequently ‘there is very little or no elasticity of demand with respect to price levels in the short or medium term’.

A value of -0.3 was used in the model, equivalent to the elasticities used for the other major construction projects of steel and cement.

4.4 Model simulation

4.4.1 Model inputs

The heavy clay ceramics subsector was modelled at the UK level due to the relatively low level of imports and exports to and from the UK.

Information on emissions intensities was gathered in consultation with the BCC (2013) and from the CITL database (European Commission, 2013b). One average emissions intensity was applied to all producers, based on fuel, process and indirect emissions from electricity generation for individual UK sites. The average emissions intensity (weighted by national production) is 0.22 tCO_2 per tonne of product for EU producers, with substantially higher values for non-EU producers. This and other model inputs are described further in Table 6.

Table 6. **Ceramic sector inputs to modelling**

Variable	Value	Notes	Source
Initial market price	£97/t		British Ceramic Confederation, (2013)
Demand elasticity	-0.3		Based on construction products such as steel and cement
UK production	3,800,000 tpa	For calendar year 2012. Total output by installation size (classed as small or large) was provided by BCC. For all large installations covered by EU ETS, direct emissions information was collected from CITL, and per-installation output estimated in proportion to the share of total emissions. All small installations were assumed to have an equal share of total small installation output.	British Ceramic Confederation, (2013)
Non-UK production (imports into UK)	280,000 tpa	For calendar year 2012	UK Trade Info, (2013)
Non-EU imports into the UK	13,000 tpa	For calendar year 2012	UK Trade Info, (2013)
Average UK (and EU) emissions intensities - direct	0.18 tCO_2e/t	Specific emissions intensities provided for large and small installations by BCC	British Ceramic Confederation, (2013)
Average UK (and EU) emissions intensities - indirect	0.036 tCO_2/t		Electro-intensity for large and small installations provided by British Ceramic Confederation, (2013); emissions intensity of electricity generation from IEA (2012)
Average UK (and EU) emissions intensities - total	0.22 tCO_2e/t		
non-EU emissions intensities - total	0.39 tCO_2e/t		British Ceramic Confederation, (2013)
Gross UK profit margins	3%		British Ceramic Confederation, (2013)

Source: *Vivid Economics*

4.4.2 UK and EU production

The heavy clay market contains firms of a variety of sizes. Combined with a low profit margin of 3 per cent, the model interprets this information as strong competition in the market, leading to a high cost pass-through rate in the long-run. BCC disputes this cost pass-through estimate and does not expect significant cost pass-through in the short run, stating that producers have had difficulty in passing on energy price changes in recent years.

Domestic production is strongly affected by carbon price increases in the model. A carbon price of €5/tCO_2 results in a fall in UK production of 3 per cent, while a carbon price of €50/tCO_2 results in UK production halving. A set of growth scenarios from 2012 to 2020 and 2030 were tested, without involving significant variation in import market share. Within the model, as the carbon price rises:

- relatively large and less emissions-intensive EU firms gain market share relative to smaller or more emissions intensive EU firms, but lose market share relative to non-EU firms;
- EU imports into the UK increase, as relatively less emissions-intensive EU firms gain market share at the expense of UK firms;
- EU firms become less competitive than non-EU firms, and EU firms lose more and more market share relative to non-EU competitors, resulting in a reduction of imports into the UK from the EU. EU import volumes become less sensitive to carbon price rises at higher levels of carbon price.

Overall, UK production levels tend to fall significantly, while non-EU market share increases. A summary of the model outputs can be found in Table 7.

4.4.3 Output and carbon leakage

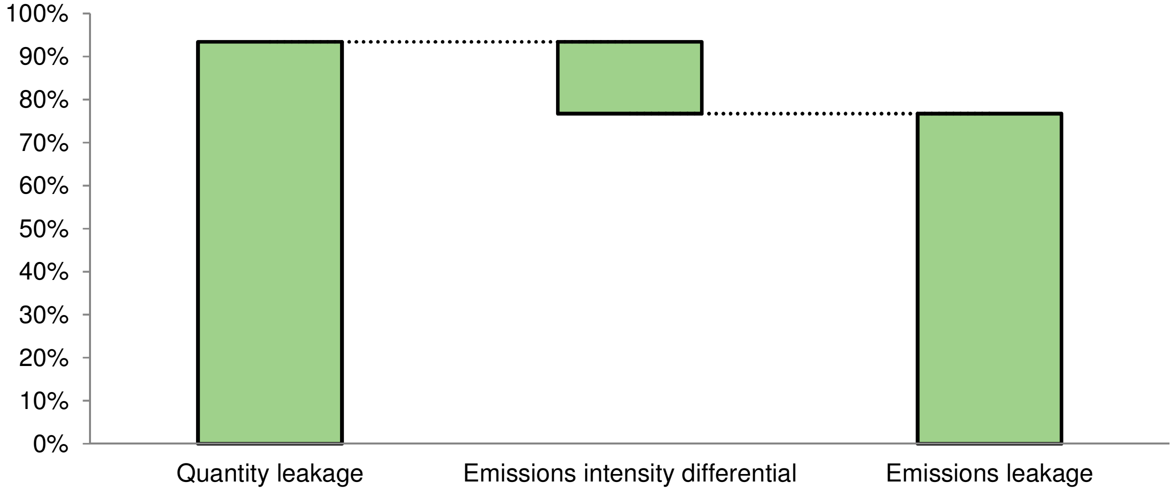
The quantity of carbon leakage can be split into two channels:

- the component resulting from the increase in non-EU production to compensate for declines in EU and UK production, where differences in the emissions-intensity of production are ignored. This is called output leakage; and
- the component resulting from differences in the emissions intensity of non-EU and EU production.

The extent to which imports increase depends on several factors, including the overall strength of competition within the sector and the price-responsiveness of demand. In the case of heavy clay ceramics, where demand is not especially responsive to price changes but there is indication of strong competition, the output leakage rate is relatively high: for every 100 units of reduction in EU production, imports to the EU increase by more than 90 units.

As the EU producers which first start to lose output are those which tend to be more emissions-intensive, the carbon leakage rate is somewhat lower, at around 43 per cent when the carbon price is €15/tCO_2. As carbon prices increase, the burden of production losses falls increasingly on relatively less emissions intensive EU and UK installations, and consequently the carbon leakage rate increases, reaching 77 per cent at a price of €30/tCO_2 (Figure 8), and exceeding 100 per cent at a price of €50/tCO_2.

Figure 8. **Output leakage is high in the ceramics sector, with the resulting carbon leakage rate only somewhat lower**



Note: *This graph shows the leakage decomposition for a €30 carbon price in the year 2020.*

Source: *Vivid Economics*

4.4.4 Additional notes

The BCC has projected an increase in heavy clay ceramic imports from 280kt in 2012 to 450kt (or higher) in 2013, based on import figures for the first half of 2013. Based on the large number of UK site closures that occurred during the recession, the BCC expects this higher import level will be sustained. While the higher figures were not used in the headline modelling numbers above, the shift is potentially significant, and consequently its effect has been investigated.

An import figure of 450kt substantially increases the impact of carbon pricing on the ceramics sector. Under the 2020 core scenario, a carbon price of €5/tCO$_2$ is associated with a fall in domestic output of 5 per cent, €15/tCO$_2$ with a fall of 21per cent, €30/tCO$_2$ with a fall of 44 per cent and that of €50/tCO$_2$ with a fall of 74 per cent.

Table 7. **The UK ceramics sector contracts at high carbon prices but some production is shifted to EU producers**

Counter-factual			UK production (t)	Imports from EU (t)	UK and EU producers' market share	Non-EU imports	UK emissions (tCO_2)	EU import emissions (tCO_2)	Non-EU emissions (tCO_2)				
2012			3,800,000	267,000	99.7%	13,000	800,000	54,000	5,000				
2020			3,500,000	246,000	99.6%	17,000	760,000	50,000	6,500				
2030			3,500,000	245,000	99%	19,000	755,000	49,500	7,500				

Year	Carbon price (€/tCO_2)	Cost shock as a fraction of price (%)	Change in UK production	Change in imports from EU	EU and UK change in market share	Change in non-EU imports	Change in UK emissions (tCO2e)	Change in EU import emissions (tCO2e)	Change in non-EU emissions (tCO2e)	Output leakage rate	Carbon leakage rate	Cost pass-through rate	Change in price
2012	5	1	-114,000	84,000	-0.3%	13,000	-270,000	17,000	5,000	43%	2%	99%	1%
2012	15	3	-481,000	57,000	-10%	387,000	-365,000	11,000	151,000	91%	43%	95%	3%
2012	30	6	-1,000,000	30,000	-23%	940,000	-480,000	6,000	365,000	93%	77%	93%	6%
2020	5	1	-110,000	77,000	-0.4%	16,000	-250,000	16,000	6,500	51%	3%	99%	1%
2020	15	3	-450,000	52,000	-10%	360,000	-340,000	10,000	141,000	91%	43%	95%	3%
2020	30	6	-960,000	31,000	-23%	870,000	-450,000	6,000	339,000	93%	77%	93%	6%
2020	50	9	-1,650,000	9,500	-42%	1,500,000	-590,000	1,200	600,000	94%	101%	92%	9%
2030	5	1	-110,000	76,000	-1%	19,000	-250,000	16,000	7,500	55%	3%	99%	1%
2030	15	3	-450,000	51,000	-10%	360,000	-340,000	10,000	141,000	91%	43%	95%	3%
2030	30	6	-960,000	30,000	-23%	870,000	-440,000	6,000	337,000	93%	77%	93%	6%
2030	50	9	-1,600,000	9,000	-42%	1,500,000	-590,000	1,100	597,000	94%	101%	92%	9%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

5 Container glass

5.1 Characteristics of production

5.1.1 Production process

The container glass manufacturing process consists of four stages. These are: batch preparation, melting and refining, forming and post-forming, see Figure 9 for a representation of the process.

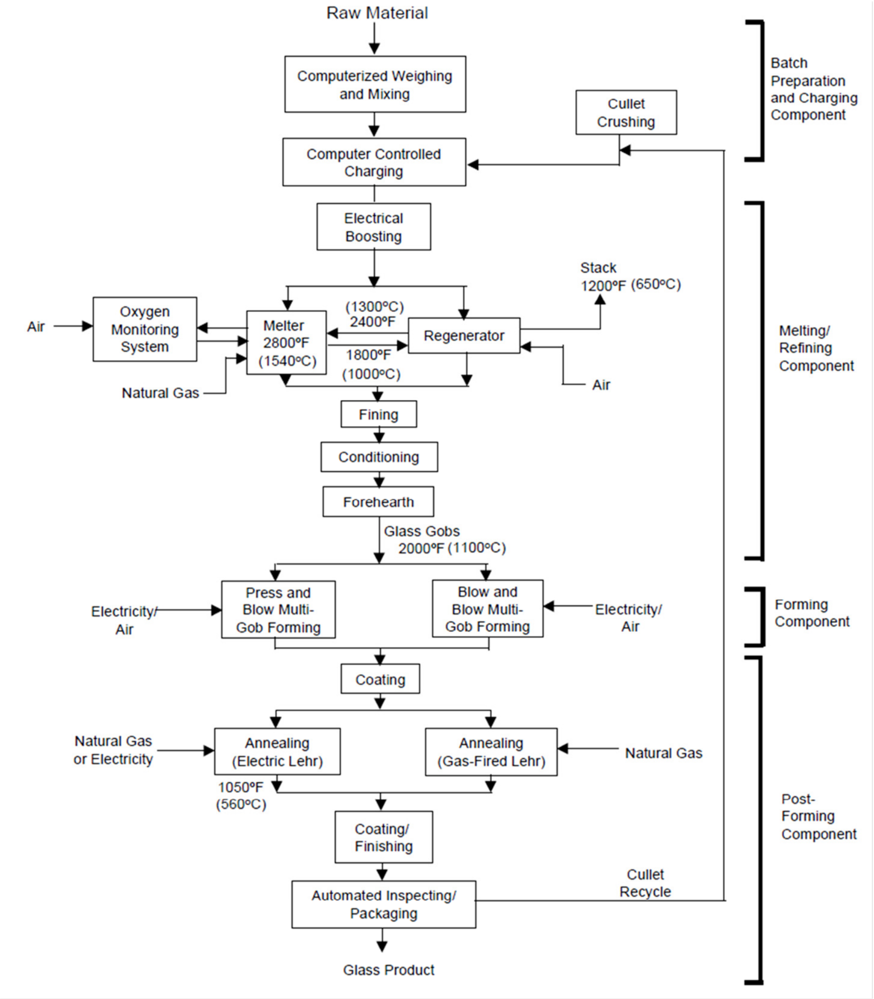
- in batch preparation, raw materials for glass are blended in accordance with the requirements of the final products. The main inputs are high-quality sand (silica), limestone, and soda ash;
- the mixed batch is melted in one of various types of furnaces, depending upon the quantity and type of glass to be produced. The melting process is complete when the glass is free of any crystalline materials;
- refining is the combined physical and chemical process occurring in the melting chamber during which the resulting molten glass is freed of bubbles, homogenised, and heat conditioned. The glass is then sent to forming operations, involving blow forming in the case of container glass (Wrap, 2008);
- the post-forming procedures include processes intended to increase workability or strength.

5.1.2 Emissions- and energy-intensity of production

The emissions and electricity intensity of container glass production are high. Direct emissions from energy use in the kilns and furnaces make up 85 to 90 per cent of emissions, with emissions stemming from the decarbonisation of carbonate raw material accounting for the remaining 10 to 15 per cent of emissions (Ecofys, 2009d).

For existing furnaces, a possible option for CO_2 reduction is heat recovery for the preheating of the batch and cullet. Another measure is further increasing the use of recycled glass (cullet), which requires elevating domestic and industrial recycling rates. In Europe there is a broad range of recycling rates, from 6 per cent in Malta to 99 per cent in Belgium. The rate in the UK is 64 per cent (FEVE, 2013). Difference in colour of imported and exported bottles creates a difficulty for the recycling sector in the UK. Glass collected as mixed colour is only acceptable for reuse if it has been sorted to a suitable level. Mixed glass is also suitable for alternative markets such as grinding and crushing for aggregates use and fibre glass.

Figure 9. **Container glass production inputs are raw materials, air, electricity and natural gas**



Source: *US Office of Industrial Technologies (2002)*

There are several furnace types in use in Europe. In the glass sector in general, furnaces are heated by natural gas, fuel oil, electricity or any combination of the three. The most efficient are regenerative furnaces, accounting for roughly three quarters of all European container glass furnaces and 100 per cent of UK container glass production. As energy efficiency improves with furnace size, large capacity furnaces are favoured where possible.

The energy efficiency of electric furnaces is two to three times higher than fuel furnaces on an input energy consumption basis. However, especially in the case of large capacity furnaces, electricity prices cannot compete with fossil fuel prices. Consequently electric furnaces at present only play a marginal role.

The three main energy sources for glass making are natural gas, fuel oil and electricity. The majority of container glass furnaces in the UK are run on natural gas with varying ability to switch to oil or other backup fuels in the event of an emergency. Changing between oil and gas is not necessarily straightforward, but is substantially easier than swapping to electricity; thus a decarbonised electricity supply as an abatement tool will only be possible given significant capital investment.

5.2 Sector composition and features

5.2.1 Market composition

Container glass production accounts for 60 per cent of glass production in the UK (GTS, 2008). It is used primarily in packaging bottles for drinks and jars for food with some revenue generated from kitchen and tableware. Three colours of glass are produced in the UK. Approximately 60 per cent of container glass produced is clear, with amber and green both making up 20 per cent (GTS, 2008). In 2012, 2.2 million tonnes of container and flat glass were produced in the UK, down from 2.4 million tonnes in 2008. Demand for container glass is procyclical but has remained robust compared to other sectors during the economic downturn. This is not necessarily the case for other glass types.

Most container glass furnaces operate almost continuously for up to 20 years. At the end of their operating life, they can be rebuilt with varying degrees of replacement of the structure depending on its final condition. The cost of rebuilding a medium sized furnace, capable of producing 250 tonnes a day, is between €40 to €50 million on average (Ecorys, 2008a), though in some instances the cost may be substantially higher.

There are six major companies operating 12 container glass production plants in the UK, which accounts for 97 per cent of the revenue generated. Ardagh Glass and Quinn Glass account for over 50 per cent of sector turnover. Geographically, 60 per cent of production by volume takes place in Yorkshire, with a small cluster of production in Scotland. In competition cases, the EC describes the geographic market size as ‘national’ and treats container glass as one product market (Ecorys, 2008a). In the EU, production is concentrated in Germany, Italy and France.

5.2.2 Employment and GVA

Employment in the UK container glass sector has fallen by more than 40 per cent since 1998. In 2011 the container glass sector employed around 29,000 persons. Container glass GVA has fallen by around 40 per cent since 1998 (ONS, 2013a).

5.2.3 Trade patterns

The UK exported £180 million and imported £410 million worth of container glass in 2012 (European Commission, 2013a). Exports went mainly to Ireland; imports came mainly from France and China. A large proportion of the exports from the UK are clear glass in the form of spirit bottles. In contrast, a large proportion of the UK imports are green glass in the form of wine bottles. The wine trade alone is responsible for approximately 680 thousand tonnes of net glass imports per year; much of which is green (GTS, 2008). Note that ‘filled imports’ represent a sizable competitive threat to the UK container glass sector: it is possible, for instance, for wine to be imported in bulk and packaged in UK-produced bottles, or to be imported pre-bottled. The total imports of filled glass containers in 2012 were 932,000t (British Glass Manufacturers Confederation, 2013a), resulting in the market share of UK producers in the UK market being around 70 per cent.

On the EU level, in 2004, exports were about five times greater than imports. With the strong growth in demand imports grew but in 2007 the EU still exported two and half times as much container glass as it imported (Ecorys, 2008a).

5.2.4 Profitability

Demand is further affected by trends in domestic food and beverage production, including beer, wine, spirits, fruit and vegetable processing, perfume and cosmetics manufacturing. Changes in these downstream markets have significant impacts on the container glass industry in the UK.

Changes in energy costs and transport costs have affected margins. The cost of haulage is related to oil prices. Operating profit is around 8 per cent of sector revenue in 2013-14 (IBISWorld, 2013b).

5.2.5 Pricing and elasticity

As the market for container glass is limited by geographic area, there is a degree of regional price setting. In particular, on the fringes of the EU container glass producers face competition from non-EU producers.

Substitutes for container glass are available and include aluminium, cardboard and plastic packaging materials. In some applications, it is a premium packaging product and faces fewer substitutes. The price elasticity of demand used in the model was -0.3, an estimate for the elasticity of demand for non-metallic mineral products, and itself an average of European Commission estimates and La Cour & Møllgaard, (2002).

5.3 Model

5.3.1 Model inputs

A summary of model inputs can be found in Table 8. Container glass was modelled at the UK level. Sectoral production was treated as a homogenous good, with differences in glass colour and other distinctions ignored. The average emissions intensity, weighted by production in the UK and the EU is 0.66 tCO_2/tonne. The average non-EU emissions intensity is slightly higher at 0.69 tCO_2/tonne. China is the largest non-EU source of imports and hence the average intensity of non-EU producers is weighted towards the emissions intensity of Chinese producers.

Table 8. **Inputs to modelling container glass**

Variable	Value	Notes	Source
Initial market price	£ 350/t		British Glass Manufacturers Confederation (2013)
Demand elasticity	-0.3	Reflects the price elasticity of demand of construction and non-metallic mineral products such as cement, ceramics and steel.	
UK production	2,300,000 t	For calendar year 2012.	IBISWorld (2013); supplemented by British Glass Manufacturers Confederation, (2013b)
Non-UK production (imports into UK)	1,000,000 t	For calendar year 2012.	European Commission, (2013); Filled glass import tonnage provided by British Glass Manufacturers Confederation (2013)
UK emissions intensities - direct	0.518 tCO2e/t		Ecofys (2009)
UK emissions intensities - indirect	0.15 tCO2e/t	This is the product of electro-intensity of container glass manufacturing in the UK (MWh/t) and the emissions intensity of electricity generation in the UK (tCO_2e/MWh)	Electro-intensity of container glass production: (British Glass Manufacturers Confederation, 2013a); Emissions intensity of electricity generation: IEA (2012)
non-UK emissions intensities - direct	0.518 tCO2e/t	In this study, all installations are given the same average process emissions factor	Ecofys (2009)
non-UK emissions intensities - indirect	0.14 tCO2e/t	It is assumed that all installations have the same electro-intensity of container glass production as in the UK. The emissions intensity of electricity generation is country specific	Electro-intensity of container glass production: (British Glass Manufacturers Confederation, 2013a); Emissions intensity of electricity generation: IEA (2012)
Gross UK profit margins	8.2%		IBISWorld (2013)

Source: Vivid Economics

5.3.2 Impact on UK production

A summary of the model outputs is contained in Table 9. Of the container glass market in the UK, 9 per cent is sourced from outside the EU. Cost pass-through rates are estimated at between 56 and 75 per cent.

As carbon prices rise, emissions-intensive EU producers lose market-share to relatively clean EU producers, as well as non-EU producers. Since UK producers constitute more than three times the market-share of EU importers, and have very similar carbon intensities, UK production is more resilient than that of EU competitors. In the 2020 core scenario, UK production declines by 4 per cent at a price of 5 Euros/tCO_2, and by 46 per cent at 50 Euros/tCO_2, whereas for the same prices, EU imports to the UK fall by 13 per cent and 87 per cent.

5.3.3 Output and carbon leakage

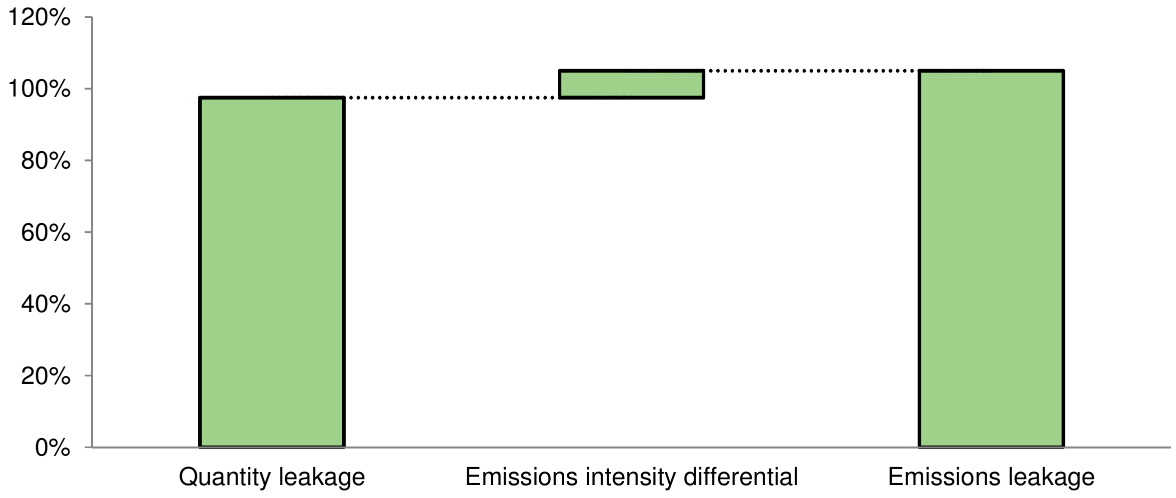
Output leakage, that is, the ratio between the increase in output in unregulated regions to output falls in regulated regions, is determined by the strength of competition, the impact of carbon price rises on margins and the sensitivity of consumer demand to changes in product prices.

In the case of container glass, with moderate demand sensitivity, output leakage in the 2020 core scenario is between 88 and 97 per cent. That is, for every 100 units of output lost from UK production or from imports into the UK from the EU, imports from outside the EU increase by around 88 to 97 units.

Carbon leakage is determined by output leakage, as well as the differential in emissions intensity between contracting EU output and expanding non-EU output. In the case of the container glass industry, relatively emissions-intensive EU producers lose market-share disproportionately, but these producers are still relatively emissions-efficient compared to their non-EU competitors. Thus, carbon leakage is higher than output leakage, at over 100 per cent under all carbon prices reported: that is, every 100 units of CO_2 reduced in the EU are replaced by more than 100 units outside the EU.

Since carbon leakage is over 100 per cent, regulation in this instance is associated with an increase in net emissions.

Figure 10. **The leakage rate of container glass is determined largely by quantity leakage**



Note: *Chart shows leakage rate decomposition for a carbon price of €30 in 2020*

Source: *Vivid Economics*

5.3.4 Sector notes

It should be noted that the model does not explicitly account for transport emissions in the event that the container is still be filled in the UK. If the production of the filled product also moves abroad then the associated carbon leakage must also be considered. In addition the transport of cullet from UK to production areas would have to be considered.

Table 9. **EU container glass producers benefit from their large market share at low prices**

Counterfactual	Price of carbon (€/tCO₂)	Cost shock as a fraction of price (%)	UK production (t)	UK imports from EU (t)	UK and EU imports market share	UK profits (€)	UK emissions (tCO₂)	EU import emissions (tCO₂)	Non-EU emissions (tCO₂)
2012	0		2,300,000	1,000,000	91%	53,500,000	1,500,000	435,000	206,000
2020	0		2,100,000	650,000	88%	49,000,000	1,400,000	400,000	260,000
2030	0		2,000,000	648,000	87%	49,000,000	1,400,000	400,000	303,000

Year	Change in price of carbon (€)	Cost shock as a fraction of price (%)	Change in UK production	Change in imports to UK from EU	Change in EU and UK market share	Change in UK profits	Change in UK emissions	Change in EU import emissions	Change in non-EU emissions	Carbon leakage rate	Cost pass-through rate	Change in price
2012	5	1%	-4%	-12%	-5%	-6%	-4%	-13%	124,000	103%	75%	1%
2012	15	2%	-12%	-36%	-17%	-19%	-12%	-37%	400,000	104%	66%	2%
2012	30	5%	-27%	-61%	-34%	-40%	-27%	-63%	776,000	105%	61%	3%
2020	5	1%	-4%	-13%	-6%	-6%	-4%	-14%	126,000	103%	72%	1%
2020	15	2%	-13%	-37%	-17%	-20%	-13%	-38%	381,000	104%	65%	2%
2020	30	5%	-27%	-62%	-33%	-40%	-27%	-63%	727,000	105%	60%	3%
2020	50	8%	-46%	-87%	-52%	-64%	-46%	-88%	1,100,000	105%	56%	4%
2030	5	1%	-4%	-14%	-6%	-7%	-4%	-14%	131,000	103%	71%	1%
2030	15	2%	-13%	-37%	-17%	-20%	-13%	-39%	384,000	104%	65%	2%
2030	30	5%	-27%	-62%	-33%	-40%	-27%	-63%	727,000	105%	60%	3%
2030	50	8%	-46%	-87%	-52%	-64%	-46%	-89%	1,100,000	105%	56%	4%

Source: *Vivid Economics*

6 Fertilisers

6.1 Characteristics of production

6.1.1 Production process

The fertiliser sector can be divided into straight fertilisers, compound fertilisers, organic fertilisers and process chemicals. The three main components of mineral fertilisers are nitrogen, phosphate and potassium. About 80 per cent of the fertiliser used in Europe is nitrogen-based, that is, derived from ammonia (NH_3) or nitric acid (HNO_3) (European Commission, 2009). The production of ammonia and nitric acid is by far the most energy and emissions intensive part of the nitrogen fertiliser supply chain. Nitrogen-based fertilisers of interest are ammonium nitrate (AN), calcium ammonium nitrate (CAN), and urea. Fertilisers that are not nitrogen-based are not included in the analysis.

Although ammonia can be produced from the gasification of coal or partial oxidation of other heavy hydrocarbons such as fuel oil or LPG, Europe's ammonia production is almost entirely based on natural gas via the steam reforming process. This is currently the most efficient production route (European Commission, 2007b). In 2009, only three plants in the EU did not operate on gas (Ecofys, 2009e).

The production process depends on the mineral composition of the fertiliser. Nitrogen fertilisers generally require the production of ammonia as an intermediate step. For instance, ammonium nitrate is produced through the following steps:
- ammonia is produced, typically through the steam reformation of natural gas, where steam, gas and air are reacted together;
- ammonia is converted into nitric acid by reacting ammonia with water in the presence of a catalyst;
- nitric acid and ammonia are combined to produce ammonium nitrate.

6.1.2 Emissions- and energy-intensity of production

The main source of emissions is the chemical process of ammonia production, rather than the combustion of natural gas. Emissions intensity factors for the production of ammonia range between around 1 to 3 tCO_2e per tonne of product (Ecofys, 2009e). Urea, another nitrogen fertiliser, has a generally slightly lower emissions intensity, between around 0.5 to 1.8 tCO_2e per tonne of product (Ecofys, 2009e).

Department of Energy and Climate Change statistics suggest that in 2007, electricity use comprised 30 per cent of total energy use within the sector (DECC, 2011a). Given that natural gas comprises around 70 per cent of the cost of producing ammonia, this implies significant electricity use (Ecofys, 2009e). However, some ammonia and nitric acid plants within integrated chemical sites make use of some of the excess steam that can be produced through the production of ammonium and urea (Ecofys, 2009e).

There is no short-term carbon abatement potential with regards to the fuel mix. Longer term options include the gasification of biomass and electricity-based ammonia production. However, both electricity and biomass would need to be available at prices competitive to natural gas while electricity would also need to be decarbonised in order to yield significant savings in CO_2. Biomass supplies in particular would also need to be shown to be consistently secure before any switch took place. Such changes in fuel mix would involve significant adaptation and replacement costs.

6.2 Sector composition and features

6.2.1 Market composition

Regulatory bodies in the EU treat straight nitrogen fertilisers, that is, urea, ammonium nitrate, and calcium ammonium nitrate, as substitutes which form a single product market (European Commission, 2013c).

Urea and ammonium nitrate form the bulk of the nitrogen fertilisers market. Whilst there are some distinctions between the two, they are considered substitutes for the purposes of modelling. Nitrogen fertiliser production in the UK is dominated by ammonium nitrate, while the bulk of ammonium fertiliser imports into the UK are urea.

Fertiliser production in the UK is concentrated in the north of England, reflecting the benefits of co-location in established chemical clusters. Approximate per-site production quantities are made publicly available by GrowHow (2013). GrowHow is, by far, the largest producer of nitrogen fertilisers in the UK, and is also the only remaining UK producer of ammonium nitrate.

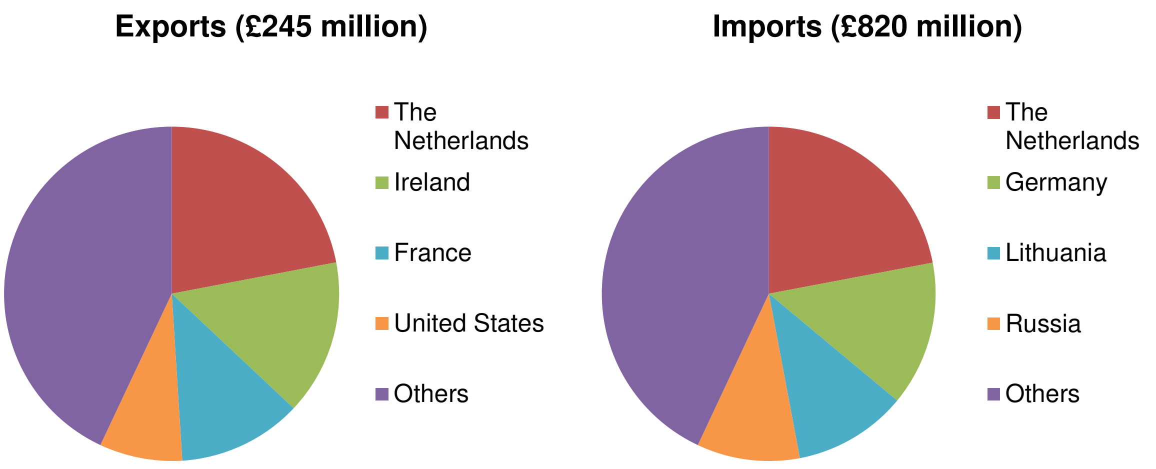
6.2.2 Employment and GVA

The fertiliser sector GVA was around £330 million in 2010 and has varied in recent years (ONS, 2013a). The price of gas, which is a key input to production, is particularly important in driving movements in fertiliser prices and profits. Employment has steadily declined since 1998. The fertiliser sector currently employs approximately 2,000 people (ONS, 2012b).

6.2.3 Trade patterns

While the UK’s largest trading partners for both exports and imports are within the EU, major non-EU producers appear within the top five (Figure 11), with the United States a major export destination and Russia a major import source. The competitiveness of imports from Russia is driven by lower natural gas prices at point of production. Should forecasts of increased shale gas production drive natural costs down further in the United States, there is the potential for significant pressure on exports to the US in coming years (and indeed, the potential for the US to increase its exports to the EU).

Figure 11. **The UK imports more fertiliser than it exports**

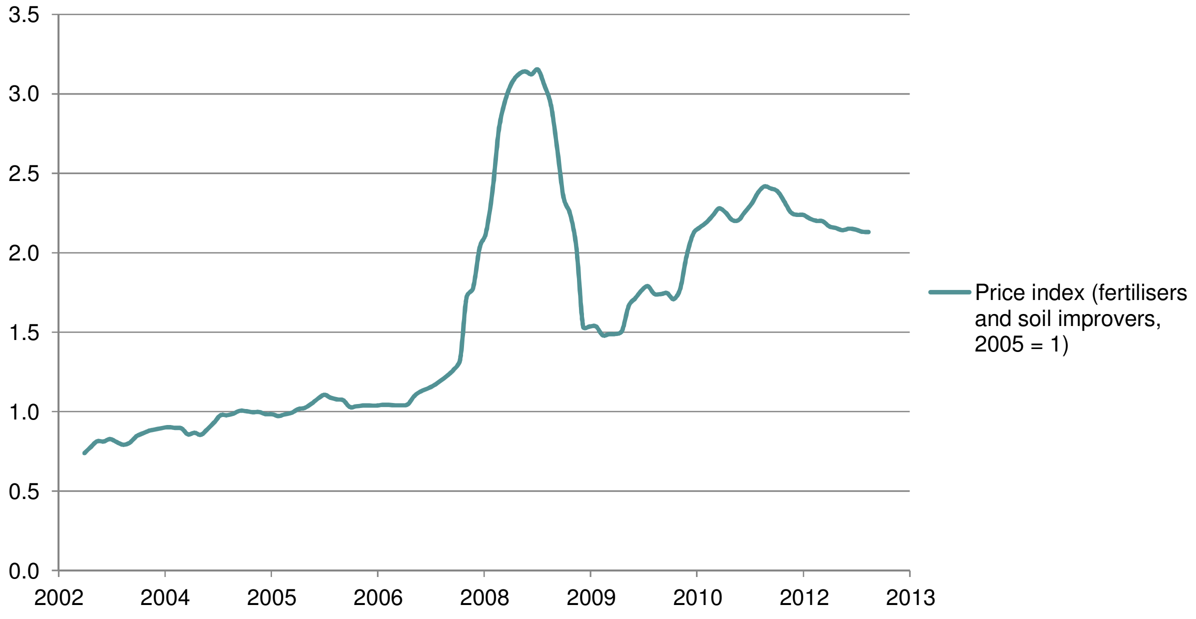


Source: *Based on* (IBISWorld, 2013c)

6.2.4 Pricing and elasticity

Fertiliser prices have been tracking upwards at a relatively stable rate, except for a sharp peak between 2008 and 2009 (see Figure 12). UK demand appears to be unresponsive to price. This reflects the lack of substitutes for fertilisers. Breen et al. (2012) estimated the price elasticity of demand for calcium ammonium nitrate in Ireland, finding that it is relatively inelastic, with a value of -0.4. This result was estimated with a reasonably high degree of statistical confidence. Other estimates of the price elasticity of demand, such as Dholakia and Majumdar's estimate for Indian fertiliser demand (1995), also found that quantities were unresponsive to price changes. The analysis uses a value of -0.37.

Figure 12. **Price of fertilisers and soil improvers (index 2005=1.0)**



Source: (DEFRA, 2013)

6.3 Model

6.3.1 Model inputs

All nitrogen fertilisers were treated as substitutable in this analysis. The ratio of the prices of ammonium nitrate (AN), urea and blends (Cheshire, 2012) was used to arrive at the conversion of tonnage between these three widely-substituted products. The fertiliser sector was modelled as a UK based market, since the value of exports is a quarter of that of imports, and a large fraction of UK capacity goes to domestic end-users (IBISWorld, 2013c). In the 2012 baseline, non-EU firms make up 18 per cent of the UK market for nitrogen fertilisers.

The average emissions intensity of UK producers weighted by production is 2.54 tCO_2/t. This is marginally more carbon efficient than EU producers, 2.59 tCO_2/t and much more efficient than the average non-EU producer that currently exports to the UK, 3.00 tCO_2/t.

Table 10. **Inputs to modelling nitrogen-based fertilisers**

Variable	Value	Notes	Source
Initial market price	£ 293/t		IBISWorld (2013)
Demand elasticity	-0.37		ICF International & Cambridge Econometrics (2013)
UK production	1,100,000 t		GrowHow (2013)
Non-UK production (imports into UK)	1,500,000 t	The ratio of the prices of ammonium nitrate (AN), urea and blends was used to arrive at the rate of conversion of tonnage between them to produce an estimate of the total size of the 'nitrogen-based fertiliser' market.	Ratio of prices between AN, urea and blended products: Cheshire, (2012) Imports of AN, urea and blends: European Commission (2013b)
UK emissions intensities	2.5 tCO_2e/t		(Wood & Cowie, (2004)
EU emissions intensities	2.6 tCO_2e/t		(Wood & Cowie, (2004)
non-EU emissions intensities	3.1 tCO_2e/t		(Wood & Cowie, (2004)
Gross UK profit margins	11%		IBISWorld (2013)

Source: Vivid Economics

6.3.2 Impact on UK and EU production

The nitrogen-based fertiliser market has a relatively small non-EU market share: EU producers make up 86 per cent of the market. The models estimate a cost pass-through rate of between around 50 to 80 per cent over different carbon prices.

As carbon prices rise, EU producers lose market-share to non-EU producers. Since UK producers are slightly less emissions-intensive than their EU competitors, UK production is somewhat more resilient to carbon price rises. In the 2020 core scenario, UK production declines by 7 per cent at a carbon price of €5/tCO_2, and 63 per cent at a price of €30/tCO_2. Over the same price interval, production of EU imports declines between 19 and 99 per cent. At a price of €50/tCO_2, UK and EU production completely ceases.

6.3.3 Output leakage and carbon leakage

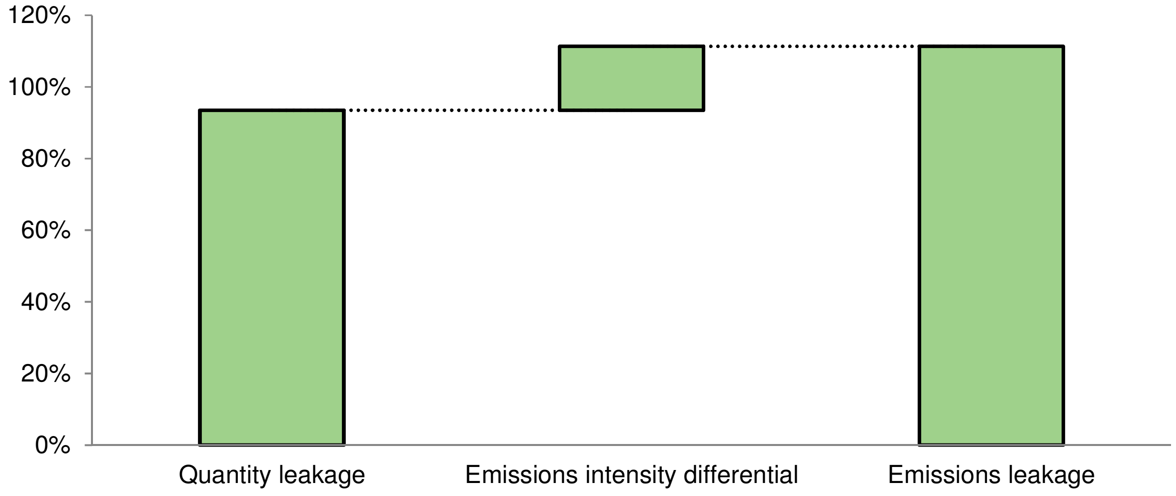
Output leakage is high in the fertiliser sector, at around 90 per cent: that is, for every 100 units of output lost imports into the UK increase by 90 per cent.

Carbon leakage increases with both output leakage and the differential between emissions intensities in regulated and unregulated regions. In a sector such as fertilisers, where EU producers have lower emissions intensities than non-EU producers, carbon leakage is greater than 100 per cent; that is, every 100 units of emissions lost in the EU are replaced by more than 100 units outside it (Figure 13).

6.3.4 Notes and summary

The fertilisers sector provides an example of a sector where it may not be economical to run an installation at anything other than relatively high levels of utilisation. Relatively small changes in production identified under modest carbon prices might render some facilities unprofitable, resulting in consolidation as firms exit.

Figure 13. **A high carbon leakage rate in the fertiliser sector is exacerbated by high differential emissions intensity**



Note: *This shows the effect of a €30/tCO₂ price in 2020*

Source: *Vivid Economics*

Table 11. **The UK fertiliser sector might contract significantly if exposed to highigh carbon prices**

Counter-factual	Price of carbon (€)		UK production (t)	Imports from EU	EU market share	UK profits (€)	UK emissions (tCO$_2$)	EU import emissions (tCO$_2$)	Non-EU emissions (tCO$_2$)			
2012	0		1,100,000	1,100,000	86%	29,000,000	2,800,000	3,000,000	1,200,000			
2020	0		1,300,000	1,300,000	87%	34,000,000	3,300,000	3,600,000	1,260,000			
2030	0		1,700,000	1,800,000	89%	45,000,000	4,400,000	4,600,000	1,300,000			
Year	**Change in price of carbon (€)**	**Cost shock as a fraction of price (%)**	**Change in UK production**	**Change in EU imports**	**Change in EU and UK market share**	**Change in UK profits**	**Change in UK emissions**	**Change in EU import emissions**	**Change in non-EU emissions**	**Carbon Leakage rate**	**Cost pass-through rate**	**Change in price**
2012	5	5%	-7%	-20%	-12%	-13%	-7%	-20%	994,000	107%	80%	4%
2012	15	12%	-24%	-64%	-43%	-42%	-24%	-63%	3,370,000	110%	74%	9%
2012	30	23%	-63%	-99%	-80%	-86%	-63%	-99%	6,200,000	111%	66%	15%
2020	5	5%	-7%	-19%	-12%	-13%	-7%	-19%	1,100,000	107%	81%	4%
2020	15	12%	-24%	-63%	-43%	-41%	-24%	-63%	4,000,000	110%	75%	9%
2020	30	23%	-63%	-99%	-81%	-85%	-63%	-99%	7,300,000	111%	66%	15%
2020	50	38%	-100%	-100%	-100%	-100%	-100%	-100%	8,900,000	119%	48%	18%
2030	5	5%	-6%	-17%	-11%	-11%	-6%	-17%	1,300,000	105%	83%	4%
2030	15	12%	-23%	-63%	-42%	-40%	-23%	-62%	5,000,000	110%	76%	9%
2030	30	23%	-62%	-99%	-81%	-85%	-62%	-99%	9,450,000	111%	67%	15%
2030	50	38%	-100%	-100%	-100%	-100%	-100%	-100%	11,500,000	118%	48%	18%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

7 Lime

7.1 Characteristics of production

7.1.1 Production process

Lime is used for diverse purposes, with two main forms: dolomitic and non-dolomitic. Lime is an alkali and serves numerous purposes, in the steel sector, in construction, sewage and water treatment, and in sugar manufacture, where it is used to remove impurities. Steel is itself energy intensive and potentially exposed to carbon leakage. Dolomitic lime is scarcer and is predominantly used in the iron and steel sector, though it also has other uses including, for example, glass manufacture and water treatment. Both dolomitic and non-dolomitic lime are produced using similar processes.

Lime is made from natural deposits of limestone or chalk. Dolomitic has a higher magnesium content. Quarrying, transport, and crushing are the initial steps in preparation. The stones are washed before entering the calcining stage of production.

The calcining process induces a chemical reaction triggered by heat, supplied in kilns:
- during pre-heating, the limestone is heated by kiln exhaust gases that enter the preheater kiln;
- the kiln fuel is burned in the preheated air from the cooling zone during the calcining stage. The limestone moves down the kiln and the increase in temperature turns the limestone into quicklime and CO_2.

Having been through the calcining process the limestone is now lime and can either be sold or crushed and water added to make hydrated lime. Hydrated lime is often used to increase the workability of cement mortar.

7.1.2 Emissions and electro-intensity of production

In the UK, high-calcium lime has an emissions intensity of between 0.985 and 1.31tCO_2/t lime (Ecofys, 2009f), of which 0.785 tCO_2/t come from direct emissions. At present, the efficiency of the most advanced lime kilns is close to the thermodynamic minimum and therefore, further efficiency gains are very limited for those kilns. Vertical and parallel flow regenerative kilns are the most efficient. The replacement of horizontal by vertical kilns is one carbon abatement option; however, less than 10 per cent of the kilns remaining in Europe are horizontal, and their replacement requires significant investment.

Other energy efficiency measures include preheaters and the recovery and use of process heat. This year in the UK, the Thrislington Lime plant near Durham will trial a waste heat to power project. It uses four 125 kW Organic Rankine Cycle Generators to create low carbon electricity to reduce the amount of electricity needed to run the lime kiln by 3,000 MWh per year (Heatcatcher, 2013). However, such technology is not economically viable for all kiln types.

Across the EU, some carbon emissions may be saved by fuel switching to natural gas; however, there is limited potential for this in the UK where, in 2012, the non-dolomitic lime sector was already fully converted to natural gas (British Lime Association, 2013).

7.2 Sector composition and features

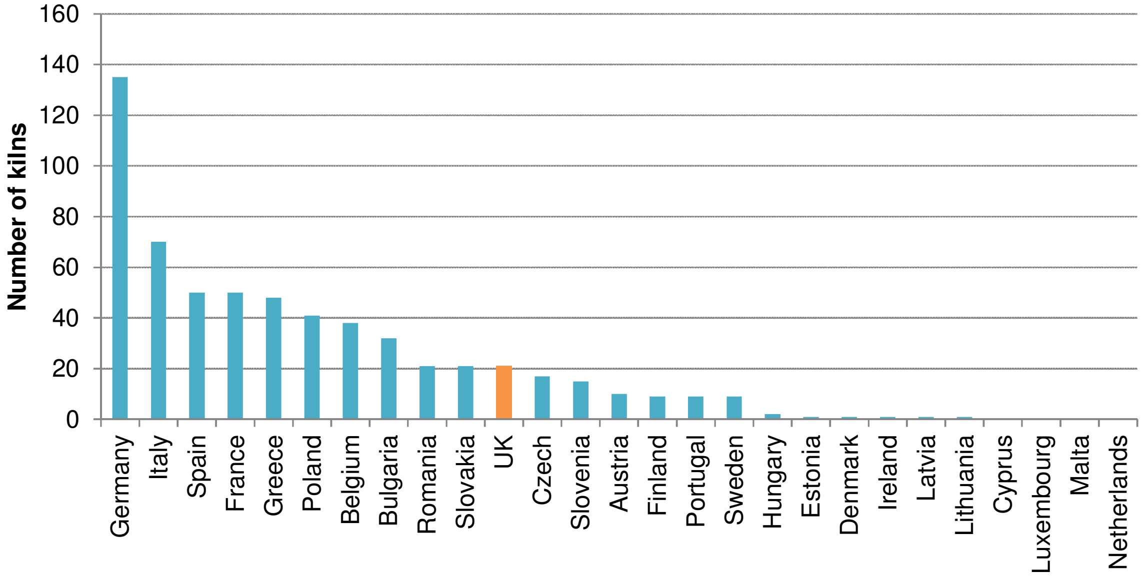
7.2.1 Market composition

Production facilities are located close to sources of limestone and centres of demand. The lime market has three major producers of non-dolomitic lime and one major producer of dolomitic lime. These producers all have sales revenues of similar magnitude.

UK producers are only a small proportion of total EU lime production (Figure 14). Around 600 lime kilns are operating in the EU, producing in total around 28.4 million tons of non-dolomitic and dolomitic lime, and contributing around €2.5 billion to Europe's GDP (EuLA, 2013). Eight companies control 65 per cent of the production and many small firms make up the residual 35 per cent. Only the largest firms operate on an international basis. The sector is mature and is unlikely to see many new plants being built (EuLA, 2013).

Lime has a large variety of uses. Demand is procyclical as the building and steel sectors make up a large share, about 50 per cent in the UK, of lime consumption. Uses for lime include the manufacture of steel (comprising about 50 per cent of demand in the UK (IBISWorld, 2012a)), limiting the emission of substances such as sulphur dioxide and hydrogen chloride, purifying drinking water, precipitating calcium carbonate (a step in the production of fine paper, foodstuffs, pharmaceuticals, and sugar refining), soil stabilisation, and rendering buildings. Overall, demand for lime tends to be procyclical.

Figure 14. **The UK operates only a small share of all EU lime kilns**



Source: (Ecofys, 2009g)

7.2.2 Trade patterns

The value of UK exports is twice the value of imports, with the EU by far the UK's largest trading partner and France and Ireland making up large portions of both the import and export market. Within the lime sector, the UK exports more dolomitic lime than high calcium lime (Mineral Products Association, 2013c), and indeed, dolomitic lime is substantially more traded globally in general. Using the European Commission's calculation of trade intensity, the UK's whole lime sector has been consistently above 15 per cent, and in more recent years, after the fall in dry shipping costs, has been higher than 20 per cent (Mineral Products Association, 2012).

7.2.3 Employment and GVA

Lime manufacture is small compared to other sectors investigated. Due to the small size of the sector, the Office of National Statistics (ONS) does not make available full time series for lime production in the UK. In 2011, estimated total sector turnover was £89 million, with GVA of £52 million (ONS, 2011). The sector in the UK employed approximately one thousand workers in 2011 (ONS, 2011). However, both these GVA and employment figures may be overstated due to the plaster sector being included within the same NACE code. British Lime Association data suggest a GVA for the UK lime section of £45 million (British Lime Association, 2013).

7.2.4 Profitability

In the EU, energy costs represent on average 40 per cent of the lime sector's manufacturing costs (EuLA, 2013). The UK average over 2004 to 2010 was substantially higher, at 55 per cent (British Lime Association, 2013). The sector is therefore sensitive to changes in energy prices. A gross margin estimate of 13 per cent was sourced from the sector report published by IBISWorld (2012).

7.2.5 Pricing, elasticity and substitutes

Demand appears to be fairly responsive to price. Cambridge Econometrics (2010) place the responsiveness of domestic demand to domestic price at -0.87. This elasticity estimate is likely to be on the high side. Many lime consumers, such as the steel, water, and chemicals sectors, do not have practical alternatives. In some instances, alternatives do exist – for instance, limestone can be used as a substitute for lime in some instances, such as flue gas desulphurisation, but this requires major retrofit and is not universally possible. No single appropriate estimate was identified; consequently, a price elasticity of demand of -0.3 was used, chosen to be the same as for other major construction products, such as steel and ceramics.

7.3 Model

7.3.1 Model inputs

All non-dolomitic lime is treated as a homogenous good. Due to a relatively low level of international trade, non-dolomitic lime is treated as a UK market (note that, if equivalent modelling for dolomitic lime were conducted, it would likely find the geographical scope of the market to be substantially broader). Imports of lime from the EU into the UK represent just over one per cent of total UK demand. Non-EU imports in the UK account for 0.1 per cent of the UK market share (see Table 12).

Table 12. **Lime sector inputs to modelling**

Variable	Value	Notes	Source
Initial market price	£67/t		IndexMundi (2013)
Demand elasticity	-0.3		Set equal to other construction products such as steel and cement
UK production	1,200,000t	For calendar year 2012.	IBISWorld (2013)
Non-UK production (imports into UK)	14,000t	For calendar year 2012.	European Commission (2013)
UK emissions intensities - direct	0.785 tCO_2e/t		Ecofys (2009)
UK emissions intensities - indirect	0.215 tCO_2e/t		Ecofys (2009)
non-UK emissions intensities - direct	0.785 tCO_2e/t	Foreign installations are assumed to have the same average direct emissions intensity as UK installations	
non-UK emissions intensities - indirect	0.16 tCO_2e/t	Foreign installations are assumed to have the same average electro-intensity of production as UK installations Foreign indirect emissions intensity is calculated by multiplying electro-intensity of production (MWh/t) by national average emissions intensity of electricity (tCO_2/MWh)	Indirect emissions factor in the UK: Ecofys (2009); Emissions intensity of electricity generation, by nation: IEA, (2012)
Gross UK profit margins	13%		IBISWorld (2012)

Source: *Vivid Economics*

7.3.2 Impact on UK production

The non-dolomitic lime sector is characterised by low margins and moderate intra-EU competition. Cost pass-through rates are over 80 per cent. However, with carbon costs of up to two-thirds of the original product price, UK and EU lime producers contract output significantly as a result of carbon cost rises.

Emissions-intensive EU producers lose market share relative to both less emissions-intensive EU producers and unregulated non-EU producers. At low carbon prices, UK producers lose market-share to their less emissions-intensive EU rivals. Thus, at a carbon price of €5/tCO_2, UK output contracts by 3 per cent, while EU imports into the UK increase by between 2 and 3 per cent. As carbon prices rise, EU producers lose more and more market-share to non-EU producers. UK output in the 2020 core scenario declines by 2 per cent at a carbon price of €5/tCO_2, and by 85 per cent at €50/tCO_2. Since EU importers make up a small fraction of the

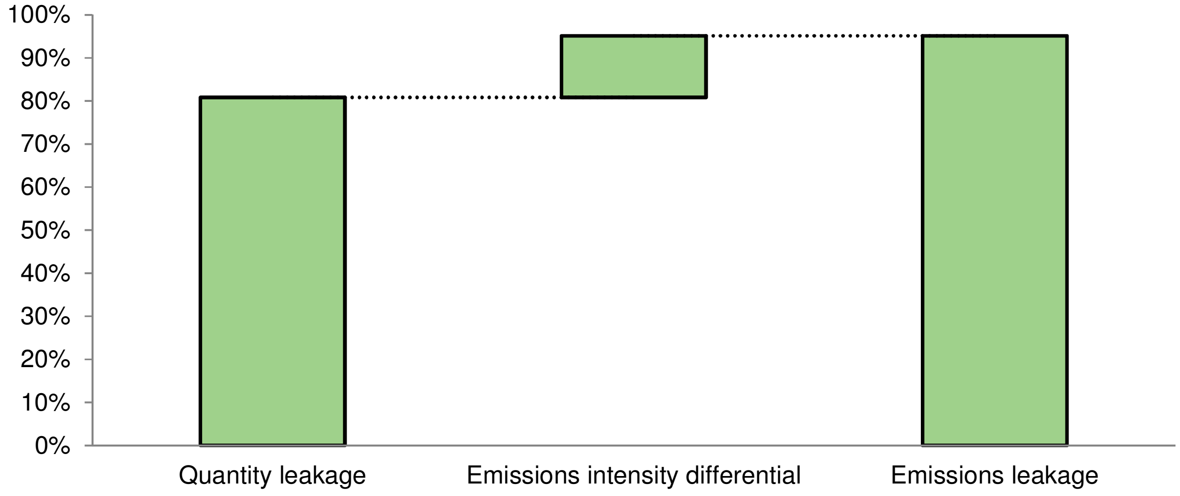
UK market, they contract output rapidly as carbon prices rise, so that as carbon prices rise to €30/tCO_2 and over, EU imports into the UK become zero.

7.3.3 Output and carbon leakage

In a low-margin, moderate-elasticity market such as lime, output leakage is expected to be relatively high. In the 2020 core scenario at prices at €15/tCO_2 and over, output leakage is between 76 and 82 per cent. This means that for every 100 units of output lost in the EU, imports into the EU increase by around 80 units.

Carbon leakage is determined by both output leakage and the emissions intensity differential between the output that is lost and the output that replaces it. In the case of lime, non-EU producers are more emissions-intensive than the EU producers they replace. That is, the EU producers who contract output are less emissions-intensive that the non-EU producers who gain market-share at their expense. Thus, carbon leakage is higher than output leakage: in the 2020 core scenario, between 89 and 97 per cent for carbon prices at €15 /tCO_2 and over. This means that for every 100 units of decline in CO_2 emissions in the EU, emissions increase by about 90 units outside the EU.

Figure 15. **Output relocates from more efficient producers to less efficient non-EU producers**



Note: *This graph shows the leakage decomposition for a €30 carbon price in the year 2020*

Source: *Vivid Economics*

7.3.4 Notes

The analysis concerns high-calcium (non-dolomitic) lime, which is traded less than is dolomitic lime. Thus, the trade exposure, impacts on output and emissions for the sector as a whole may be higher.

Table 13. **The UK lime sector is impacted strongly by high carbon prices**

Counter-factual	Price of carbon (€)	Cost shock as a fraction of price (%)	UK production	EU imports (t)	UK and EU import market share	UK profits (Euro)	UK emissions (tCO$_2$)	EU import emissions (tCO$_2$)	Non-EU emissions (tCO$_2$)
2012	0		1,200,000	13,000	99.9%	8,200,000	1,200,000	13,000	114
2020	0		1,100,000	12,000	99.9%	7,600,000	1,100,000	12,000	144
2030	0		1,100,000	12,000	99.9%	7,500,000	1,100,000	12,000	168

Year	Change in price of carbon (€)	Cost shock as a fraction of price (%)	Change in UK production	Change in EU imports	Change in EU and UK market share	Change in UK profits	Change in UK emissions	Change in EU import emissions	Change in Non-EU emissions (tCO$_2$)	Carbon leakage rate	Cost pass-through rate	Change in price
2012	5	8%	-2%	3%	-0.001%	-4%	-2%	-3%	114	0.4%	96%	8%
2012	15	21%	-20%	-77%	-17%	-34%	-20%	-81%	222,000	89%	87%	18%
2012	30	40%	-48%	-100%	-43%	-68%	-48%	-100%	553,000	95%	84%	34%
2020	5	8%	-2%	3%	-0.01%	-4%	-2%	-3%	144	0.6%	96%	8%
2020	15	21%	-20%	-77%	-17%	-34%	-20%	-81%	205,000	89%	87%	18%
2020	30	40%	-48%	-100%	-43%	-68%	-48%	-100%	510,000	95%	84%	34%
2020	50	66%	-85%	-100%	-83%	-91%	-85%	-100%	916,000	97%	83%	55%
2030	5	8%	-2%	2%	-0.1%	-4%	-2%	-3%	168	0.7%	96%	8%
2030	15	21%	-20%	-77%	-17%	-34%	-20%	-81%	204,000	89%	87%	18%
2030	30	40%	-48%	-100%	-43%	-68%	-48%	-100%	506,000	95%	84%	34%
2030	50	66%	-85%	-100%	-83%	-91%	-85%	-100%	910,000	97%	83%	55%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

8 Malt

8.1 Characteristics of production

8.1.1 Production process

Malting refers to partial germination of cereal grains. Production involves soaking, germinating, and drying the grain. Malting is not limited to barley grains, but given the composition of the EU market that is the focus here:

- barley grains are soaked in ‘steep tanks’ for several days;
- moved to aerated environments with cool, moist airflow to allow germination;
- after several days, moved to the ‘kiln’, which stops the germination process and develops additional flavour, and is the most energy-intensive part of the process;
- additional steps of cleaning and blending.

8.1.2 Emissions- and energy-intensity of production

In the UK, electricity comprises around 15 per cent of total energy use but 32 per cent of overall emissions (The Carbon Trust, 2011b). Fuel use, mostly comprising natural gas, accounts for approximately 68 per cent of emissions.

The main opportunities for energy efficiency improvement include increasing the final moisture content of the malt, some limited potential for heat recovery, implementation of CHP systems, and increased uptake of Automatic Monitoring and Targeting (AMT) systems.

Replacement of some non-natural gas fossil fuels with biomass or natural gas would reduce carbon emissions, though opportunities to do so may be limited. There are few direct emissions arising from the process; there are some biogenic CO_2 emissions, but these are effectively re-captured during the growth of the next year’s crop.

8.2 Sector composition and features

8.2.1 Market composition

Product differentiation is relatively low in the malt sector. There is some variation in quality, with different grades of malted barley classed by colour, protein content, and other variables. To some degree this corresponds to perceived variations in quality and suitability between beverages. There is also a split between unroasted and roasted malts. Roasted malt commands a price premium and makes up a relatively small share of the overall market.

Malt production consumes around 2.0 of the 6.5 million tonnes of barley produced in the UK (IBISWorld, 2013d). Resulting annual malt production capacity is approximately 1.5 million tonnes. There are five large players in the UK market, alongside two customer-owned malting companies and several smaller producers. The major firms are:

- Bairds Malt Ltd, between 15 and 20 per cent market share from four installations; Simpsons Malt Ltd, between 15 and 20 per cent market share from two installations; Crisp Malting Group Ltd, between 15 and 20 per cent market share from five installations; Boortmalt, between 15 and 20 per cent market share from four installations; Muntons Malt plc, between 10 and 15 per cent market share from two installations;
- Diageo, a distiller of Scotch whisky with between 10 and 15 per cent market share from four installations;
- Molson Coors Brewing Ltd, brewers with between 5 and 10 per cent market share from one installation.

There is sizeable variation in the capacity of individual installations. Approximately half of all malting sites are based in Scotland, due to proximity to the UK's whisky sector. The majority of installations have less than 50 thousand tonnes of throughput annually but the biggest three installations each produce over 100 thousand tonnes of malt a year (The Carbon Trust, 2011b). Five maltsters make up two-thirds of the UK market, and seven represent 98 per cent.

The sector is relatively mature. Despite production running at almost full capacity, little new plant construction is occurring (Euromalt, 2013).

8.2.2 Trade patterns

The value of UK exports is more than five times higher than the value of imports (IBISWorld, 2013d). Japan is the largest export partner, and while the identity of the largest import partner varies, it usually remains within the EU, Ireland being a consistently large import partner.

The EU malting sector accounts for more than 60 per cent of the world malt trade (Euromalt, 2013). Of the overall EU malting capacity of 9.5 million tonnes, about 2.1 million tonnes is exported to non-EU countries. Approximately 750,000 tonnes is exported to Africa; 550,000 to the Americas and 640,000 to Asia. About 200,000 tons is exported to European non-EU countries. Current revenue from EU malt exports is approximately €850 million (Euromalt, 2013). This accounts for approximately a quarter of overall production. The European malting sector does not benefit from any export subsidies or export refunds (Euromalt, 2013).

Although beyond the scope of analysis, EU malt exports have been affected by trade agreements. Following the Australia-Thailand FTA enforced in 2005, EU malt exports to Thailand dropped by 40 per cent (Euromalt, 2012).

8.2.3 Employment and GVA

Sector turnover fluctuates between £500 million and £900 million in the UK. GVA is approximately £100m (ONS, 2012b), and, since 1998, has generally kept pace with UK GDP growth, albeit with additional volatility. The number of workers has varied between approximately 1,000 to 2,000 over the past four years (ONS, 2012), though UK Malt disputes the accuracy of these figures.

8.2.4 Profitability

Malt producers are sensitive to changes in demand in the beer and whisky industries. In recent years the demand for beer in the UK has been falling while demand for whisky exports has been rising (Scottish Whisky Association, 2013). Volumes of whisky sold in the first half of 2013 were up 9 per cent which along with an increase in average price led to an increase in sales of 11 per cent. Margins in the EU are estimated to be approximately 8.5 per cent (IBISWorld, 2013d).

8.2.5 Pricing and elasticity

Direct estimates of elasticity of demand for malt are not available. The elasticity of demand for malt was taken to be equal to an estimate of the price elasticity of barley demanded for feed use, which was estimated to be approximately -0.33 (Spriggs, 1981).

8.3 Model simulation

8.3.1 Model inputs

The model treats malted barley as a homogenous product. As substantial trade occurs across the EU, the sector was modelled as an EU market. A summary of the model inputs can be found Table 14. The average emissions intensity, weighted by production, is 0.23 tCO_2 per tonne of product in the UK and 0.21 tCO_2 in the EU. The average emissions intensity of non-EU production is 0.22 tCO_2/tonne product.

Table 14. **Inputs into modelling the malt sector**

Variable	Value	Notes	Source
Initial market price	£285/t		FAO (2009)
Demand elasticity	-0.33		Spriggs (1981)
UK production	1,260,000 t	For calendar year 2012	IBISWorld (2013)
EU production	6,900,000 t	For calendar year 2012	European Commission (2013)
UK emissions intensities	0.22 tCO2e/t		The Carbon Trust (2011)
EU emissions intensities	0.21 tCO2e/t		The Carbon Trust (2011)
Non-EU emissions intensities - direct	0.22 tCO2e/t	Foreign installations are assumed to have the same average direct emissions intensity as UK installations Foreign installations are assumed to have the same average electro-intensity as UK installations (approximately around 0.2MWh/t) Vivid takes the product of electro-intensity and emissions intensity of electricity generation to arrive at indirect emissions	Electro-intensity:The Carbon Trust (2011) Emissions intensity of electricity generation: IEA 2012)
Gross EU profit margins	8.5%		IBISWorld (2013)

Source: *Vivid Economics*

8.3.2 Contraction in UK and EU output

A summary of the results can be found in Table 15. The malt sector contains a large number of firms, and gross profit margins of 8.5 per cent. The estimated cost pass-through rate is moderately high, at approximately 87 per cent.

EU firms make up an overwhelming majority of firms in the market: non-EU firms are less than 0.1 per cent of the EU malt market. In addition, carbon intensity is low relative to other emissions-intensive sectors. However, significant intra-EU competition suggests that carbon price differentials lead to moderately large impacts for domestic producers. A carbon price of €15/tCO_2 results in a 10 per cent reduction in domestic output, and a 4 per cent contraction in EU output.

8.3.2.1 Output and carbon leakage

Output leakage is determined by competitiveness in the market, both within the EU region and between EU and non-EU firms. With moderate margins, high intra-EU competition and moderate competition between EU and non-EU producers in the market, output and carbon leakage in the market would be predicted to be moderately high.

Output leakage rates are generally moderately high in the malt sector, in the neighbourhood of 93 per cent, suggesting that for every 100 units of output lost in the EU, imports into the EU increase by 93 units.

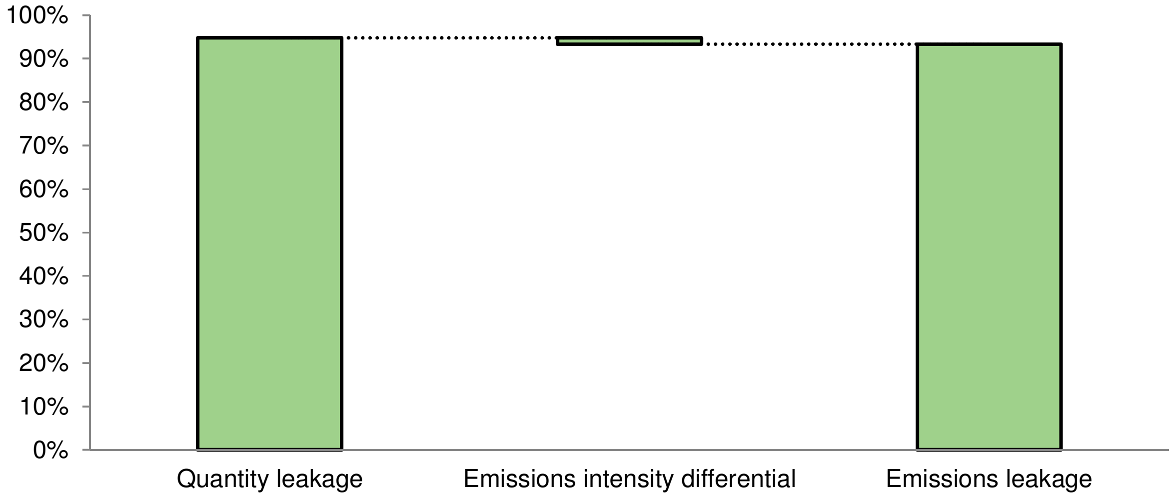
When carbon prices rise, relatively emissions-intensive EU producers contract output disproportionately relative to both non-EU competitors, and less emissions-intensive EU producers. In particular, the EU producers who reduce output the most are emissions-intensive relative not only to the rest of the EU, but also compared to non-EU rivals. Thus, carbon leakage is slightly lower than output leakage, in the neighbourhood of 90 per cent. Since carbon leakage is lower than 100 per cent, carbon price rises induce a net reduction in emissions worldwide.

At small carbon price differentials, output and carbon leakage is low. Output and carbon leakage rise sharply as carbon prices rise, but plateau at very high carbon prices. Moving from €5 to €15 /tCO_2e induces output leakage to move from 1 per cent to 93 per cent, but a move from €30 to €50 /tCO_2e leaves output leakage stable at approximately 95 per cent. As carbon prices rise, so does output leakage.

8.3.3 Sector notes

This modelling does not take into account the fact that exports to non-EU locations such as Thailand are disproportionately exposed to trade, and thus that the current modelling treatment may understate the trade exposure of this sector.

Figure 16. **Carbon leakage is slightly lower than output leakage**



Note: *This graph shows the leakage decomposition for a €30 carbon price in the year 2020.*

Source: *Vivid Economics.*

Table 15. **EU market share decreases only slightly at high carbon prices**

Counter-factual	Price of carbon (€/tCO$_2$)	Cost shock as a fraction of price (%)	UK production (t)	EU production (t)	UK and EU producers' market share	UK profits (€)	UK emissions (tCO$_2$)	EU emissions (tCO$_2$)	Non-EU emissions (tCO$_2$)
2012	0		1,260,000	6,900,000	99.998%	25,000,000	285,000	1,400,000	25
2020	0		1,350,000	7,300,000	99.998%	27,000,000	307,000	1,500,000	27
2030	0		1,400,000	7,600,000	99.998%	27,200,000	314,000	1,600,000	41

Year	Carbon price (€/tCO$_2$)	Cost shock as a fraction of price	Change in UK production	Change in EU production	Change in EU and UK market share	Change in UK profits	Change in UK emissions	Change in EU emissions	Change in non-EU emissions (tCO$_2$e)	Output leakage rate	Carbon leakage rate	Cost pass-through rate	Change in price
2012	5	0.4%	-1.3%	-0.1%	-0.0	-2%	-1.3%	-0.3%	25	1.3%	0.5%	100%	0.4%
2012	15	1%	-10%	-4%	-4%	-12%	-10%	-4%	59,000	93%	89%	89%	0.8%
2012	30	2%	-22%	-10%	-9%	-26%	-22%	-11%	148,000	95%	93%	85%	1.5%
2020	5	0.4%	-1.3%	-0.1%	-0.0	-2%	-1.3%	-0.3%	27	1.4%	0.5%	100%	0.4%
2020	15	1%	-10%	-4%	-4%	-12%	-10%	-5%	64,000	93%	89%	89%	0.8%
2020	30	2%	-22%	-10%	-9%	-26%	-22%	-11%	159,000	95%	93%	85%	1.5%
2020	50	4%	-39%	-17%	-17%	-42%	-39%	-20%	285,000	95%	95%	84%	2%
2030	5	0.4%	-1.3%	-0.1%	-0.0	-2%	-1.3%	-0.3%	41	2%	0.8%	100%	0.4%
2030	15	1%	-10%	-4%	-4%	-12%	-10%	-5%	65,000	93%	89%	89%	0.8%
2030	30	2%	-22%	-10%	-9%	-26%	-22%	-11%	162,000	95%	93%	85%	1.5%
2030	50	4%	-39%	-17%	-17%	-42%	-39%	-20%	292,000	95%	95%	84%	2%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

9 Paper and pulp

9.1 Characteristics of production

9.1.1 Production process

The modelling conducted here encompasses both pulp and paper production. UK papermaking primarily uses recycled paper and board as feedstock, accounting for more than 70 per cent of pulp fibre used. The balance is either imported processed pulp, or pulp produced in one of two integrated pulp and paper mills; pulp for market sale is no longer produced in the UK. The UK also has a number of specialist mills, some using non-wood material as feedstock.

There are four main production processes for pulp:
- mechanical;
- semi-chemical;
- sulphite;
- sulphate.

Both UK integrated mills use a mechanical process to produce their pulp. Mechanical pulping gives higher overall yields (compared to chemical pulping) but generally results in a weaker fibre.

To produce pulp from recovered paper:
- the recovered paper is combined with hot water within a pulper;
- the paper is processed back into fibres using mechanical and hydraulic processes;
- impurities are removed from the pulp by spinning and a variety of pressurised screens;
- the pulp may then be deinked or bleached, depending on the end use.

While paper mills use multiple varieties of pulp in the production of paper, the European Commission has found that pulp constitutes a single market (European Commission, 2008). For paper production, the European Commission has distinguished six separate subsectors (European Commission, 2013d):
- newsprint;
- uncoated printing and writing papers;
- coated printing and writing papers;
- packaging papers;
- tissue; and
- speciality papers.

In discussions with industry it was agreed that, for the purposes of the industrial modelling, it is reasonable to split paper into four subsectors: newsprint, printing and writing, packaging and sanitary. This combines uncoated and coated printing and writing paper into a single sector, and isolates sanitary paper from other varieties of tissue and speciality paper. Note that this may obscure the impact of carbon prices on particular subsectors which might otherwise be of interest (for instance, speciality papers tend to be relatively higher value-added, even if they make up a relatively small share of the total paper market). The impacts modelled here concern paper production for these four sub-sectors including upstream pulp production.

Paper production is capital and energy intensive and follows six basic steps:
- in non-integrated mills, pulp is mixed with water to produce a pulp slurry;

- the slurry is sprayed onto a screen;
- the web of slurry is pressed at high speed between large rolls that squeeze out water;
- the pressed sheet is passed to heated cylinders that are used to dry the slurry;
- the paper is rolled in the ‘calender’ (a series of high-pressure rollers) to provide finish and uniform consistency;
- the paper is ‘rolled up’ at the end of the machine. Later these large reels are normally rewound into smaller reels ready for shipping.

9.1.2 Emissions- and electro-intensity of production

Mechanical pulp manufacture is an electro-intensive process, but generates relatively few direct emissions. Chemical pulping processes, on the other hand, both consume and produce significant heat throughout production. Using best available techniques chemical pulping mills can even be carbon positive, as lignin released from pulped wood offers a potential energy source (Ecofys, 2009h). Producing pulp from recycled paper generates a small quantity of direct emissions, with an EU ETS benchmark of 39kg CO_2 per air dried tonne (ADT). Different pulping processes produce different grades of pulp that are subsequently used to produce different paper products; the pulp output from a mechanical mill is unlikely to be substitutable for the output of a chemical mill.

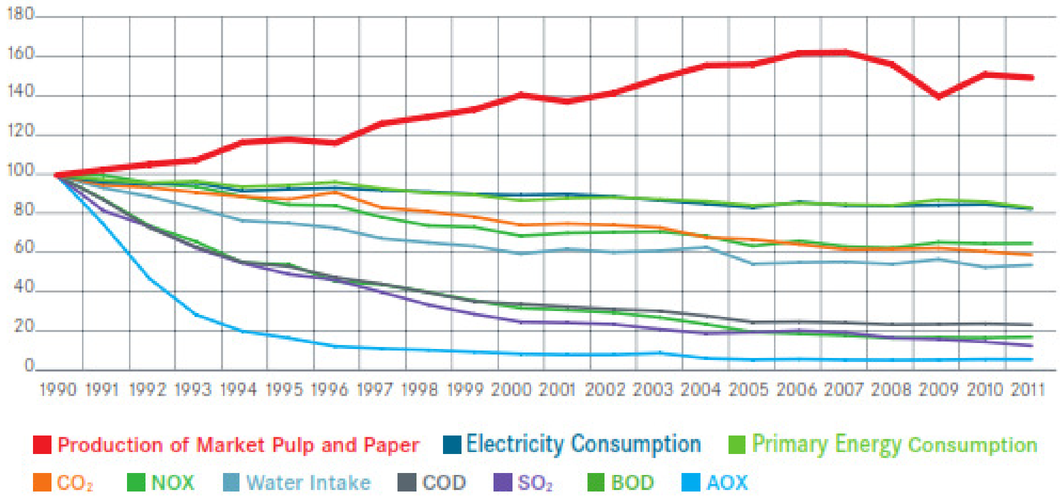
Emissions from paper manufacture vary with feedstock, product and type of fuel used, as well as with the application of specific energy efficiency technologies. In particular, co-generation of heat and power (CHP) covers a large share of total energy use and is used in most larger mills. In the UK around two thirds of total production is from mills with CHP.

Paper production benchmark emissions intensity ranges from 0.32 tCO_2 per ADT to 0.46 tCO_2 per ADT, depending on the product (Ecofys, 2009); these benchmarks essentially assume modern gas powered heat boilers and grid electricity. The fuel mix in the UK paper industry is dominated by gas, which accounted for 88 per cent of primary energy used in 2005 to 2007 (Ecofys, 2009h). Electricity use is also significant, with the UK paper sector consuming around 4 TWh of electricity in 2011 (Confederation of Paper Industries, 2013a). However, the sector also generates a significant portion of its total electricity consumption, with around 2 TWh produced through combined heat and power (Confederation of Paper Industries, 2013a).Indirect emissions have previously been estimated to be around 0.1 tCO_2 per ADT or a quarter of total emissions (Ecofys, 2009h). It has not proved possible to establish standard electricity product benchmarks, with electricity compensation assessed on the basis of actual electricity use.

The variety of production routes, products and levels of integration of industrial installations (dedicated pulp or paper plant and integrated plant) in the sector makes assessing the extent of historical energy efficiency improvements difficult. The production of paper requires heat for drying; the paper sector uses both boilers and CHP for this process. Mill CHP is normally designed to cover heat use with power demand balanced with grid import and export. Widespread use of CHP adds to security of supply and (when compared to grid displaced electricity) reduces total emissions (though may add to emissions measured on-site). Both direct and indirect emissions have fallen in tandem over the past two decades. The assessment of the sector Climate Change Agreement (by DECC) indicates a reduction of 34 per cent in energy used per tonne of production over 1990 to 2010 and a total decline in the release of fossil-fuel based CO_2 by 42 per cent (Department of Energy and Climate Change, 2011).

The sector increasingly uses biomass-based energy. Biomass fuel currently comprises approximately 54 per cent of primary energy consumption in the EU (Confederation of Paper Industries, 2013b) but a lower (though growing) fraction in the UK, where there is less virgin pulp production that can make use of low grade forest residues. Making paper out of recycled material, one of the principal paper production processes in the UK,) reduces waste and uses less energy than making paper from virgin pulp. However, it is more carbon-intensive than virgin fibre paper making when the virgin process is integrated and biomass-fired.

Figure 17. **A rise in production has been accompanied by lower emissions, index (1990 = 100)**



Note: *Excludes Hungary, Romania, Slovenia and Poland before 2003. Water Emissions are comprised of COD (Chemical Oxygen Demand), BOD (Biological Oxygen Demand), AOX (Halogenated Organic Compounds). Air Emissions are comprised of CO_2, NOx and SO_2.*

Source: *Confederation of European Paper Industries, 2013*

The direct emissions and electricity intensities used in modelling are recorded in Table 16. These figures are based on the recorded energy use of UK paper manufacturers.

To construct the carbon intensity of production, the model adjusts electricity use by producers in each country according to the carbon intensity of grid electricity within their country. In reality, the widespread use of combined heat and power implies that the carbon intensity of electricity used in particular paper mills may differ substantially from the carbon intensity of grid electricity. However, given the lack of available data on paper level emissions intensities, using the carbon intensity of grid electricity can act as a proxy for relative differences in carbon intensities between producers. The model also assumes that direct emissions intensities do not vary between EU and non-EU producers.

Table 16. **The emissions intensities vary across the different production processes**

Subsector	Direct emissions (tCO_2/t product)	Electricity intensity (MWh/t product)
Newsprint	0.27	0.91
Packaging	0.60	0.56
Printing and Writing	0.46	0.98
Sanitary	0.49	1.30

Note: Rounding to two significant figures

Source: CPI, 2013

9.2 Sector composition and features

9.2.1 Market composition

The four separate submarkets have different market compositions and features. Sanitary paper is considered as a domestic market due to the low quantity of exports, with only around 1 per cent of UK sanitary production exported in 2012. Printing and writing paper, packaging, and newsprint are treated as EU markets.

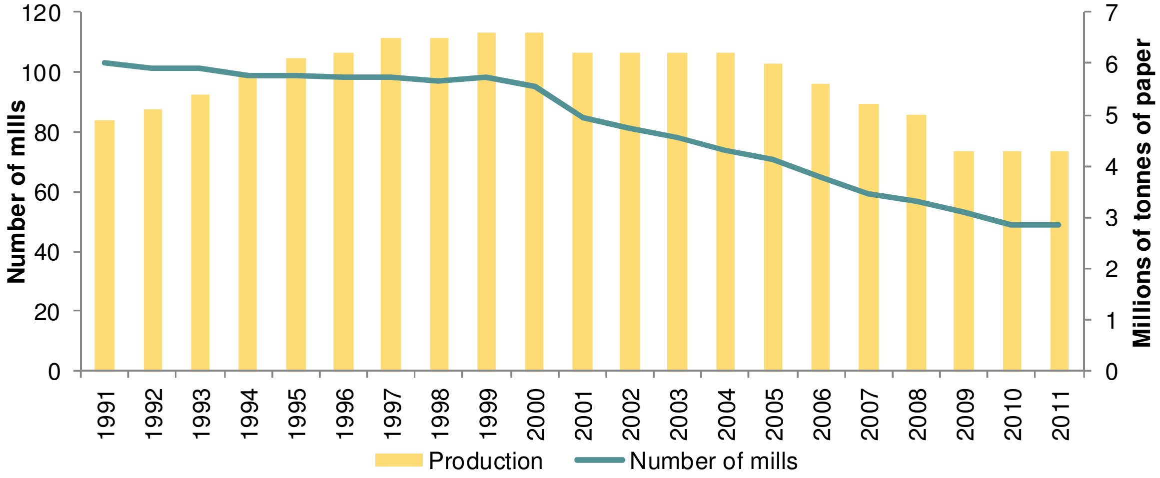
Packaging paper and newsprint are the two largest subsectors by production weight in the UK. There are currently seven UK-based firms in the packaging paper market and three UK firms in the newsprint market (CPI, 2013).

As noted above, all pulping within the UK is fully integrated with paper production. Paper production is capital intensive. A ‘paper machine’, which performs the forming, pressing, drying and smoothing, is an expensive asset with a lifespan measured in decades the cost of a new packaging mill (capacity circa 400k pa) would be in the region of £300m.

In 1991, there were just over 100 paper mills in the UK but this number has steadily declined, especially since 2000 (Figure 18), to around half that level. Of these 44 are large enough to be regulated by EU ETS, with 12 of the smaller mills (less than 25,000 tonnes CO_2 of annual emissions), in line with EU ETS regulations, choosing to opt into the alternative UK national scheme. There are two pulp plants that produce virgin pulp through the mechanical process, while the remaining paper facilities use recycled paper feedstock to produce their pulp or imported virgin pulp.

In the EU, as of 2012 there were around 789 paper mills, a decrease from around 1,274 in 1991 (Confederation of Paper Industries, 2013b). A similar downward trend can be seen in the number of pulp mills, which fell by 27 per cent between 2000 and 2012. Simultaneously, the average capacity for a paper and board mill in the EU has increased. The closure of mills was concentrated in the lower capacity plants, with the share of mills that can produce over 300,000 tonnes per annum increasing from 11.3 per cent in 2002 to 12.8 per cent in 2012 (Confederation of Paper Industries, 2013b).

Figure 18. **Between 1990 and 2011, the number of mills in the UK declined steadily**



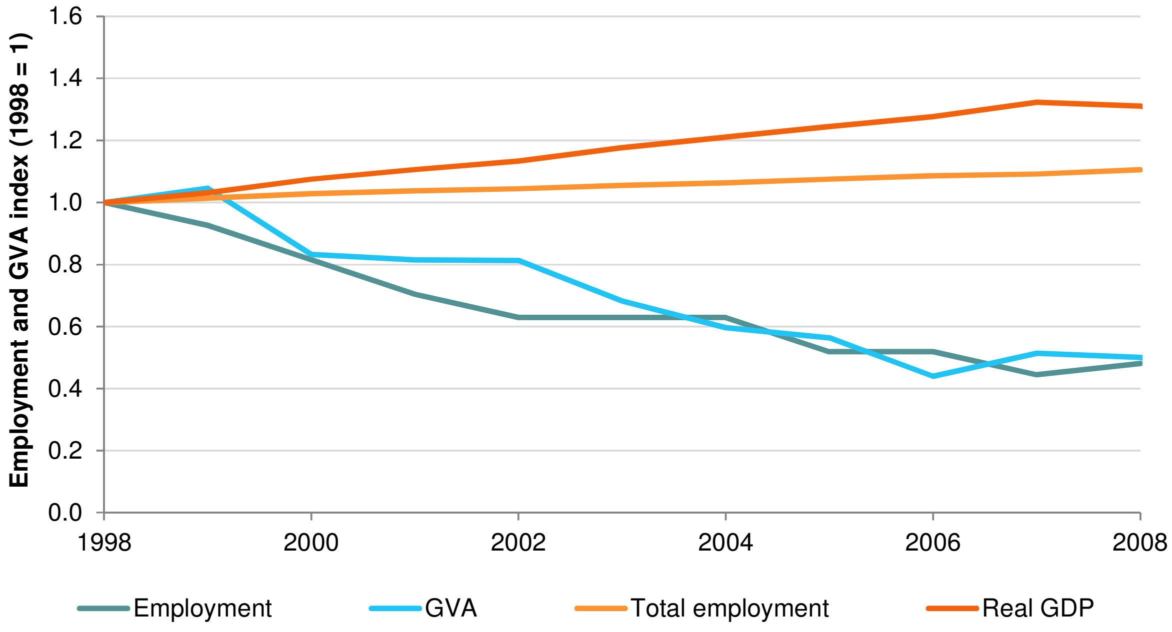
Source: CPI (2012), Vivid Economics

9.2.2 Employment and GVA

In the UK, employment and GVA of the pulp and paper sector is estimated by the ONS to have fallen approximately 50 per cent since 1998 (Figure 19). Since 2007, GVA has remained at around £700 million and employment has hovered around 29,000 employees (ONS, 2012b). However, these figures cover a wider sector than just UK pulp and paper mills (the only part of the ONS sector subject to EU ETS), and therefore include various non-papermaking activities. CPI estimates that papermaking in the UK directly employees around 10,000 individuals (CPI, 2013).

In the EU total employment fell steadily from 1991 until 2012. In 1991, there were over 400,000 workers in the EU in the sector. In 2012 there were approximately 185,000 (Confederation of Paper Industries, 2013b). The GVA for the sector is estimated to be around €15 billion in 2012 (Confederation of Paper Industries, 2013b).

Figure 19. **Employment and GVA in pulp and paper have fallen significantly since 1998, especially compared to the broader UK economy**



Note: Total employment indicates employment across the entire economy, indexed to unity in 1998.

Source: ONS, 2012, Vivid Economics

9.2.3 Trade Patterns

The UK runs a large trade deficit in paper and paper products. The total value of paper and paperboard imports in 2012 exceeded £4 billion; exports totalled around £1.3 billion. Both imports and exports are largely from the EU; however, significant non-EU trade partners exist, including the United States, Brazil, and Canada as importers, and the United States, Australia, and Russia as export destinations.

By contrast, in 2011, the EU exported around 18 million tonnes of paper and board, about four times as much as it imported (Confederation of European Paper Industries, 2011). In the same year the EU exported 3 million tonnes of pulp, less than ten per cent of total production. Pulp imports in 2011 were over 8 million tonnes, with the majority of imports coming from Latin America.

Table 17. **EU countries are the UK's largest trading partners, but a notable share of both imports and exports are sourced from elsewhere**

Country	Share of imports	Country	Share of exports
Sweden	18%	Irish Republic	18%
Germany	17%	Germany	12%
Finland	15%	France	10%
France	10%	United States	6%
United States	4%	Netherlands	5%

Note: *Calculated using value of imports and exports in 2012*

Source: *CPI, 2013a*

9.2.4 Profitability

Profit margins have stayed relatively stable over the last few years, albeit at low levels. Publically available accounts indicate that profit margins in pulp and paper, measured as operating profits with interest payments excluded, are around four to six per cent (IBISWorld, 2012b). For modelling purposes, a profit margin of three per cent was applied, based on data provided by CPI (CPI, 2013).

9.2.5 Pricing, elasticity and substitutes

Paper products attract different prices and, within each subsector, paper prices vary according to grade. For instance, low grade packaging paper is likely to be priced at around £400 per tonne, which is the figure used within our modelling, but higher cost grades can cost up to £1,000 per tonne. By necessity, the model assumes a single uniform price across each subsector. As noted above, the model may therefore miss some of the effects of an increased carbon price on highly specialised paper mills producing niche products.

For modelling purposes, elasticity estimates ranging from -0.38 to -0.16 were used for the different subsectors, based on the results of a UNECE study (Kangas & Baudin, 2003). Elasticities in this range generally suggest that demand is unresponsive to price, indicative of the paucity of available substitutes for many paper applications.

9.3 Model simulation

9.3.1 Modelling paper

The combination of paper and pulp was modelled as four distinct subsectors: newsprint, printing and writing paper, packaging paper and sanitary paper. The first three subsectors were modelled at the EU level, whereas sanitary paper was modelled at the UK level due to low rates of sanitary paper export from the UK. This leads to a distinction in the results reported here: variables reported for three of the four subsectors, such as carbon leakage rates and changes in production, refer to the outcome at the EU level. For sanitary paper, variables are reported in reference to the outcome at the UK level.

In the newsprint subsector, EU production as a share of the EU market is 89 per cent in 2012 but falls to 83 per cent in the 2030 counterfactual. The printing and writing subsector experiences a smaller contraction from 97 per cent in 2012 to 94 per cent in 2030, while packaging shrinks from 96 per cent to 92 per cent.

Table 18. **Inputs to modelling paper subsectors**

Variable	Newsprint	Packaging	Printing & writing	Sanitary	Source
Initial market price	£375/t	£400/t	£685/t	£800/t	CPI, 2013b
Price elasticity of demand (%)	-0.38	-0.16	-0.25	-0.16	Kangas & Baudin, 2003
UK production (t) (for calendar year 2012)	N/A	N/A	N/A	786,000	CPI, 2013b
EU production (t) (for calendar year 2012)	8,590,000	40,787,000	31,607,000	N/A	CEPI, 2013
Direct emissions intensity (tCO_2e/t)	0.27	0.6	0.46	0.49	CPI, 2013b
Gross UK profit margins (%)	3	3	3	3	CPI, 2013b

Notes: *EU production is not specified for sanitary because modelling is conducted at the UK level, whereas UK production is not specified for the remaining sectors because modelling is conducted at the EU level.*

Source: *As specified above*

9.3.2 Impact of carbon price rises on UK and EU output

Cost pass-through rates are consistently above 75 per cent across subsectors (Table 20, Table 21, Table 22, and Table 23). These results are driven by the relatively large market share of EU producers in all of the relevant sectors, combined with the competitive nature of the internal EU market. The first factor implies that changes in EU production levels will have significant effects on market prices, while the second implies that EU producers, operating with slim profit margins, will pass on cost increases. Despite high cost pass-through there is a substantial impact on EU and UK profit margins and production in all carbon price scenarios, with newsprint tending to have the strongest proportional reaction.

9.3.3 Output and carbon leakage

Amongst the paper subsectors, sanitary paper shows the highest rate of carbon leakage, and is the only subsector with a carbon leakage rate above 100 per cent. This suggests that for every 100 units of carbon emissions reduced in the EU, more than 100 units would be produced and embodied in additional imports.

All subsectors show output leakage rates above 85 per cent (Table 19). This is indicative of a large share of imports in the EU market, and, in the case of sanitary paper, a large import market into the UK. Carbon leakage is below quantity leakage in sectors where the major competing non-EU exporters are states with low carbon intensities of electricity. For instance, subsectors that face significant competition from Canada, which has a low carbon intensity of grid electricity, are likely to find that carbon leakage is lower than output leakage.

Carbon pricing leads to a net increase in global emissions in the case of sanitary paper, and only a relatively small decline in the case of packaging. The decline in global emissions as a consequence of carbon pricing is somewhat larger for newsprint and printing and writing paper, but nonetheless the bulk of reductions in EU emissions are still offset elsewhere (Figure 20, Figure 21, Figure 22, and Figure 23).

Table 19. **Quantity and carbon leakage rates varies across subsectors**

Subsector	Quantity leakage rate	Carbon leakage rate
Newsprint	0.94	0.72
Packaging	0.94	0.97
Printing and Writing	0.88	0.76
Sanitary	0.97	1.09

Note: *Shows the leakage rates for or a €30/ tCO_2 carbon price in the year 2020*

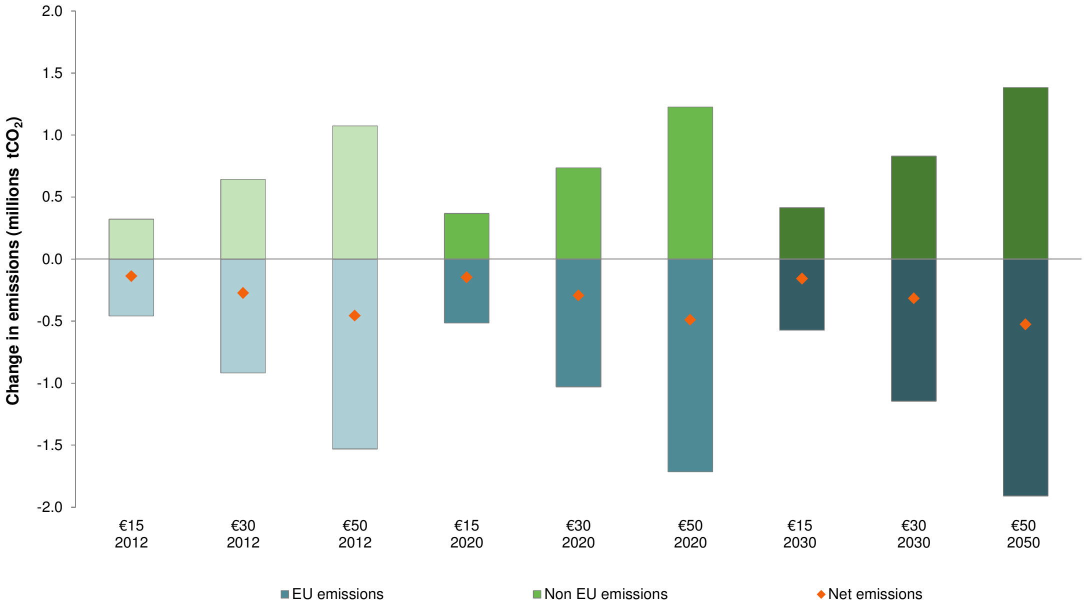
Source: *Vivid Economics*

9.3.4 Sector notes

One proviso worth noting is that, due to the absence of relevant comprehensive data, the modelling does not account for autogeneration of electricity during the production process, which is common amongst both UK and other producers. Accounting for autogeneration has the potential to alter the estimated rates of carbon leakage – for instance, if autogeneration is more prevalent in the UK, leading to a relatively lower emissions intensity per unit of production, then carbon leakage rates would be understated.

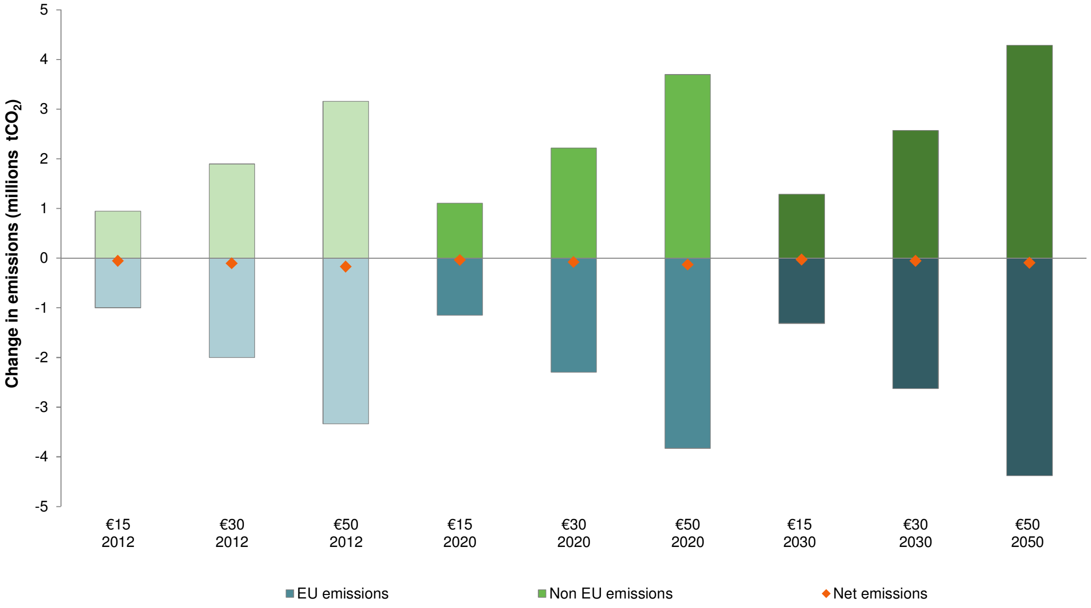
Other complexities in this sector are not addressed in the modelling. For instance, UK producers' integration of recycled paper processing can mean that they can appear more carbon-intense than users of virgin pulp. Note also that reliance on recycled pulp requires the injection of imports produced from virgin pulp, to maintain the quality of the recycled stock; consequently, paper imports represent both a competitive threat and an input into production for the bulk of UK producers.

Figure 20. **Newsprint: change in emissions compared to counterfactual of no carbon price**



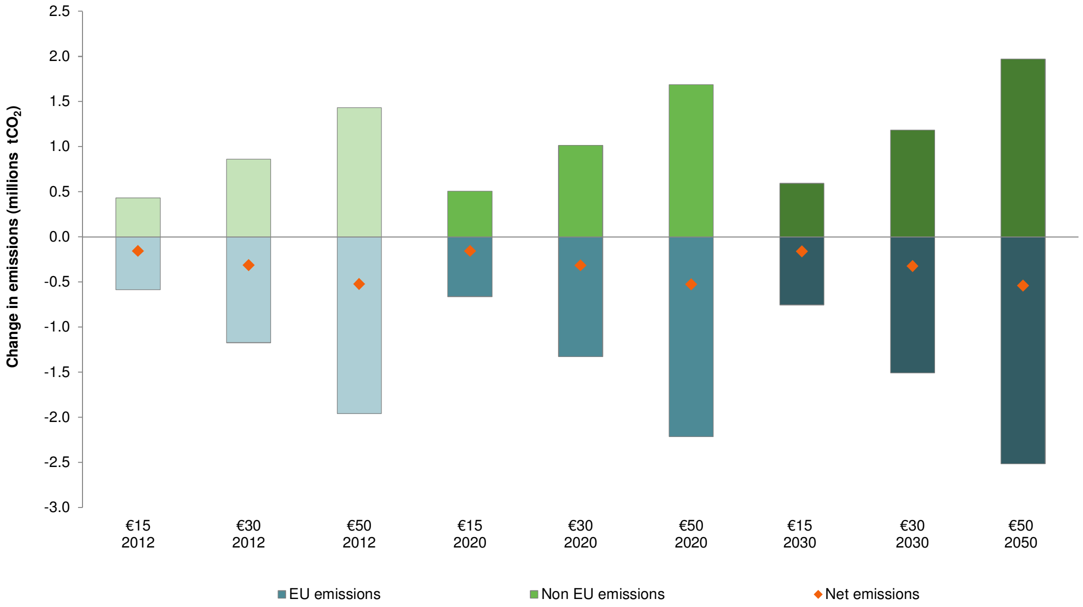
Source: *Vivid Economics*

Figure 21. **Packaging: change in emissions compared to counterfactual of no carbon price**



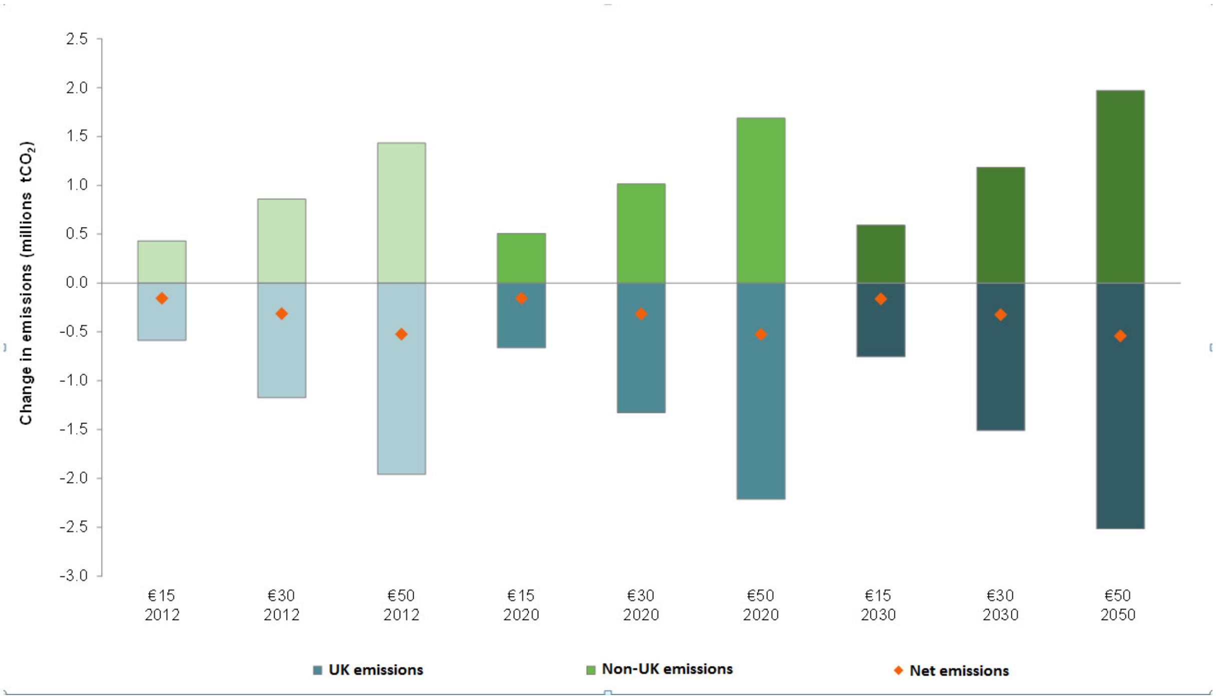
Source: *Vivid Economics*

Figure 22. **Printing and writing paper: change in emissions compared to counterfactual of no carbon price**



Source: *Vivid Economics*

Figure 23. **Sanitary: change in emissions compared to counterfactual of no carbon price**



Source: *Vivid Economics*

Table 20. **Newsprint**

	Price of carbon (€/tCO_2)	EU production (t)	EU market share	Gross margin	Elasticity	Price (£/t)
2012 Counterfactual	0	8,900,000	89%	3%	0.38	372
2020 Counterfactual	0	7,800,000	86%	3%	0.38	372
2030 Counterfactual	0	7,000,000	83%	3%	0.38	372

Date of Policy	Change in price of carbon (€)	Change in EU production	Change in market share	Carbon leakage rate	Cost pass-through rate	Change in price
2012	15	-9%	-8%	70%	86%	2.0%
2012	30	-18%	-17%	70%	86%	4.0%
2012	50	-30%	-28%	70%	86%	6.6%
2020	15	-11%	-11%	72%	82%	2.0%
2020	30	-23%	-22%	72%	82%	4.0%
2020	50	-38%	-37%	72%	82%	6.6%
2030	15	-14%	-14%	72%	78%	2.0%
2030	30	-28%	-27%	72%	78%	4.0%
2030	50	-47%	-46%	72%	78%	6.6%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

Table 21. **Packaging**

	Price of carbon (€/tCO_2)	EU production (t)	EU market share	Gross margin	Elasticity	Price (£/t)
2012 Counterfactual	0	41,000,000	96%	3%	0.16	397
2020 Counterfactual	0	37,000,000	94%	3%	0.16	397
2030 Counterfactual	0	33,000,000	92%	3%	0.16	397

Date of Policy	Change in price of carbon (€)	Change in EU production	Change in market share	Carbon leakage rate	Cost pass-through rate	Change in price
2012	15	-5%	-5%	95%	94%	2.5%
2012	30	-11%	-10%	95%	94%	5.1%
2012	50	-17%	-16%	95%	94%	8.5%
2020	15	-7%	-6%	97%	92%	2.5%
2020	30	-134%	-13%	97%	92%	5.1%
2020	50	-23%	-22%	97%	92%	8.5%
2030	15	-9%	-8%	98%	89%	2.5%
2030	30	-17%	-17%	98%	89%	5.1%
2030	50	-29%	-28%	98%	89%	8.5%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

Table 22. **Printing and writing**

	Price of carbon (€/tCO$_2$)	EU production (t)	EU market share	Gross margin	Elasticity	Price (£/t)
2012 Counterfactual	0	32,000,000	97%	3%	0.25	682
2020 Counterfactual	0	28,000,000	95%	3%	0.25	682
2030 Counterfactual	0	25,000,000	94%	3%	0.25	682

Date of Policy	Change in price of carbon (€)	Change in EU production	Change in market share	Carbon leakage rate	Cost pass-through rate	Change in price
2012	15	-2.3%	-2.0%	73%	95%	1.4%
2012	30	-4.6%	-4.0%	73%	95%	2.8%
2012	50	-7.7%	-6.6%	73%	95%	4.7%
2020	15	-3.0%	-2.6%	76%	94%	1.4%
2020	30	-5.9%	-5.3%	76%	94%	2.8%
2020	50	-9.9%	-8.9%	76%	94%	4.6%
2030	15	-3.7%	-3.4%	78%	92%	1.4%
2030	30	-7.5%	-6.9%	78%	92%	2.7%
2030	50	-12.5%	-11%	78%	92%	4.6%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

Table 23. **Sanitary**

	Price of carbon (€/tCO$_2$)	UK production (t)	UK and EU producers' share of UK market	Gross margin	Elasticity	Price (£/t)
2012 Counterfactual	0	800,000	92%	3%	0.16	795
2020 Counterfactual	0	710,000	89%	3%	0.16	795
2030 Counterfactual	0	640,000	86%	3%	0.16	795

Date of Policy	Change in price of carbon (€)	Change in UK production	Change in EU and UK market share	Carbon leakage rate	Cost pass-through rate	Change in price
2012	15	-6%	-6%	108%	89%	1.8%
2012	30	-12%	-12%	108%	89%	3.5%
2012	50	-21%	-20%	108%	89%	5.9%
2020	15	-8%	-8%	109%	86%	1.8%
2020	30	-16%	-15%	109%	86%	3.5%
2020	50	-26%	-26%	109%	86%	5.9%
2030	15	-10%	-10%	110%	83%	1.8%
2030	30	-20%	-19%	110%	83%	3.5%
2030	50	-33%	-32%	110%	83%	5.9%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

10 Refineries

10.1 Characteristics of production

10.1.1 Production process

Crude oil and natural gas are naturally occurring hydrocarbons which appear in a range of compositions and levels of purity. Refineries transform these hydrocarbons into:

- fuels for cars, trucks, aeroplanes, ships and other forms of transport;
- combustion fuels for the generation of heat and power for industry and households;
- raw materials for the petrochemical and chemical industries;
- speciality products such as lubricating oils, paraffins and waxes, and bitumen. By-products such as sulphur may also be produced;
- energy, largely for own use as process heat (as direct firing and distributed steam) and electricity (with surplus electricity exported to the grid at some refineries).

The refining of crude oil into usable petroleum products takes place, broadly speaking, in three steps: crude oil is first passed through a desalter unit to remove salt (from seawater), sand and other contaminants and then subjected to a two-stage distillation process, resulting in a number of fractions, separated by their respective boiling points;

- a number of these fractions are subjected to further upgrading processes to improve their suitability for use as fuels. Some of the lighter components are reformed or combined with other fractions, whilst heavier low value materials are cracked and subjected to further processing to provide additional higher value products;
- the third step involves final processing and blending to meet various fuel specifications, in particular to remove sulphur, improving fuel emissions performance;
- the refining processes are supported by on-site energy generation and a number of emissions abatement processes including waste water treatment, waste gas treatment and sulphur recovery.

Refineries are complex plants, where the processes employed depend on characteristics of the raw materials and the desired final product. The complexity of the production process, and variations in the feedstock and type of final fuel produced, result in variations in carbon intensity and other metrics of environmental performance across refineries.

10.1.2 Emissions- and energy-intensity of production

Across the EU, there is substantial heterogeneity in the emissions produced per tonne of crude oil processed. In general, refinery emissions depend on the type of crude oil processed including its gravity, sulphur content, and the complexity of the processes required:

- refining heavier crudes increases emissions;
- refining acidic crudes with a high sulphur content increases emissions;
- upgrading, in particular using hydrocracking (to increase diesel and jet fuel yields) or cracking processes (to increase petrol yields) increases emissions (but improves overall refinery margins).

The refineries sector in the EU accounted for 18 per cent of industrial total consumption of final energy (SERPEC-CC, 2009). Typical improvements in energy efficiency and emissions include further heat integration and use of CHP. The SERPEC-CC (2009) identified a number of abatement opportunities for the refineries sector including:

- improving the use of energy monitoring and process control systems;
- process integration where, for example, cooling and heating are required at different stages of the production process;
- steam generation through waste heat recovery;
- improvement of steam distribution;
- efficient drive systems;
- advanced distillation processes are being developed to improve on the energy transfer within the distillation column;
- fluid catalytic cracking (FCC) processes often operate with high flue gas velocities and temperatures or in partial burn mode, offering potential for energy recovery.

However, while a large number of overall abatement opportunities may be identifiable, this is largely a result of the innate complexity of the refinery process. Many of the opportunities above will have limited applicability: for instance, the level of process integration in UK refineries is already high, and additional heat recovery or variable speed drives are likely to be expensive and raise practicality issues. Improved energy efficiency techniques are more likely to be economical in the case of new build refineries, but as noted below, new builds are relatively rare.

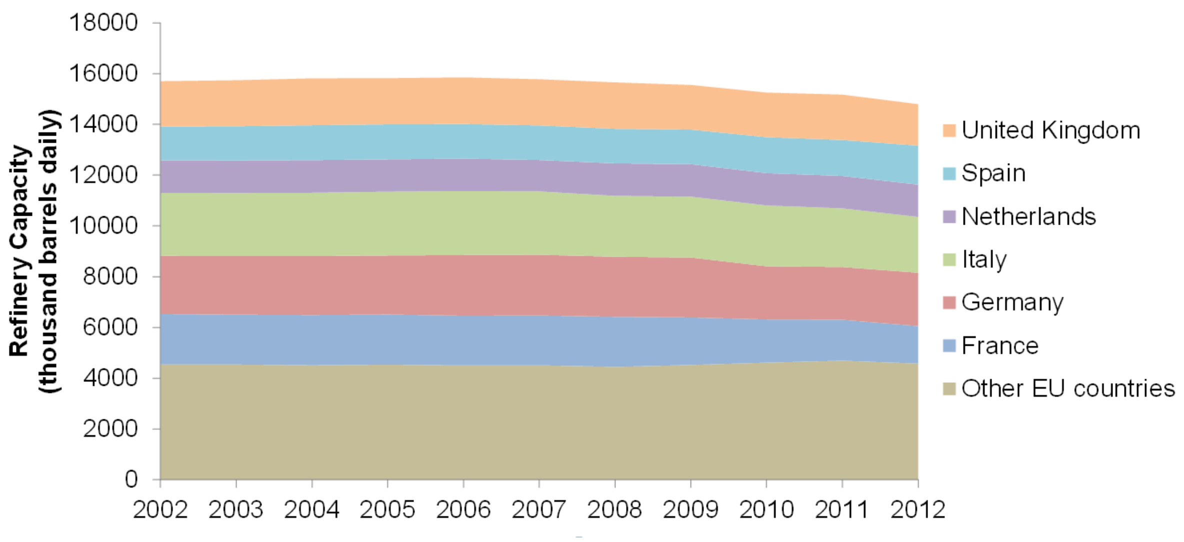
10.2 Sector composition and features

10.2.1 Market composition

Competition cases associated with mergers in the sector that defined the market as the EU. In the BP/Mobil case in 1996, the EC found that the geographic market appeared to be the EU or Western Europe (European Commission, 1996). In more recent cases, such as PKN/Mazeikiu, it has been suggested that the market is probably EEA wide (European Commission, 2006). Petroleum product prices in the EEA track each other closely. The fuel quality requirements within the EU currently limit imports from Russia and other CIS countries.

Following the recent closure of the Coryton refinery in May 2012, there are seven refineries operational within the UK. Every facility is located on the coast and most take feedstocks from the North Sea (UKPIA, 2013a). North Sea production is declining. Since 1990, UK refining capacity has fallen by five per cent while global sector capacity has increased 25 per cent (ONS, 2013b). UK refining capacity however still accounts for approximately 11 per cent of EU refining capacity (Figure 24).

Figure 24. **The UK has around 11 per cent of EU refinery capacity**



Source: BP, 2013, *Vivid Economics*

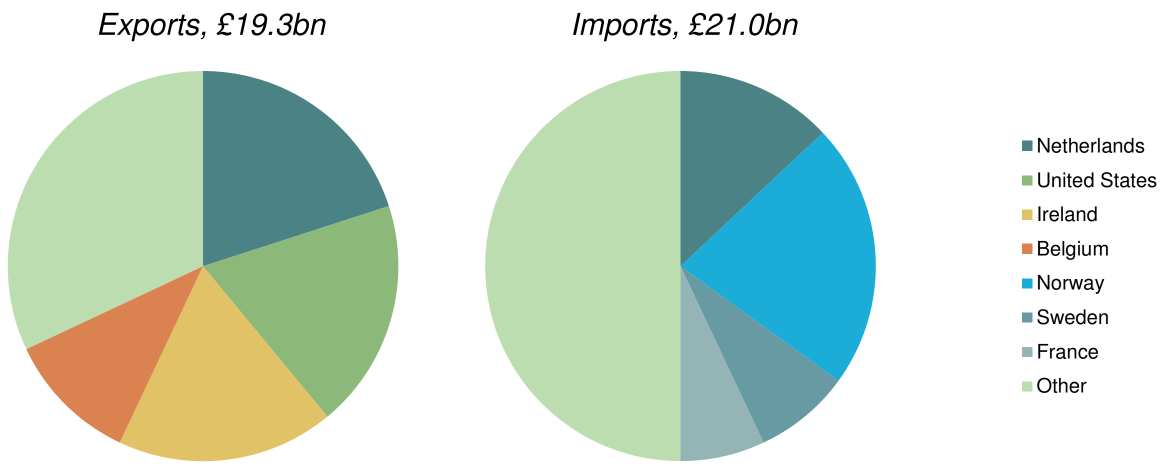
Numerous European oil refineries have closed in the last 25 years, with 15 refineries shut-down between 2008 and 2013 (IEA, 2013). Historically, there was a progressive increase of EU crude oil processing capacity since the 1990s, mainly by 'capacity creep', debottlenecking, improvements in equipment reliability and longer cycles between turnarounds, to cope with a one to two per cent increase in product demand per year in Europe. However, since 2005, there has been a stabilisation and even a slight decrease in the overall European demand (IEA, 2013). The EU in 2012 accounted for about 16 per cent of global refining capacity, with an average capacity utilisation of approximately 80 per cent (BP, 2013). Global average refinery utilization in 2012 was approximately 82 per cent (BP, 2013).

10.2.2 Trade patterns

Approximately 62 per cent of oil products processed at UK refineries are consumed within the UK. Refined products are highly traded, with high imports and exports to and from the UK. For example, usage of air transport has dramatically increased over the last 50 years, driving demand for jet fuel upwards to a point where jet fuel imports are now at parity with domestic supply in the UK, and are sourced mainly from outside the EU (IEA, 2013). The UK is a net exporter of petrol, gas oil and fuel oil (UKPIA, 2013a); though note that, for instance, UK production of diesel is only sufficient to meet 73 per cent of domestic demand.

The UK has been a net exporter of petroleum products in volumes over the last decade. In 2012, the volume of exports of petroleum products decreased by three per cent. In that year, the UK was a net importer of petroleum products by value due to the relatively high cost of jet fuel compared to gasoline (Figure 25). Most of the UK's trade partners are situated within the EU, however the UK also exported gasoline to the US.

Figure 25. **Most UK trade flows in refined products are intra-EU**



Source: European Commission, 2013b, *Vivid Economics*

10.2.3 Employment and GVA

The oil refining sector employs approximately 8,500 people (UKPIA, 2013b) and has a GVA of 2,159 million GBP in 2007 (ONS, 2012a).

10.2.4 Profitability

Refining margins are volatile, driven by fluctuations in capacity utilisation and product demand. As a result the refining sector is subject to cyclical trends. BP has a Refining Marker Margin Basis that offers an international comparison of the margins in the different refining hubs. European and Asian refinery margins have been significantly lower than those achieved in the USA in recent years (UKPIA, 2013b). Refinery margins declined sharply during the recent recession. The average north west Europe cracking refining margins dropped to $zero/bbl and the hydroskimming margins fell to $-2.2/bbl (UKPIA, 2013a). Average margins in the petroleum refining sector in the UK during the period were estimated to be around 0.6 per cent (IBISWorld, 2013e). Since 2011, margins have recovered somewhat, although the hydroskimming margins remain negative (UKPIA, 2013a). Estimates of gross margins for UK petroleum producers were approximately 1.6 per cent in 2012 (IBISWorld, 2013e). The margins used in the modelling were three per cent to represent an average over a longer period.

10.2.5 Prices and elasticity

The real price of refined products increased rapidly between 2009 and 2012. This reflects the rising price of crude oil and demand growth in emerging economies. Wholesale ex-refinery product prices tracked trends in crude prices closely throughout 2012 (UKPIA, 2013a). The price used in the model is £715/tonne (ONS, 2013a).

A survey of evidence on the demand elasticity of gasoline, for instance, found that short-run elasticities were typically estimated to be in the region of -0.3 (Graham & Glaister, 2002). In the long-run, consumers have a variety of means of responding to increased prices. Increased fuel efficiency in transport and in home heating, for instance, tend to arise over the course of long-run price increases. As a result, demand is significantly more elastic in the long-run, with estimates typically falling between -0.6 and -0.8 (Graham & Glaister, 2002). The value used in modelling was of -0.7.

10.3 Model

10.3.1 Modelling refining

Following the approach of the European Commission, the market for petroleum products was treated at the EU level. EU producers account for approximately 80 per cent of the EU market; this varies across the scenarios due to the comparative growth rates of EU production and non-EU production. A summary of model inputs can be found in Table 24.

Specific emissions for each refinery in the EU are available from CITL. The average emissions intensity of EU production is equal to 0.21 tCO_2 per tonne of product, compared to that of the non-EU wide average at 0.29 tCO_2 per tonne of product.

See ‘Sector Notes’ for a discussion of complexities in the treatment of refineries sector emissions that are not considered in this analysis.

Table 24. **Refining inputs to modelling**

Variable	Value	Notes	Source
Initial market price	£715/t		ONS (2012)
Demand elasticity	-0.7		Graham & Glaister (2002)
UK production	68,690,000 t	(for calendar year 2012)	UKPIA (2013c)
EU production	642,000,000 t	(for calendar year 2012)	European Commission, (2013); Europia (2011)
UK emissions intensities	0.21 tCO_2e/t	Assumptions: that all refineries have the same electro-intensity as the UK average; indirect emissions equal the product of electro-intensity and emissions intensity of electricity generation; non-EU refineries are more emissions intensive than EU refineries and equal to 67 centile of EU refineries	Direct emissions (EU refineries): European Commission(2013b); Electro-intensity of UK refineries: DECC, (2011); Emissions intensity of electricity generation: IEA (2012)
EU emissions intensities	0.21 tCO_2e/t		IEA (2007)
Non-EU emissions intensities	0.29 tCO_2e/t		IEA (2007)
Gross UK profit margins	3%		IBISWorld (2013)

Source: *Vivid Economics*

10.3.2 Impact of carbon price rises on UK and EU output

The refineries sector has strong intra-EU competition and moderately high exposure to non-EU firms. EU firms pass on approximately 65 per cent of carbon costs to consumers.

The effect of carbon prices on UK and EU output is muted by the relatively low fraction of retail prices accounted for by carbon price rises. UK producers, representing a small fraction of the EU market, are on average slightly less resilient to large carbon price rises, contracting output by more than the EU average. In the 2020 core scenario, a carbon price rise of 5 Euros/tCO_2 induces domestic output to contract by 2 per cent, roughly equal to the proportionate contraction in the EU market. A carbon price rise of 50 Euros/tCO_2 induces a UK output contraction of 19 per cent, compared to a 17 per cent reduction for the EU average.

10.3.3 Output and carbon leakage

Output leakage, the ratio between output gains in unregulated regions to output losses in regulated regions, is determined by the strength of competition, the impact of carbon prices on margins, and demand sensitivity to product price.

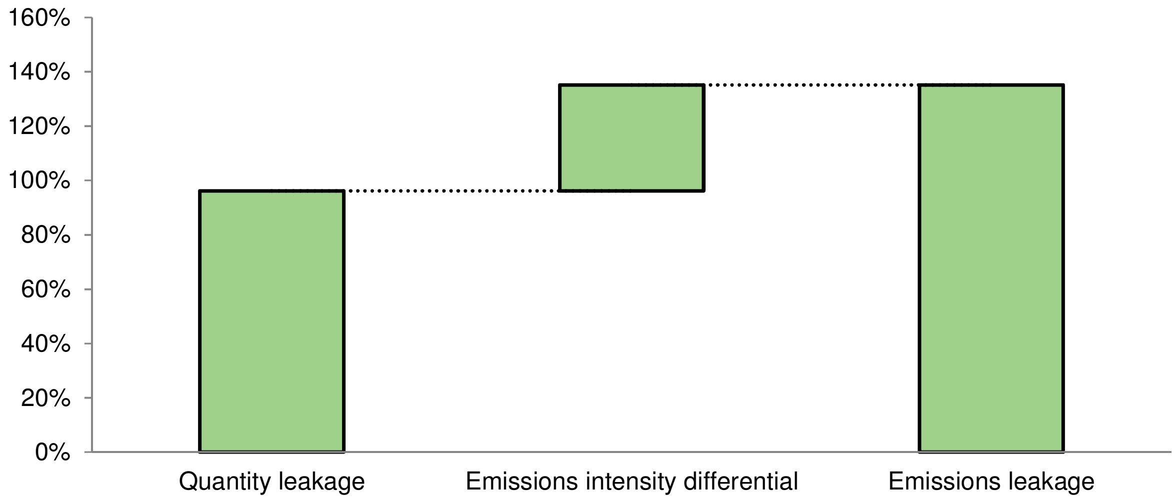
In the case of refining, competitiveness and demand sensitivity is high, but carbon price rises constitute a small fraction of product price. The former two effects dominate, leading to an output leakage rate of about 96 per cent, that is, every 100 units of output lost in the EU are replaced by 96 units outside it.

Carbon leakage increases with both output leakage and the emissions intensity differential between regulated and unregulated firms. In the case of the refining sector, since the EU is on average less emissions-intensive than non-EU firms, carbon leakage exceeds output leakage and is about 135 per cent. That is, every 100 units of CO_2 emissions reduced in the EU are replaced by 135 units outside it. Thus, incomplete environmental regulation is associated with a net increase in global emissions from the refining sector.

10.3.4 Sector notes

The emissions factor figure used in this analysis is not adjusted for considerations of refinery technology or the interaction between crude throughput and other inputs in the refinery process. A technique employed by studies tailored to the refineries sector is that of the Complexity Weighted Tonne (CWT) (Ecofys, 2009i). The results here use CITL emissions figures, however, if the relative ranking of emissions intensities between the UK, EU and non-EU refineries is retained, the broad thrust of the results would be the same when using CWT figures.

Figure 26. **Carbon leakage compounds output leakage owing to the differential in emissions intensities between EU and non-EU refineries**



Note: *This graph shows the leakage decomposition for a €30/tCO_2 carbon price in the year 2020.*

Source: *Vivid Economics*

Table 25. **Refineries are relatively moderately impacted by carbon pricing**

Counter-factual	Price of carbon (€/tCO₂)	Cost shock as a fraction of price (%)	UK production (t)	EU production (t)	EU market share	UK profits (€)	UK emissions (tCO₂)	EU emissions (tCO₂)	Non-EU emissions (tCO₂)
2012	0		69,000,000	642,000,000	83%	1,116,000,000	19,000,000	163,000,000	38,000,000
2020	0		71,000,000	664,000,000	82%	1,155,000,000	19,000,000	169,000,000	44,000,000
2030	0		75,000,000	703,000,000	80%	1,221,000,000	20,000,000	178,000,000	51,000,000

Year	Change in price of carbon (€)	Cost shock as a fraction of price (%)	Change in UK production	Change in EU production	Change in EU and UK market share	Change in UK profits	Change in UK emissions	Change in EU emissions	Change in non-EU emissions	Output leakage rate	Carbon leakage rate	Cost pass-through rate	Change in price
2012	5	0.1%	-2%	-2%	-2%	-4%	-2%	-2%	11%	96%	135%	65%	0.1%
2012	15	0.4%	-6%	-5%	-4%	-9%	-6%	-5%	30%	96%	135%	65%	0.3%
2012	30	1%	-12%	-10%	-9%	-17%	-12%	-10%	57%	96%	135%	64%	0.5%
2020	5	0.1%	-2%	-2%	-2%	-4%	-2%	-2%	10%	96%	135%	65%	0.1%
2020	15	0.5%	-6%	-5%	-4%	-9%	-6%	-5%	26%	96%	135%	65%	0.2%
2020	30	1%	-12%	-10%	-8%	-17%	-12%	-10%	51%	96%	135%	64%	0.5%
2020	50	1.2%	-19%	-17%	-14%	-28%	-19%	-17%	82%	96%	135%	64%	1%
2030	5	0.1%	-2%	-2%	-2%	-4%	-2%	-2%	9%	96%	135%	65%	0.1%
2030	15	0.4%	-6%	-5%	-4%	-9%	-6%	-5%	23%	96%	135%	65%	0.2%
2030	30	1%	-12%	-10%	-8%	-17%	-12%	-10%	45%	96%	135%	64%	0.5%
2030	50	1.2%	-19%	-17%	-14%	-28%	-19%	-17%	73%	96%	135%	64%	1%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%. There is an absence of accurate, complete public information on variation in emissions intensity within the fleet. Adjustment of public data is not feasible as refineries have complex patterns of hydrogen and power flows. As a consequence, the homogenous data is the most reliable set to use, but the consequence is that the results behave similarly to the RIMM model: the rates calculated are invariant with the carbon price.*

Source: *Vivid Economics*

11 Steel

11.1 Characteristics of production

11.1.1 Production process

Liquid steel is cast into semi-finished product, and then rolled into flat or long steel products. Long steel refers to long products that can be used in construction, engineering, heavy machinery, rail track and other similar applications. Flat steel refers to sheets and plates of steel that can used for cladding, decking, shipbuilding, tubemaking, white goods, car bodies, containers and so on.

Basic Oxygen Furnance (BOF) steel is made in several stages:

- coke is produced from coal. Iron ore may be prepared in the form of pellets.
- the coke, iron ore and limestone are combined and ‘cooked’ to produce sinter.
- sinter and coke are charged in a blast furnace, where further carbon may be added, to produce liquid iron and slag.
- the liquid iron is transported to the basic oxygen furnace for conversion to liquid steel.
- this liquid steel may undergo further processing, known generically as secondary steelmaking.
- liquid steel is finally continuously cast into semi-finished steel in the form of blooms, billets and slabs.

Electric Arc Furnace (EAF) in the UK uses mainly scrap metal, although iron may also be used for higher grades, and consists of two or more stages:

- The first stage charges the scrap and/or iron in the furnace. Electrodes are lowered onto the charge, and an electric arc is created; simultaneously, oxygen is blown into the scrap to speed scrap meltdown and a foaming slag is formed to increase energy efficiency and arc stability.
- melted steel is tapped out into a ladle, where it may undergo secondary steelmaking, and cast into a variety of products: ingots for forging or other specialist applications: blooms, billets and slabs, and castings.

Blooms, billets and slabs are then rolled into finished steel products. In the case of Outokumpu’s EAF plant in Sheffield and SSI’s BOF plant on Teesside this subsequent rolling does not take place on site. These two plants produce only semi-finished products which are both shipped to other mills within their respective groups and sold externally. This production is not included in the modelling which, as noted, focuses on long and flat products.

11.1.2 Emissions- and electro-intensity of production

The majority of emissions stem from the iron and steelmaking processes (Ecofys, 2009j). In BOF production, direct carbon emissions result from coke making, sinter and from the coke and other carbon input for the blast furnace. In EAF production, direct carbon emissions result from fuel use and from the carbon emitted through the oxidisation of the electrodes and scrap. Indirect emissions from electricity consumed, based on the UK’s average power generation emissions factor, are significantly greater than direct emissions. Downstream emissions, from processes such as foundry casting, hot rolling, cold rolling, surface treatment (tinning and galvanizing) and further processing, can add significantly to the emissions total. Indeed, in the case of EAF production, as direct emissions are relatively low, downstream processes can make up more than 50 per cent of total emissions.

Steel production in the UK is emissions-intensive compared to that in the EU, but less emissions-intensive than outside the EU. BOF production is more emissions-intensive than EAF production, and flat steel, with its higher proportion of BOF use in the UK, is more emissions-intensive on average than long steel. Flat steel production in the UK has an emissions intensity of 1.8 tCO_2e/t, compared to 1.7 tCO_2e/t in the EU, and long steel production has an emissions intensity of 1.2 tCO_2e/t in the UK, compared to 1 tCO_2e/t in the EU.

There have been gradual improvements in the energy efficiency of steel making over time. The average energy per tonne of steel in the UK has fallen from 31.7 GJ per tonne in 1973 to 18.8 GJ per tonne in 2011 (UK Steel Association, 2013a). Most of this progress took place between 1973 and 1995. The CO_2 intensity of the EAF route is today around 70 to 90 per cent below the CO_2 intensity of the BOF route (IEA, 2007).

In the future, increased scrap availability together with continued de-carbonisation of the power sector and implementation of other technologies are expected to lead to a reduction in emissions intensity globally However, availability of scrap is unlikely to be of assistance to UK industry; current scrap availability already exceeds steel industry needs, and the bulk of UK scrap is exported. According to a sector association, an economically feasible reduction in BOF emissions intensity in the EU is 10 per cent in 2030 and 15 per cent in 2050 compared to 2010 levels (Eurofer, 2012).

The integrated steel production process must use carbon as a chemical reductant in the blast furnace Although coke is the normal reductant, alternative sources of carbon can be used such as oil, pulverised coal and biomass to improve operational efficiency or reduce emissions. Where natural gas is relatively cheap, it may also be used as an alternative reductant, for example through the direct reduction process. This process is operated in the US and some Middle Eastern countries but is not a realistic option for the western EU (and it should be noted that even in the US the blast furnace is still the predominant iron making technology).

Due to the scale of the blast furnace operations, steel is a candidate for carbon capture and storage. A sector association estimates that CCS, in combination with other measures, could lead to a 60 per cent decrease in CO_2 intensity by 2050 compared to 2010 (Eurofer, 2012).

11.2 Sector composition and features

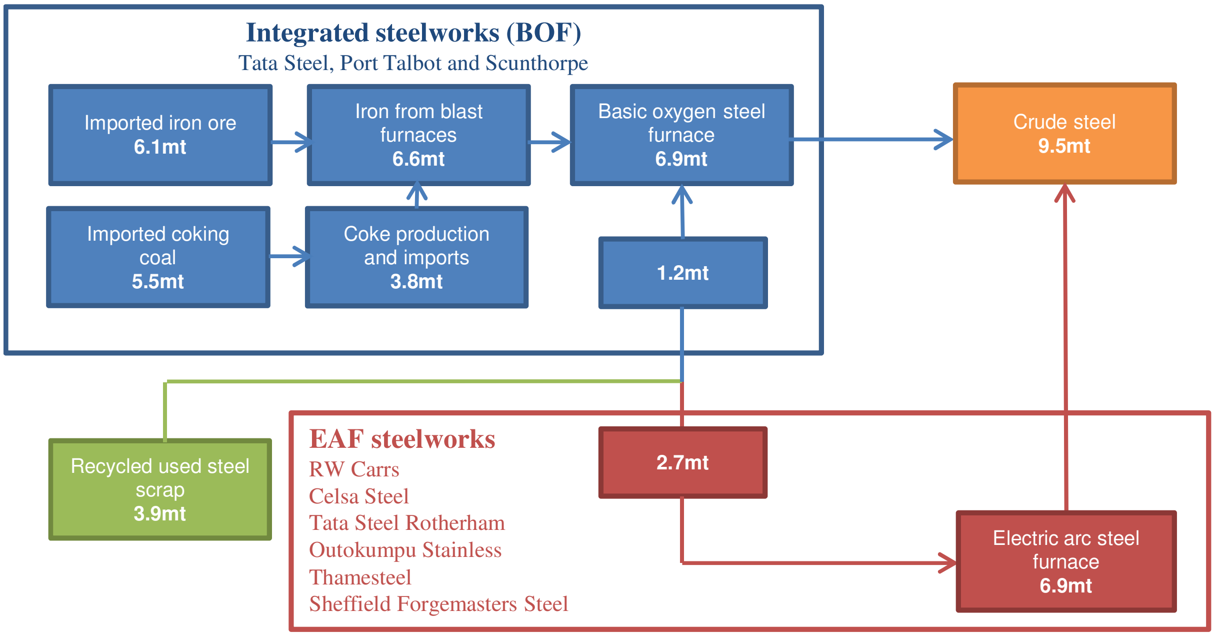
11.2.1 Market composition

In 2011, UK crude steel production totalled 9.5 million tonnes, with 73 per cent taking place in integrated plants using BOF. The integrated steel mills have capacities above 3 million tonnes of crude steel per year. EAF production largely takes place in smaller units, with capacities of up to 1 million tonnes of crude steel per year. There are three integrated steel works and four operational EAF plants in the UK, with ownership split between five companies. Due to the large degree of product differentiation within the sectors, there is not much direct competition between facilities.

UK production has been in decline for 40 years, though there has been some recent investment in the sector. Having been mothballed in 2010, the Teesside integrated steel works was bought by Sahaviriya Steel

Industries and reopened in 2012. Tata Steel has also announced a major investment package(BBC News Wales, 2012)(BBC News Wales, 2012). Globally, in 2012, average plant utilisation was 78 per cent (UK Steel Association, 2012). The mix of BOF and EAF production in the UK can be seen in Figure 27.

Figure 27. **Integrated steelworks and EAF plant in the UK produced 9.5mt of crude steel in 2011**



Integrated steelworks (BOF)
Tata Steel, Port Talbot and Scunthorpe

- Imported iron ore **6.1mt**
- Iron from blast furnaces **6.6mt**
- Basic oxygen steel furnace **6.9mt**
- Imported coking coal **5.5mt**
- Coke production and imports **3.8mt**
- **1.2mt**

Crude steel **9.5mt**

Recycled used steel scrap **3.9mt**

EAF steelworks
RW Carrs
Celsa Steel
Tata Steel Rotherham
Outokumpu Stainless
Thamesteel
Sheffield Forgemasters Steel

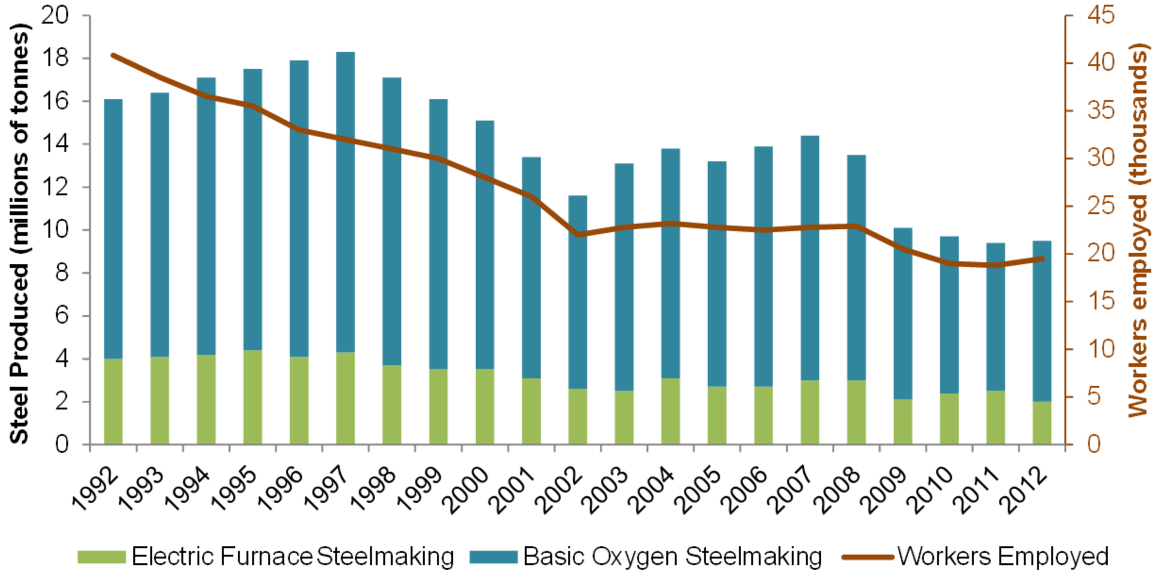
- **2.7mt**
- Electric arc steel furnace **6.9mt**

Source: UK Steel Association (2012), Vivid Economics

11.2.2 Employment and GVA

Production in the UK steel sector has fallen from its peak in 1997 of 18.3 million tonnes (UK Steel Association, 2013b) to 9.5 million tonnes in 2012. In line with the fall in production, the gross value added to the UK has also fallen by around half since 1998 (ONS, 2012b). During this time the number of employees in the steel sector has been declining, with employment now standing at around 20,000 in the UK (ONS, 2012b).

Figure 28. **The UK steel sector has halved its workforce over the past two decades**



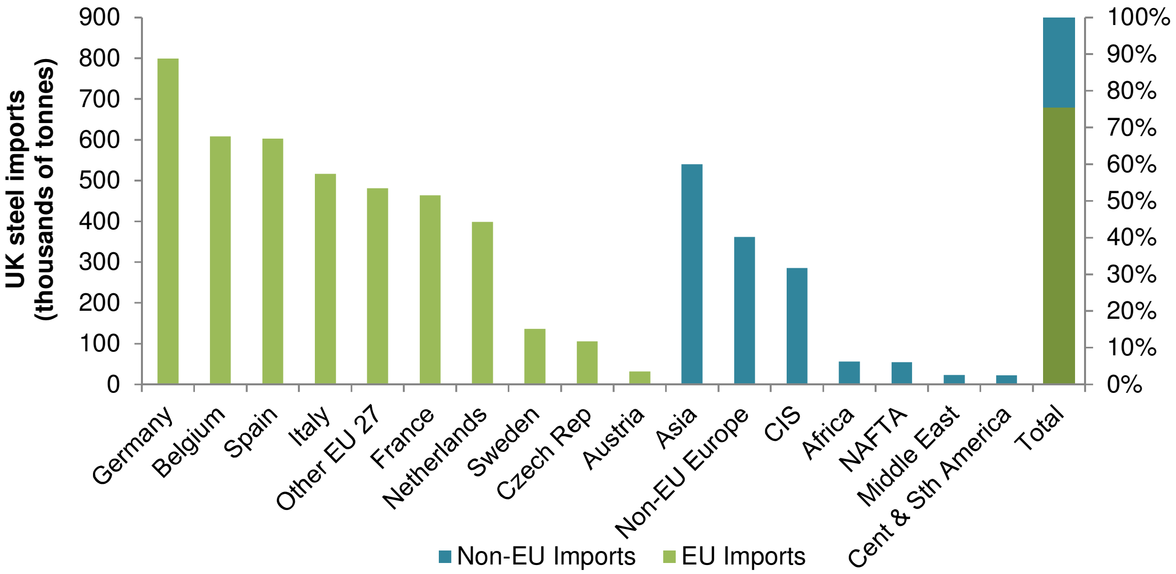
Note: *Employees as engaged on SESC steel sector activities. Variations in aggregated totals due to rounding*

Source: *Based on* (UK Steel Association, 2013b), *Vivid Economics*

11.2.3 Trade patterns

In 2012, the UK imported 5.5 million tonnes of steel (UK Steel Association, 2013b), just over four million tonnes of which was sourced from the EU (UK Steel Association, 2013b). Imports from the EU grew five per cent over 2011 levels whilst imports from outside the EU fell 16 per cent in the same year (UK Steel Association, 2013b). In 2012, 56 per cent of the UK's demand for steel was met by imports from Germany. The major trading partners outside the EU were Russia, Turkey and China. The EU absorbed 53 per cent of UK exports in 2012. However, this figure is down from the 72 per cent in the previous year. In contrast, exports to Asia rose 340 per cent to 1.6 million tonnes (ISSB, 2013). It should be noted, however, that the current analysis does not take into account semi-finished steel, or recent openings and expansion of export-heavy installations (British Steel, 2013). This figure, therefore, reflects what may be the lower edge of the envelope of trade exposure in this sector.

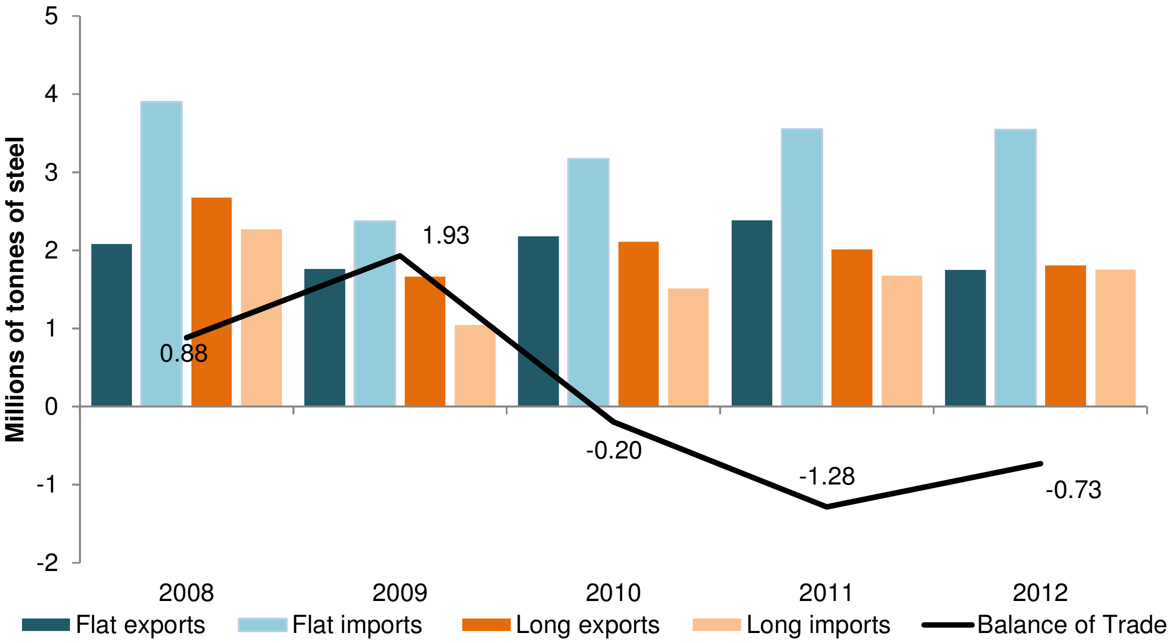
Figure 29. **In 2012 the EU supplied the majority of UK steel imports**



Source: (UK Steel Association, 2013b), *Vivid Economics*

The UK was a net exporter of crude steel over the period 2007-2009. With the Teesside plant mothballed in 2010, the UK became a net importer of steel products. The plant was reopened in 2012 which helped close the trade imbalance. However, throughout this period, the UK was consistently a net importer of flat steel and a net exporter of long steel, see Figure 30.

Figure 30. **The UK is a net importer of flat steel and a net exporter of long steel**



Note: *Included in the balance of trade are semi-finished steel, tubes and other steel products.*

Source: *Vivid Economics,* (ISSB, 2013)

11.2.4 Profitability

Both long steel and flat steel sectors have similar macroeconomic demand drivers. Despite the current downturn, global steel demand and production remain at historically high levels. For the year 2013, the sector association, (UK Steel Association, 2012), forecast Chinese steel demand to grow three per cent and USA steel demand four per cent. EU production was predicted to fall by two per cent (UK Steel Association, 2012). Despite record demand, steel producers are experiencing poor profitability levels because of global over-capacity. Globally, average capacity utilisation fell from its peak in 2006 of 85 percent to 69 per cent in 2009 (UK Steel Association, 2012). The sector has been recovering slowly with global average capacity utilisation now at 78 per cent (UK Steel Association, 2012).

In the UK, demand fell in 2012, down from 10.3 to 9.8 million tonnes of steel products, a reduction of five per cent on 2011 and 31 per cent below the pre-recession peak of 2007 (UK Steel Association, 2012). Some of this can be attributed to the pound strengthening against the Euro in the final quarter of 2011. In 2012, the exchange rates moved again and the EU share of imports into the UK rose from 69 per cent in 2011 to 72 per cent in 2012 (UK Steel Association, 2012).

Chinese demand for raw materials continues to drive up the price of iron ore. The price of contract iron ore rose to peak in 2011 but prices eased during 2012. Although iron ore prices have fallen more than steel product prices in 2012, there is still cost pressure in historical terms. In the period 2005 to 2012 nominal iron ore prices rose 419 per cent. In the same period the price of hot rolled coil fell 30 per cent.

11.2.5 Pricing, elasticity and substitutes

During the period 1987 to 2012 the price of steel in the UK, as measured by the Average UK Steel Price Index, increased less than the Retail Price Index. In July 2012, the price of hot rolled coil in Russia was around $570/t and the price in Brazil was $850/t (EEF, 2012). The price in the EU at the time was just over $600/t (EEF, 2012). World prices differ less in the market for rebar (reinforcing bar), a long steel product. Prices for rebar in all major consuming markets fell throughout 2012.The price in the EU fell from almost $800/t to just around $700/t (EEF, 2012).

Both long steel and flat steel products have quite imperfect substitutes. In the automotive markets, aluminium, in some applications, can be used as a replacement for flat steel. In the construction industry, steel structures compete with steel-reinforced concrete structure, that is, the main competition is between different types of steel product, with varying total steel content.

Over 25 per cent of all finished steel products are not consumed within the country in which they were produced. Transport costs amount to between 5 and 15 per cent of the final selling price (Ecorys, 2008b).

A recent study estimated a price elasticity of demand of approximately -0.3 for both long and flat steel (Zhu, 2012). This is the value used in modelling, consistent with the values used for the other major construction products of heavy clay ceramics and cement.

11.3 Model

11.3.1 Long and flat steel inputs

Table 26 summarises steel sector model inputs. Both long and flat steel were modelled at the EU level.

Impact on steel production

Imports from non-EU firms make up around 15 per cent of the EU market. With profit margins at around 8 per cent, European firms pass on approximately 80 per cent of carbon costs to consumers in the case of long steel, and 89 per cent of carbon costs in the case of flat steel.

Table 26. **Long and flat steel inputs to modelling**

Variable	Value	Notes	Source
Initial market price: long steel	£456/t		MEPS (2013)
Initial market price: flat steel	£473/t		IndexMundi (2013)
Demand elasticity	-0.3		Zhu (2012)
UK production: long steel	4,000,000 t	For calendar year 2012.	British Steel (2013)
UK production: flat steel	3,000,000 t	For calendar year 2012.	British Steel (2013)
EU production: long steel	58,000,000 t	For calendar year 2012.	European Commission, (2013)
EU production: flat steel	135,000,000 t	For calendar year 2012.	European Commission, (2013)
UK emissions intensities: long steel	1.2 tCO_2e/t	IEA (2007) provide average emissions intensities for Electric Arc Furnace (EAF) and Basic Oxygen Furnace (BOF) production, and the fraction of total crude steel production from EAF and BOF processes by country. Vivid takes the average emissions intensity of each country, weighted by the proportion of output accounted for by each technology.	IEA (2007)
EU emissions intensities: long steel	1.06 tCO_2e/t		IEA (2007)
non-EU emissions intensities: long steel	1.25 tCO_2e/t		IEA (2007)
UK emissions intensities: flat steel	1.8 tCO_2e/t		IEA (2007)
EU emissions intensities : flat steel	1.7 tCO_2e/t		IEA (2007)
non-EU emissions intensities: flat steel	2.1 tCO_2e/t		IEA (2007)
Gross UK profit margins	8%		British Steel (2013)

Source: *Vivid Economics*

UK firms are carbon-intensive relative to competitors in the EU and are consequently harder-hit by carbon price rises than the EU average. In the 2030 core scenario, UK long steel output declines by between 8 and 54 per cent as the carbon price rises from €5 to €50/tCO_2. EU long steel, at the same respective prices declines between 4 and 32 per cent, while UK flat steel declines between 5 and 44 per cent, and EU flat steel declines between 5 and 43 per cent.

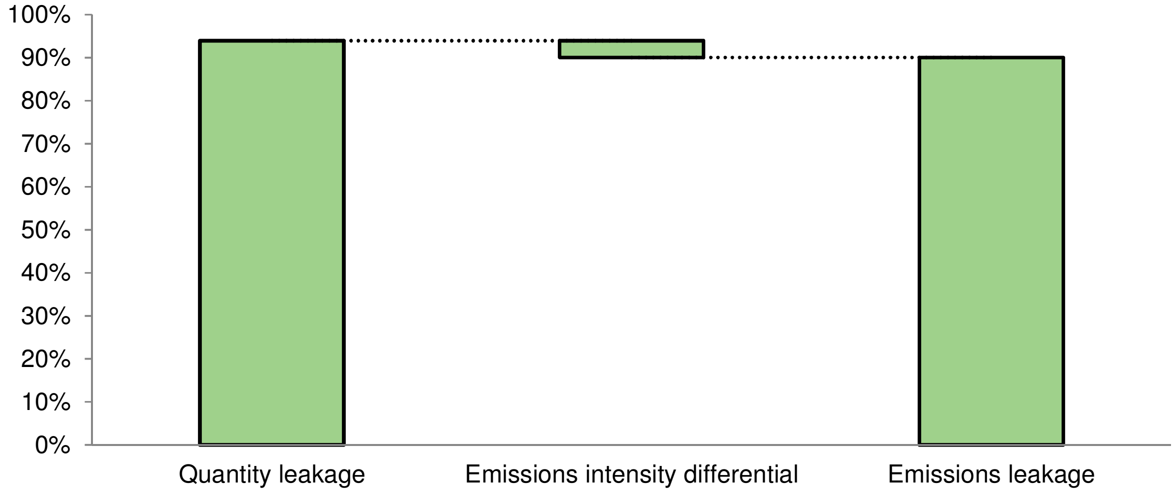
11.3.2 Output and carbon leakage rates

Output leakage is determined by a number of factors, including market structure and the strength of competition in the market, the impact of the cost shock on margins and the sensitivity of product demand to changes in price. In a sector such as steel, with relatively strong competition and a moderate price elasticity of demand, output leakage is expected to be relatively high.

Output leakage in the model is around 92 per cent, suggesting that for every 100 units of output that are lost in the EU, imports into the EU increase by 92 units.

Carbon leakage is determined by output leakage, as well as the differential between emissions intensity in the EU and outside it. Carbon leakage in the model is generally around 86 per cent (in the case of flat steel) and 90 per cent (in the case of long steel), suggesting that for every 100 units of CO_2 emissions that are reduced in the EU, between 86 and 90 units increase outside it (Figure 31 and Figure 32). Carbon leakage is lower than output leakage in this model because, while EU emissions intensities are on average lower than outside the EU, the EU firms that disproportionately reduce output are emissions-intensive compared to not only their EU competitors, but also to the non-EU average.

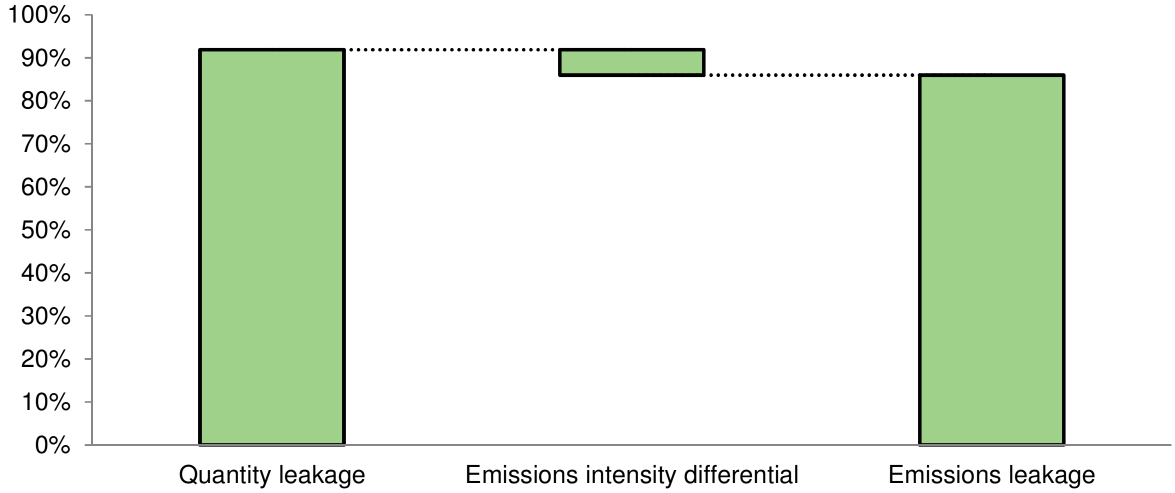
Figure 31. **Long Steel output relocates from less carbon-efficient EU producers to relatively efficient non-EU producers**



Note: *This graph shows the leakage decomposition for a €30/tCO_2 carbon price in the year 2020.*

Source: *Vivid Economics*

Figure 32. **Flat Steel output relocates from less carbon-efficient EU producers to relatively efficient non-EU producers**



Note: *This graph shows the leakage decomposition for a €30/tCO$_2$ carbon price in the year 2020*

Source: *Vivid Economics*

11.3.3 Notes and summary

The model does not take into account the production of semi-finished steel, owing to difficulties in correctly accounting for intra-company transfers. However, two plants in the UK produce only semi-finished steel, and semi-finished steel is observed to be more highly trade exposed than finished steel products (British Steel, 2013). This analysis may thus be understating the trade exposure of the steel sector. Specific trade arrangements for individual installations, particularly, for instance, for installations trading with Thailand, may result in some producers having a greater exposure to carbon pricing than described here.

Table 27. **UK long steel producers reduce their production more than EU producers**

Counter-factual	Price of carbon (€/tCO₂)		UK production (t)	EU production (t)	UK and EU producers' market share	UK profits (€)	UK emissions (tCO₂)	EU emissions (tCO₂)	Non-EU emissions (tCO₂)
2012	0		4,000,000	58,000,000	83%	117,000,	4,900,000	62,000,000	15,000,000
2020	0		3,600,000	54,000,000	77%	108,000,	4,500,000	57,000,000	20,000,000
2030	0		3,500,000	52,000,000	71%	104,000,	4,400,000	55,000,000	27,000,000

Year	Carbon price (€/tCO₂)	Cost shock as a fraction of price (%)	Change in UK production	Change in EU production	EU and UK change in market share	Change in UK profits	Change in UK emissions	Change in EU emissions	Change in non-EU emissions	Output leakage rate from the EU	Carbon leakage rate from the EU	Cost pass-through rate	Change in price
2012	5	1%	-8%	-5%	-4%	-10%	-8%	-6%	28%	83%	89%	78%	1%
2012	15	3%	-19%	-14%	-11%	-27%	-19%	-15%	78%	94%	90%	77%	2%
2012	30	6%	-36%	-27%	-23%	-48%	-36%	-30%	152%	94%	90%	78%	4%
2020	5	1%	-8%	-5%	-4%	-11%	-8%	-6%	18%	94%	90%	76%	1%
2020	15	3%	-29%	-14%	-11%	-27%	-19%	-16%	50%	94%	90%	76%	2%
2020	30	6%	-36%	-27%	-21%	-48%	-36%	-30%	97%	94%	90%	77%	4%
2020	50	10%	-53%	-45%	-35%	-70%	-53%	-50%	158%	94%	90%	81%	7%
2030	5	1%	-8%	-5%	-4%	-11%	-8%	-6%	13%	93%	89%	75%	1%
2030	15	3%	-19%	-14%	-10%	-28%	-19%	-16%	35%	94%	90%	76%	2%
2030	30	6%	-36%	-27%	-20%	-48%	-36%	-31%	68%	94%	90%	77%	4%
2030	50	10%	-54%	-45%	-32%	-70%	-54%	-50%	110%	94%	90%	80%	7%

Table 28. **EU flat steel producers reduce their production less than UK producers**

Counter-factual	Price of carbon (€/tCO$_2$)	Cost shock as a fraction of price (%)	UK production (t)	EU production (t)	UK and EU producers' market share	UK profits (€)	UK emissions (tCO$_2$)	EU emissions (tCO$_2$)	Non-EU emissions (tCO$_2$)
2012	0		3,000,000	135,000,000	89%	93,000,000	4,500,000	200,000,000	30,000,000
2020	0		2,800,000	125,000,000	85%	86,000,000	4,100,000	184,000,000	40,000,000
2030	0		2,700,000	121,000,000	80%	83,000,000	4,000,000	178,000,000	54,000,000

Year	Carbon price (€/tCO$_2$)	Cost shock as a fraction of price (%)	Change in UK production	Change in EU production	EU and UK change in market share	Change in UK profits	Change in UK emissions	Change in EU emissions	Change in non-EU emissions (tCO$_2$e)	Output leakage rate from the EU	Carbon leakage rate from the EU	Cost pass-through rate	Change in price
2012	5	2%	-4%	-4%	-4%	-6%	-4%	-5%	48%	91%	84%	84%	1%
2012	15	3%	-13%	13%	-11%	-18%	-13%	-16%	140%	92%	86%	83%	3%
2012	30	8%	-27%	-26%	-23%	-34%	-27%	-31%	278%	92%	86%	85%	7%
2020	5	2%	-5%	-5%	-4%	-7%	-5%	-6%	31%	91%	85%	82%	1%
2020	15	4%	-13%	-13%	-11%	-18%	-13%	-16%	86%	92%	86%	82%	3%
2020	30	8%	-27%	-26%	-22%	-34%	-27%	-31%	168%	92%	86%	84%	6%
2020	50	13%	-43%	-43%	-37%	-53%	-43%	-50%	275%	92%	87%	89%	11%
2030	5	2%	-5%	-5%	-4%	-7%	-5%	-6%	22%	91%	85%	81%	1%
2030	15	4%	-14%	-14%	-11%	-19%	-14%	-16%	59%	91%	86%	82%	3%
2030	30	8%	-27%	-26%	-21%	-35%	-27%	-31%	115%	92%	86%	84%	6%
2030	50	13%	-44%	-43%	-35%	-53%	-44%	-50%	187%	92%	87%	89%	10%

Notes: *Changes in market share are expressed in percentage points; that is, a -1% change represents a movement from a market share of 50% to 49%.*

Source: *Vivid Economics*

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