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CUMULATIVE IMPACTS OF ENERGY AND CLIMATE CHANGE POLICIES ON CARBON LEAKAGE

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Cumulative Impacts of Energy and Climate Change Policies on Carbon Leakage

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The Views expressed within this report are those of the authors and should not be treated as Government policy

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Executive Summary

Background

As part of a wider piece of work on the impacts of energy and climate change policies on UK competitiveness, AEA, in partnership with CE Delft, were commissioned by the Department for Business, Innovation and Skills (BIS) to investigate the cumulative impacts of such policies on carbon leakage. Based on a review of the primary literature, the main objective of the study was to shed light on the headline question ‘what is the cumulative impact of energy and climate change policies on carbon leakage?’

Carbon leakage occurs when there is an increase in carbon dioxide emissions in a country without a binding emissions target as a result of an emissions reduction by a second country with a strict climate policy that limits emissions. This is a concern for the environment as it will undermine the effectiveness of climate change policy. It is also a concern for competitiveness as it will result in a reduction in domestic production.

Whilst there are a large number of studies that have examined the incidence and scale of carbon leakage, the wide range, and sometime conflicting, findings makes it difficult for policy makers to have a clear understanding of the issues. Drawing together the results from previous research, this study aims to provide some further clarity. A wide range of studies have been reviewed as part of the analysis. These include the results from empirical work, as well as outputs from modelling studies. The evidence base captures a range of energy intensive industries including aluminium, cement and clinker, steel, ceramics and lime and gypsum. Where possible, the results from the previous work have been used to draw conclusions relevant to the situation in the United Kingdom. However, since most of the existing studies have a different scope, consider the impacts at a company, sector or EU level, the conclusions are in some cases more broad.

Main findings

Various economic hypotheses and modelling approaches have been used to assess carbon leakage, which can lead to some conflicting results.

In the empirical research three different hypotheses (Pollution Haven Hypothesis, Factor Endowment Hypothesis and Porter Hypothesis) have been used to analyse carbon leakage. The pollution haven hypothesis suggests that countries without environmental regulations attract investment from energy intensive industries and through economies of scale obtain a competitive advantage in production. On the other hand the factor endowment hypothesis states that capital abundant countries will further specialise in capital (and pollution intensive) industries because of economies of scale. Environmental policy makes industry in the end more capital intensive by increasing abatement costs. While the Porter Hypothesis asserts that environmental policy, if rightly implemented, will induce cost savings in industry that make these industries more competitive.

Independently the findings from all three hypotheses are relevant but taken together the findings can partly contradict each other (see section 3.4). Some studies found a positive effect of environmental regulation on productivity of businesses, which supports the Porter hypothesis. Some studies found no (or marginal) impacts on trade whereas others found exports being significantly affected. However, when these three hypotheses are combined in ex-post empirical work they tend to show that the Pollution Haven Hypothesis is slightly stronger than the other two hypotheses, resulting in a net decrease in GDP, at least for the Energy Intensive Sectors considered by the modelling.

Some of the differences in results can also be explained by the modelling approach that is used, although assessing the robustness of the results is not straightforward as it is not always clear what assumptions have been adopted.

Within the models, the estimates of the impact of energy and climate change policies on carbon leakage are driven by a few key assumptions.

The most important assumptions that determine the level of carbon leakage are the:

1. **Cost of meeting the environmental targets**, as a function of both the CO_2 reduction target and the marginal abatement cost curves of the technologies or measures;

2. **Elasticity of substitution for energy**, indicating both the substitution between various energy sources (gas, coal and renewable) and the substitution between energy and other factors of production (labour, capital)

3. **Trade elasticities**, the extent to which goods produced in the EU can be substituted for goods produced in non-EU countries;

4. **Ability to pass the cost of regulatory compliance to consumers**; and

5. **Extent to which other economies have similar carbon and energy policies in place** - most models assume that the rest of the world has no environmental regulations in place which is not necessarily true in many non-EU/UK countries.

The relative importance and sensitivity of these assumptions to the findings are not adequately discussed in the literature. As a result it is not straightforward to determine the robustness of individual studies without an in-depth analysis of the chosen parameters and assumptions used.

Carbon leakage occurs due to a shift in production due to the relative difference in the price of energy between EU/UK and non-EU/UK countries. The leakage rate is defined as the change in emissions in the rest of the world as a percentage of domestic emission reductions (Böhringer, 2010). There are a number of assumptions which leads to wide variation in leakage rates:

- **The stringency of the climate policy causing carbon leakage (e.g. emission reduction target)** – the findings show that relatively lenient climate policy can lead to lower levels of carbon leakage.

- **The carbon price assumed -** while the carbon price is an influential variable, the responsiveness of carbon leakage to a change in the carbon price ranges from 0.7% to 2% for a €1 increase in the price of carbon. On the other hand comparing the carbon price and leakage rates for the cement sector in Demailly & Quirion (2006) and Carbon Trust (2010) shows that leakage rate can increase by 5% for every €1 increase in carbon price. It is hard to draw a conclusion on which factor has a stronger influence, but the evidence provided shows the effects of changing the carbon price is not the biggest factor for leakage.

- **Assumptions on allocation -** Five studies include free allocation in their assessment of the EU ETS. In these studies, carbon leakage estimates range from 0.5% to 50%, with an average of 18% (Demailly and Quirion, 2006, 2008 and Reinaud, 2008). Quantitative information and background assumptions on the impact of free allocation as a method for preventing carbon leakage are sparse in the literature. DECC (2010) however use export volumes as an indicator of the effects on carbon leakage. They find that the distribution of free allowances only impacts on demand through the reduction of direct costs and not indirect costs. As a result, sectors which have a large direct-to- indirect cost ratio (such as ceramics and lime) are affected most by the allocation of free allowances. By contrast, Manufacture of Basic Metals and Steel and of Ferro Alloys are only partly protected by the use of free allocations because it faces a significant indirect cost and because of the level of trade and product homogeneity (DECC, 2010).

- **Assumption regarding climate policies in non-EU/UK regions -** the studies covered in detail all assume that the climate policy region is completely unilateral in its approach, whilst conceding that this is not realistic and that climate policy elsewhere would reduce the leakage rates. Different regional coverage of the climate policy can have its own effects on leakage rates. The magnitude and the nature of leakage can change with the size of the coalition. The wider the country coverage, the smaller the market share losses affecting energy-intensive industries in participating countries, but the larger the impact of policy action on international fossil fuel prices (OECD, 2008). The fact that carbon leakage may become very small in a large coalition does not imply that output effects for energy-intensive industries in domestic and international markets are negligible.

The leakage rate in the literature varies widely for Annex 1 countries and the EU.

Few studies have provided a reliable quantitative estimate of the level of carbon leakage. Some studies provide an economy or EU wide estimate of the effects on carbon leakage of a particular policy (e.g. the EU ETS, Kyoto Protocol) while others provided estimates of a bundle of policies to specific industry sectors. Of the studies that have quantified the level of carbon leakage, some of the main findings were:

- Sijm (2004) analysed the effect the Kyoto Protocol on Annex I countries and found that without emissions trading schemes, carbon leakage could vary between 5-21% with a mean of 13% from eight different estimates.

- Cement and Clinker and Iron and Steel are the most reported and highest at risk sectors, with estimates up to 70% and 26% respectively (Kuik, 2010; Reinaud, 2008).

- Carbon leakage could be as high as 41% if non-EU suppliers gain a competitive advantage over EU suppliers leading to more carbon intensive production outside the EU. The chemicals and iron and steel sectors make the highest contributions (20% and 16% respectively) to total global leakage under the same modelling assumptions (IPCC, 2007).

- Energy intensive industries based in coastal areas tend to be more at risk than inland industries. This is because of the increased distribution requirements that imported goods would face, which effectively protect local industries with established networks (Boston Consulting Group, 2010)[1].

- By incorporating all greenhouse gases rather than just CO_2, the OECD found that the EU ETS could open up more cost effective abatement opportunities and thus reduce carbon leakage (OECD, 2008).

The main carbon leakage related economic impacts reviewed in the literature have focussed on employment, GDP and trade effects.

Detailed estimates on job leakage and net impact on jobs due to unilateral climate policies are generally lacking. In the UK, a report by Climate Strategies (2009a) shows that less than 0.5% of jobs are in the sectors deemed most at risk to carbon leakage. In addition, EU studies state that ambitious climate policies can create additional jobs due to the shift of jobs from energy intensive sectors towards sectors producing clean technologies (PIK and Oxford University, 2011).

GDP impacts are typically low and sensitive to assumptions on trade elasticities, cost pass-through ability and private capital and government investment. Overall economy wide impacts tend to be under 2% of GDP, but some studies predict an increase (Böhringer, 2009b; European Parliament, 2008) and some a decrease (PIK and Oxford University, 2011). Only a few sectors, accounting for up to 1-2% of EU GDP, would ‘face significant cost increases’ through a higher carbon price. In the UK, only 1% of all economic activities face significant cost increases relative to their value added and in Germany less than 2% of all economic activities are affected (European Parliament, 2008).

Trade is often used as an indicator for carbon leakage. The evidence on the impact of trade due to carbon leakage is more substantial than for the other impact areas. Studies indicate that under the EU ETS, European manufacturing firms can lose market share in the EU market and in export markets. This is a result of demand being largely unaffected by the EU ETS, and consumption switching to cheaper supply alternatives from regions without climate policy pressures. Overall EU export demand is predicted to fall by 9.1% and demand for imports could rise by 8.1% (Jaeger, 2008) as a result of unilateral

[1] This study is focussed on cement only and so the conclusions would apply mostly to bulky goods.

climate policy. The sectors most at risk are cement, chemicals, iron and steel and aluminium (IPCC, 2007). Cement sector imports can increase by 4%, steel imports can increase by 9% and domestic supply decreases by 1.6% and 2% for mineral products and steel respectively (Kuik, 2010)[2].

A number of policy options to mitigate the extent of carbon leakage have been proposed, although most are untested.

The success of these mitigation measures will depend on a number of variables (e.g. market power, cost pass through ability, allowance price) the importance of which is not explicitly considered in most studies[3]. The main options proposed are:

- **Free allocation of allowance (under the EU ETS) is a favourable policy option where companies are not able to pass through costs.** Several studies have argued that the free allocation of allowances is the most effective way to reduce carbon leakage (European Commission, 2010a; Reinaud, 2009; DECC, 2010; European Commission, 2008; CE Delft, 2009). The main argument is that a free allocation of allowances will lessen the cost burden associated with the EU ETS on energy intensive industries and reduce carbon leakage as a result. These reports estimate that the leakage rate ranges from 0.5% to 50% with free allocation, with an average of 18%.

- **Sectoral agreements are the preferred policy option for energy intensive sectors.** Sectoral agreements create a global sector-wide agreement between all emitters in a particular industry, including those in countries that do not have an economy-wide emission target. This is a very interesting possibility for energy intensive sectors, because possibilities for leakage would be virtually eliminated (CE Delft, 2009) especially if a sectoral agreement takes the form of national sectoral binding targets in major economies (Reinaud, 2009).

- **Recycling of revenues is a useful policy option for sectors that cannot pass through costs.** In the absence of an international agreement, auctioning of allowances would harm the competitiveness of European companies, particularly energy intensive industries (Fridtjof Nansen Institute, 2008). Recycling auction revenues can be targeted towards those sectors that are particularly susceptible to carbon leakage (Demailly and Quirion, 2008; FitzGerald, 2009) although this has implications for overall economic welfare (Jaeger, 2008).

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[2] Taking no account of free allocation and assuming no climate action on the part of third countries.

[3] Note that the factors listed would influence the levels of risk of leakage but not the success of mitigation measures. Success of mitigation would depend on whether the levels of free allocation/BAM were set at an appropriate level and whether they were targeted at the right sectors.

A number of research gaps and uncertainties affect the robustness of the results.

Studies have used a number of different methods and assumptions to estimate the impacts of carbon leakage. In addition to the assumptions, the robustness of the results is affected by the inherent nature of the models and the scope of the analysis. In particular:

- There is very little ex-post empirical evidence of the impacts of energy and climate change policy, including the EU ETS, on international competitiveness or carbon leakage. Most studies take an ex-ante perspective and model the estimated impacts, which is to be expected given minimal levels of auctioning in Phases I and II;
- There is little evidence on the best way to counter leakage (Kuik, 2010; OECD, 2008). Indeed empirical research focuses on the costs imposed by the EU ETS and not the effects of climate policy measures; and
- There is a need to investigate the impacts of a broad range of possible international climate policy arrangements, including various combinations of economy-wide and sector-wide mitigation actions in order to gain insight into the strengths and weaknesses of policy options in practice.

1 Introduction

1.1 Study objectives and purpose

Current energy and climate change policies impose a carbon constraint on domestic production of energy intensive goods in the UK/EU, but leaves imports from the same goods unaffected. This leads to an equity and efficiency consideration. First, it might appear unfair that UK/European producers have to compete on an unequal footing, which would mean their profits would be lower. Second, the unevenness of the playing field threatens at least partially to defeat the purpose of the introduction of stricter energy policies. Energy efficient and therefore less CO_2 intensive production in participating countries might be replaced by less energy efficient production in, e.g., non-EU ETS countries.

As part of a wider piece of work on the impacts of energy and climate change policies on UK competitiveness, the main objective of this project was to answer the headline question 'what are the cumulative impacts of energy and climate change policies on carbon leakage?'

Carbon leakage could have a range of implications for UK (and EU) businesses; particularly at a time when businesses face rising costs, growing competition from non-EU/UK companies and increasing environmental and non-environmental regulatory burden. Applying pressure on businesses to reduce their emissions might encourage UK/EU businesses to reduce domestic production or relocate production activities to another country. This could have a significant impact on jobs and output in the UK and EU.

In recent times, a number of studies have investigated the impact of carbon leakage due to unilateral climate and energy policies. The sheer number of studies tends to obscure the clarity on the issue. The evidence suggests a wide range of carbon leakage impacts. In particular, it raises a number of questions:

- To what extent environmental regulation causes production to relocate from a highly regulated zone to a less regulated zone?
- Is competitiveness compromised as a result? Does it have an impact on jobs, output and trade? Are certain sectors or activities more at risk than others?

Or, alternatively,

- Do businesses change their production methods to comply with regulation, seeing this as an opportunity to improve their environmental performance?
- Has environmental regulation lead to enhanced competitiveness and innovation, as predicted by the Porter hypothesis?

And lastly,

- Can tailored and well targeted policy options mitigate the impact of carbon leakage?

In order to shed light on these issues AEA and CE Delft have conducted a review of the existing literature and investigated whether common lessons can be drawn.

1.2 Methodology

The first stage was to collate a list of key literature sources to review. We then collated evidence from the literature, using a number of criteria and indicators.

- GDP and sector/industry growth rates
- Trade (exports and imports)
- Energy markets
- Employment
- Investment and product market leakage
- Global carbon emissions
- Innovation and quality improvements (hard and soft)

We were also interested in the type of report (academic, press, consultation, publicly available report) and the analytical basis (theoretical, modelling or empirical). Other criteria included the geographic coverage (UK, EU or international), sectoral coverage, firm size and the policy coverage.

Once we had reviewed all of the sources, we carried out analyses of the literature, including the various types of models and assumptions that were used by the authors where available.

1.3 Structure of the report

Chapter 2 presents the findings of the literature review based on a number of different criteria;

Chapter 3 analyses the findings by discussing the various assumptions for estimating carbon leakage and outlining the impacts of carbon leakage;

Chapter 4 presents the policy options to reduce carbon leakage that were examined in the literature; and

Chapter 5 concludes the findings of the study.

2 Literature review

2.1 Introduction

During the study we reviewed a total of 60 sources. This section provides an indication of the quality and scope of the research material. We developed a number of indicators and criteria to review the literature, and these are reflected in the sub headings for this chapter.

2.2 Classification of reports

We classified each of the reports reviewed in the study according to the type of source and its analytical approach. More information on these classifications is provided below. The reports are listed in Annex 1 and referred throughout the report by '(Name, Year)'.

2.2.1 Type of source

Sources were classified as one of the following types:

1. **Academic** - 'Academic' sources are defined as having been peer-reviewed and published in a scientific journal, e.g. (Demailly and Quirion, 2008) European Emission Trading Scheme and competitiveness: a case study on the iron and steel industry. Energy Economics, 30, (Böhringer, 2009a; Demailly and Quirion, 2005). We reviewed 10 academic sources.

2. **Consultation response** - A 'consultation response' is defined as a response by an organisation on potential impacts of public policy on that organisation. We reviewed one consultation response on carbon leakage (Rio Tinto Alcan, 2009).

3. **Press** - A 'press' source is defined as having been published in a newspaper or professional periodical. We reviewed five press sources: a press release by EuroGypsum, the trade body for European manufacturers of gypsum-based products, articles from The Guardian, a press release on the 'EurActive' website presenting the views of industry bodies, and articles from The Economist and ENDS Report.

4. **Publicly available document** - A 'publicly available document' is defined as a source that is readily accessible to the public, typically accessed via the internet. We reviewed 43 publicly available sources, with authors including the European Commission, Department for International Development (DFID) and Chatham House, Department for Energy and Climate Change (DECC), Carbon Trust and House of Lords.

2.2.2 Analytical basis

Sources were classified as having one of the following analytical approaches:

1. Theoretical - 'Theoretical' sources explore different economic theories in relation to the impacts of energy and climate change policies on carbon leakage, e.g. Armington Elasticities (Armington, 1969), the New Trade Theory and the Porter Hypotheses (Porter, 1991). We reviewed 12 theoretical sources, with authors including the European Commission, the Carbon Trust, DECC, the Scottish Government and Michael Grubb from Climate Strategies.

2. Empirical - 'Empirical' sources tend to investigate the impacts of environmental costs on trade and investment patterns. Most of this research centres on the question of whether the Porter Hypothesis can be justified by empirical data. Due to its hypothesis-testing nature, this literature takes an ex-post perspective. We reviewed 26 empirical sources, with authors including Sijm for Netherlands Research Programme on Climate Change; Reinaud for International Energy Agency; Climate Strategies and Barker.

3. Modelling – 'Modelling' sources are based on either a partial or general equilibrium setting to determine the potential impacts of climate change policies on carbon leakage. Most of this literature is quite recent, as the arguments of carbon leakage became more relevant during the negotiations for the third phase of the EU-ETS, although some preliminary work has been conducted, especially in the Netherlands. We reviewed 21 modelling sources. Models referenced in the sources included general equilibrium models GTAP-E, GEM-E3, MIT-EPPA, a combination of GEO international trade model and CEMSIM, a partial equilibrium model of the cement industry, a multi-sector CGE model of global trade and energy use, WorldScan and PACE.

2.3 Scope of reports

In this section we describe how well the sources addressed carbon leakage impacts in different industries/sectors, geographic scales (international, EU and UK) and within the UK regions.

2.3.1 Sector coverage (industry type and size/SICs/mobility)

The literature provided wide coverage of different sectors, as shown in Table 1 below. The main sectors covered by the literature were energy-intensive industries such as aluminium, cement, clinker and steel. Other sectors covered to a lesser degree were gypsum, ceramics, lime, paper and pulp. One source looked at carbon leakage impacts on the economy as a whole and many were non-sector specific.

Table 1 - Coverage of sectors within literature

Sector	Number of sources reviewed	Examples
Aluminium	4	IEA, 2008; Rio Tinto Alcan, 2009; Carbon Trust, 2010; and Grubb, 2010.
Cement and clinker	8	Reinaud, 2009; Carbon Trust, 2010; Demailly and Quirion, 2005; Grubb, 2010.
Steel	8	Reinaud, 2009; CBI Wales, 2010; Grubb, 2010.
Ceramics and lime	1	DECC, 2010 provided an assessment of carbon leakage in light of an international agreement on climate change
Main sectors (i.e. cement, aluminium, steel, iron, paper and pulp, refineries, chemicals)	13	Economist, 2008; CE Delft, 2008; Climate Strategies, various reports; Barker, 2007; Barker for IPCC, 2007.
Gypsum	1	Eurogypsum, 2008: Carbon leakage 'already happening'
Multiple others	2	Fitzgerald, 2009 looks at the impact on pulp, paper and board, wood and wood products, basic chemicals, pharmaceuticals, non-metallic mineral products, basic metals, food and beverages. The latter is used as a comparator.
Economy as a whole	1	OECD, 2008 examines the economics of climate change mitigation: policies and options for the future.
Non-sector specific	21	Authors include European Parliament, 2008; European Commission, 2006; Congressional Research Service, 2010; Kuik, 2010; Böhringer, 2009a.

2.3.2 Geographic coverage - UK, EU, International

Geographic coverage amongst the sources we reviewed showed less variation than sectoral coverage. The majority of sources reviewed focused on the EU level, with only a small number covering specific impacts on the UK. There is a lack of evidence on the economic impacts of energy and climate change policy in the UK. This might be due to the nature of the EU ETS as a main driver for carbon leakage. Over a quarter of the sources we reviewed looked at the broader international level with countries including Japan and the United States.

Table 2 – Geographical coverage of sources

Geographic scale	Number of sources reviewed	Examples
UK	8	Scottish Government, 2010; CBI Wales, 2010; Carbon Trust, 2010; ENDS Report, 2010; European Parliament, 2008.
EU	33	Kuik, 2010; EuroGypsum, 2008; German Federal Ministry for Environment, Nature Conservation and Nuclear Safety, 2011; Fitzgerald 2009.
International (Japan, Asia, United States)	18	OECD, 2010; Cooper, 2009; Cooper, 2010; Barker, 2007.

2.3.3 Regional coverage (within UK)

There is a lack of regional data on the impacts of energy and climate change policies in the regions of the UK. Evidence is very limited and confined to the national level (UK wide) or to specific sectors, namely steel which is an anchor industry in Wales. A document prepared by the House of Lords (2008) examines how UK industries might be affected by carbon leakage.

To illustrate, evidence was found to suggest that around 0.7% of Scottish GDP and less than 0.5% of employment is in industries that could potentially see cost increases of greater that 5% as a result of energy and climate change policies. Impacts are likely to be confined to aluminium and cement (Scottish Government, 2010) [4].

[4] First referenced in Committee on Climate Change (2008) Building a Low Carbon Economy: the UK's contribution to tackling climate change (http://www.theccc.org.uk/pdf/TSO-ClimateChange.pdf)

Report 25 (CBI Wales, 2010) discusses the impact of energy and climate change policies on the steel industry in Wales, which has an estimated turnover of £2.7bn and over 7000 employees. It concludes that a heavy industry advisory forum is needed to protect against carbon leakage and ensure Wales' anchor industries get the right support.

2.3.4 Impacts examined

The literature review examined the impact of energy and climate change policies on the following factors.

1. GDP and sector/industry growth rates - 15 reports discussed impacts on profits and/or GDP e.g. (Demailly and Quirion, 2008; Böhringer, 2009a; Böhringer, 2009b; Barker, 2007). Only three reports looked specifically at industry/sector growth rates (Barker, 2007; European Parliament, 2008; Jaeger, 2008).

2. Trade (exports and imports) - There was some coverage of trade in the literature: 10 sources discussed impacts on exports and imports e.g. (Böhringer, 2010; Reinaud, 2009; Carbon Trust, 2010).

3. Energy markets - There was little coverage of the impacts on energy markets, with only eight sources providing discussion in this area e.g. (Kuik, 2010; Reinaud, 2009; European Parliament, 2008; IPCC, 2007; CE Delft, 2008).

4. Employment - 13 reports discussed employment effects, but only eight of these provided quantitative data on existent or predicted impacts e.g. (CBI Wales, 2010; Boston Consulting Group, 2010; Climate Strategies, 2009a).

5. Investment and product market leakage - There was good coverage of magnitude and direction of investment and product market leakage, with 13 sources providing qualitative and quantitative discussion e.g. (Reinaud, 2009; Carbon Trust, 2010; Climate Strategies, 2010a).

6. Global carbon emissions trajectories - There was extensive coverage of impacts on global carbon emissions trajectories, with 29 sources covering this subject. Of these, well over half provided quantitative data on emissions increase/decrease e.g. (Demailly and Quirion, 2008; Kuik, 2010; Boston Consulting Group, 2010). Please refer to Annex 2 for the full list of reports.

7. Innovation and technology improvements (hard and soft) - There was little coverage on the role of innovation and technology improvements in mitigating carbon leakage, with only six reports covering this topic explicitly e.g. (Reinaud, 2009; OECD, 2008; IPCC, 2007).

Please see Chapter 3 for more discussion and analyses of each of these impacts.

2.4 Climate change and energy policy coverage

The coverage of energy and climate change policies and their impact on the economy was largely limited to the EU ETS and the European Union's proposal to increase Europe's emissions reduction target from 20% to 30%, e.g. (Demailly and Quirion, 2008; Kuik, 2010; European Commission, 2010a; IEA, 2008; European Commission, 2008). 15 out of the 60 sources reviewed are classified as covering the impacts of the EU ETS. This included coverage of the impacts of Phase III of the EU ETS e.g. (ENDS, 2010; Boston Consulting Group, 2010) in relation to the European Cement Industry).

One report (Demailly and Quirion, 2005) examined the impacts of implementing a CO_2 emissions trading scheme or carbon tax for the cement industry in Europe, Russia and the Ukraine, Japan and Canada.

Another report (IPCC, 2007) looked at carbon leakage and trade patterns resulting from unilateral Environmental Tax Reforms in Europe between 1995 and 2005. The authors compared CO_2 emissions in ETR regions (namely Germany and UK) with CO_2 emissions in non-ETR countries, namely Spain, Italy and France as a result of the tax reform.

There is also discussion of an EU unilateral policy scenario and a 'Grand Coalition' scenario in which global emission reduction efforts take place (Jaeger, 2008). In both scenarios the EU '20 20 in 2020' strategy is modelled, although the set of countries differs.

33 sources examined the impacts of energy and climate change policy on a more general level and did not specify any particular policies.

Mitigation options to reduce carbon leakage

The literature provided a wide range of views on mitigations options to reduce carbon leakage that could be considered. These options include:

- Free allocation and access to international credits e.g. (European Commission, 2010a);
- Establishing a level playing field whereby all countries impose carbon costs on production in relevant sectors e.g. (Carbon Trust, 2010);
- Border adjustment mechanisms e.g. (Jaeger, 2008; Böhringer, 2010), and
- Including imports in the ETS in order to restore competitiveness e.g. (European Commission, 2010a).

Each of these options have advantages and disadvantages: whichever options are considered, it is important that governments assess tailored solutions to deal effectively with the different forms of leakage (production and investment leakage) as they may not require the same type of action (Reinaud, 2009). These policy options are discussed in more detail in Chapter 4.

3 Analysis of literature review findings

3.1 Introduction

Carbon leakage occurs when there is an increase in carbon dioxide emissions in one country as a result of an emissions reduction by a second country with a strict climate policy. In general, the term carbon leakage is used to describe undesirable side-effects of climate policies that undermine the initial emission reduction target. More precisely, carbon leakage is defined as the change in emissions in the rest of the world as a percentage of domestic emission reductions (Böhringer, 2010).

Carbon leakage has economic and environmental implications. The economic implication is that carbon leakage may be associated with a loss in competitiveness, jobs and welfare in countries with unilateral climate policies. The energy intensive industries in the EU/UK are operating and selling their products in a worldwide market. Prices are not determined by regional or local markets, but by worldwide competition or international exchanges (e.g. for aluminium). This distortion of competition can lead to outsourcing of production and subsequently to carbon leakage, which goes against the international objective to decrease global CO_2 emissions. The main environmental consequence is that the effectiveness of the unilateral climate policy is undermined (Table 3). Carbon leakage results in an underachievement of intended emissions savings because rather than being mitigated from the global atmosphere, emissions are simply transferred across borders to countries with less stringent standards and high-carbon technologies. Table 3 discusses the economic rationality of an unlevelled playing field leading to carbon leakage.

Any form of carbon constraint limited to the EU/UK could result in inefficient production decisions, where cost increases at the same level as under a global carbon constraint but product prices increase less than under a global carbon constraint if only the real costs are passed through and not the opportunity costs of freely allocated allowances in the ETS. Thus production levels in EU/UK under an EU/UK only carbon constraint will generally be lower than in the absence of a carbon constraint (BAU) but even lower than under a global carbon constraint.

Table 3 - Economic impacts of an EU/UK directed carbon constraint compared to a global carbon constraint

	Impact of Global carbon constraint on optimal production and consumption decisions	Impact of EU/UK only carbon constraint on optimal production and consumption decisions: In EU/UK	In non-EU/UK countries
Production costs	Production cost increases due to regulatory cost (e.g. cost of allowances)	Production cost increases through the cost of allowances	No increase in production costs
Product prices	Increase in prices due to increase in compliance costs	If costs are passed through a similar increase in prices, if costs are not passed through a smaller increase in prices	Effect not entirely clear. Prices could rise due to decrease in EU supply of goods. Price could stay the same if fall in EU supply is met by non-EU supply
Consumer demand	Fall in demand if prices increase	Fall in demand	Fall in demand or no change
Production level	Small fall compared to no carbon constraint	Least efficient producers will reduce output	Increase in output due to higher prices with constant costs
Emission levels	Fall with externalities internalised	A relative rise if efficient producers cut output if % increase in costs is more than % in price	Rise in emissions from inefficient technologies

3.2 Causes of carbon leakage

Carbon leakage can occur through various mechanisms. It is common in the literature to distinguish three main causes of carbon leakage: impacts through the capital market (leading to investment leakage), the product market (leading to trade leakage) and the fossil fuels markets (leading to energy price leakage). How these types of leakage come about and their effect on global carbon emissions is explained in the following sections.

3.2.1 Type 1 - Investment leakage

Unilateral environmental policies create unintentional incentives for companies to invest in regions / areas with less stringent environmental regulations.

Investments are then made outside of the area under stringent climate regulation, rather than the regulated industry introducing changes to make their own production more carbon efficient. Therefore, global emissions are unaffected by climate policy as emissions have simply transferred jurisdiction. This only directly implies carbon leakage if in the counterfactual case investment would have occurred in the region under climate policy.

3.2.2 Type 2 - Trade leakage

The unilateral environmental policies create a competitive disadvantage for regulated companies to compete on EU and export markets.

Consumption of products within the borders of a regulated market is substituted with imported goods from countries outside the regulated area whose products are now more competitive because they do not face comparable costs from climate legislation. A similar effect may also occur on the export market of the regulated area.

3.2.3 Type 3 - Energy price leakage / supply side leakage

The reduced demand for fossil fuels due to the unilateral climate change policies in the EU creates a downward pressure on global energy prices through energy price elasticity. In other words, relative energy costs for non-EU countries are lower leading to cost advantage.

Lower prices in countries without stringent energy and climate policies in place result in higher use of fossil fuels. In this instance the carbon has not ‘leaked’ in the same way as it does in the first two instances, but there is an increase in global emissions as a result of unilateral carbon regulation.

Note that the third type of carbon leakage only has an environmental impact but no direct economic impact. Lower energy prices in China result in more consumption by households and in the transport sector but do not have a competitive impact.

3.2.4 Other impacts

A fourth channel can be added to this analysis, although it is less common in the literature and more difficult to test empirically (Climate Strategies, 2010a). It refers to the positive effect that more stringent climate policies have on technology and innovation in the domestic market. If new low carbon technologies have time to mature, they may eventually become the most cost effective production method, and other countries might also adopt these new technologies. In contrast to the three aforementioned channels, this fourth channel might actually reduce emissions in the rest of the world.

3.3 Economic hypotheses for assessing economic impacts from unilateral climate change and energy policies[5]

Economic impacts from environmental policies in a globally linked world have been an intensively studied subject since the 1980s. In this literature three key hypotheses have been developed:

1. the Pollution Haven hypothesis
2. the Factor Endowment hypothesis
3. the Porter hypothesis.

The hypotheses give conflicting views on the economic impact of unilateral environmental policies. It is important to understand the arguments behind these hypotheses as this will facilitate the discussion of the economic models that are being used to address carbon leakage.

[5] This section leans heavily on the dissertation by Onno Kuik (Kuik, 2005), "Climate change policies, international trade and carbon leakage: an applied general equilibrium analysis", a paper by Umed Temurshoev, "Pollution Haven Hypothesis or Factor Endowment Hypothesis: Theory and Empirical Examination for the US and China" and CE Delft (2009), "Resource Productivity, Competitiveness and environmental policies".

Table 4 - Overview of theoretical hypotheses

Approach	What it says	Is it proven?
Pollution Haven Hypothesis	Countries without environmental regulations attract investment from energy intensive industries and through economies of scale obtain a competitive advantage in production.	The recent empirical literature finds a small but significant negative effect of strict environmental policies on trade and investment flows. Kuik also finds evidence for this effect in his economic models for carbon leakage (Kuik, 2005).
Factor Endowment Hypothesis (FEH)	Capital abundant countries will further specialize in capital (and pollution intensive) industries because of economies of scale. Environmental policy makes industry in the end more capital intensive by increasing abatement costs.	Older empirical literature generated evidence to prove the FEH. However, it seems that this is mostly valid for countries in Africa and Latin America. China is an important exception to this pattern so that in trade with China, the FEH does not seem to hold (Kuik, 2005).
Porter Hypothesis	Environmental policy, if rightly implemented, will induce cost savings in industry that make these industries more competitive.	Empirical work shows that environmental policies induce innovation in pollution abatement and lower cost of pollution abatement but does not find that this results in general cost savings for the firms resulting in enhanced competitiveness.

The three hypotheses are discussed in more detail in the sections below. The empirical literature that investigated which of these hypotheses most accurately reflects real world behaviour is discussed in section 3.4.

3.3.1 Pollution Haven Hypothesis

The Heckscher-Ohlin model applied to pollution has resulted in two hypotheses: the Pollution Haven Hypothesis (PHH) and the factor endowment hypothesis (FEH). The pollution haven hypothesis is based on the relative cost differences for firms between countries with and without environmental regulation. According to the PHH, under free trade, multinational firms will relocate the production of their pollution-intensive goods to countries where no environmental policies are in place and hence less costs occur.

In this way, developing countries without or lower environmental standards tend to have relatively higher polluting production activities while developed economies, with stricter environmental regulation, have much cleaner production processes

This theory forms the basis of the classic fear of carbon leakage: due to unilateral climate policies the competitiveness of energy intensive industries is in danger and they will relocate to countries without climate policies in place to save costs.

The main criticism of this hypothesis is that there are a number of other factors (e.g. employment policy, access to natural resources, etc.) that are important in determining the location of production. Secondly, competition may be around non-price factors (e.g. quality) or there may be a number of barriers to trade (e.g. import tariffs, transport costs) which mean that domestic producers are able to pass on the costs of production to their consumers without losing significant market share.

3.3.2 Factor Endowment Hypothesis

The factor endowment hypothesis (FEH), on the contrary, asserts that it is not the differences in pollution policy, but the differences in production technology (in economic language: factor endowments) that determine trade. This hypothesis is particularly based on the notions of economies of scale that make it profitable for countries to specialize in a certain production process.

The hypothesis predicts that capital intensity is a good approximation of pollution. The capital abundant countries will specialize on capital-intensive (dirty) goods and the capital-scarce countries will specialize in cleaner goods. For the EU, traditionally characterized as a relatively capital intensive region, this could as well imply that dirty production has a competitive advantage due to economies of scale despite the environmental policies that try to control emissions (Di Maria and Smulders, 2004[6]). As pointed out by a few authors e.g. (Bouman, 1988[7]), the capital intensity of a country applying environmental abatement technologies may even increase.

3.3.3 Porter Hypothesis

The Porter hypothesis is built on an assumption that a company itself is unable to take economically beneficial measures on its own. This may occur because companies are unable to find the most efficient way to produce, because they do not have the ability or capacity to make investment decisions that benefit the company in the long term, or because they will sub-optimally invest in innovation from a society perspective due to not being able to fully capture all of the benefits of innovation directly (spillovers). Although the hypothesis is controversial, there is a general consensus in literature that it has validity in cases where there is a systematic lack of information or limited or bounded rationality e.g. (Brannlund and Lundgren, 2009[8]).

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[6] Di Maria, C., and S.A. Smulders (2004), “Trade Pessimists vs. Technology Optimists: Induced Technical Change and Pollution Havens,” Advances in Economic Analysis and Policy, Vol. 4, No. 2, Article 7.
[7] Bouman M., Environmental costs and capital flight, Tinbergen Institute Research Series n. 177, 1988.
[8] Brännlund, R. and T. Lundgren (2009) Environmental Policy without Costs? A Review of the Porter Hypothesis, The International Review of Environmental and Resource Economics, 3(2), 75-117.

According to Porter, more stringent environmental policies, if they are implemented correctly, can lead to higher productivity, or a new comparative advantage, which can lead to improved competitiveness. In other words, environmental policy can lead to a win-win situation, or an extra profit of environmental regulation (in addition to net benefits related to less pollution).

Porter points out two main reasons why environmental policies can lead to improved competitiveness:

1. more stringent environmental regulations can reveal inefficiencies within firms that were previously hidden and in this way put pressure on a company to become more efficient; and

2. more stringent regulations induce innovation in companies.

These effects may lead not only to neutralizing the regulation's initial costs but also to improving the company's competitive position (Porter and Van der Linde, 1995[9]). Porter states that the final impacts depend on the type of regulation that is imposed on firms. Governments must design and implement the 'right type of policy instruments, i.e. the instruments that lead to new technical solutions and innovation, which in turn leads to improved resource allocation.

In the literature two variants of the Porter hypothesis can be distinguished. The 'weak' version says that environmental regulation stimulates innovations that can make the country develop a leading "edge" in production of clean technologies. Applied to the carbon leakage debate this implies that the loss in energy intensive production can be more than compensated by the gains in cleaner production technologies and innovations.

The 'strong' version of the hypothesis asserts that properly designed regulation may induce cost-saving innovation which more than compensates for the costs of compliance to the regulations (Lanoie et al., 2009[10]). When applied to the carbon leakage debate, this hypothesis suggests that effectively designed policy instruments may yield a win-win situation resulting in enhanced competitiveness also in energy intensive industries.[11]

It is important to note the impact on GDP may differ from the impact on leakage;

[9] Porter, M.E. and C. van der Linde (1995), "Toward a new conception of the environment competitiveness relationship," Journal of Economic Perspectives 9(4), 97-118.

[10] Paul Lanoie & Michel Patry & Richard Lajeunesse, 2008. "Environmental regulation and productivity: testing the porter hypothesis," Journal of Productivity Analysis, Springer, vol. 30(2), pages 121-128, October.

[11] Well-designed regulations, according to Porter, serve several purposes. First, regulations can give a signal that efficiency gains and technological improvements are possible. Such a signal may be given in a price form (as with introducing taxes or tradable permits) or for example as a reference to the outcomes achieved with best available techniques. Second, regulations can contribute toward a company's increased environmental awareness. Environmental regulations are often implemented in conjunction with regular reporting requirements – this transparency is meant according to Porter not only for the public but also for the company itself. The third characteristic of a well-designed regulation is that it reduces the uncertainty that is associated with some investments. This argument assumes that environmental policies will be consistently implemented over a long time period. The fourth purpose of good regulation, as pointed out by Porter, is that regulations contribute to an improved environmental awareness in general, which affects consumers' preferences. Thus, regulations force companies to transform themselves and their products in the direction that is in accordance with the demand trends of society (Porter, 1991).

- The Pollution Haven and Porter Hypotheses together could facilitate significant leakage rates within heavy industry, while at the same time allowing higher growth rates from other sectors and an overall positive impact on GDP.

- Alternatively, higher costs of production and energy could result in lower GDP (in line with neo-classical growth theory). However if these lower production levels are accompanied by equivalent reductions in domestic demand then leakage rates should be relatively low. Such a situation could arise where output and consumption contract in industries that have very low trade intensities.

3.4 Empirical findings of total costs from environmental policies

Given the fact that economic theory is not providing one answer on the trade impacts of unilateral climate policies, the issue has received considerable interest in empirical publications from the academic world. Studies have not only investigated CO_2 and energy costs, but also a measure for total environmental costs. The first branch of literature on the empirical testing of these issues examined relatively simple statistical exercises on trends of “dirty goods” production, consumption, or trade, and largely lacked sound theoretical background or a decent econometric background. This literature focussed primarily on the relationship between environmentally motivated costs for companies and their export position. A widely cited paper, (Jaffe et al., 1995) provides a survey of papers focusing on changes in US international trade competitiveness as a result of relatively stringent environmental regulations in the 1970s. Most of these studies concluded that environmental stringency was not a statistically significant determinant of net exports. The same paper also searched for evidence of creation of pollution havens in countries with relatively lax environmental regulations. Shifts in world trade patterns were examined in the period 1965-1988 and reported that developing countries gained a comparative advantage in pollution-intensive products at a greater rate than developed countries (Low and Yeats, 1992). They also noted, however, that industrialized countries accounted for the lion’s share of the World’s exports of pollution-intensive goods in the period under examination, contradicting the notion that pollution-intensive industries have fled to developing countries. They notice that the phenomenon could also be explained by natural resource endowment – as some industries require easy access to natural resources needed for production.

Another early study concluded that environmental stringency (constructed using an index) had no negative impact on trade flows (Van Beers and van den Bergh, 1997). However, using improved techniques and data, a different study later concluded that especially exports are significantly negatively affected by more stringent regulations but imports seem to be unaffected (Harris et al., 2002). More recent studies, however, do find a significant effect of costs of environmental regulations on net imports as well as exports (Jug and Mirza, 2005). They give a few examples of such studies, which used data from different states of the US. For example, a high positive effect of the US abatement costs on US imports has also been found (Ederington and Minier, 2003; Levinson and Taylor, 2004). They also pointed out that environmental regulations and trade are endogenous to each other.

The impact of environmental regulations is weak or insignificant because of measurement errors and the estimation of the wrong model (endogeneity arising due to pooling of countries or industries) (Jug and Mirza, 2005). After controlling for these biases, the authors obtained a significant elasticity of import demand to the stringency of regulation. The authors used European abatement cost data as a measure of environmental stringency. They found that environmental stringency matters more for Eastern European exporters, since EU importers might be more sensitive to the perceived lower quality of products and lack of variety in relation to this region.

Another branch of studies investigate the effects of environmental regulation on productivity. Some recent papers find evidence of positive relationships between more stringent environmental regulation and productivity, which is in line with the strong version of the Porter hypothesis. For example, refineries located in the Los Angeles area enjoyed a significantly higher productivity than other US refineries despite more stringent air pollution regulation (Berman and Bu, 2001). The productivity of the Mexican food processing industry is estimated to be increasing with more stringent environmental regulation (Alpay et. al, 2002). These are, however, unique examples which cannot be interpreted as evidence for existence of a general rule.

In spite of some positive examples that are in line with strong version of the Porter hypothesis, most studies find that the effect of environmental regulation on business performance is weak or ambiguous. For instance, better environmental performance enhances business performance, but a stringent environmental policy regime has a negative impact (Darnall et al., 2007). Results of an empirical model applied on a dataset of 4,200 business facilities from seven OECD (Canada, France, Germany, Hungary, Japan, Norway and the US) countries were collected in 2003[12] (Lanoie et al., 2009). This study found strong evidence for the weak version of the Porter hypothesis, i.e. according to the study results, more stringent environmental regulations implied more investment in environmental R&D. With respect to the strong version of the Porter hypothesis, evidence was found that the direct effect of stringency of environmental policy on business performance is negative. However, there is also a positive indirect effect of stringency of environmental regulation on business performance. Namely, environmental regulation induces environmental R&D investments, which in turn have a positive effect on business performance. This indirect positive effect was found to be weaker than the direct negative effect, which suggests that innovation only partially offsets the costs of complying with environmental policies[13]. One Swedish report did not find any significant relationship between environmental regulation and productivity (Brannlund and Lundgren, 2009). The results from studying the effects of the CO_2 tax on the Swedish industry between 1990 and 2004 show no support for the Porter hypothesis except for the rubber and plastic sector, where improved environmental performance was accompanied with improved productivity.

Summing up, literature on impact of environmental regulations on trade flows and location of direct investment is not entirely conclusive. However, recent literature indicates that with appropriate model specification a significant effect in international trade can be found, so

[12] Respondents of the survey included CEOs and environmental managers who answered questions related to environmental performance, environmental R&D and business performance.

[13] The econometric estimates were not conclusive regarding the issue if market-based instruments give a better incentive for innovation than other instruments. The authors conclude that this may be due to the fact that in practice, such measures are frequently applied at too low a level to induce innovation.

that imports from countries with less stringent environmental regulations tend to be higher than imports from countries with relatively tighter regulations. However, this effect is relatively small and comes primarily from the inclusion of fast growing economies like China in the analysis. China is therefore an example of a country that supports the Pollution Haven Hypothesis (Kuik, 2005).

3.5 Assessment of economic models used to analyse carbon leakage

Carbon leakage has been calculated using traditional economic models. Three types of models can be distinguished (Table 5): partial equilibrium models, general equilibrium models and econometric models.

Table 5 - Overview of approaches

Approach	Strengths	Weakness	Examples from the literature
Partial equilibrium analysis	Easier to understand for politicians, less of a black box character and based on more robust empirical data. Better suited for sectoral impacts of carbon leakage	Carbon leakage is often not estimated, or only limited to type 2 outlined above (trade leakage). Not suited for economy wide impact of carbon leakage	Demailly and Quirion, 2008; Graichen, 2008; IEA, 2008, Reinaud, 2008; Hourcade, 2007; CE Delft, 2008.
General equilibrium analysis	Complete modelling of all markets and all types of carbon leakage. Better suited for economy wide impacts of carbon leakage	Black box character and outcomes on carbon leakage are highly dependent on chosen model parameters	Kuik, 2010; IEA, 2008; PIK and Oxford University, 2011; Jaeger, 2008; OECD, 2008; Climate Strategies, 2010b, PBL, 2009
Forecasting models	Parameters of the variables are directly empirically estimated from data	Black box character and sometimes arbitrary or loose model formulation	Barker, 2009; DECC, 2010.

3.5.1 Partial Equilibrium Models

Description

Partial equilibrium models are economic models in which not the whole economy is being modelled, but rather a specific market, such as the steel or aluminium market. A partial equilibrium is a type of economic equilibrium, where the clearance on the market of some specific goods is obtained independently from prices and quantities demanded and supplied in other markets. In other words, the prices of all substitutes and complements, as well as income levels of consumers are constant and not influenced by the changes in the market under study.

Examples

Most of the partial equilibrium research does not directly estimate carbon leakage, but rather focuses on the additional costs to industry of legislation. Some studies do estimate carbon leakage on a sectoral level through investigation of the cost differentiation between EU and non-EU suppliers. In this way they are able to specify carbon leakage Type 2. In our literature review Refs. (Demailly and Quirion, 2008; Graichen, 2008; Eurogypsum, 2008; IEA, 2008; Reinaud, 2008; Hourcade, 2007; CE Delft, 2008) are based on a partial equilibrium model. Despite the clear limitation of partial equilibrium models, this approach has been influential in the analysis of potential impacts of Phase 3 of the EU ETS with contributions from Climate Strategies (Climate Strategies, 2007), Okö-Institut (Graichen, 2008) and CE Delft (CE Delft, 2008). In this work, the additional costs to industry of various allocation mechanisms have been identified. However, these studies did not estimate the amount of carbon leakage directly.

Key assumptions driving results on carbon leakage and impacts

Partial Equilibrium models assume that non-EU suppliers can unlimitedly augment their capacities to serve the EU market. This approach by design is very much supporting the Pollution Haven Hypothesis and cannot underline properly the Factor Endowment Hypothesis (see Section 3.3).

Robustness of this approach

Partial Equilibrium models are less suited for economy wide analysis of carbon leakage. For individual sectors, that are more prone to carbon leakage from a full-economy model, this approach can have additional information as the statistical sectoral basis is often better than that of general equilibrium models.

3.5.2 General Equilibrium Models

Description

A general equilibrium model is a model where all markets are modelled simultaneously and simulations are executed until all markets reach equilibrium where demand equals supply. The most commonly used general equilibrium model is the so called computable general equilibrium model (CGE). CGE models are based on a set of mathematical equations that use actual economic data to estimate how an economy might react to changes in policy, technology or other external factors. The equations tend to be neo-classical in spirit, e.g. assuming cost-minimizing behaviour by producers and prices set equal to marginal costs and all markets and institutions are clearing (supply meets demand, government revenues equal income, trade balance, etc).

Examples

Well-known CGE models applied to the field of carbon leakage include ENV-LINKAGES, GTAP-E, WorldScan and GEM-E3. This type of model has frequently been applied in the literature on carbon leakage (Kuik, 2010; PIK and Oxford University, 2011; Jaeger, 2008; OECD, 2008; Böhringer, 2010; PBL, 2009).

Key assumptions driving results on carbon leakage and impacts

The outcomes of CGE models are very sensitive to the chosen parameters in the models. Especially energy substitution elasticities (both with respect to fuel types and the factors of production) and trade elasticities (so-called Armington elasticities) are important determinants of carbon leakage (see Section 3.5). However, none of the studies in this literature review clearly account for the chosen values of these parameters. Therefore it is not possible to assess which modelling gives a more precise account of the “true” carbon leakage. This adds to the black-box character of economic models that makes them probably less influential in the policy arena. Equally, innovation (the Porter hypothesis) is difficult to model in CGE models as it conflicts with the neoclassical view that most models take. Exception to this is the WorldScan model (PIK and Oxford University, 2011) that does attempt to estimate the impact of regulation on innovation. The model’s calculations result in general in a lower estimated impact as it assumes that part of the negative impacts from climate and energy policies are mitigated by more innovation.

Robustness of this approach

In principle the results from CGE models are robust in the sense that there is a systematic consistency in the functioning of markets that is underpinned by economic theory. However, the robustness of the results on carbon leakage, trade, investments, GDP and employment crucially hinges on the chosen parameters and assumptions (See section 3.5) that are not properly defined and accounted for in the literature.

As with the partial equilibrium models, CGE models are only as robust as the economic theory that underpins them; the economic theory is essentially an input into the model. Thus it is almost by design that CGE models built with neo-classical equations (e.g. OECD (2008)) estimate that climate change policy has a negative impact on GDP, while those built assuming the Porter Hypothesis (e.g. PIK (2011)) estimate a positive impact on GDP.

3.5.3 Forecasting models

Description

Forecasting models, also called econometric models, are models that derive certain economic trends from calculations based on existing data. Each of these relations is then extrapolated in to the future so that a forecast is obtained of how the economy will evolve in a business as usual scenario. Because a forecasting model itself does not require equilibrium at markets, such models are more flexible but have the risk of a great deal of arbitrariness in setting up the equations.

Examples

Well-known forecasting models are E3ME and Ginfors (Barker, 2007; DECC, 2010).

Key assumptions driving results on carbon leakage and impacts

Forecasting models do not make assumptions about the way markets function or the relevant elasticities. Rather they infer these relationships from econometric analysis of the relevant data. In this way, forecasting models are believed to be better able to depict the realities of real-world economic systems than the stylized general equilibrium models. Positive impacts of environmental regulation on innovation (the Porter hypothesis) are fully acknowledged in these models. The disadvantage, however, is that the forecasting model is probably only accurate for marginal changes. For large systematic changes, forecasting models have limited validity, as past realities are then no longer a good basis to predict future developments. In the aftermath of the recent economic crisis, it appeared that forecasting models had serious difficulties in predicting developments in production levels for the next year.

Robustness of this approach

In principle, the estimates from forecasting models should be robust in the sense that they are derived from actual economic data including imperfect functioning of markets. However, under large systemic changes the reliability of the outcomes of forecasting models is limited. It is an unresolved debate whether the future climate policies of the EU should be seen as a systemic change of our economy.

3.6 Key assumptions of economic models

A number of assumptions drive the economic models discussed above and subsequently impact on assessments of carbon leakage. These assumptions specifically influence various variables in an economic model. The most important assumptions of carbon leakage that have been identified in the literature are the:

1. Costs of meeting the environmental targets, as a function of both the CO_2 reduction target and the marginal abatement cost curves of the technologies or measures;

2. Elasticity of substitution for energy, indicating both the substitution between various energy sources (gas, coal and renewable) and the substitution between energy and other factors of production (labour, capital)

3. Trade elasticities, the extent to which goods produced in the EU can be substituted for goods produced in non-EU countries;

4. Ability to pass cost of regulatory compliance to consumers; and

5. Extent to which other economies have similar carbon and energy policies in place.

The relative importance of these assumptions has not been adequately covered in the literature. One exemption is the dissertation by Kuik (Kuik, 2005) that investigated the influence of a 50% increase in both the costs of meeting the targets, the trade elasticities and the energy elasticities (Kuik, 2005). He concluded that these assumptions had an equal impact on export losses to the Dutch economy. He also found that a 50% higher environmental target, higher trade substitution elasticities and lower energy substitution elasticities would each have the impact of reducing exports by 1.5%. Hence the crucial determinant of each of these assumptions for the impact on carbon leakage is the certainty with which these variables can be estimated (see Table 6).

Sensitivity analyses of these assumptions are largely missing in the literature. Therefore it is very difficult to assess how important each of these assumptions is for the final estimate of carbon leakage. In Table 6, an overview is provided from our own judgement on the importance of these assumptions. Sections 3.6.1 to 3.6.5 discuss each assumption in more detail.

Table 6 - Summary of critical discussions of the assumptions

Assumption	Important for	Commonly used in	Variation in literature	Conclusion/Relevancy for the impact on carbon leakage
Abatement cost curve	Costs of meeting target and carbon price faced by industry	CGE, PE, Forecasting	Low, but substantial differences among sectors	Not a key variable for total economy wide outcomes but a key variable for sectoral outcomes
Energy elasticities	Costs of avoiding carbon emissions and considered as a key variable	CGE, Forecasting	Very high. In general energy elasticities are recently being lowered in CGE models thereby increasing the amount of carbon leakage in more recent studies.	A key variable for the outcome for both economy and sector and relevant for carbon leakage type 2 and 3.
Trade elasticities	The threat of non-EU suppliers to increase their market share.	CGE, Forecasting	Very high. A wide range of different values in the literature can be found. There is discussion of how Armington elasticities can be correctly estimated empirically under non-marginal changes due to unilateral climate policies.	A key variable for the outcome for both economy and sector and mostly relevant for carbon leakage type 2.
Cost pass through	Profit levels of firms and the threat of non-EU suppliers to increase their market	CGE, PE Forecasting,	Medium. Differs substantially between forecasting (on average 50% cost-pass-through) models and CGE models (higher cost-pass-through).	Important for determining whether carbon leakage type 1 or type 2 will occur.
Non-EU climate and energy policies	The threat of non-EU suppliers to increase their market share and investment leakage.	CGE, Forecasting	High. Most of the literature ignores the fact that non-EU countries are also pursuing climate policies that impose additional costs on producers	A key variable for carbon leakage type 1, 2 and 3.

3.6.1 The abatement cost curve

The abatement cost curve is essential for estimating the costs that sectors will face when confronted with energy- and climate change policies. The curve not only allows one to estimate the cost of abatement for sectors to reduce emissions, it is also one of the main determinants in estimating the carbon price. This carbon price in turn determines the marginal cost of production for producers covered by emission trading schemes. For most studies, it is unclear which data is being used for the abatement cost curves and the source of the abatement costs is often not clear. However, most studies do seem to agree on the total costs of meeting climate targets if the business as usual is defined similarly among the studies. At a sectoral level, the divergence can be much bigger. In particular if the study takes a longer time period into perspective, there is more uncertainty in the abatement cost curve.

Clearly a greater cost of carbon would lead to higher marginal costs to producers, and therefore imply greater carbon leakage (taking into consideration factors identified above).

3.6.2 Price elasticity of energy demand across countries, fuels, factor of production and sectors

Most economic models rely on a large number of energy elasticities for estimating carbon leakage. The modelling results are particularly sensitive to the fuel-substitution elasticities. Higher fuel-substitution elasticities mean that the climate targets can be achieved at a lower cost, for example by switching from coal to natural gas or renewables. Moreover, the difference in sectoral energy price elasticities between price elasticities between EU and non-EU countries is crucial. Lower price elasticities in the EU result in higher costs of meeting the target and thus in more carbon leakage (Type 2). High price elasticities in non-EU countries result in higher responses to the relative fall in non-EU energy price and therefore a higher risk of carbon leakage Type 3.

Another important aspect is the factor price elasticities between energy and the production factors, labour and capital. This gives possibilities to meet the climate targets through factor substitution. In Kuik (Kuik, 2005) it is shown that GTAP-E, a commonly used model for analyzing carbon leakage, actually had very high substitution elasticities (Kuik, 2005). This meant that the EU could reduce emissions more cheaply by switching energy for capital and labour.

However, in recent years, these elasticities of substitution have been lowered resulting in higher estimates of carbon leakage, both Type 2 and Type 3. There is still a wide range of energy elasticity estimates used in various models to estimate carbon leakage. However, studies suffer from two main issues with respect to price elasticities of energy demand. First, studies do not explicitly explain how price elasticities are estimated. Sensitivity analyses of these assumptions are largely missing in the literature. Secondly, none of the studies explicitly state why a particular value for the price elasticity of energy demand has been used compared to others. Thus, it is not possible in this review to determine why elasticities are falling over time in the various economic models. It is also difficult to accurately determine the leakage impacts which can be directly associated to price elasticity of energy demand.

3.6.3 Trade elasticities

Trade elasticities define the extent to which goods produced in the EU can be substituted for goods produced in other countries. Foreign produced goods are not perfect substitutes for domestically produced goods (Armington, 1969). This is due to various trade barriers, such as formal (import tariffs) and informal (security of supply, long-term renewed contracts, transport costs) barriers. The elasticities of substitution between products of different countries are commonly referred to as Armington elasticities.

In general, high Armington elasticities give rise to Type 2 carbon leakage (trade leakage). Unfortunately all studies only imply the use of Armington elasticities in the models employed. In a presentation of Armington elasticities across several models, Felix Matthes from the Oko-Institute in Germany concluded that they differ considerably between the various models.[14]

3.6.4 The degree to which other countries will have similar climate change and energy policies in place

Most of the modelling work assumes that other countries have no climate and energy policies in place, while only the EU is facing such policies. This is of course not very realistic. A recent study by Vivid Economics compares the costs of electricity generation in various economies and calculates that in China substantial implicit climate costs in the price of electricity also apply (Vivid Economics, 2008). With respect to the debate about carbon leakage, a report by the Netherlands Environmental Assessment Agency tries to correct for plans in other countries but does not estimate a quantitative impact of carbon leakage (Jaeger, 2008). A study for DG-Trade (DG Trade, 2011) by the same group has a quantitative assessment of the amount of carbon leakage under various assumptions on carbon policies in other countries.

We also notice that many studies are not explicit with regard to other countries' climate policies, despite the importance of this assumption. The positive effects, for example, have been achieved by assuming that other countries will follow the high pledges that have been made during the Copenhagen Accord (IEA, 2008). It is clear that if other countries are also committed to undertake climate change policies, carbon leakage will be substantially reduced.

[14] Presentation by Felix Matthes on EU Stakeholder consultation, 26 September 2008.

3.6.5 Cost pass-through

The cost pass-through rate is defined as the change in output price in response to a change in input costs. If the cost pass-through rate is equal to one, then an increase in total costs will lead to an equivalent percentage increase in prices. The estimate of cost pass through differs due to the methods and assumptions used to estimate cost pass through and the various modelling approaches (Section 3.4) used to investigate carbon leakage.

Methods and assumptions used for estimating cost pass-through

The increase in cost due to carbon prices could either be absorbed by industry through a reduction of its operating margins or passed onto consumers through product price increases. Any price increase would be followed by a reduction in sales; the crucial question is these industries' ability to remain profitable while sustaining output levels. Cost pass through can be estimated using econometric production functions or by estimating directly by using price elasticities and using this to infer pass-through rates. Estimating cost-pass through directly is the only way to obtain cost pass-through rates if it is not possible to assume profit maximisation. If the assumption of short-term profit maximisation is relaxed there is no direct link between costs and prices as firms are able to set prices regardless of costs. Therefore cost pass-through rates and price elasticities must be estimated separately. This is the method used in the large-scale econometric models (for example Cambridge Econometrics, 2009[15]) that do not assume profit maximisation (in contrast to the CGE models, such as PACE, that do make this assumption).

The ability to pass cost increases through to prices depends on three main factors:

1. **Price-responsiveness of demand**. Sectors in which demand is not very sensitive to price will not suffer a significant loss in volume of sales when prices are increased, particularly if possible substitute products are exposed to similar cost uplifts as a consequence of climate policy.

2. **International trade and market conditions**: The degree of trade openness and proportion of EU demand met by imports. Companies outside the EU will not see any cost increase as a result of unilateral climate policy, though some (such as in Japan) may be affected by other domestic policies associated with implementing the Kyoto Protocol.

3. **Nature of domestic competition**. Market structure will influence pricing dynamics, driven both by the number of players in the market and extent of state involvement either through regulation (e.g. product standards, quality assurance, etc.) or direct ownership. In general, markets with more players are more competitive and costs affect sector pricing more directly.

[15] Cambridge Econometrics (2009), 'E3ME manual', version 4.6, available online athttp://www.camecon-e3memanual.com/cgi-bin/EPW_CGI

These factors are not easy to estimate and most studies make assumptions regarding the difference in prices due to extra costs to the EU/UK producers as a result of unilateral climate policy. These assumptions are not clearly discussed in the literature and would require more in-depth analysis to infer how sensitive they are for estimating cost pass-through levels. Most studies assume that a change in input prices is likely to have an impact on output prices. This one-way causation in reality, however, is not necessary true. Firms with large market power often have the ability to set the price they wish to pay to their suppliers in exchange for buying in large quantity. Firms who participate in price wars with their competitors usually fix retail prices and instead bargain down costs from suppliers.

In terms of data requirements, estimation of cost pass-through usually requires two main variables: input prices (wholesale price, farm price, spot price, etc.) and final output price (retail or consumer price). One of the main data issues is the data availability on the input costs side. While price data are relatively easy to find, availability of cost data is limited. Firms often conceal their input costs as they are regarded as highly sensitive (both to their suppliers and to their competitors) and considered to be potentially damaging to the business if released. Sectoral cost data are not collected as part of the national accounts (although maybe inferred from the difference between gross and net output, plus the cost components of GVA). In general commodity prices are much easier to find than manufacturing input costs.

Table 7 gives an overview of the cost-pass-through rates that ex-post empirically have been observed for a range of products from various sectors. It shows a wide range of ex-post cost-pass through estimates. This is mostly due to the methods that have been used to determine the empirical cost-pass through rates. More simple econometric methods were being used by Walker (2006) and Sijm (et al., 2006), while the studies by Alexeevi-Talebi (2010), Oberndorfer et al. (2010) and CE Delft (2010) contained more advanced econometric time-series analysis. The markets method, as used in CE Delft (2010) seems to have resulted in an estimate of higher costs pass through rates than the methods based on input costs (all the other studies listed in the Table 7). However, as explained in the literature, cost pass through rates of above 100% could emerge in competitive markets if supply and demand exhibit certain characteristics (Sijm, 2004).

Table 7 - The cost-pass through rates differs significant by sector

Study	Product	Country	Method	Cost pass-through*
Electricity				
Sijm, 2006	Peak electricity	Netherlands	Costs	78%
Sijm, 2006	Off-peak electricity	Netherlands	Costs	74%
Sijm, 2006	Peak electricity	Germany	Costs	117%
Sijm, 2006	Off-peak electricity	Germany	Costs	67%
Refineries				
Oberndorfer, 2010	Diesel	UK	Costs	50%
Oberndorfer, 2010	Gasoline	UK	Costs	75%
CE Delft, 2010	Gasoline	EU	Markets	500%
CE Delft, 2010	Diesel	EU	Markets	350%
Chemicals				
Oberndorfer, 2010	LPDE	EU	Costs	100%
Oberndorfer, 2010	Ammonium	EU	Costs	50%
CE Delft, 2010	PE		Markets	100%
CE Delft, 2010	PS		Markets	33%
CE Delft, 2010	PVC		Markets	100%
Alexeeva-Talebi, 2010	Dyes and pigments	EU	Costs	37%
Alexeeva-Talebi, 2010	Other basic inorganic chemicals	EU	Costs	10%
Alexeeva-Talebi, 2010	Fertilizers and nitrogen compounds	EU	Costs	16%
Alexeeva-Talebi, 2010	Plastics in primary forms	EU	Costs	42%
Alexeeva-Talebi, 2010	Perfumes and toilet preparations	EU	Costs	0%
Alexeeva-Talebi, 2010	Other rubber products	EU	Costs	75%
Paper				
Alexeeva-Talebi,	Paper and	Germany	Costs	0%

Study	Product	Country	Method	Cost pass-through*
2010	paperboard			
Alexeeva-Talebi, 2010	Household and toilet paper	Germany	Costs	38%
Glass				
Alexeeva-Talebi, 2010	Hollow glass	Germany	Costs	60%
Alexeeva-Talebi, 2010	Glass fibres	Germany	Costs	27%
Alexeeva-Talebi, 2010	Other glass, processed	Germany	Costs	24%
Oberndorfer, 2010	Hollow glass	Germany	Costs	20-25%
Oberndorfer, 2010	Container glass	Germany	Costs	0
Cement				
Alexeeva-Talebi, 2010	Cement, lime and plaster	Germany	Costs	73%
Walker, 2006	Cement	France	Costs	<30%
Walker, 2006	Cement	Germany	Costs	<30%
Walker, 2006	Cement	Italy	Costs	<10%
Walker, 2006	Cement	UK	Costs	<31%
Walker, 2006	Cement	Greek	Costs	<11%
Walker, 2006	Cement	Portugal	Costs	0
Walker, 2006	Cement	Spain	Costs	<37%
Steel				
CE Delft, 2010	Hot rolled coil	EU	Markets	120%
CE Delft, 2010	Cold rolled coil	EU	Markets	110%
Ceramics				
Oberndorfer, 2010	Ceramic goods	EU	Costs	>100%
Oberndorfer, 2010	Ceramic bricks	EU	Costs	30-40%

Modelling approaches used to investigate carbon leakage

Partial equilibrium analyses rarely include cost-pass through – although it would be possible to derive an estimation of the cost-pass-through using this type of analysis. Exceptions are Demailly and Quirion, 2008 and CE Delft, 2008 that estimated the cost-pass through of individual sectors. CE Delft, 2008 estimated that on average about half of the costs were passed through[16]. Forecasting models derive cost-pass-through from data and also assume that on average about half of the costs are being passed through.[17]

CGE models typically assume a higher share of cost pass through (even if allowances under an ETS are distributed at no costs to firms). This is based on the theory that the firm decides at the margin on the production level given a certain price and cost structure. For one additional unit, under an ETS system, the firm must buy additional EUAs so that marginal costs rise irrespective of whether the allowances are being auctioned or grandfathered (the only exception here is yearly updated output-based allocation). As a result of the rise in marginal costs, firms will reduce output. The impact that the reduction of output will have on product markets is that supply declines and prices will rise. The extent to which prices rise will depend on the elasticities of demand and supply in the product market. The Armington elasticities will subsequently determine to what extent foreign suppliers of the product will capture the market.

The extent to which costs will be passed through in prices has recently been assessed by a growing body of empirical research (Sijm, 2004; CE Delft, 2010, Alexeeva-Talebi, 2010; Oberndorfer, 2010; Walker, 2006). This literature takes an ex-post perspective and analyzes to what extent during Phase 1 and 2 of the EU ETS, prices of various products at the EU market could be explained by price variation in CO_2 markets. Most of the literature uses a cost-model where the price of products is being explained by prices of input factors, such as crude oil or energy. CE Delft (2010) analyzes price differentials between the US (without climate policies) and the EU (with EU ETS; CE Delft, 2010).

[16] In later analysis in 2010 (available only in Dutch) this was augmented to 60% based on a literature review.
[17] Personal communication with H. Pollitt, Cambridge Econometrics.

3.6.6 Conclusions on assumptions and drivers underpinning differing results

The most important variables for assessing the amount of carbon leakage are dealing with the cost-differential of EU industry in comparison to non-EU industry and the extent to which non-EU industry can capture the EU market share. Economic models must make assumptions on the value for these variables and how they evolve over time.

The cost differential for EU business is determined by:

- the abatement cost function;
- the extent to which other countries install climate policies;
- the various energy elasticities; and
- the extent to which business can pass through these costs to consumers.

The extent to which non-EU industries can capture the EU market is determined by

- the trade elasticities; and
- the extent to which EU industry does pass through the additional costs to consumers.

We notice that the literature is not explicit in these assumptions. It is therefore very difficult to determine the credibility of results obtained by single studies.

3.7 The Impacts of carbon leakage

The literature covers a wide range of economic and environmental impacts of carbon leakage, with the majority focussing on trade and GDP.

The most severe cases are reported to be in energy intensive industries with high indirect emissions. The reason for this is that firms which purchase large amounts of electricity face high cost pass through by power generators. This reduces industries' profits, especially in industries with a cost pass through rate of zero because prices are set on international exchanges and competition amongst suppliers is fierce.

However, in-depth ex-post analysis of carbon leakage and its impact on the energy intensive sectors is scarce in the literature. This is because energy contracts tend to run for long periods of time and therefore have not responded to recent climate policy developments. The IEA predict that relationships between climate policy and carbon leakage will start to become clearer from now on as the majority of these long term energy contracts will need renegotiating and the EU ETS reduces free allocation (IEA, 2008).

Predicted impacts from models however are available, and some relationships have been drawn in the literature based on proxies for carbon leakage such as changes in trade flows. The main findings are discussed in the following sections.

3.7.1 Effects on employment

In most instances, the literature highlights the number of jobs exposed to the risk of leakage across entire sectors or economies, rather than the likely proportion of jobs which would actually leak. It is therefore hard to understand the real effects on employment, other than in a few case studies where lobbying papers have been reviewed.

UK Studies

A report by Climate Strategies (Climate Strategies, 2009a) shows that less than 0.5% of jobs in the UK are in the sectors deemed most at risk to carbon leakage.

A study by the aluminium company, Rio Tinto Alcan (Rio Tinto Alcan, 2009) estimated that 620 direct jobs and 3000 indirect jobs would be lost without government compensation in Phase III of the EU ETS owing to leakage. This is because of an EU decision to classify the on-site coal power plant, used primarily for the smelter, as a power generator. This means it will receive no free allocation of emissions under Phase III. It is believable that this will cause the closure of the plant and all job losses stated, because unlike other power generators, Alcan cannot pass costs through. Cost pass through from the power generation is zero because they consume the energy so would only be passing costs on to themselves (Rio Tinto Alcan, 2009). Cost pass through in the end product is zero because aluminium prices are set on the London Metals Exchange and the Shanghai Futures Exchange (IEA, 2008). This is believed to be a genuinely unique situation.

A report by Boston Consulting Group on the UK cement industry states that 81% of production is at risk, which translates to approximately 32,000 jobs and €3,400m of gross value added (Boston Consulting Group, 2010). The study also emphasised the fact that the lack of infrastructure and natural resources in non-EU countries is not a barrier to carbon leakage.

Focussing on steel, Corus at Port Talbot has a turnover of £2.7m and 7000 employees at risk of leakage from Wales (CBI Wales, 2010).

EU/International studies

In contrast a number of EU and International studies found that climate policy had a positive impact on jobs.

A report by the Netherlands Environmental Assessment Agency (Jaeger, 2008) estimated the impact of EU climate policy on jobs. In a scenario without the Clean Development Mechanism and 20% targets within the EU, jobs are expected to decline by 3.2%. A study by the European Parliament advocates tightening of climate policy (European Parliament, 2008). It states that a move to a 30% target by 2020 for the EU could create up to 6 million additional jobs.

Studies that find positive impacts on employment (e.g. European Parliament, 2008; PIK and Oxford University, 2011), do so under the assumption that climate policies imply a shift of jobs from energy intensive activities to low carbon activities. Over the coming decade, raising the EU's climate target from 20% to 30% can create up to 6 million additional jobs Europe-wide according to the Potsdam Institute and Oxford Economics (PIK and Oxford University, 2011). As the labour productivity of these cleaner activities is much lower (the amount of workers per unit of value added), employment tends to increase while GDP tends to fall. This effect was also shown in studies such as the European Climate Foundation (CE Delft, 2010).

3.7.2 Impact on GDP growth

Impacts of unilateral climate policy on GDP and growth are reported to be fairly low, due to the economy's relatively larger sensitivity to other factors such as exchange rates and relative factor (labour, energy and capital) costs.

A report by the Scottish Government (Scottish Government, 2010), whilst not giving specific figures on employment, found that around 0.7% of Scottish GDP and less than 0.5% of companies could see their cost increase by 5% as a result of climate policy.

The Potsdam Institute and Oxford Economics suggests over the coming decade raising the EU's climate target from 20% to 30% can increase the growth rate of the European economy by up to 0.6% per year; it may also increase European GDP by up to $842 bn and increase GDP by up to 6% (PIK and Oxford University, 2011).

One piece of academic literature by Böhringer, Tol and Rutherford (Böhringer, 2009a; Böhringer, 2009b) uses three general equilibrium models to look at the welfare effects of a 20% emissions reduction target in the EU by 2020. The study concludes that welfare losses[18] would be between 0.5-2% in their least cost scenario where the carbon price is the same across the EU (Böhringer, 2009a; Böhringer, 2009b).

Growth may be distorted by the government policy chosen to mitigate carbon leakage. If free allowances are allocated to certain industries, this reduces the allowances sold by auctioning. By restricting allowance supply in this way, and assuming that those receiving free allocation are less likely to undertake abatement or pass on the costs to consumers, prices will rise for other industries and affect their ability to grow (Carbon Trust, 2010).

A study by the German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety estimated that only a few sectors, accounting for up to 1-2% of EU GDP, would 'face significant cost increases' from higher carbon prices. In the UK, only 1% of all economic activities would face significant cost increases relative to their value added. In Germany less than 2% of all economic activities would be affected by higher carbon prices (European Parliament, 2008).

3.7.3 Effects on business decisions

In the EU, the chemical and steel industries are the most exposed to investment or re-investment leakage (European Parliament, 2008). According to a study by Resources for the Future (2010) looking at the global effects of unilateral climate policies, the chemical and non-ferrous metals sectors are probably the most at risk in the EU with production declining by 3.2% (Böhringer, 2010).

The Climate Strategies report (Climate Strategies, 2009a) concur with the small impact of unilateral climate policies on GDP and growth as discussed above, stating that labour and other input costs outweigh the effects of carbon policies. Fluctuating exchange rates and energy costs are far more likely to impact business decisions than differing carbon costs across borders. For example, the euro/dollar exchange rate appreciated by more than 50% between 2001 and 2006, with a much bigger impact on costs for most sectors than projected carbon prices to 2020. However, climate policy and energy prices cannot be looked at in isolation. An academic publication asserted that the EU ETS was directly responsible for a 12% increase in the price of energy (Kuik, 2010).The IPCC still does not believe this will cause net welfare loss, even arguing that there is likely to be a net benefit in the longer run through investment in clean technology (IPCC, 2007). This is supported by a few modelling studies, such as the German Environmental Ministry (PIK and Oxford University, 2011).

The steel industry in the EU was at full capacity between 2005-2008 (CE Delft, 2009) triggering transfer of the energy intensive part of the production process to outside of the Ukraine and Russia. There has been speculation that EU ETS may have provided a further stimulus for this movement in 2008/2009 (CE Delft, 2010), however this cannot be directly proven. Whether overall, net investment has increased or decreased is hard to judge. On one hand, there could be EU ETS induced carbon leakage occurring, which

[18] Please note that welfare is not equivalent to GDP.

explains the tail off in energy intensive industry in Europe. Counterbalancing this is the investment in new technologies to improve efficiency (European Commission, 2010a). To add further complexity, such clean technology investments and shifts in investment could have occurred regardless of climate policy. Clean technology investment is covered in more detail in Section 3.7.6.

3.7.4 Impact on trade

Overall, there is better evidence on the impact on trade due to carbon leakage. However, the studies cannot isolate the impact of climate policies on trade effects due to the complex range of factors involved in industries' decisions to relocate or reduce supply. The IEA state that the relationships should be clearer in coming years due to the renegotiations of energy contracts taking into consideration Phase III of the EU ETS (IEA, 2008).

Looking at the most widespread piece of climate legislation, the Kyoto Protocol, sectors most at risk are cement, chemicals, iron and steel and aluminium (IPCC, 2007). The Institute for Environmental Studies in Amsterdam states that under the EU ETS, without border adjustments or free allocations, competing foreign imports increase by 4.1% (mineral products) to 9.0% (steel) and domestic supply decreases by 1.6% and 2.0% for mineral products and steel respectively (Kuik, 2010). Across all sectors, EU export demand is predicted to fall by 9.1% and demand for imports rise by 8.1% (Jaeger, 2008).

For cement and clinkers, the spatial model of Demailly and Quirion (2006) for world cement trade shows potential loss of market share of EU producers under EU ETS of 12% (Kuik, 2010). Therefore, under the EU ETS, European manufacturing firms lose market share on the EU market and in export markets. This is a result of demand being largely unaffected by the EU ETS, and therefore consumption switches to cheaper supply alternatives from regions without climate policy pressures.

Trade in cement and clinker globalised in the last decade causing rapid changes in trade flows. EU Imports of cement and clinker rose up to 2007, but sharply decreased since then. Decoupling the EU ETS part of these trends in trade is not straight forward (Kuik, 2010; Reinaud, 2009).

Another element for consideration is the terms of trade, the economic term for the ratio of the price of exports to the price of imports. An increase in the terms of trade is said to reflect higher levels of welfare, and in the US the reduction in economic welfare from climate policy is outweighed by the improvement in terms of trade. It is also said that the terms of trade benefits contribute significantly to reducing the overall costs of climate policies (Böhringer, 2010).

Statistical analysis from 1999-2006 by the IEA on trade does not confirm that CO_2 prices affected EU primary aluminium trade flows (IEA, 2008). However, at the same time, growing demand in Europe has not triggered investment in local primary smelting capacity. This has led the IEA to conclude the region is less attractive for new capacity than regions that guarantee lower energy costs, i.e. do not have a CO_2 price constraint.

3.7.5 Impacts on global carbon emissions

Carbon leakage can be measure in a number of ways. In this report we focus on the most common measure which is represented by the formula below:

$$\text{Carbon leakage} = \frac{\text{Increase in emissions outside climate policy area}}{\text{Decrease in emissions inside climate policy area}}$$

The leakage estimates are presented as a percentage. For example, a carbon leakage of 20% means that 20% of emissions reductions made in the climate policy region are actually counteracted by increases in emissions outside the climate policy area. This represents a market failure, although a global reduction in emissions is still achieved if the carbon leakage rate is less than 100%.

As discussed in Section 3.6, the reports analysed in this study do not provide all of the modelling assumptions for estimating carbon leakage. However, there are six key accessible assumptions which are important for understanding the variation in carbon leakage estimates. In addition to the main modelling techniques used, leakage estimates are sensitive to these assumptions. Where a report looks at the impacts of varying a single assumption, we have stated the effect on carbon leakage. It is not possible to compare the results from different reports which have used different assumptions because it is impossible to correctly attribute impacts to assumptions. Where possible, results from separate reports have been compared against each other too. These are of course less certain because of the likely variations in underlying modelling assumptions which influence final results.

The assumptions are discussed below and summarised in Table 8.

The stringency of the climate policy causing carbon leakage (e.g. emission reduction target)

Clearly the more stringent a climate policy is, the higher the risk of carbon leakage. The strength of this relationship can be gauged by comparing the assumptions for two different leakage estimates from the (OECD 2008) study. Climate policy is imposed on Annex I countries and covers all greenhouse gas emissions across all major emitting sectors, with no measures in place to protect against carbon leakage. The stringency of the climate policy varies in terms of the CO_2 reduction targets by 2050. In the first scenario, all Annex I countries are required to reduce their greenhouse gas emissions by 50% of total Annex I emissions against a baseline of 2005, leading to a carbon leakage rate of 9.1%. Based on the same parameters, but with the less stringent requirement for the same group of countries to reduce emissions by 50% of just EU levels in 2005, or 2.7 Gt of CO_2 equivalent, the rate of leakage falls to just 1.4%. The EU level and Annex 1 level 2005 baselines are different, which affects the stringency of the requirement.

Demailly and Quirion (2006) use the same GEO-CEMSIM model in two studies covering the cement sector. One of the studies looks at the impact on leakage by using the EU ETS requirements/assumptions and another using the Kyoto protocol. Since, they use the same model we have judged it reasonable to compare the two studies. In their EU ETS example, with 90% of allocations being given for free based on historical emissions (grandfathering) and a carbon price of €20, the rate of carbon leakage is 50% (Demailly and Quirion, 2006). As in the OECD study, the leakage rate declines under the less stringent Kyoto protocol to 25% (Demailly and Quirion, 2005). Not all of this effect can be linked to the change in scheme however, as the carbon price assumed under the Kyoto protocol is also lower at €15. It is hard to draw a conclusion on which factor has a stronger influence, but the evidence provided below shows the effects of changing the carbon price is not the biggest factor for leakage. Hence, it can be concluded that a relatively lenient climate policy can lead to lower levels of carbon leakage.

Theoretically, a tighter cap could also have the reverse effect. For example, it could be the case that emissions abatement is cheap in the climate policy area. This would mean that the more stringent cap on emissions could be met without the cost increases associated with climate policy which leads to carbon leakage. So long as this percentage reduction in carbon emissions in the climate policy area is greater than the percentage increase in emissions outside the climate policy area, the rate of carbon leakage would fall under a tighter cap. However, there is no evidence of this happening in the literature covered by this study, most probably because the costs of emissions reduction or compliance with a scheme are sufficiently high.

The carbon price assumed

Carbon price is an important factor affecting carbon leakage. The reports analysed in this study indicate certain peculiar trends with respect to carbon price and leakage. Most studies do not explicitly test the assumption on carbon price. Further, conclusions cannot be drawn about the impact of carbon price on leakage across studies because other parameters and modelling assumptions vary between models. However, three main trends worth indicating are:

- ***The responsiveness of carbon leakage to carbon price differs within and across studies*** – for example Reinaud (2008), looked at the impact of different carbon prices on a hypothetical carbon tax covering the iron and steel sector in the old EU-15 Member States and Japan. No measures are assumed to be in place to prevent against leakage, and the scheme covers CO_2 emissions only. For example, three price scenarios assumed a carbon tax of €11, €21 and €42 per tonne of CO_2 respectively. Carbon leakage rates were estimated to be 35%, 55% and 70% respectively. This shows that while the carbon price is an influential variable, the responsiveness of carbon leakage to a change in the carbon price ranges from 0.7% to 2% for a €1 increase in the price of carbon. On the other hand comparing the carbon price and leakage rates for the cement sector in Demailly & Quirion (2006) and Carbon Trust (2010) shows that leakage rate can increase by 5% for every €1 increase in carbon price.

- ***Similar impact on leakage for widely difference carbon prices*** - for example, Kuik (2010) estimated a leakage rate of 35% for the iron and steel sector with a carbon price of €35 per tonne using a General Equilibrium Model. The equivalent estimate from the Carbon Trust (2010) study was 40% based on a carbon price of €14.5 per tonne. This result is counterintuitive, and can be explained by differences in the assumed climate policy. Kuik's assumption of climate policy was a simplified

EU ETS covering electricity, mineral products and iron and steel sectors only. These sectors are capped, and there is no possibility of trade outside this ETS. All allowances are auctioned, and participants can trade between themselves. The Carbon Trust on the other hand considers the EU ETS as it stood in 2010, with all 30 participant countries and free allocation. It follows that even with a lower carbon price and a less stringent climate policy, the Carbon Trust result is a higher rate of carbon leakage.

- ***Widely different impact on carbon leakage for similar carbon prices*** – For example, for a carbon price of €20 for the steel sector in Kuik (2010), Demailly & Quirion (2008) and Reinaud (2008), the impact on leakage ranges from 5% to 55%.

Table 8 – Studies with similar carbon prices

Study	Carbon Leakage Estimate	Carbon price
Kuik (2010)	35%	€ 20
Kuik (2010)	29%	€ 20
Demailly & Quirion (2008)	5%[19]	€ 20
Reinaud (2008)	55%	€ 21
Reinaud (2008)	25%	€ 20

See Table 8 for a more complete explanation of the variation between estimates. This table simply seeks to demonstrate that the carbon price assumed is only one of a number of influential variables in calculating carbon leakage estimates.

To what extent measures such as free allocation or border tax adjustments have been implemented in order to protect against carbon leakage

Very few reports provide clear assumptions regarding the measures to reduce leakage.

The most comparable results which assess free allocation are in reports by DECC (2010) and Demailly and Quirion (2006 and 2008).

DECC's assessment does not look at estimates of carbon leakage, but the impact of a change from 50% to 80% free allocation on export volumes. Export volumes can be assumed to be carbon leakage under the assumption that foreign producers fill the gap left by the shift away from EU producers. This assumption overstates the results slightly, but the international data are not sufficient to estimate a robust relationship between export volumes and carbon leakage (DECC, 2010), so it provides a reasonable indicator. Selected results from DECC's work are presented below.

[19] With full free allocation assumption.

Table 9 – Effects of free allocation

	Percentage Change in Export Volume due to low uptake of the Copenhagen Accord[20]		
Sector	50% free allocation	80% free allocation	Percentage Change
Manufacture of ceramic tiles and flags	-22.6	-14.9	-34%
Manufacture of lime	-17.2	-11.3	-34%
Manufacture of basic iron and steel and of ferro-alloys	-7.3	-5.9	-19%
Casting of steel	0	0	0%

The distribution of free allowances only impacts on demand through the reduction of direct costs and not indirect costs, as a result, sectors which have a large direct-to- indirect cost ratio (such as ceramics and lime) are affected most by the allocation of free allowances. By contrast, Manufacture of Basic Metals and Steel and of Ferro Alloys are only partly protected by the use of free allocations because it faces a significant indirect cost and because of the level of trade and product homogeneity (DECC, 2010).

Demailly and Quirion (2006) look at two different ways of allocating allowances for free in the iron and steel sector under a simplified EU ETS: grandfathering allowances and an output based approach. Grandfathering is the most common approach used in modelling, and simply assumes an allocation of emissions for free based on historic emissions levels. There is no consideration of the efficiency of production here, i.e. the tonnes of CO2 per unit of output. This is what the second method tries to account for, whereby a certain amount of allowances per unit of output is determined and multiplied by the total output level. The results showed very different levels of carbon leakage, under grandfathering 50% of emissions leak outside the EU in an EU ETS compared with 9% under an output based approach. However, they concluded that whilst carbon leakage is smaller under an output based approach, so are overall emissions reductions, leading to little difference in the final reduction in global emissions.

In 2008, Demailly and Quirion went on to show a modest leakage rate of 5% in their central scenario for the iron and steel sector with full free allocation unadjusted over time. The leakage rate is lower (3%) if updating of allocations occurs based on the CO_2 per unit of output, softening the international trade impact of the ETS. It is in between the two if updating occurs based on historical emissions (4.5%).

[20] EU honours its commitment to a 20% fall in greenhouse gas emissions by 2020, and the rest of the world honours the commitments announced as part of the Copenhagen Accord. EU's commitment has a carbon cost of €30/tCO2, with trading partner carbon costs based on an analysis of their carbon targets by the project team of this study.

OECD (2008) shows that countervailing border tax adjustments for competing imported goods equal to the level of the carbon price can be effective in reducing carbon leakage. The climate policy assumption requires the EU to reduce all greenhouse gas emissions by 50% in 2050. Initial estimates, with no countervailing policy, show carbon leakage to reach 20%, falling to 6.5% with countervailing border tax adjustments.

Estimates from Kuik (2010) show that carbon leakage in the iron and steel sector fell from 35% to 29% if importers were required to pay for allowances on goods covered by climate policy if produced in the EU. This is equivalent to making the border tax adjustment equal to the carbon price imposed. However, this is not to say that iron and steel is a sector which is not as responsive to border tax adjustments as other sectors just because the reduction in leakage rate is lower than the OECD (2008) estimate. The difference could be explained by a number of other differences in the parameters set or the model used in the study.

Demailly and Quirion (2005) also looked at the effectiveness of countervailing measures such as border tax adjustments. In this instance, competing imports are taxed, and exports are subsidised so as to protect both domestic and export markets. Keeping all other assumptions the same in their model of the effects of the Kyoto Protocol on the 27 EU MSs and the rest of Western Europe, Russia and the Ukraine, Japan and Canada, carbon leakage falls from 25% to -6% in 2010 at a carbon price of €15 per tonne.

The sectors being assessed

Sijm (2004) cites eight carbon leakage estimates which look at the effect the Kyoto Protocol has had on Annex I countries. Without emissions trading schemes, carbon leakage is believed to be between 5-21% with a mean of 13% from eight different estimates.

Cement & Clinker and Iron & Steel are the most reported and highest at risk sectors, with estimates up to 70% and 26% respectively. According to Kuik (2010), mineral products are also at a very high risk. These higher estimates show the effect of the increased stringency of climate policy compared to the Sijm estimates of 2004 which were based solely on the Kyoto Protocol.

Carbon leakage occurs through trade flows and impacts on the energy price (Type 3). Energy price leakage arises due to the reduction in demand of fossil fuels in the EU/UK and the subsequent fall in price of fossil fuels and thus greater demand in non-EU/UK countries. This would result in, for example, power generation methods being more energy intensive outside the EU/UK (Kuik, 2010). However, clear evidence of this process is not provided in the literature as this would require an understanding of the marginal power plants displaced.

Global carbon emissions may also rise by carbon leakage that occurs because non-EU suppliers gain a competitive advantage over EU suppliers leading to more carbon intensive production outside the EU. If this is the case, it would be compounded by the fact that the EU is modelled to be the worst affected region from the Kyoto Protocol, accounting for 41% of total leakage caused by its mandatory commitments. The chemicals and iron and steel sectors make the highest contributions (20% and 16% respectively) to total global leakage under the same modelling assumptions (IPCC, 2007).

In terms of the geographic coverage of carbon leakage, it is suggested that most of the 35% of emissions leakage from the EU steel sector will leak to Russia, China and South Africa (Kuik, 2010).

Geographic coverage and assumption regarding climate policies in regions outside of that being assessed

The studies covered in detail all assume that the climate policy region is completely unilateral in its approach, whilst conceding that this is not realistic and that climate policy elsewhere would reduce the leakage rates.

However, the studies do cover a range of regions. For example, Reinaud (2008) looks at a simplified EU ETS only covering 15 EU MSs, many of the others consider the EU ETS with 27 MS and the OECD (2008) look at the impacts of the EU ETS compared with the Kyoto Protocol which covers Annex I countries.

Different regional coverage of the climate policy can have its own effects on leakage rates. The magnitude and the nature of leakage can change with the size of the coalition. The wider the country coverage, the smaller the market share losses affecting energy-intensive industries in participating countries, but the larger the impact of policy action on international fossil fuel prices (OECD, 2008).

The fact that carbon leakage may become very small in a large coalition does not imply that output effects for energy-intensive industries in domestic and international markets are negligible. In fact, OECD (2008) show the world output would fall, and furthermore this world output loss would be unequally distributed across regions. In particular, under the Kyoto Protocol, European energy-intensive industries would be less affected than their less energy-efficient foreign competitors, not least from developing countries. The overall size and unequal distribution of the output loss of energy-intensive industries hint at possible political obstacles to including them in a wide international agreement (OECD, 2008).

Whether or not the model includes just carbon dioxide, or all greenhouse gases converted into carbon dioxide equivalent

Research undertaken by the OECD (2008) shows that by extending emissions trading systems beyond CO_2, it is possible to reduce the risk and size of carbon leakage. OECD (2008) modelled a European Union only climate policy for CO_2 against the same parameters but for all greenhouse gases. The carbon leakage rate jumped from 20% to 29% under the CO_2 only scheme. This reflects both lower marginal abatement costs when all GHGs are included, and the fact that incorporating non-CO_2 gases shifts some of the burden of emission reductions onto sectors, such as agriculture, that have only a small influence on world fossil fuels markets[21].

[21] Note that EU ETS and EU targets do not only relate to CO_2. The EU ETS will include PFCs from aluminium production and N2O from Nitric Acid production in Phase III. The EU economy wide targets are GHG based.

The year in which the leakage rate is estimated

OECD (2008) shows that carbon leakage increases over time if no action is taken. Referring again to their scenario of cutting all greenhouse gases in the EU by 50% in 2050 against a 2005 baseline, carbon leakage increases from 12.6% to 20% between 2020 and 2050 across all sectors.

This is not the case in the cement sector according to Demailly and Quirion (2005). In their model of the effects of the Kyoto Protocol on the 27 EU MSs and the rest of Western Europe, Russia and the Ukraine, Japan and Canada, with a price of €15 per tonne of CO_2, the rate of carbon leakage falls from 25% in 2010 to 13% in 2020 and then rises 16% in 2030.

Table 10 - Summary of carbon leakage estimates and assumptions from different models

Annex Ref.	Reference	Sector	Carbon Leakage Estimate	Year of estimate	Carbon price per tCO_2	Climate Policy causing carbon leakage	Regions covered	Greenhouse gases covered	Leakage prevention measures
[30]	OECD, 2008	All	19.9%	2050	N/A	50% reduction in CO_2 on 2005 levels by 2050	European Union	All GHGs	None
[30]	OECD, 2008	All	6.5%	2050	N/A		European Union	All GHGs	Countervailing tariff equal to carbon price
[30]	OECD, 2008	All	9.1%	2050	N/A		Annex I	All GHGs	None
[30]	OECD, 2008	All	5.2%	2050	N/A		Annex I	All GHGs	Countervailing tariff equal to carbon price
[30]	OECD, 2008	All	28.7%	2050	N/A		European Union	CO_2 only	None
[30]	OECD, 2008	All	30.2%	2020	N/A		European Union	CO_2 only	None
[30]	OECD, 2008	All	12.6%	2020	N/A		European Union	All GHGs	None
[30]	OECD, 2008	All	-0.1%	2020	N/A	2.7Gt CO_2 which is equivalent to 50% of EU emissions on 2005 in 2050	Annex I	All GHGs	None
[30]	OECD, 2008	All	1.4%	2050	N/A		Annex I	All GHGs	None
[30]	OECD, 2008	All	-0.7%	2020	N/A		Annex I and Brazil, India and China	All GHGs	None
[30]	OECD, 2008	All	-0.3%	2050	N/A		Annex I and Brazil, India and China	All GHGs	None

Annex Ref.	Reference	Sector	Carbon Leakage Estimate	Year of estimate	Carbon price per tCO_2	Climate Policy causing carbon leakage	Regions covered	Greenhouse gases covered	Leakage prevention measures
[8]	Kuik, 2010	Iron and Steel	35.0%	N/A	€ 20.0	Simplified EU ETS including electricity, mineral products and iron and steel sectors only. These sectors are capped, and there is no possibility of trade outside this ETS. All allowances are auctioned, and participants can trade between themselves.	27 EU Member States plus Iceland, Liechtenstein and Norway	CO_2 only	None
[8]	Kuik, 2010	Iron and Steel	29.0%	N/A	€ 20.0			CO_2 only	Obligatory purchase of allowances by importers based on direct CO_2 emissions per unit of similar product in the EU
[8]	Kuik, 2010	Iron and Steel	2.0%	N/A	€ 20.0			CO_2 only	Obligatory purchase of allowances by importers based on average direct CO_2 emissions per unit of production in the foreign (exporting) country
[8]	Kuik, 2010	Mineral Products	19.0%	N/A	€ 20.0			CO_2 only	None
[8]	Kuik, 2010	Cement	50.0%	N/A	€ 20.0			CO_2 only	None
[1]	Demailly & Quirion, 2008	Iron and Steel	5.0%	N/A	€ 20.0	EU ETS	EU 15	CO_2 only	Full free allocation. Leakage rate drops to 3.5% in case of linear reduction in allocation between periods.

Annex Ref.	Reference	Sector	Carbon Leakage Estimate	Year of estimate	Carbon price per tCO_2	Climate Policy causing carbon leakage	Regions covered	Greenhouse gases covered	Leakage prevention measures
[23]	Reinaud, 2008	Iron and Steel	35.0%	2020	€ 11.0	Carbon tax	EU15 and Japan	CO_2 only	None
[23]	Reinaud, 2008	Iron and Steel	55.0%	2030	€ 21.0			CO_2 only	None
[23]	Reinaud, 2008	Iron and Steel	70.0%	2030	€ 42.0			CO_2 only	None
[23]	Reinaud, 2008	Iron and Steel	45.0%	N/A	€ 25.0	OECD wide carbon tax on steel and electricity for steel sectors.	OECD	CO_2 only	None
[23]	Reinaud, 2008	Iron and Steel	60.0%	N/A	€ 25.0	Unilateral carbon tax on steel and electricity for steel sectors.	OECD	CO_2 only	None
[23]	Reinaud, 2008	Cement	20.0%	N/A	€ 15.0	Carbon tax	Annex B countries except the US, Australia and New Zealand	CO_2 only	None
[23]	Reinaud, 2008	Iron and Steel	0.5%		€ 20.0	EU ETS	EU 15	CO_2 only	Approximately 95% free allocation. Leakage rate drops to 3.5% in case of linear reduction in allocation between periods.
[23]	Reinaud, 2008	Iron and Steel	25.0%		€ 20.0			CO_2 only	
[47]	Demailly & Quirion, 2006 (Climate Strategies)	Cement	9.0%	2010	€ 20.0		EU 27	CO_2 only	90% Allocation given based on output of previous period

Annex Ref.	Reference	Sector	Carbon Leakage Estimate	Year of estimate	Carbon price per tCO_2	Climate Policy causing carbon leakage	Regions covered	Greenhouse gases covered	Leakage prevention measures
[47]	Demailly & Quirion, 2006 (Climate Strategies)	Cement	50.0%	2010	€ 20.0			CO_2 only	90% Allocation grandfathered
[10]	Demailly & Quirion, 2005	Cement	25.0%	2010	€ 15.0	Kyoto Protocol	Europe (EU 27 and the rest of Western Europe), Russia and the Ukraine, Japan, Canada	CO_2 only	None
[10]	Demailly & Quirion, 2005	Cement	13.0%	2020	€ 15.0			CO_2 only	None
[10]	Demailly & Quirion, 2005	Cement	16.0%	2030	€ 15.0			CO_2 only	None
[10]	Demailly & Quirion, 2005	Cement	-6.0%	2010	€ 15.0			CO_2 only	Border tax adjustments which make imports into the climate policy area equal on cost to domestic produce, and subsidies for exporters from within the climate policy area which make the price equal to that in the non-climate policy area

Annex Ref.	Reference	Sector	Carbon Leakage Estimate	Year of estimate	Carbon price per tCO_2	Climate Policy causing carbon leakage	Regions covered	Greenhouse gases covered	Leakage prevention measures
[10]	Demailly & Quirion, 2005	Cement	4.0%	2010	€ 15.0			CO_2 only	Border tax adjustments which tax CO_2 based on emissions which would have occurred using best available technologies. Added to imports and subsidised on exports from climate policy area.
[19]	DECC, 2010[22]	All sectors[23]	<25%	2020	€ 30.0	20% Reduction in EU	EU 27	CO_2 only	None
[19]	DECC, 2010[22]	Inorganic Based Chemicals	>25%	2020	€ 30.0			CO_2 only	None
[19]	DECC, 2010[22]	Ceramic tiles and flags	>25%	2020	€ 30.0			CO_2 only	None
[19]	DECC, 2010[22]	Bricks, tiles and construction products, in baked clay	>100%	2020	€ 30.0			CO_2 only	None
[19]	DECC, 2010	Agricultural tractors	>100%	2020	€ 30.0			CO_2 only	None

[22] Reference scenario only assessed as other scenarios only look at changes in demand. There is no way of converting changes in demand to comparable carbon leakage figures without further analysis on the carbon intensities of production used and the electricity generation mixes.

[23] Except Manufacture of inorganic basic chemicals, Manufacture of ceramic tiles and flags, Manufacture of bricks, tiles and construction products, in baked clay, Manufacture of agricultural tractors

Annex Ref.	Reference	Sector	Carbon Leakage Estimate	Year of estimate	Carbon price per tCO_2	Climate Policy causing carbon leakage	Regions covered	Greenhouse gases covered	Leakage prevention measures
[20]	Carbon Trust, 2010	Steel	40%	2016	€ 14.5	EU ETS	27 EU Member States plus Iceland, Liechtenstein and Norway	CO_2 only	None
[20]	Carbon Trust, 2010	Cement	20%	2016	€ 14.5			CO_2 only	None
[20]	Carbon Trust, 2010	Aluminium	20%	2016	€ 14.5			CO_2 only	None
[20]	Carbon Trust, 2010	All	10%	2016	€ 14.5			CO_2 only	None

3.7.6 Impacts on innovation and quality improvements

According to the European Parliament, a move to a 30% 2020 target in the EU could stimulate, not harm the economy (European Parliament, 2008). The study has estimated increasing the target would boost European investments on the whole from 18% to up to 22% of GDP. However, the OECD (OECD, 2008) states that such investment will not come about from carbon pricing alone for two reasons:

i. carbon pricing does not address the market failures undermining R&D, which are larger in climate mitigation than in most other areas,

ii. the price signals are not credible or consistent enough to encourage long term committed investment.

Increasing prices for primary production processes is effective in incentivising greater recycling of material however. Recycling materials is generally less energy intensive than producing materials from ore, and it is a more efficient use of natural resources. In the steel industry, carbon pricing is said to have increased scrap metal recycling by 2.3% (Kuik, 2010).

It is possible that innovation and clean technology development would thrive best under border carbon adjustments as opposed to free allocation (Holmes and Rollo, 2010; Vox, 2010). This however runs the risk of creating “murky protectionism” that would either involve impossibly complex administrative demands or result in arbitrary charges. Further, countries within the EU are not always the cleanest just because of the climate policies imposed (Climate Strategies, 2010a).

If the cost of relocation outweighs the cost of investing in cleaner technologies, the chances of carbon leakage are reduced and the environmental credibility of the climate policy stands a better chance of being enhanced (Barker, 2007).

However, not all carbon leakage involves complete industry relocation – non-EU countries may have spare capacity which could be used to meet demand at lower prices. Further, McKinsey and Ecofys show aluminium production declining entirely over the next 20 years in the US and Europe, meaning climate policy will just act as an accelerator (European Parliament, 2008).

3.7.7 Impacts on Energy Security

Across all literature, the potential for some states to compromise on energy security as a result of climate policy features relatively scarcely. However, the European Commission has looked at this issue in some detail because of the unique situation of some of the EU Baltic States purchasing energy from non-EU countries.

Power producers are, on the whole, not deemed to be at risk of carbon leakage because of transmission losses, fuel supply constraints and relocation costs. However, because of the Baltic States border with countries not bound by the EU ETS, it is possible that regulatory pressures within the EU result in a switch away from domestic power production. The issue leads to reduced energy security, and carbon leakage (Demailly and Quirion, 2008; European Commission, 2010a). This issue is reflected by the European

Commission's decision to grant temporarily free allowances under EU ETS to power generators in regions where this is a possibility.

3.7.8 Regional impacts of carbon leakage in the UK

Overall in the UK, only a few of around 150 manufacturing activity sectors are likely to be exposed to a loss of competitiveness and carbon leakage under the EU ETS. These are mainly the energy intensive industries such as, cement and clinker, steel from blast oxygen furnaces and aluminium (Kuik, 2010).

A consultation response by Rio Tinto Alcan suggested that under Phase III of EU ETS, their business in Northumberland will not be sustainable (Rio Tinto Alcan, 2009). The source quotes 620 direct jobs and 3000 indirect jobs would be affected if the UK government does not sufficiently compensate the aluminium smelter for its indirect emissions. The aluminium industry's problem comes about because prices are set on the London Metals Exchange and the Shanghai Futures Exchange (IEA, 2008), leaving no room for cost pass through (CE Delft, 2008).

Although Rio Tinto's problems are due to its indirect emissions not its location, being placed close to the coastline can also make installations more susceptible to carbon leakage (Carbon Trust, 2010; Boston Consulting Group, 2010); although the location of demand is also highly relevant.

3.7.9 Impacts by firm size

The EU ETS is the most debated policy on carbon leakage as it covers nearly half of the emissions from all sources in the European Union and is the largest carbon market in the world. Since the EU ETS qualification criteria are based on a level of annual emissions and thermal capacity, it largely covers heavy industry, and this is where most of the literature focuses on. In the UK, the cement, aluminium, fertiliser and iron and steel sectors have been identified as the sectors at greatest risk (Carbon Trust, 2010; Climate Strategies, 2010a). It follows that the impacts of carbon leakage are likely to be largest for the big emitters, leading to a focus on steel, cement, aluminium and a small number of other industries.

UK think tank Climate Strategies came to a similar conclusion, stating: "all studies identify only a limited number of sectors, repeatedly including steel, cement, aluminium, paper and pulp, some chemical subsectors and refineries. The ranking of sectors could vary depending on the industry structure of a country, and the length of the list depends on the political formulation of thresholds e.g. the CO_2 covered, the cost impact or trade intensity" (Climate Strategies, 2010a). In the context of the current status of climate policies around the world, this inevitably comes down to the qualification criteria of the EU ETS which focuses on power and heat generation and heavy industry.

Thus implications for firms with relatively low levels of emissions are not generally covered in the sectoral literature.

3.8 Robustness of results

Table 9, provides a summary of the variation in the impacts of carbon leakage. It outlines the key reports that have estimated these impacts recognising their modelling assumptions and limitations.

The main carbon leakage impacts (section 3.6) are covered in the first column. The second column describes the findings from the literature for the impacts including the variation in the evidence base. The third column shows some of the recurring themes in the literature for each impact. Column four shows which models are typically used to estimate the impact. The final three columns are intended to give direction for further investigation. 'Gaps in the literature' highlights areas where the authors believe there is lack of clarity and need for further information.

'Assumptions lacking clarity in the literature' should be viewed in tandem with Table 6 - Summary of critical discussions of the assumptions' above. The column shows the assumptions used, but not clearly discussed in the reports. The impacts in the literature are a result of the assumptions used. As discussed in section 3.4, without understanding the basis for the values used for each assumption, we cannot comment on the robustness of the impacts in great detail. This constraint also means that a like for like comparison of various studies is not possible without further research and engagement with the authors of the study.

However, by using Table 9 - "Carbon leakage impacts are sensitive to type of models and assumptions" as a basis for screening the quality of the reports, we have identified the reports that could be the focus of gaining more detailed information on underlying assumptions and methodologies. This is important because whilst a value - such as zero cost pass through across all sectors - may seem irrational, the authors could have used certain assumptions deliberately to demonstrate or emphasise particular impacts.

Some of the reports which we found to be particularly relevant to understand the impacts of carbon leakage are given below:

- Broader economy wide employment impacts were influenced by Potsdam Institute and Oxford Economics 2011 study (PIK and Oxford University, 2011), whilst local/regional and sectoral effects tend to be drawn from industry consultations or lobbying papers (Rio Tinto Alcan, 2009; CBI Wales, 2010; Boston Consulting Group, 2010).

- The Potsdam Institute and Oxford Economics 2011 study (PIK and Oxford University, 2011) also covers GDP and growth, supported by similar figures by academic publication Böhringer, Tol and Rutherford (Böhringer, 2009a; Böhringer, 2009b) and the European Parliament report (European Parliament, 2008).

- The impact on business decisions are well covered in the European Parliament report (European Parliament, 2008) as well as Climate Strategies report by Michael Grubb: ‘Ten (plus one) insights from the EU Emissions Trading Scheme, With Reference to Emerging Systems in Asia’ 2009 (Climate Strategies, 2009a).

- Trade impacts are covered at the EU level (Reinaud, 2009; Kuik, 2010).

- Global carbon leakage effects as a result of the Kyoto Protocol are provided by the IPCC (IPCC, 2007). Concurrent information on potential increases in global carbon emissions from EU based policy is provided (European Parliament, 2008; OECD, 2008; Barker, 2007) and UK specific effects are also covered (Carbon Trust, 2010; Climate Strategies, 2010a)

- Conflicting views on innovation and technology developments incentivised by climate policies are provided by European Parliament report (European Parliament, 2008) and Climate Strategies (Climate Strategies, 2010a).

- Demailly and Quirion (Demailly and Quirion, 2008) and the European Commission (European Commission, 2010a) cover the possible loss in energy security in the Baltic States due to the possibility of importing from bordering nations.

- Regional impacts of the cement industry in several European countries are covered by Boston Consulting Group (Boston Consulting Group, 2010). Sector specific studies are also very helpful in this respect (Rio Tinto Alcan, 2009; CBI Wales, 2010).

- Finally, the above reports tend to focus on industries most affected by carbon leakage. Most of which are the large energy intensive industries, as confirmed by Climate Strategies report for the European Parliament ‘Tackling Leakage in a world of unequal carbon prices’ (European Parliament, 2008).

Table 11 - Carbon leakage impacts are sensitive to type of models and assumptions

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Employment	UK cement industry could lose approximately 32,000 jobs (Boston Consulting Group, 2010). Rio Tinto Alcan state that 620 direct and 3000 indirect jobs at certain sites will be at risk (Rio Tinto Alcan, 2009). Potsdam Institute and Oxford Economics suggest net increase in employment of about 2% in the EU (PIK and Oxford University, 2011).	Reports covered either focus on one company or the EU as a whole. Employment effect at EU level seems to be a shift from energy intensive industries towards relatively more labour intensive clean technology.	General equilibrium, Forecasting models	Sectoral and regional impacts on jobs. Net impacts on jobs (winners and losers)	No discussion of possibilities of scaling back production activity at installations, assumption is all jobs would be lost. Trade elasticities and cost pass through not stated in modelling reports.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
GDP and growth	Wide range from small negative to small positive impact European Parliament reports (27, 36) and academic report by Böhringer, Tol and Rutherford show overall effect - 2% or less (Böhringer, 2009a; Böhringer, 2009b). Potsdam Institute and Oxford Economics suggest that EU's climate target from 20% to 30% can lead to net change in GDP between -0.66% and 1.37% in the EU (PIK and Oxford University, 2011) and GDP increases of $842 bn and up to 6% by 2020.	Economy wide impact is low but impacts for energy intensive industries may be substantial. Growth in clean technology will be enhanced.	General equilibrium, Forecasting models	Precise sectoral break down.	Elasticities, abatement costs not stated. Status of non-EU/UK climate policy not discussed.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Business decisions	Qualitative analysis shows small impact: European Parliament (European Parliament, 2008). Very difficult to model this impact. Exchange rates e.g. euro/dollar 50% fluctuation between 2001-2006) and energy/labour costs are more important factors: Climate Strategies (Climate Strategies, 2009a).	European Parliament (European Parliament, 2008): chemical and steel industries most at risk of investment leakage, but still quite low. 1-2% of all economic activities face significant cost increases relative to their value added. Resources for the future estimate that Chemical sector is at most risk in the EU with production declining by 3.2% (Böhringer, 2010). Climate Strategies concur with the above findings (Climate Strategies, 2009a).	General equilibrium, Partial equilibrium, Forecasting models	Qualitative surveys of industry on the impact of climate policy on business decisions compared to other factors.	Elasticities used are not stated. Cost pass through and Abatement cost curve also not stated. Weights given to different factors in business decisions.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Trade	Overall EU export demand in EU ETS sectors is predicted to fall by 9.1% and demand for imports rises by 8.1% (Jaeger, 2008). Cement sector imports can increase by 4% to 12% (Demailly and Quirion, 2006). Under the EU ETS, without border adjustments, competing foreign imports increase by between 4.1% (mineral products) to 9.0% (steel) and domestic supply decreases by 1.6% and 2.0% for mineral products and steel respectively. Therefore, under the EU ETS European manufacturing firms lose market share on the EU market and in export markets. (Kuik, 2010). Lack of evidence of trade changes due to climate policy in far east: (OECD, 2008).	Steel and cement consistently reported as worst affected with a possibility of up to 50% carbon leakage reported (8, 18). Difficult to isolate the impact of climate policies on trade effects due to the complex range of influences (IEA, 2008).	General equilibrium, Partial equilibrium, Forecasting models	Distinction between short- and long-term influences. Ex-post analysis.	Rates of cost pass through and elasticities not stated.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Global carbon emissions	In terms of carbon leakage, figures range from negative leakage (emissions reduction beyond the boundaries of the climate policy area) to over 100%, but more than half of the results are between 5-30%. Sectoral figures could be higher e.g. Cement & Clinker 50% (Barker, 2007). Industry sources have higher estimates than government publications. By incorporating all Greenhouse Gases, more cost effective reductions are possible; this could reduce leakage by 9%. OECD (OECD, 2008). Measures such as free allocation or border tax adjustments can substantially reduce leakage rates. OECD (2008) shows that countervailing border tax adjustments can reduce leakage from 20% to 6.5%. Chemical and Iron and Steel sectors deemed to be most affected sectors from Kyoto Protocol, contributing to 20% and 16% of total carbon leakage respectively (IPCC, 2007). UK sectors at most risk are cement, aluminium, fertiliser and iron and steel: (Carbon Trust, 2010; Climate Strategies, 2010)	Non-EU producers' processes believed to be more carbon intensive: European Parliament and Press (European Parliament, 2008; Eurogypsum, 2008). Increase in global emissions due to climate policy possible if this is the case. Most studies do not explicitly test the assumption on carbon price and subsequent impact on leakage. Leakage impacts differed for similar carbon prices and vice versa.	General equilibrium, Forecasting models	Ex-post analyses. Responsiveness of carbon leakage to carbon prices	Abatement cost curve information. Information on elasticities. Cost pass through information. Link between carbon price an leakage

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Innovation and quality improvements	Evidence of clean tech development, more efficient practices and recycling (up 2.3% in steel): Amsterdam Institute for Environmental Studies (Kuik, 2010) and academic report by P.Holmes, and J.Rollo (Holmes and Rollo, 2010). Protection of industry could hinder innovation outside climate policy zone: Climate Strategies (Climate Strategies, 2010a).	Creation of clean tech jobs.	Partial equilibrium, Forecasting models	Net effect on jobs and investment not considered directly. More information on possible side effects of protectionist policies.	Elasticities and cost pass through rates not stated.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Energy security	Likely to take time to see effects because of long term energy contracts still in place. EU ETS phase III could lead to greater energy demand for non-EU supplier, especially for Baltic states. Free allocation could be sufficient to protect suppliers, if free allocation not gauged correctly there is possibility of change to non-EU power generators.	Eastern EU Member States importing power generated from outside EU. Recognised as a risk to Baltic State energy security and the credibility of the EU ETS: academics Demailly and Quirion, D. and P. Quirion (Demailly and Quirion, 2008) and in European Commission papers (European Commission, 2010a).	General equilibrium, Forecasting models	Variation of possible impacts and quantification of benefit and costs. Improvements in energy security from clean technology development. Longevity and likely expiry date of electricity contracts in this region not stated.	Elasticities and abatement cost curve not stated.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Regional impacts in the UK	Devolved Administration level employment and GDP effects: less than 0.5% of employment and around 0.7% of Scottish GDP is in industries that could potentially see cost increases greater that 5%: Scottish Government (Scottish Government, 2010). Case studies at individual installation level showing employment and revenue impacts:(Kuik, 2010; CBI Wales, 2010) Rio Tinto Alcan may lose 620 Jobs at Lynemouth smelter and a further 3000 related jobs in the North East would be affected. 3.5 $MtCO_2$ could leak and Rio Tinto Alcan's £120m contribution to economy would be lost (Rio Tinto Alcan, 2009; Kuik, 2010) Corus steel at Port Talbot has a turnover of £2.7m and 7000 employees at risk of leakage from Wales: Welsh CBI (CBI Wales, 2010)	All jobs at risk at installation level. Coastal areas most at risk of competition: Boston Consulting Group (Boston Consulting Group, 2010). Rio Tinto Alcan at Lynemouth, (Rio Tinto Alcan, 2009) Corus Steel at Port Talbot (CBI Wales, 2010).	Partial equilibrium	Sectoral and regional impacts and proportion of jobs likely to be at risk.	Case studies present impacts based on assumption that all jobs at site are at risk. Elasticities not stated.

Impacts	Description of impact (including variation)	Common themes	Models used for estimating factor	Gaps in literature	Assumptions lacking clarity in the literature
Smaller companies	Not considered Heavy industry main focus, ranking of heavy industries in terms of their exposure: Climate Strategies (Climate Strategies, 2010a).		Partial equilibrium	Impact on smaller companies. Information on future of climate policy and how it will address smaller companies.	

4 Mitigation policy options considered

4.1 Introduction

In the literature, several options have been identified potentially to limit carbon leakage while maintaining ambitious climate change and energy policies. In this section we discuss these policy options, which include the use of free allocations compared to full auctioning of emissions allowances and free allocation compared to border adjustment mechanisms as covered in the literature. We also discuss mitigating actions taken up by firms and governments in response to policies.

4.2 Policy options identified in the literature

The aim of mitigation policy options discussed in this section is to remove any ‘free rider’ effect or unfair competition from third countries that have unconstrained carbon prices (European Commission, 2010a). It is apparent from the literature that addressing loss of competitiveness and carbon leakage in an effective manner will require a variety of sector specific policy approaches (Reinaud, 2009; European Parliament, 2008).

There is an order of preference emerging from the literature for mitigating policies. The preferred option seems to be to establish a level playing field and, in conjunction with this, implement free allocation and/or border adjustment mechanisms e.g. (Sijm, 2004; Climate Strategies, 2009a; European Commission, 2008; CE Delft, 2009). Obviously there are advantages and disadvantages of each policy option, and these are discussed in the following sections.

The policy options are defined as follows:

- **Allowances** indicate the amount of greenhouse gases that an industry can emit. Allowances have mainly been allocated for free during the initial phases (Phase I and II) of the ETS and will continue to be allocated for free in Phase III to sectors considered at risk of leakage (sectors not at risk will receive transitional free allocation, declining to 30% in 2020), in order to limit the cost to EU industries compared to non EU competitors who are not constrained by such a cap on emissions. Parties can sell to or buy allowances from one another as needed.

- **Auctioning of allowances** will be the main allocation method in the EU ETS as of 2013 (Phase III). Instead of allowances being given out for free they will be auctioned off to the highest bidder, either by Member States or through a central European platform (as proposed for Phase III).

- **Sectoral agreements** create a global sector-wide agreement on emission reduction targets between all emitters in a particular industry, including those in countries that do not have an economy-wide emission target.

- **Border tax adjustments (BTA)** are meant to restore competitiveness and either make imports more expensive (to internalise the CO_2 price) or subsidise exports (thereby compensating EU producers for the cost of allowances). The EU could also decide to introduce an import levy.

- **Cap and Trade Systems** are a mechanism for controlling greenhouse gas emissions. The EU ETS works on a "cap and trade" basis so that the total greenhouse gases that can be emitted in the system are limited. Within this cap, companies receive emission allowances which they can sell to or buy from other participants as required.

4.2.1 Free allocation to sectors prone to carbon leakage

It is argued that maintaining the free allocation of allowances to sectors prone to carbon leakage is an obvious and effective way to combat carbon leakage (European Commission, 2010a; Reinaud, 2009; DECC, 2010; European Commission, 2008). This is the route that has been used in the EU ETS from the very beginning to prevent carbon leakage. Studies that discuss free allocation all conclude that it can soften the impacts of the ETS on energy-intensive industries and reduce leakage as a result. This belief in the benefits of free allocation crucially hinges on the assumption that companies do not pass through the costs of their freely obtained allowances in the product prices.

Some ex-post empirical research has shown that some energy intensive industries have passed through the prices of their freely obtained allowances during Phase 1 and Phase 2 of the EU ETS (see section 3.6.5). In this case, free allocation may still limit investment leakage but not necessarily trade leakage[24]. Alternatively, it could be evidence that EU producers are able to increase their prices without losing significant market share and thus there is less risk of carbon leakage for these firms.

Indeed one challenge is to devise measures to mitigate carbon leakage without over-compensating and distorting trade (Reinaud, 2009; Climate Strategies, 2010d). Policy-makers analysing changes in European industry sectors' competitiveness following the introduction of the EU ETS will need to disseminate what impacts / changes are attributable to climate policy and which are due to other factors e.g. slowdown in demand, changes in exchange rates, etc.).

It is suggested for the steel industry, that free allocation with new entrant reserve[25] can go some way to prevent steel from being 'locked in' to the "suboptimal incentives created by free allocation". However, this will need to be complemented by either border levelling, specific agreements with principal producer regions e.g. Russia, Ukraine, Kazakhstan, Brazil, South Africa) or a global sectoral agreement imposing carbon costs on steel production in all significant producer countries (Carbon Trust, 2010).

It is argued that while free allocations might reduce carbon leakage from energy intensive sectors, they require the rest of the economy to 'work harder' to reach a given emissions

[24] CE Delft (2010)

[25] New entrant reserves would effectively offset the carbon cost from new investment decisions, but since these could operate for decades, industry is likely to want assurances of continuing protection well beyond the end-point of EU ETS Phase III in 2020.

target because they are more exposed to market pressures due to the higher targets imposed on them (Climate Strategies, 2010d; CE Delft, 2008). Free allocations degrade the underlying incentives to decarbonise, if they are based on historic emissions and there is an expectation that future levels of emissions may determine future allocations.

The literature reports that there is a strong economic foundation for auctioning. It ensures that price signals remain intact to drive efficient corporate and private decisions on consumption, innovation and low-carbon investments. The revenues created could be used to invest in low carbon technology and to compensate consumers as carbon costs start to be reflected in product prices (Climate Strategies, 2009a; CE Delft, 2008).

It is argued that in the steel sector a large proportion of the allowances may be auctioned without threatening the profitability of regulated firms (Demailly and Quirion, 2008). Conversely, it is claimed that in the absence of a comprehensive international agreement, auctioning of allowances would harm the competitiveness of European companies, especially in the energy-intensive industries (Fridtjof Nansen Institute, 2008)[26].

4.2.2 Recycling auction revenues to sectors prone to carbon leakage

Another option to minimise carbon leakage is to recycle and reallocate auction revenues to sectors prone to carbon leakage, for example through using revenues for energy saving investments in energy intensive industries. These revenues can also be used to stimulate R&D, either through specific projects or through economy wide R&D (Jaeger, 2008). The approach can be refined through the targeting of specific sectors that are vulnerable, e.g. sectors with low market power (Fitzgerald, 2009). Also energy-saving investment cost curves could be incorporated in the analysis, to see which sector has the largest scope for implementing technologies. However, targeted recycling of revenues is slightly welfare decreasing compared to lump-sum redistribution of auction revenues (Jaeger, 2008).

4.2.3 Sectoral agreements

Sectoral agreements are another policy option involving a global sector-wide agreement between all emitters in a particular industry. This is a very interesting possibility for energy-intensive sectors, because possibilities for leakage to other countries would be virtually eliminated, especially if a sectoral agreement takes the form of national sectoral binding targets in major economies (Reinaud, 2009). The international shipping and aviation industry would be good example for such an agreement due to the boundary transgressing and mobile nature of the industry. Sectors in developing countries could be supported financially and technologically to convince them to participate (Reinaud, 2009; OECD, 2008), 30). An important disadvantage of global sectoral agreements is that they can become costly if sectoral and economy-wide trading schemes are not interlinked e.g. through flexible market mechanisms such as the Clean Development Mechanism (CDM), because in that case, cheap options to reduce emissions in other sectors cannot be used. Furthermore, sectoral agreements may not necessarily take the form of emission trading, meaning that there may not be a binding cap but a performance standard. To our knowledge, such sectoral agreements do not yet exist and the above difficulties and risks may hinder their near future establishment.

[26] Reuters Planetark, January 16 2008.

It is suggested that a targeted approach to the nature and recognition of international credits in the ETS could be considered, for example, reinforcing efforts to move towards sectoral crediting based on ambitious crediting thresholds. Another approach could be to restrict the use of CDM credits generated in energy-intensive sectors e.g. steel, cement and aluminium) in third countries other than the Least Developed Countries (European Commission, 2010a).

4.2.4 Border tax adjustments

Border tax adjustments are the most commonly mentioned policy instrument in the literature. Adjustments may entail import levies, export subsidies or both, compensating for the disadvantage that EU based industry faces through compliance with ambitious climate policies and a price put on carbon (European Commission, 2010a; Reinaud, 2009). To prevent carbon leakage and competitiveness loss, border adjustments would need to level the playing field by covering all products vulnerable to carbon leakage, for example, used in an international framework (European Parliament, 2008; Climate Strategies, 2010d). In many modelling studies border tax adjustments reduce the risk of carbon leakage and the effect becomes larger from smaller coalitions of nations e.g. (OECD, 2008).It is suggested that border adjustment taxes can reduce carbon leakage in the iron and steel sector "forcefully" and the cement sector to a lesser extent (Kuik, 2010; Carbon Trust, 2010). A comparison of an Optimal Tax (which has been adjusted for technology and region specific differences in carbon-intensity) with a simple Border Tax (which is based on the average carbon intensity of steel making in non Annex B countries) conclude that both taxes reduce the level of carbon leakage. However, the level of Optimal Tax is less than or equal to the marginal environmental costs per unit of output. This is because an Import Tax lowers world market price of steel, decreases steel production in non Annex B countries and stimulates steel demand in these countries[27]. Conversely, it is suggested that border tax adjustments may lead to a slightly higher increase in cement price, impacting negatively on consumers in Annex B countries (Demailly and Quirion, 2008).

Border levelling[28] may be impractical for a sector with high trade value and diverse processes and products, making implementation extremely difficult and costly (Carbon Trust, 2010). Conversely, it is useful for energy intensive sectors which operate in international markets, produce homogenous products and have high operating carbon cost impacts (Climate Strategies, 2010d).

There are questions over whether border tax adjustments are in line with WTO agreements. A 'WTO-proof' version is suggested (Demailly and Quirion, 2008), whereby import is taxed up to the value of CO_2 that would have resulted from production in the home country with the most energy-efficient technique available and the least carbon-intensive fossil fuel, export is subsidised to the same amount. If not used in an international framework, border tax adjustments run the risk to be criticised for being 'protectionist' (Demailly and Quirion, 2008; Holmes and Rolle, 2010; CE Delft, 2009). Contrary to this argument, it is suggested that border adjustments do not discriminate

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[27] Mathiesen and Maestad (2004) in Kuik and Hofkes, 2010.

[28] Border levelling aims to include importers in order to avoid discriminating between domestic and foreign production of particular, exposed carbon-intensive products consumed in the EU. Border levelling is distinct from border adjustment measures.

against regions, nor do they threaten trade or political relations (Climate Strategies, 2010d).

There are other arguments which state that border tax adjustments could involve overly complex administrative systems, including measuring, monitoring and verifying the emissions from imported products or setting an appropriate baseline of emissions produced in other countries and establishing ‘fair’ greenhouse gas pricing for these goods. This could lead to arbitrary charges, thus impeding attempts to ensure that green growth strategies are based on the most competitive technologies (Demailly and Quirion, 2008; Holmes and Rolle, 2010; Reinaud, 2009; CE Delft, 2009).

To summarise, the two main challenges associated with border adjustment mechanisms are suggested to be providing clear justification for border measures (assessing carbon leakage) and establishing a price to impose on imported products to bring prices in line with domestic cost of compliance with ETS.

4.2.5 Other actions

Joined up trading systems

It is argued that the threat of carbon leakage and job losses lends weight to the argument of ultimately creating a global cap-and-trade regime that is as inclusive as possible. The more countries, particularly all major economies, that participate under the same constraints (bringing efforts closer to those of the EU), the less the scope for carbon leakage and competitiveness concerns (European Commission, 2010a; European Commission, 2008). In theory, this option would appear the most straightforward. In practice, it is the most difficult and currently politically unfeasible judging from several failed climate negotiations in the past. If the whole world was covered by the same climate change policy (and carbon price), carbon leakage would not exist as it would eliminate any potential for avoidance.

One Carbon Trust report (2009) suggests that emissions trading systems should be interlinked so that one system’s trading units can be used in other countries’ trading systems and hence make emission reduction more cost effective. This could increase the carbon market by connecting otherwise isolated domestic systems, include more participants with greater abatement options, and thereby improve market liquidity and efficiency. Potential benefits of this approach include greater stability and predictability, higher economic efficiency (cost effectiveness), and reduced competitiveness distortions; it would also greatly reduce the administrative complexity for multinational companies in managing different systems. Importantly, the EU has expressed a desire to establish, though linking, an OECD-wide carbon trading market by 2015 and to extend this to other developing country emitters by 2020 (Carbon Trust, 2009).

Investment in low carbon products and technology

Meeting ambitious emissions reduction targets will require new approaches to creating large-scale low-carbon investment in technologies, services and products (European Commission, 2010a; Reinaud, 2009). The EU could help partners to meet European policy standards and close any potential competitive gap, by promoting low carbon technology transfer for developing countries and emerging economies. For developed partners, the rapid development of an international carbon market covering, in the first place, the most energy-intensive sectors across the world, would remove the need for special measures to be taken (European Commission, 2010a). However winning political support for this kind of actions will require demonstrating the potential benefits of ambitious climate action and low carbon technologies rather than the costs of the low-carbon transition[29].

Investment subsidies

It is reported that investment subsidies would protect carbon intensive producers from the cost of carbon (European Parliament, 2008). In particular, the aluminium industry would benefit from investment subsidies. These would need to be considered on a case-by-case basis consistent with EU State Aid restrictions. This should be conditional on the basis that industry steps up efforts to obtain power from low-carbon sources (Carbon Trust, 2010; European Parliament, 2008).

Environmental tax reforms

Leaving aside issues of subsidiarity, Europe-wide use of environmental tax reform, by contrast with a unilateral application by individual countries, would give less cause for concern about loss of competitiveness within the EU, but not on a global scale. An advantage of ETR over environmental regulations lies in the availability of tax revenues that can be used in ways that reduce the inclination of an industry/company to relocate (Fitzgerald, 2009).

Other mitigation options

Implementing full carbon-added accounting procedures for aluminium and other electricity-intensive processes at the international scale could also prove effective. Product labelling could increase consumer demand for ‘low carbon’ aluminium and provide the basis for border levelling that reflects the carbon embedded in the product. Product labelling would reward low carbon intensive manufacturers wherever they are located (Carbon Trust, 2010).

4.3 Examples of reactions by industries in response to European climate policies

There is some coverage of responses by industries to energy and climate change policies. Most of this information is reported by industry representatives. For example, on January 11th 2008, the Alliance of Energy-intensive industries sent a letter to all 27 Commissioners stating that they were ‘very concerned that the European Commission does not take upfront a firm stand on free allocation to globally competing industries’[30] (Fridtjof Nansen Institute, 2008).

Jean-Pierre Clavel, president of Eurogypsum which represents European manufacturers of gypsum-based products, argues that the European Commission must understand that the

[29] Chatham House, 2008 in Reinaud, 2009
[30] Alliance of Energy Intensive Industries, January 11 2008; ENDS Daily, January 15 2008

industry takes its investment decisions with a long term perspective of thirty years in line with different criteria of profitability.

A reaction by Corus Steel suggested targeted measures for different sectors rather than a blanket free allocation which could undermine incentives to decarbonise[31]. Their report proposed free allocation for steel, under serious competitive pressure with little imminent chance of technological breakthrough, measures to reduce electricity costs for aluminium and compelling cement importers to buy carbon allowances to cover the CO_2 emissions embedded in their imports (ENDS, 2010).

It has been reported that much of the EU primary smelter capacity is still under long-term electricity contracts and the specifics of these contracts are unknown (IEA, 2008). Hence, it is difficult to assess the exact impact of the ETS. By 2010, power supply contracts will have expired for 65% of European capacity. The reaction of smelters to this new environment will be an indication of the seriousness of climate policy.

4.4 Mitigating actions taken by governments (UK, EU and International)

While there is very good coverage of mitigation policy options that could be adopted by governments, the literature does not provide a lot of discussion on actions that have already been taken in response to energy and climate change policies. This is suggested as an area for further research.

[31] ENDS Report 422, pp 15-16

5 Conclusions

This study has reviewed a wide range of publications to analyse the evidence regarding carbon leakage which might be expected from cumulative cost of energy and climate change policies. The evidence and conclusions relate to the UK where possible but most studies are at company, sector or EU level. Sectoral breakdown of the impacts of carbon leakage have been provided but these are limited to energy intensive industries such as cement, steel and chemicals. Economic impacts such as GDP changes, job effects, trade impacts, investment decisions, innovation/quality improvements were also covered in some of the studies. However, the methods and assumptions used have a number of shortcomings that can be the focus of further research. We have also reviewed a number of policy options to mitigate leakage impacts. Policy options covered the impacts of free allowances compared to full auctioning of emission allowances as well as options such as sectoral agreements and border tax adjustments.

5.1 Coverage of literature review

This study has examined a wide range of sources, from academic and press, to consultation responses and publicly available documents. These sources had varying analytical approaches: theoretical, empirical and modelling. The majority of sources reviewed were classified as empirical or modelling. Modelling sources used a range of models, including general equilibrium models, partial equilibrium models and forecasting models.

The sources covered a range of sectors, namely energy intensive industries including aluminium, cement and clinker, steel, ceramics and lime and gypsum. A number of reports were non-sector specific.

Geographic coverage of sources was less varied than sectoral coverage. Most of the sources were applicable at the EU level, focusing on the impacts of the EU ETS. Some sources were relevant to the international debate, e.g. Japan, United States. There is a lack of regional data on the impacts of energy and climate change policies in the UK. Evidence is very limited and confined to the national level (UK wide) or to specific sectors.

5.2 Theory and drivers underpinning analysis

The economic theory of impacts of unilateral climate and energy policies is well developed. In the empirical research three different hypotheses (pollution haven hypothesis, factor endowment hypothesis and Porter hypothesis) have been used to analyse carbon leakage. Independently the findings from all three hypotheses are relevant but partly contradict each other. The total economic impacts can therefore be considered as the sum of the partial impacts described by these hypotheses.

The Pollution Haven Hypothesis predicts that energy intensive industries will gradually relocate to countries with lax environmental policies. The trade balance for energy intensive products will deteriorate for countries that install unilateral climate and energy policies. This impact was shown ex-post in the empirical literature and ex-ante in the economic models that have estimated the amount of carbon leakage. However, the impact is relatively small. Due to various formal and informal trade barriers energy intensive industries in the EU are partly protected against suppliers from countries where no climate policies are in place.

The Factor Endowment hypothesis predicts that economies of scale dominate international trade and that in energy intensive industries energy will be substituted for capital. The higher capital intensity of energy intensive industries will give them a further competitive advantage to countries that do not have such industries. This hypothesis seems to hold especially in trade with Africa and Latin America, but does not hold in the case of trade with China.

The Porter Hypothesis suggests that innovation will be enhanced in the short to medium-term so that energy intensive industries will experience lower costs of meeting energy and climate policies and can even save on costs of energy and material inputs that could make them more competitive in comparison with industries from countries that are not being faced with environmental regulation. While it is generally shown in empirical work that environmental policies do enhance innovation in clean technology and lower the costs of complying with environmental regulations, the cost-saving part of the Porter hypothesis does not seem to outweigh the cost increase of investments in clean technology. Hence, in other words, environmental regulation seems still to be a cost-factor for business although the costs tend to be lower than initially anticipated due to innovation.

When these three hypotheses are combined in ex-post empirical work they tend to show that the Pollution Haven Hypothesis is slightly stronger than the other two hypotheses, resulting in a net decrease in GDP. However, due to innovation and economies of scale, the impact is much lower than predicted in studies that only take into account the impact of the Pollution Haven Hypothesis alone. This could explain why some partial equilibrium analysis, mainly industry commissioned studies find much higher leakage impacts. Costs and trade impacts tend to be much smaller if innovation and economies of scale are properly defined and integrated into the model.

In economic models, a few key factors can be defined that determine the total outcome on carbon leakage. These are:

1. the abatement cost curve;
2. the elasticities of substitution for energy;
3. the trade elasticities;
4. the ability to pass cost of regulatory compliance on to the consumer; and
5. the extent to which non-EU/UK countries have put similar carbon and energy policies in place.

Out of these factors, the elasticities (energy and trade) are considered to be most important but also the most difficult to discern in empirical work. It may be the case that most of the variation in carbon leakage is actually due to the combination of the chosen parameters for energy and trade elasticities, but we cannot know this for certain as the studies do not report on which values have been chosen. Also the extent to which non-EU/UK countries have put similar carbon and energy policies in place is often ignored in ex-ante economic modelling. It is often assumed that other countries do not adopt ambitious climate policies. Studies that integrated these additional climate policies found in general much lower leakage and impacts on GDP. For example, even in China new power and iron and steel plants must comply with strict environmental regulations (OECD, 2008; Vivid Economics, 2010) that make them often cleaner and more efficient than EU plants. Although local air pollution seems to be the major driver for these regulations, they do have auxiliary benefits for energy efficiency and climate policies and entail considerable costs for businesses. Therefore one conclusion is that economic models should incorporate actual policy positions and not assume lack of similar initiatives in other parts of the world.

5.3 Carbon leakage findings

Over half of the 29 studies which commented specifically on the effects of carbon leakage on global carbon emissions and only a handful provide reliable quantitative estimates. Some provided a single estimate which gauged the effects of carbon leakage of a particular policy e.g. the EU ETS, while others provided several sector specific estimates. Findings from some of the key reports are discussed below.

Whilst emissions within EU borders are likely to fall under the current climate policies, over half of the studies estimates around 5% to 30% (with a mean of 21%) of this decrease to be carbon leakage, but not absolute reduction. This signifies that production and emissions from industries outside the EU will increase slightly (OECD, 2008; European Parliament, 2008; DECC, 2010; Sijm, 2004).

Five studies include free allocation in their assessment of the EU ETS. In these studies, carbon leakage estimates range from 0.5% to 50%, with an average of 18% (Demailly and Quirion, 2006, 2008 and Reinaud, 2008). Quantitative information and background assumptions on the impact of free allocation as a method for preventing carbon leakage are sparse in the literature. DECC (2010) however use export volumes as an indicator of the effects on carbon leakage. They find that the distribution of free allowances only impacts on demand through the reduction of direct costs and not indirect costs. As a result, sectors which have a large direct-to- indirect cost ratio (such as ceramics and lime) are affected most by the allocation of free allowances. By contrast, Manufacture of Basic Metals and Steel and of Ferro Alloys are only partly protected by the use of free allocations because it faces a significant indirect cost and because of the level of trade and product homogeneity (DECC, 2010).

Percentages of leakage could be even higher if marginal power generating plants and industry processes are more carbon intensive outside of the EU (European Parliament, 2008).

Impacts described in the literature are mainly focussed on heavy and energy intensive industry because of their particularly high exposure to risks of carbon leakage (Climate Strategies, 2010a). Cement & Clinker and Iron & Steel are commonly reported to be the most at risk (Kuik, 2010; Carbon Trust, 2010; Reinaud, 2008).

Energy intensive industries based in coastal areas tend to be more at risk than inland industries. This is because of the increased distribution requirements that imported goods would face, which effectively protect local industries with established networks (Boston Consulting Group, 2010).

By incorporating all greenhouse gases rather than just CO_2, the OECD found that the EU ETS could open up more cost effective abatement opportunities and thus reduce carbon leakage (OECD, 2008).

5.4 Economic impacts

Trade, GDP and employment effects are the main carbon leakage related economic impacts reviewed in the literature.

The evidence shows that the impact on jobs attributed to climate leakage varies quite significantly. Precise estimates on job leakage and net impacts on job numbers due to unilateral climate policies are lacking. The UK-based evidence, mainly from industry studies, lobbying papers and consultation responses by heavy industry points to direct and indirect job losses in local communities for specific sectors such as cement and aluminium (Rio Tinto Alcan, 2009; CBI Wales, 2010). On the other hand, EU studies state that ambitious climate policies can create additional jobs due to the shift of jobs from energy intensive sectors towards sectors producing clean technologies (PIK and Oxford University, 2011).

GDP impacts are sensitive to assumptions on trade elasticities, cost pass through ability and private capital and government investment. It follows that GDP impacts do not formulate a consistent pattern in the literature. Overall economy wide impacts tend to be under 2% of GDP, but some studies predict a decrease in GDP (Böhringer, 2009b; European Parliament, 2008) and some an increase (PIK and Oxford University, 2011). Only a few sectors, accounting for up to 1-2% of EU GDP, would ‘face significant cost increases’ through a higher carbon price. In the UK, only 1% of all economic activities face significant cost increases relative to their value added and in Germany less than 2% of all economic activities are affected (European Parliament, 2008).

Certain studies attempt to estimate the effects of policy on business decisions, and results tend to be low (European Parliament, 2008) – for example 3.2% investment leakage in the Chemicals industry (Climate Strategies, 2009a). Consensus is strong on the uncertainty around the impact of climate policy on business decisions, citing exchange rate fluctuations and labour costs as significantly more influential (Climate Strategies, 2009a).

Trade is often used as an indicator for carbon leakage. Overall EU export demand is predicted to fall by 9.1% and demand for imports rise by 8.1% (Jaeger, 2008) as a consequence of climate policy. Many studies rank which sectors are most at risk. Looking at the most widespread piece of climate legislation, the Kyoto Protocol, sectors most at risk are cement, chemicals, iron and steel and aluminium (IPCC, 2007). In the UK, the cement, aluminium, fertiliser and iron and steel sectors have been identified as the sectors at greatest risk (Carbon Trust, 2010; Climate Strategies, 2010a). Cement sector imports can increase by 12%, steel imports can increase by 9.0% and domestic supply could decrease by 1.6% and 2% for mineral products and steel respectively (Kuik, 2010).

Nations bordering the EU, such as Russia, have a comparative advantage over nations within the area covered by the EU ETS because they do not bear the cost of climate legislation. It follows that they may be able to offer cheaper energy supplies to nearby installations within the EU. Baltic States will therefore be importing energy, leading to carbon leakage and a lower level of energy security (Demailly and Quirion, 2008; European Commission, 2010a).

On the whole, there is strong evidence that climate policies stimulate technological innovation (Holmes and Rollo, 2010; European Parliament, 2008). Further, improvements in current manufacturing practices such as increased recycling are evident in the steel industry.

5.5 Implications of mitigation policy options

Most mitigating policy options discussed below are currently being reviewed by policy makers and have not been implemented at national or EU level. The implications of these options depend on a range of assumptions (e.g. market power, cost pass through ability, allowance price) not explicit in the literature. It is therefore difficult to assess the accuracy of the implications of policy options identified in the literature (see section 3.5.7). One must therefore examine the range of possible impacts which are summarised below.

Free allocation of allowance (under the EU ETS) is a favourable policy option where companies are not able to pass through costs.

The literature suggests that free allocation of allowances is the most effective way to reduce carbon leakage (European Commission, 2010a; Reinaud, 2009; DECC, 2010; European Commission, 2008; CE Delft, 2009). In particular, it is thought that free allocation can lessen the impacts of the EU ETS on energy-intensive industries and reduce leakage as a result. This belief hinges on the assumption that companies do not pass through the opportunity costs of their freely obtained allowances in the product prices. However, this is not always the case. In addition, it is argued that while free allocations might reduce carbon leakage from energy intensive sectors, they require the rest of the economy to 'work harder' to reach a given emissions target (Climate Strategies, 2010d; CE Delft, 2008).

Sectoral agreements are the preferred policy option for energy intensive sectors.

Sectoral agreements create a global sector-wide agreement between all emitters in a particular industry, including those in countries that do not have an economy-wide emission target. This is a very interesting possibility for energy-intensive sectors, because possibilities for leakage would be virtually eliminated (CE Delft, 2009) especially if a sectoral agreement takes the form of national sectoral binding targets in major economies (Reinaud, 2009). Closely connected to the use of sectoral agreements is the creation of a global cap-and-trade regime, built on the premise that the more countries (particularly major economies) participate under the same constraints, (bringing efforts closer to those of the EU) the less scope for carbon leakage and competitiveness concerns (European Commission, 2010a; European Commission, 2008).

Recycling of revenues is a useful policy option for sectors that cannot pass through costs

In the absence of an international agreement, auctioning of revenues would harm the competitiveness of European companies, particularly energy-intensive industries (Fridtjof Nansen Institute, 2008) [32]. If a company cannot pass through costs, it is likely to be more susceptible to leakage. Recycling auction revenues can be targeted towards those sectors that are particularly susceptible to carbon leakage (Demailly and Quirion, 2008; FitzGerald, 2009) although this has implications for welfare (Jaeger, 2008). This would help to raise funds for low carbon investments, thus helping companies to reduce the emissions associated with production.

[32] Reuters Planetark, January 16 2008

Border tax adjustments are an effective policy option for the iron, steel and cement industries

It is suggested that border tax adjustments could “forcefully” reduce leakage in the iron and steel industries (Kuik, 2010) and to a lesser degree in the cement sector (Demailly and Quirion, 2008; Kuik, 2010; Carbon Trust, 2010). However to help reduce carbon leakage and competitiveness loss, it would be helpful if border tax adjustments had a level playing field covering all products vulnerable to carbon leakage, for example, used in an international framework (European Parliament, 2008; Climate Strategies, 2010d). They could otherwise be criticised for being ‘protectionist’ (Demailly and Quirion, 2008; Holmes and Rollo, 2010; CE Delft, 2009). In many modelling studies border tax adjustments reduce the risk of carbon leakage and the effect becomes larger from smaller coalitions of nations (OECD, 2008).

5.6 Common elements in the literature driving the results

The common elements in the literature mainly concern the assumptions used in the modelling and the scope of the analysis (see section 5.7). Most studies assumed that similar climate policies are lacking in non-EU/UK countries. Non-EU producers’ processes were believed to be more carbon intensive. Reports mainly focussed on company, sector or EU as a whole.

Studies generally found that the economy wide impact is low but impacts for energy intensive industries may be substantial, particularly for the cement, steel and chemical sector (Kuik, 2010; Reinaud, 2009). Coastal areas were most at risk of competition due to relatively easier access to imported products.

Jobs seem to be more at risk at installation level than sector and economy level. Employment effects at EU level seem to be a shift from energy intensive industries towards relatively more labour intensive clean technology.

Most studies acknowledged the difficulty to isolate the impact of climate policies on trade effects due to the complex range of influences, modelling assumptions and approaches.

Studies acknowledged that growth in clean technology will be enhanced due to climate policies in the EU.

5.7 Remaining research gaps and uncertainties

We found that a number of different methods and assumptions have been used in the literature to estimate the impacts of carbon leakage. In addition to the assumptions, the robustness of the results is affected by the inherent nature of the models and the scope of the analysis. The main research gaps and uncertainties related to the modelling approach and assumptions are provided in Table 10 and discussed below.

It is stressed that there is very little ex-post empirical evidence of the impacts of energy and climate change policy, including the EU ETS, on international competitiveness or carbon leakage. Most studies take an ex-ante perspective and model the estimated impacts. It is expected that greater empirical ex-post analyses would be required on assumptions like trade elasticities, energy elasticities and cost-pass through and to understand the critical determinants that shape their values.

Similarly, there is little evidence on the best way to counter leakage (Kuik, 2010; OECD, 2008). Indeed empirical research focuses on the costs imposed by the EU ETS and not the effects of climate policy measures[33]. Furthermore, in order to progress towards EU emissions reduction targets, there needs to be greater consensus on the intensity of threat at sectoral level (ENDS, 2010). Studies that predict carbon leakage ratios and ranges of competitiveness loss tend to overstate the vulnerability of a sector. First, some form of free allocation proves the climate policy effects to be different from a pure CO_2 tax. Secondly, models do not take into account the broader reality of industrial activities in the global economy. For example, cost estimates for aggregate industry hide considerable intra-sector variations (Reinaud, 2008)[34].

Further simulations could be carried out to investigate the impacts of a broad range of possible international climate policy arrangements, including various combinations of economy-wide and sector-wide mitigation actions in order to gain insight into the strengths and weaknesses of policy options in practice.

[33] Reinaud, 2008, Convery et al, 2008
[34] Accredited to Herrnstadt et al, 2007 in Ref. (23).

Table 12 – Main research gaps and robustness of results

Study	Model used	Energy elasticities	Trade elasticities	Non-EU climate policies	Robustness
(Kuik, 2010) Institute for Environmental Studies Energy policy	GTAP-E, (CGE model)	Not provided	Not provided, but from GTAP-E, (adjusted)	None, just EU ETS	Difficult to assess
(Jaeger, 2008) Dutch Central Planning Bureau	World Scan	Not provided	Armington, central values varying from 4.6 to 7.4 for different products	One scenario includes a 'Grand coalition', emissions -30% in 2020 below 1990 levels	Difficult to assess
(OECD, 2008) OECD	ENV-linkages	Not provided	Not provided	BAU scenario, as well as -50% below 2005 levels by 2050 for the EU, Annex I or world	Difficult to assess
(Böhringer, 2010) RFF	CGE-model	Supply elasticities of 1 for crude oil & natural gas, 4 for coal	Not provided, but based on empirical estimates in GTAP	Reference scenario = 2004. Other scenario's: 20% reduction by US, EU or both.	Difficult to assess
(PIK and Oxford University, 2011) Potsdam Institute for Climate Impact Research (PIK) and Oxford University	GEM-E3	Not provided	Not provided	High pledges from Copenhagen agreement	Difficult to assess

The variation in the impacts of carbon leakage is affected by the modelling approach and the assumptions discussed in section 3.6. Assessing the robustness of the CGE model results is, however, difficult given that the crucial assumptions in these models are not made explicit in the literature reviewed Sensitivity analyses of these assumptions are largely missing in the literature. The research gaps and uncertainties related to the modelling assumptions are discussed below:

- More work is needed to assess fossil fuel supply elasticities, as well as their influence on the leakage rate and competitiveness effects of mitigation policies. Better sensitivity analysis relating to other parameters, not least international trade elasticities, is quite important (OECD, 2008). This could lead to constructive discussions and empirical work on the assumptions that are crucial for estimating the amount of carbon leakage.

- Cost-pass through ability is a crucial parameter in the context of carbon leakage and related economic impacts. It is important for understanding how the regulatory compliance burden is shared between producers and consumers. If costs are not passed through, companies will mostly pay the costs of meeting climate targets and profits will fall. However, if costs are passed through, then consumers would bear most of the compliance costs and profits of companies would remain largely unaffected. There were two main issues identified in the literature: 1) Cost-pass through rates were not reliable due to lack of robust data; and 2) there was a wide range of cost-pass-through rates. Hence, it would be useful to investigate this topic further especially for sectors most at risk from carbon leakage. Better understanding of cost-pass through rates is also important to assess the impacts of auctioning a larger share of emission allowances in an ETS. If companies are passing through the costs, auctioning can be a more efficient allocation mechanism in an ETS. Also if companies demand part of the auction revenues from national governments as compensation for additional compliance costs, then it is important to determine accurately the possibility of passing on costs to consumers.

- Precise modelling of environmental regulations in non-EU/UK countries. Too often it is assumed in models that the rest of the world has no environmental regulations in place which is an understatement of the true situation in many non-EU/UK countries. Studies generally assume that non-EU/UK producers' processes are more carbon intensive (European Parliament, 2008, Eurogypsum, 2008). This assertion has been contested in recent reports (Jaeger, 2008; Vivid Economics, 2010) though quantitative assessments of the amount of carbon leakage under various assumptions on carbon policies of non-EU/UK are still not available.

It is imperative that these assumptions should be made explicit in future studies to enable a clear understanding of the drivers underpinning the results. Also the authors could be consulted to provide additional information on their modelling assumptions and background materials. In addition, a meta-analysis of the various studies that do report quantitative figures on carbon leakage could be undertaken, as could an investigation of the most critical assumptions driving the results.

6 Annex

6.1 Annex 1: Literature Reviewed

The table below shows the studies reviewed in this project. The categories for the colour coding are as follows:

(#): Academic
(#): Consultation response
(#): Press
(#): Publicly available report

Table 13 – Literature review matrix

#	Organisation	Author (optional)	Commissioned by	Title	Year
(1)	Energy Economics	Demailly and Quirion, D. and P. Quirion		European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry. 30(4)	2008
(2)	Journal of Environmental Planning and Management	John FitzGerald; Mary Keeney; Sue Scott	Economic and Social Research Institute, Dublin and Economic Analysis and Research Department, Central Bank of Ireland, Dublin	Assessing vulnerability of selected sectors under environmental tax reform	2009
(3)	Energy Economics	Böhringer, Christoph, Andreas Löschel, Ulf Moslener and Rutherford Thomas F	Own research	EU Climate Policy Up to 2020: An Economic Impact Assessment. 31 (S2), 295-305	2009a
(4)	Energy Economics	Böhringer, C., Tol, R. S. J., Rutherford, T.F.	Own research	The EU 20/20/2020 Targets: an Overview of The EMF22 Assessment. 31(2), 268-273.	2009b
(5)	Öko-Institut – Institute for Applied	Graichen et al	Öko-Institut – Institute for Applied	Impacts of the EU Emissions	2008

#	Organisation	Author (optional)	Commissioned by	Title	Year
	Ecology		Ecology	Trading Scheme on the Industrial Competitiveness in Germany	
(6)	Fridtjof Nansen Institute		Fridtjof Nansen Institute	EU Energy-intensive Industries and Emissions Trading: Losers becoming Winners?	2008
(7)	Vox	P.Holmes, and J.Rollo	Vox	Border Carbon Adjustments: A leadership Role for the EU	2010
(8)	Institute for Environmental Studies Energy policy, 38 (4)	Kuik, O and Hofkes, M.	Institute for Environmental Studies, VU University Amsterdam	Border adjustment for European emissions trading: Competitiveness and carbon leakage	2010
(9)	Energy Policy	Barker	Department of Land Economy, Cambridge Centre for Climate Change Mitigation Research, University of Cambridge	Carbon leakage from unilateral Environmental Tax Reforms in Europe, 1995-2005. (35, 6281 - 6292)	2007
(10)	Venice Summer Institute	Damien Demailly and Philippe Quirion	Venice Summer Institute	Leakage from Climate Policies and Border Tax Adjustment: Lessons from a Geographic Model of the Cement Industry	2005
(11)	Rio Tinto Alcan	AEA		Consultation response on carbon leakage	2009
(12)	Eurogypsum	Jean-Pierre Clavel	Eurogypsum, trade body	Carbon leakage 'already happening'	2008
(13)	The Guardian		Press	Industry threats to relocate over carbon targets exposed as	2010

#	Organisation	Author (optional)	Commissioned by	Title	Year
				'misleading'	
(14)	EurActiv		Press	Commission faces revolt over 'carbon leakage' plans	2009
(15)	The Economist		Press	Are Countries that Regulate Greenhouse Gases Exposing their Industry to unfair Competition from Those that do not?	2008
(16)	ENDS report		Press	Should carbon leakage stifle EU climate goals?	2010
(17)	European Commission		European Commission	Analysis of options to move beyond 20% greenhouse gas emission reductions and assessing the risk of carbon leakage	2010a
(18)	DFID and Chatham House	Reinaud, J	DFID and Chatham House	Trade, Competitiveness and Carbon Leakage: Challenges and Opportunities	2009
(19)	Cambridge Econometrics		DECC	Assessment of the degree of carbon leakage in light of an international agreement on climate change	2010
(20)	Carbon Trust		Carbon Trust	Tackling Carbon Leakage: Sector specific solutions for a world of unequal carbon prices	2010

#	Organisation	Author (optional)	Commissioned by	Title	Year
(21)	Netherlands Research Programme on Climate Change	Sijm et al	Netherlands Programme on Climate Change	An assessment of the incidences of carbon leakage and induced technological change due to CO_2 abatement measures	2004
(22)	IEA		IEA	Climate policy and carbon leakage: impacts of the EU ETS on Aluminium	2008
(23)	IEA	Reinaud, J	IEA	Issues behind competitiveness and carbon leakage: focus on heavy industry	2008
(24)	Scottish Government		Scottish Government	Low Carbon Scotland: Draft Report on Proposals and Policies: Scotland - a Low Carbon Society	2010
(25)	CBI Wales		CBI Wales	Blueprint for a green economy	2010
(26)	Climate Strategies		Greens/EFA Group in European Parliament	Tackling Leakage in a world of unequal carbon prices	2010a
(27)	European Parliament	Policy Department	European Parliament	Economic and Scientific Policy. Competitive distortions and leakage in a world of different carbon prices Trade, competitiveness and employment challenges when meeting the post-	2008

#	Organisation	Author (optional)	Commissioned by	Title	Year
				2012 climate commitments in the European Union	
(28)	Potsdam Institute for Climate Impact Research (PIK) and Oxford University		German Federal Ministry for the Environment, Nature Conservation and Nuclear Safety	A New Growth Path for Europe	2011
(29)	Dutch Central Planning Bureau	Carlo C. Jaeger L. Paroussos, D. Mangalagiu, R. Kupers A. Mandel J. D. Tàbara	Netherlands Environmental Assessment Agency	Border tax adjustment and the EU-ETS, a quantitative assessment	2008
(30)	OECD		OECD	The economics of climate change mitigation: policies and options for the future. Economics department working paper, no. 658	2008
(31)	Resources for the future	Christoph Böhringer, Carolyn Fischer and Knut Einar Rosendahl	Resources for the Future, Washington	The Global Effects of Subglobal Climate Policies, Resources for the Future discussion paper	2010
(32)	Carbon Trust		Carbon Trust	Linking emission trading systems - Prospects and issues for business	2009
(33)	Boston Consulting Group		Boston Consulting Group	Assessment of the impact of the 2013-2020 ETS proposal on the European Cement Industry	2010
(34)	Environment		Environment Agency	Guidance on	2006

#	Organisation	Author (optional)	Commissioned by	Title	Year
	Agency			Assessing the IPCC Affordability Criterion	
(35)	European Commission		European Commission	Statistical analysis of the pass-through of carbon costs into electricity prices	2006
(36)	European Parliament		European Parliament	Study on the future elements of the EU ETS, including carbon leakage	2008
(37)	Congressional Research Service	Parker, L and Grimmett, J	Congressional Research Service	Climate Change: EU and proposed US approaches to carbon leakage and WTO implications	2010
(38)	European Commission	AEA for DG Climate Action	European Commission	Study on the impact of carbon leakage on Member States' energy security and appropriate measures	2010
(39)	Climate Strategies	Michael Grubb, Misato Sato	Climate Strategies	Ten (plus one) insights from the EU Emissions Trading Scheme, With Reference to Emerging Systems in Asia	2009a
(40)	Climate Strategies	Simone Cooper	Climate Strategies	Overview of competitiveness issues in Japan	2009b
(41)	Climate Strategies	Simone Cooper	Climate Strategies	Overview of competitiveness issues in Japan	2010b
(42)	Climate Strategies	Simone Cooper	Climate Strategies	Overview of competitiveness issues in Japan	2010c
(43)	Climate Strategies	Michael Grubb	Climate Strategies	Carbon leakage – myths and realities	2010d

#	Organisation	Author (optional)	Commissioned by	Title	Year
(44)	European Commission		European Commission	Impact Assessment accompanying the Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020	2008
(45)	Climate Strategies	Hourcade et al	Climate Strategies	Differentiation and Dynamics of EU ETS Industrial Competitiveness Impacts	2007
(46)	IPCC	Barker, T. et al	IPCC	"11.7.2 Carbon leakage", in B. Metz et al. Mitigation from a cross-sectoral perspective	2007
(47)	Climate Strategies	Demailly and Quirion, D., Quirion, P.	Climate Strategies	CO_2 abatement, competitiveness and leakage in the European cement industry under the EU ETS: grandfathering versus output-based allocation	2006
(48)	House of Lords		UK Parliament	Select Committee on European Union Thirty-Third Report : Chapter 5, Carbon Leakage	2008
(49)	PBL (Netherlands Environment Assessment Agency)	Den Elzen, M.G.J, Mendoza Beltran, J. van Vliet, S.J.A. Bakker T. Bole	PBL	Pledges and Actions. A scenario analysis of mitigation costs and carbon market impacts for developed and developing countries	2009

#	Organisation	Author (optional)	Commissioned by	Title	Year
(50)	CE Delft	S.M. de Bruyn, D. Nelissen, M. Korteland M. Davidson J. Faber G. van de Vreede.	Dutch ministry of Economic Affairs	Impacts on Competitiveness from EU ETS An analysis of the Dutch Industry	2008
(51)	CE Delft	Stephan Slingerland, Luc Werring, Sander de Bruyn, Marisa Korteland.	CIEP	The Climate for Steel - Actions for, and conditions to, a Copenhagen climate agreement from the perspective of the EU steel sector	2009
(52)	CE Delft	Sander de Bruyn, Agnieszka Markowska, Femke de Jong, Mart Bles.	European Climate Foundation	Does the energy intensive industry obtain windfall profits through the EU ETS? An econometric analysis for products from the refineries, iron and steel and chemical sectors. Publication number 10 7005 36	2010
(53)	Jusen ASUKA Tohoku University, Japan	Ning, Tonooka	OECD	Competitiveness and carbon leakage: the case of Japan and international comparisons	2008
(54)	Vivid Economics		The Climate Institute	The implicit price of carbon in the electricity sector of six major economies	2010
(55)	VRIJE UNIVERSITEIT	Onno Kuik	VRIJE UNIVERSITEIT	Climate change policies, international trade and carbon leakage: an applied general equilibrium analysis	2005

#	Organisation	Author (optional)	Commissioned by	Title	Year
(56)	University of Groningen - Faculty of Economics and Business	Umed Temurshoev	University of Groningen - Faculty of Economics and Business	Pollution Haven Hypothesis Or Factor Endowment Hypothesis: Theory And Empirical Examination For The Us And China	2008
(57)	Centre for European Economic Research (ZEW), Mannheim, Germany	Alexeeva-Talebi	Centre for European Economic Research (ZEW), Mannheim, Germany	Cost Pass-Through in Strategic Oligopoly : Sectoral Evidence for the EU ETS	2010
(58)	Centre for European Economic Research (ZEW), Mannheim, Germany	Oberndorfer, Ulrich, Victoria Alexeeva-Talebi and Andreas Löschel	Centre for European Economic Research (ZEW), Mannheim, Germany	Understanding the Competitiveness Implications of Future Phases of EU ETS on the Industrial Sectors	2010
(59)	Department of Planning and Environmental Policy	Walker, Neil	Dublin : University College Dublin, 2006	Concrete Evidence? : An Empirical Approach to Quantify the Impact of EU Emissions Trading on Cement Industry Competitiveness	2006
(60)	DG Trade	Johannes Bollen, Paul Koutstaal and Paul Veenendaal	European Commission	Trade and Climate Change	2011

6.2 Annex 2: Reports providing quantitative and qualitative data on global carbon emissions trajectories.

#	Organisation	Author (optional)	Commissioned by	Title	Year
(1)	Energy Economics	Demailly and Quirion, D. and P. Quirion		European Emission Trading Scheme and competitiveness: A case study on the iron and steel industry. 30(4)	2008
(8)	Institute for Environmental Studies Energy policy, 38 (4)	Kuik, O and Hofkes, M.	Institute for Environmental Studies, VU University Amsterdam	Border adjustment for European emissions trading: Competitiveness and carbon leakage	2010
(9)	Energy Policy	Barker	Department of Land Economy, Cambridge Centre for Climate Change Mitigation Research, University of Cambridge	Carbon leakage from unilateral Environmental Tax Reforms in Europe, 1995-2005. (35, 6281 - 6292)	2007
(10)	Venice Summer Institute	Damien Demailly and Philippe Quirion	Venice Summer Institute	Leakage from Climate Policies and Border Tax Adjustment: Lessons from a Geographic Model of the Cement Industry	2005
(11)	Rio Tinto Alcan	AEA		Consultation response on carbon leakage	2009
(15)	The Economist		Press	Are Countries that Regulate Greenhouse Gases Exposing their Industry to unfair Competition from Those that do not?	2008
(16)	ENDS report		Press	Should carbon leakage stifle EU climate goals?	2010
(17)	European Commission		European Commission	Analysis of options to move beyond	2010a

#	Organisation	Author (optional)	Commissioned by	Title	Year
				20% greenhouse gas emission reductions and assessing the risk of carbon leakage	
(18)	DFID and Chatham House	Reinaud, J	DFID and Chatham House	Trade, Competitiveness and Carbon Leakage: Challenges and Opportunities	2009
(19)	Cambridge Econometrics		DECC	Assessment of the degree of carbon leakage in light of an international agreement on climate change	2010
(20)	Carbon Trust		Carbon Trust	Tackling Carbon Leakage: Sector specific solutions for a world of unequal carbon prices	2010
(21)	Netherlands Research Programme on Climate Change	Sijm et al	Netherlands Programme on Climate Change	An assessment of the incidences of carbon leakage and induced technological change due to CO_2 abatement measures	2004
(22)	IEA		IEA	Climate policy and carbon leakage: impacts of the EU ETS on Aluminium	2008
(23)	IEA	Reinaud, J	IEA	Issues behind competitiveness and carbon leakage: focus on heavy industry	2008
(26)	Climate Strategies		Greens/EFA Group in European Parliament	Tackling Leakage in a world of unequal carbon prices	2010a
(27)	European Parliament	Policy Department	European Parliament	Economic and Scientific Policy. Competitive distortions and leakage in a world of different carbon	2008

#	Organisation	Author (optional)	Commissioned by	Title	Year
				prices Trade, competitiveness and employment challenges when meeting the post-2012 climate commitments in the European Union	
(29)	Dutch Central Planning Bureau	Carlo C. Jaeger L. Paroussos, D. Mangalagiu, R. Kupers A. Mandel J. D. Tàbara	Netherlands Environmental Assessment Agency	Border tax adjustment and the EU-ETS, a quantitative assessment	2008
(30)	OECD		OECD	The economics of climate change mitigation: policies and options for the future. Economics department working paper, no. 658	2008
(31)	Resources for the future	Christoph Böhringer, Carolyn Fischer and Knut Einar Rosendahl	Resources for the Future, Washington	The Global Effects of Subglobal Climate Policies, Resources for the Future discussion paper	2010
(33)	Boston Consulting Group		Boston Consulting Group	Assessment of the impact of the 2013-2020 ETS proposal on the European Cement Industry	2010
(36)	European Parliament		European Parliament	Study on the future elements of the EU ETS, including carbon leakage	2008
(39)	Climate Strategies	Michael Grubb, Misato Sato	Climate Strategies	Ten (plus one) insights from the EU Emissions Trading Scheme, With Reference to Emerging Systems in Asia	2009a

#	Organisation	Author (optional)	Commissioned by	Title	Year
(41)	Climate Strategies	Simone Cooper	Climate Strategies	Overview of competitiveness issues in the midwest	2010b
(43)	Climate Strategies	Michael Grubb	Climate Strategies	Carbon leakage – myths and realities	2010d
(44)	European Commission		European Commission	Impact Assessment accompanying the Package of Implementation measures for the EU's objectives on climate change and renewable energy for 2020	2008
(46)	IPCC	Barker, T. et al	IPCC	"11.7.2 Carbon leakage", in B. Metz et al. Mitigation from a cross-sectoral perspective	2007
(51)	CE Delft	Stephan Slingerland, Luc Werring, Sander de Bruyn, Marisa Korteland.	CIEP	The Climate for Steel - Actions for, and conditions to, a Copenhagen climate agreement from the perspective of the EU steel sector	2009
(52)	CE Delft	Sander de Bruyn, Agnieszka Markowska, Femke de Jong, Mart Bles.	European Climate Foundation	Does the energy intensive industry obtain windfall profits through the EU ETS? An econometric analysis for products from the refineries, iron and steel and chemical sectors. Publication number 10 7005 36	2010
(53)	Jusen ASUKA Tohoku University, Japan	Ning, Tonooka	OECD	Competitiveness and carbon leakage: the case of Japan and international comparisons	2008

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