Nordic Council of Ministers

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in the Nordic countries

What are the risks and how to design effective preventive policies?

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Helge Sigurd Næss-Schmidt, Martin Bo Westh Hansen,
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TemaNord 2019:525

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ISBN 978-92-893-6145-3 (PRINT)
ISBN 978-92-893-6146-0 (PDF)
ISBN 978-92-893-6147-7 (EPUB)
http://dx.doi.org/10.6027/TN2019-525

TemaNord 2019:525
ISSN 0908-6692

Standard: PDF/UA-1
ISO 14289-1

Cover photo: Unsplash.com

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Acknowledgements

This report was written by experts from Copenhagen Economics. Copenhagen Economics has re-ceived valuable comments and input from the associated steering group, but all results and conclusions are solely the views of the authors. The authors would like to thank everyone involved in the project for their time and valuable input.

26 March 2019

Preface

This is a follow-up to an analysis on carbon leakage published by the Nordic Council of Ministers in 2011. This report has been written by the consultancy Copenhagen Economics which also provided the analysis for the original report in 2011. In many ways the new report is in an update and a refinement of the analysis carried out eight years ago.

The problem caused by carbon leakage is still one of the priorities on the EU´s climate policy agenda. It is being debated especially as part of the design and implementation of the Union's emissions trading scheme (EU ETS). The EU ETS has mechanisms such as compensation through free allocation, which are included in the scheme in order to diminish the risk of carbon leakage. In a number of member states, a scheme has been introduced in order to compensate industry for higher power prices caused by the EU ETS.

In this report the risk of carbon leakage for industry is assessed especially from a Nordic perspective. The results of the analysis indicate that it is especially the energy intensive industry in the Nordic countries, which deserve attention with regard to the risk of carbon leakage. The report tells us that we should focus on the market conditions in which industries operate but also pay attention to their use of electricity and bioenergy. It turns out that the Nordic industry has some special features which are relevant with regard to the level of risk of carbon leakage.

The consultant discusses possibilities to improve and design a more focused scheme for preventing carbon leakage as part of the EU ETS. The perspective applied in the report is aiming for a more efficient climate policy. In that regard the conclusion of the Paris Agreement in 2015 was definitely a step in the right direction towards a level playing field. The policy recommendations offered in the report are the responsibility of the consultant and do not necessarily reflect the views of the Nordic Working Group for Environment and Economy.

December 2018

Signe Krarup
Chairman of the Working Group on Environment and Economy under the Nordic Council of Ministers

Executive summary

The risk of carbon leakage is an intensely debated issue in the European Union (EU) and in the Nordic region. Carbon leakage is a situation in which a policy-induced reduction in CO_2 emissions domestically is followed by increased emissions abroad. If climate policy increases production costs for domestic industries this puts them at a competitive disadvantage compared to foreign industries. As a result, domestic industrial production and CO_2 emissions will decrease, and foreign production and CO_2 emissions will increase. Hence, global CO_2 emissions are not reduced but merely moved from one region to another.

The scene of the debate on how to deal with the risk of carbon leakage is predominantly set in Brussels and is done in relation to the European Union's Emissions Trading System (ETS); EU's flagship climate policy instrument. To avoid carbon leakage, energy-intensive industries in direct competition with foreign companies are granted free allowances. However, deciding which industries should be considered at risk of carbon leakage and therefore given free allowances is not a straight-forward task. Currently, the European Commission does this by looking at the industries' characteristics at a European level. Hence, regional differences could be missed.

The question is: From a Nordic perspective, what industries are at risk of carbon leakage, and are there specific Nordic perspectives to bring forward to the EU debate?

Our assessment of risk of carbon leakage is based on market conditions

An analysis of the *risk* of carbon leakage should inherently be forward-looking. A specific industry can be subject to the *risk* of carbon leakage even if carbon leakage is not occurring under present market conditions. This is because current CO_2 policies might not be strong enough to trigger carbon leakage or that compensation schemes are successful in compensating companies for their higher costs, but if CO_2 policies were tightened carbon leakage could occur. Empirical studies have not found empirical evidence of significant carbon leakage, but we conclude that this cannot be used to say something about the risk in the future.

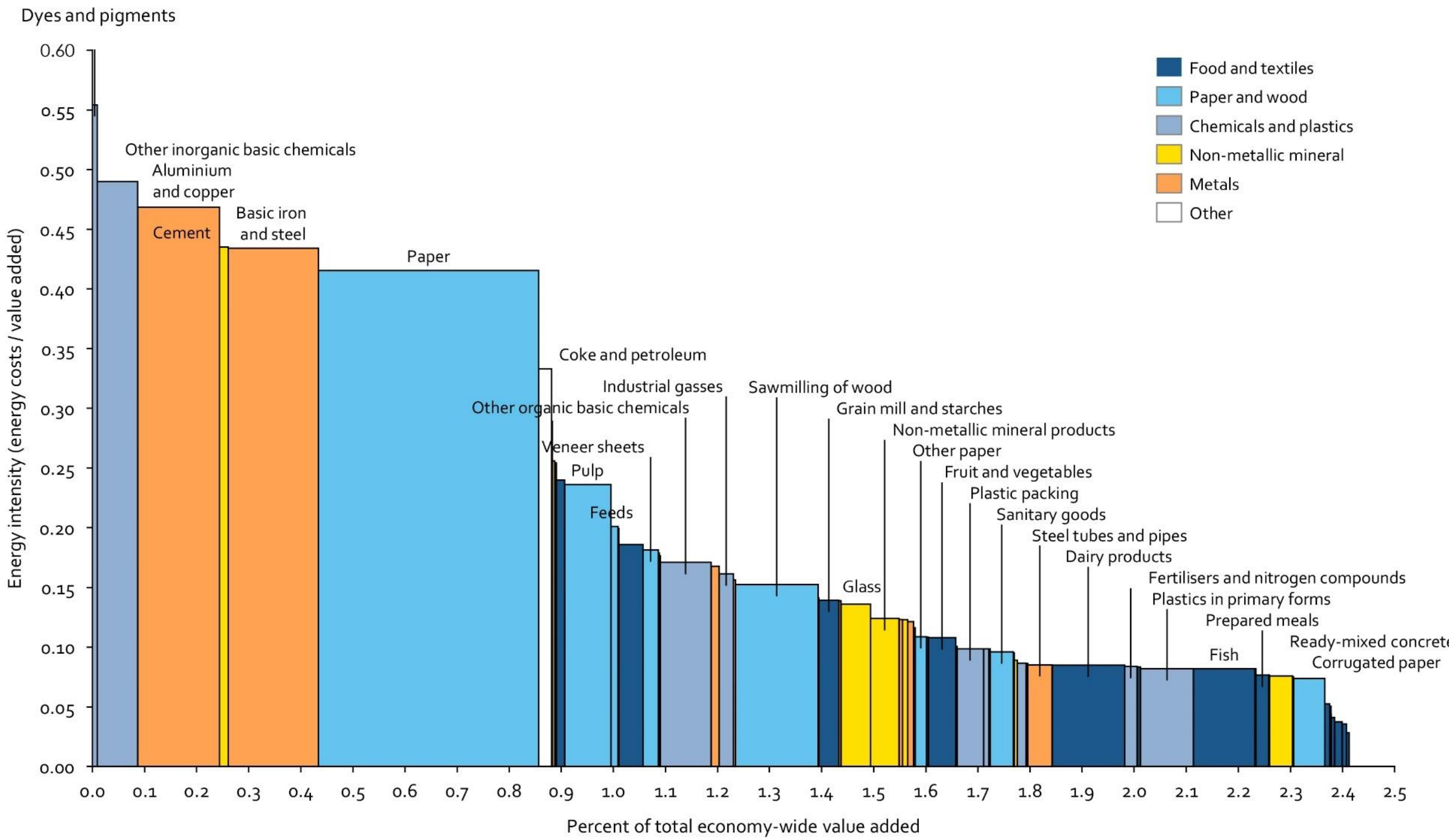
Our approach to analysing the risk of carbon leakage therefore focuses on indicators which highlight important aspects of the market conditions under which the industries operate. The most important aspects are the cost implications for the industries (i.e. how much is their production cost affected) and whether or not they are under international competitive pressure. For analysing the international competitive pressure, it is not enough to look at how much a given product is traded at current market conditions. A product can be shielded from international competition by high transportation costs or import tariffs which make foreign production costs higher than domestic production costs. However, an increase in domestic CO_2 prices can change this balance and spur more international competition and cause carbon leakage.

Nordic metal and paper industries are particularly at risk of carbon leakage

Based on a range of numerical indicators, we have constructed a list of industries in the Nordics which we find to be at risk of carbon leakage (see figure on next page). Amongst the top scorers are *aluminium and copper; basic iron and steel*; and *paper.* Each of these three industries have energy intensities above 40%. These sectors also represent large shares of the economic value added in the Nordics, which highlight the potential economic consequence of carbon leakage.

Nordic industries have significantly improved their energy intensity over time. Since 2008 the average energy intensity of the industries at risk of carbon leakage has dropped 28%. One of the main contributors to this is the paper industry, which has reduced energy intensity by almost 40% since 2008. This has been driven by amongst other things large investments in energy efficiency supported by governments. For instance, in Finland the government offers a voluntary energy efficiency agreement for energy-intensive industries supporting such investments. In the period 2008-2016, Finnish paper industries invested a total of EUR 230 million which has led to total energy savings of 5.4 TWh.

Figure 1: Industries at risk of carbon leakage in the Nordic countries



Source: Copenhagen Economics.

Nordic industries are more electricity and biofuel-intensive than in the EU

The energy-intensive industries in the Nordic countries use more electricity and biofuels compared to industries in the EU. Looking at all industrial sectors, 68% of the industrial energy use in the Nordic countries is from either electricity or biofuels and only 25% fossil fuels. In the EU, the corresponding figures are 39% and 53%, respectively. The largest differences in the composition of fuels are seen in the paper and pulp industry, where 59% of the energy is from biofuels in the Nordic countries compared to only 38% in the EU.

The more intensive use of electricity and biofuels in the Nordic region has important policy implications.

Firstly, the compensation system for higher electricity prices because of the EU ETS (so-called indirect costs) is not used in a systematic and centralised way. Instead of an EU-wide mechanism, national Member States decide themselves whether or not to compensate their own industries subject to the EU State aid rules which only allow for partial compensation. This creates an uneven playing field between the European countries (although the existence of state aid rules ensures some level of consistency). Since electricity intensity is higher in the Nordic countries, this issue is more urgent for Nordic industries.

Secondly, using biofuels are considered CO_2 neutral, which means that one could wrongly conclude that an industry which uses biofuels will not be affected by the EU ETS, and is therefore not at risk of carbon leakage. In fact, as the cost of using fossil fuels increases (because of a CO_2 price) demand for biofuels will increase, and hence the price will increase (all else equal). Therefore, industries using biofuels could also be at risk of carbon leakage. This point is intensified for the paper and pulp industry (one of the largest industries in the Nordic region), which does not only use biomass as a fuel, but also as a raw material input. Thereby, a higher price of biomass will impact the production costs of paper and pulp industries more.

Policy to prevent carbon leakage could be significantly improved

Within the framework of the EU ETS, compensation of higher CO_2 costs is dealt with by allocating free CO_2 emissions allowances to industries deemed at risk of carbon leakage. As a concept, this is very reasonable as it ensures that European industry face a price on emitting CO_2 while also compensating the industries exposed to competition. Nonetheless, the free allowance system has been criticised over the years, among others because it has been blamed for the low ETS allowance prices. Consequently, the response suggested has been to limit the amount of free allowances. We conclude that this is an inappropriate response. It is important to distinguish between a general oversupply of allowances and whether allowances are given out for free as leakage compensation or auctioned out at a price. We argue that an appropriate response would instead be to increase the ETS price by reducing the total amount of allowances while ensuring that industries truly facing a risk of leakage remain compensated by receiving these allowances for free.

We conclude in this report that the compensation mechanism for *direct emission* costs faces two major drawbacks. *Firstly*, all industries/processes on the carbon leakage list obtain a lower amount of compensation than they need. This is problematic, because if an industry truly is at risk, a too low compensation will not be effective in preventing leakage. Instead, the amount of free allowances could be determined with a look towards main competitors and how these countries impose climate costs on their industries. *Secondly*, industries/processes on the carbon leakage list facing relatively low (potential) foreign competition will receive the same compensation treatment as industries on the list facing high (potential) foreign competition. Consequently, free allowances are relatively equally spread out across industries leaving industries at high risk "undercompensated" and industries at low risk "overcompensated".

Where direct CO_2 emissions are compensated through an institutionalised EU-based setup through free allowances, compensation for *indirect emissions* is done in a significantly different – and less encompassing – way. As mentioned above, national Member States can decide whether or not to compensate their own industries as long as they adhere to the EU State aid rules allowing only partial compensation, adding substantial additional risk to electricity intensive consumers. Currently, at least 10 countries have some sort of compensation mechanism approved by the European Commission. While most are aligned with the state aid guidelines for the maximum allowed compensation of up to 85% compensation, some grant significantly less, e.g. Finland where compensation is only up to 40% of the costs. Moreover, and importantly, all of the adopted schemes are only approved for the current State Aid directive ending in 2020, making compensation after 2020 highly uncertain.

The political process determining climate ambitions and carbon leakage compensation should be more integrated. Measures to increase carbon pricing are often met with opposition from industry organisations, as this is seen as reducing EU competitiveness thereby risking domestic production simply to see an increased production abroad. A key reason for industry's reluctance to support ambitious climate policies is the lack of certainty about leakage compensation. The problem is that political discussions of strengthening of the EU ETS and compensation of carbon leakage are not done in the same package. Key issues such as determining the leakage list and the leakage compensation in the State aid guidelines are decoupled from general discussions about how to strengthen the EU ETS, hence the leakage-exposed industry could consider it risky to support ambitious climate policies before they know how the leakage compensation will be. As long as this is not addressed, it risks blocking any real progress in strengthening the ETS and other attempts at carbon pricing.

Collective global action on climate change is key to limit the risk of carbon leakage. Despite the United States withdrawing and doubts about implementation, the most significant step forward in this respect is the Paris Agreement within UNFCCC from 2015. When all countries move and take actions to reduce CO_2 emissions, single regions will not be left with a competitive disadvantage if they were to impose stricter climate policies on their own. Our modelling results suggest that the leakage rates for the energy intensive industry from unilateral ambitious EU targets could be as high as 70%, and even as high as 85% if the Nordic countries unilaterally adopt more ambitious targets.

1. What is carbon leakage and how to evaluate the risk?

1.1 What is carbon leakage?

Carbon leakage is a situation in which a policy-induced reduction in CO_2 emissions in one region is followed by increased emissions in another region. Carbon leakage can occur when one region implements policies restricting CO_2 emissions by imposing higher production costs for industries within that region. If the higher production costs put the domestic industrial producers at a competitive disadvantage, they can lose market shares to foreign competitors (or relocate their production to other region with less strict CO_2 policies). As it does not matter from which country CO_2 emissions originate, this movement of production reduces the effectiveness of the CO_2 policy, since total global CO_2 emissions are not reduced (or only partially), but merely moved from one region to another. CO_2 emissions may even increase, because the new region can be more CO_2-intensive.

There are different ways of regulating CO_2 emissions, many of them will increase the production costs for industries which emit CO_2. For instance, imposing a CO_2 price increases the cost of using fossil fuels, thereby providing an incentive for the emitter to find ways to reduce the emissions in the cheapest way possible. Other types of regulation such as subsidies to integrate renewable energy into electricity systems, higher energy taxes to incentivise energy efficiency and/or mandatory energy efficiency standards on industrial equipment can put an *implicit* price on CO_2 if such policies increase the production cost for producers. Therefore, such policies can also create a risk of carbon leakage.

It is therefore natural that Nordic policy makers are concerned about carbon leakage especially for energy-intensive industries where high CO_2 prices will have high cost implications. In the Nordic region the risk of carbon leakage is as relevant as in the rest of the European Union (EU) as the industrial sector in the Nordic region[1] accounts for over one-third of the energy consumption compared to one-quarter in the whole of

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[1] Throughout this report we define the Nordic region as Denmark, Finland, Iceland, Norway and Sweden.

EU.[2] In fact, there are challenges that are more predominant in the Nordic region, because Nordic industries are very electricity-intensive.

In 2012, the Nordic Council of Ministers therefore published a report showing that there is a range of industries in the Nordic region which is at risk of carbon leakage.[3] Since 2012 global climate policies have evolved, converging in some regions and diverging in others. The Paris Agreement within the United Nations Framework Convention on Climate Change in 2015 was a big step forward on global collective action on curbing CO_2 emissions. The important feature of the Paris Agreement to prevent carbon leakage is that countries commit to stricter policies, thereby contributing to convergence in policy strictness. It remains to be seen, however, whether countries will live up to their commitments and implement the necessary measures. For instance, the withdrawal of the United States from the agreement casts these global efforts into doubt.

1.2 How can the risk of carbon leakage be assessed?

Evaluating the risk of carbon leakage is inherently difficult, because it depends on the very specific market conditions for each industry. Investigating precise market conditions for all industries is a very big task. Therefore, most studies on carbon leakage risk focus on a selection of indicators which reveal important aspects of the market conditions in which the industries operate. However, such indicators need to be supplemented by a deeper analysis for some industries to evaluate the true risk of carbon leakage. When focusing on indicators only, one risks making wrong conclusions for some industries, because the indicators will not capture important aspects of some industries' market conditions. For instance, it is hard to capture an industry's ability to split up the value chain and move the energy-intensive part to other regions with a numerical indicator, although this aspect is important for its risk of carbon leakage (we return to this point later).

We argue that an assessment of the risk of carbon leakage needs to address the following questions (we will go through each step in subchapters below):

[2] Source: Own calculations based on Eurostat table nrg_110a.
[3] Copenhagen Economics (2012).

- How large is the *cost implication* of the regulation on the industry's production costs? The higher the cost implication, the higher the risk of carbon leakage provided competing producers in other regions do not face same increase;
- Is the industry under *international competitive pressure*? If yes, the risk of carbon leakage is high;
- If the industry is at risk of carbon leakage, *when will it happen*? If the industry is capital-intensive, it might wait until investments have depreciated;
- Are there any *other important aspects* of the industry which cannot be captured by indicators, but affects the risk of carbon leakage?

Going through these questions as a way to assess carbon leakage risk can be compared to the approach used by the European Commission. The European Commission is currently updating the list of industries considered at risk of carbon leakage for the next trading phase of the EU Emission Trading System (ETS) starting in 2020. Their approach is a two-step approach. *First*, they conduct a quantitative assessment (based on CO_2 intensity and trade intensity) and make a preliminary list of industries at risk of carbon leakage. *Second*, industries can (under some conditions) apply for a second-round qualitative or quantitative assessment, if they were not deemed at risk of carbon leakage in the first round (see Box 0.1). The procedure for electing industries in the second round is relatively complex and lacks transparency, which can lead to too many industries being elected. In the current list of carbon leakage industries (covering the current trading phase of the EU ETS), such ad hoc assessments led to 97% of the industrial emissions in the EU to be considered at risk of carbon leakage.[4]

Box 0.1 The European Commission's assessment of which industries are at risk of carbon leakage

The procedure for which the European Commission assesses which industries are at risk of carbon leakage is documented in the EU Emission Trading System (ETS) Directive. The preparations for the fourth phase of the EU ETS covering the period 2021 to 2030 has included a revision of this Directive and the procedure for which carbon leakage risk is assessed. According to the revised Directive, the European Commission bases its assessment on a metric which is the result of multiplying the industries' carbon intensity and trade intensity. This metric is called the *carbon leakage indicator*.

The carbon intensity is measured in $kgCO_2$ divided by gross value added (in euros). This covers both direct emissions and indirect emissions through electricity consumption. Trade intensity is defined as the ratio between the total value of exports to third countries plus the value of imports from third countries

[4] See EC (2015).

and the total market size for the European Economic Area (annual turnover plus total imports from third countries).

The carbon leakage indicator is the basis of the *first round* of the European Commission assessment of carbon leakage risk. If the carbon leakage indicator is above 0.2 for a particular industry, the industry is immediately considered at risk of carbon leakage. However, industries which have a lower indicator than 0.2 can apply for a *second round* if one of the following conditions applies:

- The carbon leakage indicator is between 0.15 and 0.2
- The CO_2 intensity exceeds 1.5 kgCO_2 per value added
- Free allocation is calculated on the basis of the refineries benchmarks
- The industry is listed on the EU ETS 2015-2020 carbon leakage list at a 6 or 8-digit level.

In these cases, the European Commission makes a further quantitative or qualitative assessment of the industry. This assessment is based on the technical possibilities to reduce emissions, the industry's ability to pass on costs to consumers and whether profit margins provides incentives to stay within the EEA.

Source: EU (2018) and DG Climate Action (2018).

1.2.1 How large is the cost implication?

The primary driver of the risk of carbon leakage is how the regulation will impact industries' production costs. If the implemented policy is a tax on CO_2 emissions, then the immediate impact will be higher production costs proportional to the size of the tax and the industry's CO_2 emissions.

An indicator for this cost implication could be the CO_2 emission intensity measured as kg of CO_2 emitted per unit of value added for each industry. This is the approach used in many analyses of the risk of carbon leakage, including the European Commission's own assessments (see Box 0.1).[5] This is typically done in two steps, firstly by using historical data on CO_2 emissions (from the EU ETS plant registry) for the direct impact, and secondly estimating the indirect impact from higher electricity prices based on electricity consumption and fuel mix in electricity production.

Using CO_2 emission intensity has several drawbacks. *Firstly*, the estimation of the indirect impact through electricity prices involves debatable assumptions about the passing-through of CO_2 prices on electricity prices. The European Commission assumes that CO_2 prices are passed through to electricity prices in proportion to the average CO_2

[5] See Ecofys and Öko institut (2013) and EU (2018). For other recent analyses using this indicator, see Sato et al. (2013) and Wang et al. (2015).

content of electricity production in the whole of EU. However, we find this approach problematic. We would argue that one should use the marginal CO_2 content, since optimal dispatch of electricity supply suggests that fossil fuel technologies are the marginal power plant in most regions. Further, one would need to account for limited interconnecting capacity meaning marginal power plant in different regions are different. *Secondly,* this method does not take into account price effects on other non-CO_2-emitting fuels from a CO_2 price. For example, if the price of using coal increases (because of a CO_2 tax), the relative price of biomass will be lower, spurring demand for biomass, all else equal. Higher demand for biomass will likely increase the price of biomass, whereby users of biomass can be affected by the CO_2 tax. The mistake of neglecting the price effect on biomass is amplified for industries using biomass as a raw material, for instance the paper and pulp industry. In this industry the impact of a CO_2 tax on biomass prices affect not only their energy costs, but also their cost of the raw materials.

Because of these drawbacks, we will look at the energy intensity of production measured as total energy expenditures per unit of value added. The indicator will regard all types of energy equally, which has the advantage of avoiding methodological issues of estimating the indirect impact, but also requires a complementary perspective on the fuel uses in the Nordic countries and the specific industries. As an example of the need to have a larger understanding on the fuel use and linkage between different electricity markets, look at Iceland. Energy-intensive industries in Iceland use a lot of electricity, but electricity production in Iceland is predominantly hydro and geothermal (which does not emit CO_2), and there are no interconnectors to other electricity markets. Therefore a CO_2 price in Iceland will not affect electricity prices directly.[6] However, electricity prices in Iceland are largely determined by the national power company (Landsvirkjun), which increasing sets industrial prices linked to prices elsewhere for instance Norway.[7] Hence a higher CO_2 price in Norway through a strengthening of the EUs ETS may affect electricity prices in Iceland indirectly.

One important disadvantage of using energy intensity is that it disregards process emissions. Several industrial processes involve CO_2 emissions not because of energy consumption, but simply as a result of the process (one example is the fertiliser industry). Because of this, using energy intensity could underestimate the risk of carbon leakage for industries with significant process emissions.

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[6] This holds as long as Iceland has enough renewable energy resources to meet demand at lower cost than power production based on fossil fuels.
[7] Copenhagen Economics (2017).

It is very important to note that both carbon intensity and energy intensity ignore an important aspect of carbon leakage, namely the costs of investing in more carbon and/or energy efficient production technology. Such investments will reduce the energy consumption and/or carbon emissions from production, and are important steps in order to meet climate ambitions. However, it is important to recognise that undertaking such investments does not necessarily make an industry less at risk of carbon leakage even though its energy/carbon intensity is reduced. In fact, the opposite may easily be true if the industry is obliged for climate reasons to invest in expensive new equipment that reduces its overall competitiveness. The implication is that an industry or process that has undergone a reduction in energy or carbon intensity can still very much be at risk of leakage, and should be treated accordingly.

1.2.2 Is the industry under international competitive pressure?

An important aspect of an industry's market condition is whether it is under international competitive pressure. Passing on the extra cost of a national CO_2 tax to consumers is not possible if the industry is under international competitive pressure. If it did pass on the cost, it would lose market shares, since its product would have increased in price relative to foreign competitors' products. And carbon leakage would occur. If the industry is not under international competitive pressure, it could pass on the cost to consumers without losing market share, and there would not be any carbon leakage.

Some analyses try to estimate the relation between differences in production costs and differences in product prices (pass-through rates) for certain industries and argue that high pass-through rates mean low risk of carbon leakage. However, we argue that such analyses capture several different dynamics with very different implications for carbon leakage. *Firstly*, a high pass-through rate could be the result of a cost increase in both EU and non-EU production, e.g. increased transport costs within the EU. Such pass-through rates are uncorrelated with carbon leakage risk as it also affects the production costs outside the EU. *Secondly*, if EU consumers become less price-responsive, this will increase pass-through ability, but will not reduce the risk of carbon leakage.[8]

The most important indicator revealed in this regard is the current exposure to foreign competition. If a highly energy-intensive product is currently traded extensively with other regions, this reveals that the product is internationally tradable. In that case,

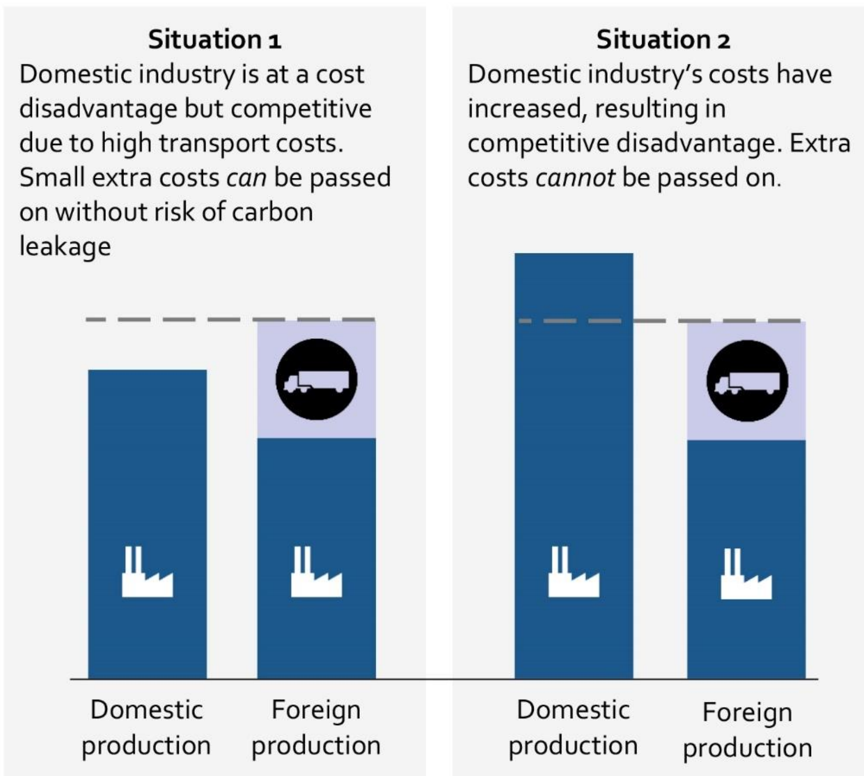
[8] See Copenhagen Economics (2012) and (2015).

the risk of carbon leakage would be deemed as high, since passing on the extra cost to consumers would likely mean loss of market shares to foreign companies. In that sense a high trade intensity reveals that underlying market conditions promote international competition. The use of trade intensity as an indicator is widely used in the literature (and by the European Commission, see Box 0.1).[9] A recent study highlights that it is in particular trade with less developed countries which indicate risk of carbon leakage, since such countries often have very different CO_2 policies than the EU.[10]

However, an industry can be at risk of carbon leakage even if the *current* trade intensity is low. An industry can (at present) be sheltered from foreign competition through for instance transportation costs and import tariffs, which limits competition on domestic markets. This is illustrated in Figure 2. In situation 1 in the figure, transportation costs give domestic companies a competitive advantage, even though their production costs are higher than foreign companies. This also means that small increases in CO_2 prices can be passed on to consumers. In situation 2, however, domestic production costs have increased beyond foreign production costs including transportations costs. Therefore, this situation would spur international competition, and the domestic company would not be able to pass on extra CO_2 prices to consumers. We call the level of the cost differential that spurs foreign competition *the tipping point*.

[9] See Ecofys and Öko institut (2013) and EU (2018). For other recent analyses, see Sato et al. (2013) and Wang et al. (2015).
[10] See Martin et al. (2014b).

Figure 2: Illustration of ability to pass through costs and the tipping point



Source: Copenhagen Economics (2015).

Even though the current trade intensity might be low for an industry, high enough extra CO_2 costs can push the industry passed the tipping point and spur international competition and hence carbon leakage. It is therefore essential to evaluate whether a particular industry is close or far from the tipping point. This can be done by looking at product characteristics, specifically whether the product is costly to transport and is subject to trade barriers in the form of import tariffs:

- Transportation costs: Industries whose products are costly to transport will be shielded from carbon leakage risk at low levels of CO_2 prices. For products with high weights-to-value ratios, transportation costs will make up a disproportionate share of total unit costs if transported far away. This reduces the incentive of foreign producers to export to local market leaving local producers better off (and vice versa). A high weight-to-value ratio would therefore act as a brake for the risk carbon leakage;[11]

- Trade barriers: If a region has set up trade barriers, e.g. in the form of import tariffs, foreign products will be more expensive and hence less attractive in the domestic market. Trade barriers therefore act as a brake on the risk of carbon leakage if CO_2 prices are low.

If a product is cheap to transport and has low trade barriers, then an industry could still be at risk of carbon leakage even though the current trade intensity is low, because this indicates that the industry is close to the tipping point.

1.2.3 When will carbon leakage materialise?

If industries are under risk of carbon leakage, their capital intensity can affect *when* the industry responds to a CO_2 tax. Capital-intensive industries have undertaken significant investments. In such industries, companies may respond to a CO_2 tax by keeping product prices unchanged and remaining in business until new investments are due. When the capital stock is depreciated, the companies may find it unprofitable to undertake new investments and close production or relocate to another region. In this case, the risk of carbon leakage may not materialise in the short run, but only in the long run. Capital intensity therefore acts as a short-term brake on the risk of carbon leakage, although it does not affect the risk of carbon leakage.

1.2.4 Other important aspect affecting carbon leakage risk

To evaluate industries' true risk of carbon leakage, it is necessary to go a step deeper and look at other aspects of their market conditions. While this can be time consuming, it is recommended to ensure 1): that industries that only face limited risk of leakage do not get unnecessary compensation (so-called windfall profits), and 2): that industries that are really at high risk of leakage are sufficiently compensated.

Such an assessment could include considerations of:

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[11] Other product characteristics can affect the transportability of products, and thus the risk of carbon leakage. Some products will have obstacles to transportability due to a fragile or hazardous nature, which involves increased transportation costs from handling with excessive care. This is the case for many chemical products for which highly specialised transport units are used to minimise the associated risks.

- *Production value chain*: Where in the value chain is the energy-intensive part?
- *Product differentiation*: Is the product in direct competition with foreign companies, or is their product seen as different by consumers?
- *Technical options to reduce energy intensity*: What is the industries' options to reduce energy intensity and what are the costs?
- *Production cost differentials to close competitors and profit margins*: Are profit margins already indicating that the industry would relocate?
- *Specific understanding of transportation costs:* The cost of transporting goods does not only differ on the weight of the goods, but also other parameters for instance access to close sea ports.

An illustrative example of the first point of production value chain is cement. Cement is a highly energy-intensive product with a high weight-to-value ratio. Consequently, it is not traded to a great extent. Therefore, one could wrongly conclude that the cement industry is not at risk of carbon leakage. The fact is that the most energy-intensive process in the production value chain (burned limestone called clinkers) is cheaper to transport relative to its value. Therefore, cement manufacturers could respond to CO_2 prices by importing clinkers from other regions and mixing the cement close to consumers. Such relocation of the production value chain in cement already takes place and would likely be intensified with higher CO_2 prices.

1.3 Empirical estimates suggest low historical degree of leakage but suffer methodological problems

An analysis of the risk of carbon leakage is inherently forward-looking as a specific industry can be subject to the risk of carbon leakage even if it is not occurring under present market conditions. This is because current CO_2 policies might not be strong enough to trigger carbon leakage (or that compensation schemes are successful in compensating companies for their higher costs), but if CO_2 policies were tightened carbon leakage could occur. For instance, the EU ETS allowance price has been quite low and has therefore not increased production costs significantly (see Figure 3).

Figure 3: EU ETS allowance prices have so far been low

Source: EEX.

Researchers can, however, analyse historical data to investigate whether carbon leakage has taken place. Several recent analyses find no or limited historical evidence of carbon leakage (see Table 1). Branger et al. (2013), for example, do not find production leakage in Europe due to the EU ETS as they find that the import share has been unaffected. Martin et al. (2014a) find no significant production plant exit or employment impact due to the carbon tax in the UK. Wagner et al. (2014) find only little evidence of carbon leakage within firms due to the EU ETS, and that firms are able to at least partly pass through carbon costs indicating no risk of carbon leakage. This finding is replicated by CE Delft (2010, 2015) and Oberndorfer et al. (2010) who also find evidence of firms' ability to pass on carbon costs to consumers. Klemetsen et al. (2016) find that the EU ETS has not had an impact on the emission intensity of Norwegian firms, because they have been able to pass on the extra cost.

Although most studies do not support the existence of carbon leakage there are some studies to do. Alexeeva-Talebi (2010) finds that strategic competitive behaviour induces companies to absorb carbon costs through a reduction of profit margins thereby creating an incentive to move abroad. Furthermore, although only focussing on the symptoms of potential carbon leakage, Verde et al. (2016) find that during phase I-III of the EU ETS, significantly more firms exited that entered the area.

A problem associated with these analyses is the use of present or historic conditions in order to predict future outcomes. Although an econometric model might accurately determine carbon leakage in the past, this estimate might not be useful for predictions due to two reasons. *First*, ETS prices have been rather low, triggering carbon leakage only in industries with low profit margins. Given the tipping-point mechanics of carbon leakage, these rates will not be linear in the ETS price, leading to an underestimation at high ETS prices. *Second*, empirical analysis is unlikely to capture investment leakage, describing the situation when production facilities are moved out of the implementing country/region.

Table 1: Literature review of recent studies

Study	Question	Method	Result
Alexeeva-Talebi (2010)	Do Oligopolies pass through cost, favouring carbon leakage?	Time-series model, Germany,1995–2008	Low cost pass-through for some industries likely to encourage carbon leakage
Arlinghus (2015)	What are the impacts of carbon prices on competitiveness?	Literature review of empirical studies	No economic effect on competitiveness
Arvantis et al. (2016)	What is the impact of energy policies on export performance of firms?	Regression and matching approaches, Germany, Switzerland and Austria, 2012–2014	Small impact
Branger et al. (2013)	Is there operational leakage, i.e. more imports due to EU ETS?	Time-series model, European region vs. the rest of the world, 1999–2012	No significant evidence of operational leakage i.e. short-term carbon leakage
CE Delft (2010)	What is the scope of cost pass-through of freely obtained allowances?	Time-series model, EU countries, Phase I and II of EU ETS	High cost pass-through suggesting no carbon leakage
CE Delft (2015)	What is the scope of carbon cost pass-through?	Time-series model, EU countries, Phase II and III of EU ETS	Significant cost pass-through
Martin et al. (2014a)	What is the impact of a carbon tax on manufacturing plants?	Panel data regression (DiD), UK, 2002–2004	No impact on revenues, employment or plant exit
Oberndorfer et al. (2010)	Are firms able to pass through cost?	Time-series model, UK, 2001–2007	Mostly partial pass-through of cost
Klemetsen et al. (2016)	What is the impact of EU ETS on economic performance?	Panel data regression (DiD), Norway, 2001–2013	No effect on emission intensity, positive effect on value-added
Verde et al. (2016)	What drives entries and exits of installations into and from the EU ETS?	Maximum Likelihood model, EU ETS countries, 2005–2013	More facilities, less employees in EU ETS, listed companies, smaller profitability encourage exit; significantly more exits than entries
Vivid Economics (2014)	What determines the risk of carbon leakage under EU ETS?	Partial equilibrium model, EU ETS countries, Phase I, II, partly III	Competition, carbon cost share, price sensitivity of demand, product homogeneity.
Wagner et al. (2014)	What are the impacts of the EU ETS?	Panel data regression (DiD), France, 1993–2007	Reduced employment, little evidence on within firm leakage of carbon emissions

Source: Copenhagen Economics.

2. Identification of Nordic industries at risk of carbon leakage

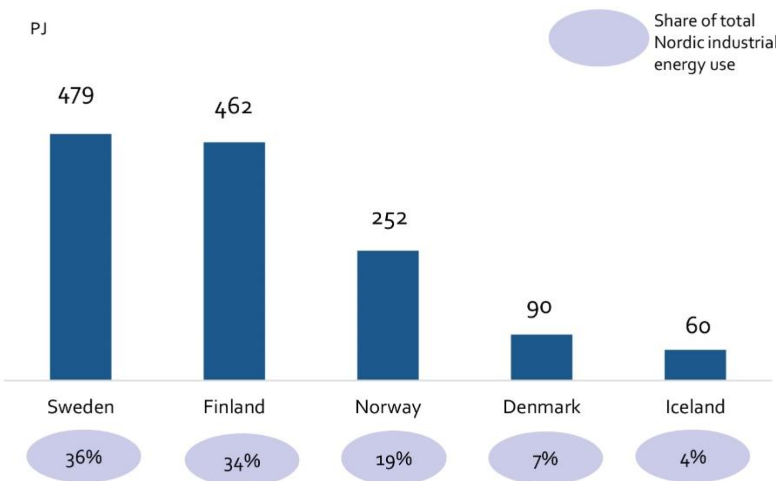
We now move to our analysis of which industries are at risk of carbon leakage in the Nordic region. On the basis of the "theory" developed in Chapter 1, we have developed an approach for the numerical indicator analysis. This approach can capture important aspects of the industries' market conditions and therefore be used to extract a list of industries likely to be at risk of carbon leakage. We elaborate on this approach in subchapter 2.2 and show the results in subchapter 2.3–2.5. We complement this analysis with a deep-dive into the aluminium industry (subchapter 2.6) and the fertiliser industry (subchapter 2.7).

But first, we start this chapter by looking at industrial energy consumption in the Nordic countries (subchapter 2.1) and ask the questions: Where does the consumption take place, which industries are Nordic countries specialised in and what types of fuels do Nordic industries typically use? The answers to these questions give some important insights into how Nordic industries differ from the average EU, and which industries are large.

2.1 A first glance at the Nordic industry sectors and their energy use

Most of the industrial energy use in the Nordic region takes place in Finland and Sweden (see Figure 4). These two countries account for 70% of the industrial energy use in the Nordic region. This share is higher than their share of total final energy consumption (61%), which means these countries are more industry-heavy than the Nordic region as a whole. In Finland and Sweden, *Pulp, paper and print* account for around half of the industrial energy use and is by far the largest industry. In Norway the largest sector is *Aluminium* (which accounts for 31%) and *Chemical and petrochemical* (accounts for 23%). *Aluminium* is also the largest in Iceland, in which this industry accounts for almost four-fifths of industrial energy use (the remainder is primarily *Iron and steel*). In Denmark the largest energy user is *Food* and *Non-metallic minerals*, the latter being predominantly cement production. Both sectors account for around one-third of Denmark's industrial energy use.

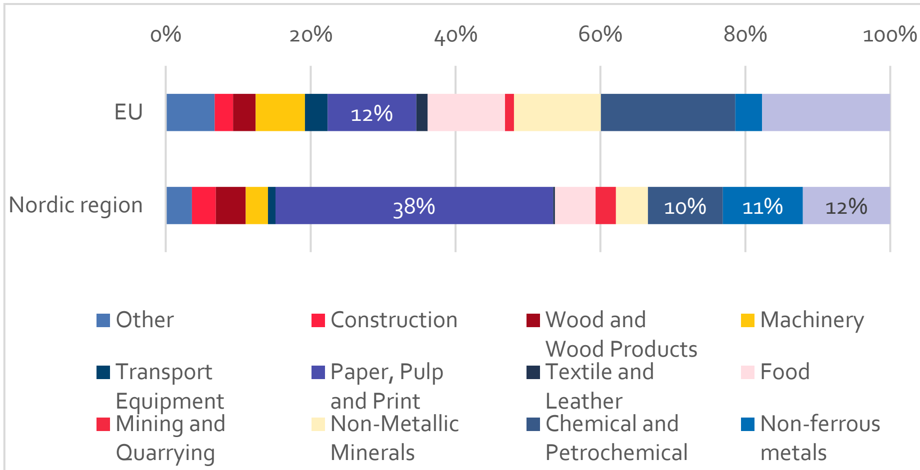
Figure 4: Industrial energy use in the Nordic countries, 2016



Source: Copenhagen Economics based on Eurostat table nrg_110a.

A large part of the industrial energy use in the Nordic region lies in the *Paper, pulp and print industry*. Figure 5 shows that this industry represents 38% of the industrial energy use in the Nordic region. This is a significant overrepresentation compared to the EU share of 12%. Finland and Sweden account for the vast majority of this industry (96%). Besides the *Paper, pulp and print* industry, large industrial energy users in the Nordic region are *Iron and steel*, *Non-ferrous metals* (which is mostly aluminium production in the Nordic countries) and *Chemical and petrochemical*. Aluminium production is primarily located in Norway and Iceland, which collectively account for 84% of the Nordic region's energy use in this industry.

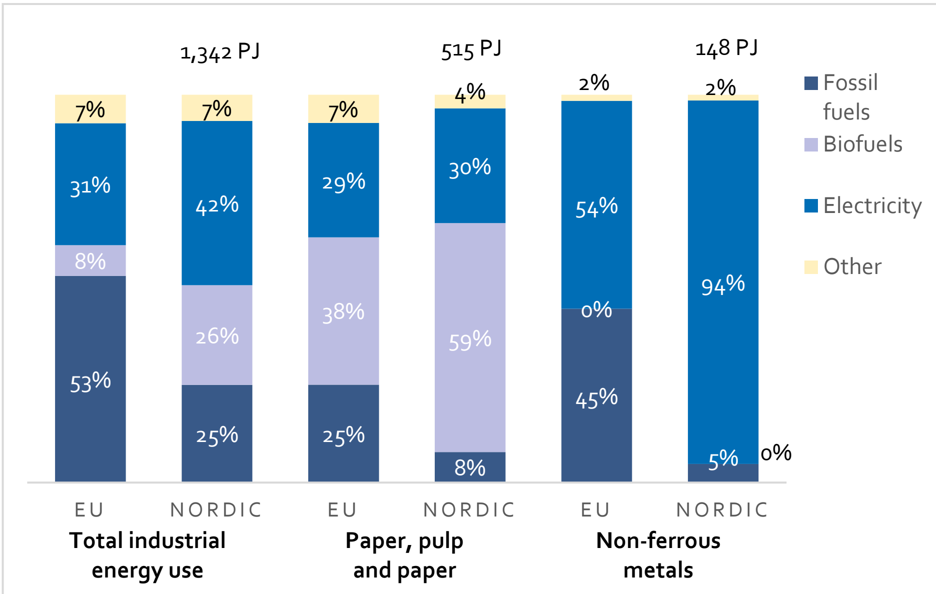
Figure 5: Industrial sectors' energy use in the EU and the Nordic region, 2016



Source: Copenhagen Economics based on Eurostat table nrg_110a.

The energy-intensive industries in the Nordic countries use more electricity and biofuels compared to industries in the EU. Looking at all industrial sectors, over half of the energy use is from direct use of fossil fuels in the EU, whereas this share is only 25% in the Nordic countries. Conversely, around two-thirds of the industrial energy use in the Nordic countries are from either electricity or biofuels (see Figure 6). The largest differences in the composition of fuels are seen in the *Paper, pulp and print* and the *Non-ferrous metals* (mostly aluminium in the Nordic region) industries. In the former, 59% of the energy is from biofuels in the Nordic countries compared to only 38% in the EU. In the latter, almost all of the energy use is from electricity in the Nordic countries, whereas industries in the EU also use a significant share of fossil fuels.

Figure 6: Fuel use in selected industries in the EU and the Nordic countries, 2016



Note: In the Nordic countries, non-ferrous metals are primarily aluminium production.

Source: Copenhagen Economics based on Eurostat table nrg_110a.

The higher share of electricity and biofuels in the Nordic industries does not mean that these industries are not subject to carbon leakage risk. As mentioned in Chapter 1, a higher carbon price will increase the opportunity cost of using biofuels, which will increase the price of biofuels all else equal. Further, the common electricity market Nordpool means that a higher carbon price affects the electricity price in all continental Nordic countries, when the marginal power plant is CO_2-emitting.

The exemption to this is Iceland. About 90% of the industrial energy use in Iceland is based on electricity, which is almost 100% produced by hydro and geothermal energy.[12] As this is domestically produced and not directly affected by carbon prices, these Icelandic industrial sectors are not subject to carbon leakage risk. However, there are developments that can change this. Electricity prices in Iceland are largely determined by the national power company (Landsvirkjun), which increasingly sets industrial prices which are linked to prices elsewhere (for instance Norway).[13] This

[12] Source: IEA (2015) Electricity information.
[13] Copenhagen Economics (2017).

means that a higher CO_2 price in for instance Norway through a strengthening of the EU ETS may affect electricity prices in Iceland indirectly thereby importing carbon leakage risk.

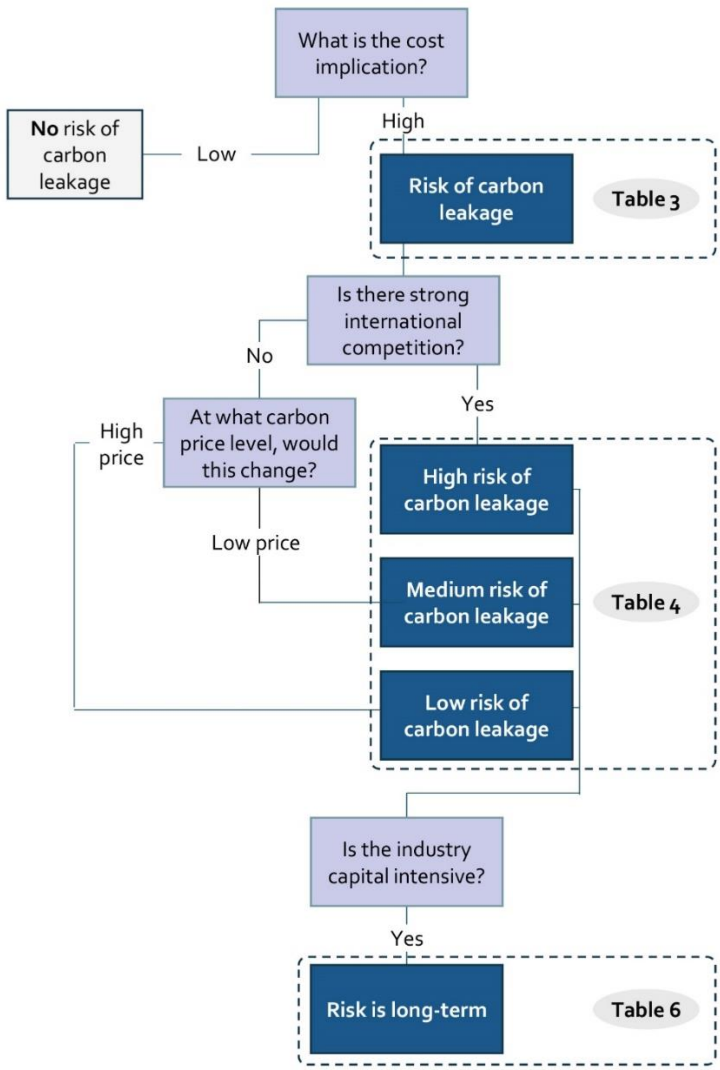
2.2 Indicators of risk of carbon leakage

Based on the "theory" in Chapter 1, we have developed an approach to evaluate the risk of carbon leakage based on a range of numerical indicators in three steps.

1. We evaluate *which industries* are at risk of carbon leakage. We will do this by evaluating the cost implication by looking at the energy intensity of all industries. If the energy intensity in a specific industry is low, the industry is deemed to be at no risk of carbon leakage, because their production costs would not change much. If it is high, we deem the industry at risk of carbon leakage.
2. We evaluate *the level of risk of* carbon leakage. This is done in two steps.
   a. We evaluate the degree of international competition by looking at the trade intensity. If the trade intensity is high, then the industry is deemed at high risk of carbon leakage. If the trade intensity is low, we move on to the second step.
   b. We evaluate whether the industry is close to the tipping point for which international competition could take place. We will evaluate transportability and trade barriers. If these indicate that the product is tradable (i.e. low import tariffs and/or low weight-to-value ratio), then the industry is deemed at medium risk of carbon leakage, because it could be close to the tipping point. If the industry is shielded by a high weight-to-value ratio and import tariffs, the industry is deemed at low risk of carbon leakage, because the industry is far from the tipping point. Being far from the tipping point means that CO_2 prices need to be high to spur international competition.
3. We evaluate the investment rate of the industries at risk of carbon leakage to find out whether it is a long-term or short-term risk.

Figure 7 visualises our approach.

Figure 7: Our approach to identify industries at risk of carbon leakage



Source: Copenhagen Economics.

The numerical indicators rely on publicly available official data, primarily Eurostat (see more information on the calculation of each of them in Table 2). The data source of the most important indicator – energy intensity – is Eurostat's structural business statistics. Eurostat notes that using this data on a detailed level for small countries has to be done with a certain caution. If the number of companies within a specific sector is small, the data is not public because of confidentiality concerns. Because of this fact we have had to choose between NACE level 3 or 4 to minimise the data loss. As a result, our list is a mix of NACE level 3 and 4 industries. This also means we could be underestimating the industries' share of the total economy, and some energy-intensive industries could be underrepresented in our analysis, because of missing data.

Table 2: Indicators and data sources

Indicators	Data sources
Energy intensity	This metric is calculated as energy expenditures divided by value added. The data source for both is Eurostat's structural business statistics table sbs_na_ind_r2 variables *value added at factor cost* and *purchases of energy products*. Data is available for sector classification NACE revision 2 on a 4-digit level. However, for some industries, data is only available on 2 or 3-digit level because of confidentially concerns. When this is the case we use the level at which data is available. Newest available data year is 2015. Our reported energy intensity is the average over the period 2013–2015.
Trade intensity	Trade intensity is calculated as the sum of imports into EU28 from the rest of the world and the exports from EU28 to the rest of the world divided by the sum of imports into EU28 and the turnover inside EU28 for each sector. The data source is Eurostat's structural business statistics table sbs_na_ind_r2 for the variable *turnover* and Eurostat's traditional international trade database *comext* for *import* and *export*. Data is available for sector classification CPA2008 on an 8-digit level for trade variables and for sector classification NACE revision 2 on a 4-digit level for turnover. To establish a link between the sector classifications, we have used the Ramon correspondence tables. Newest available data year is 2016 but due to a lack of observations, we report trade intensity from 2015.
Trade barriers	We measure the extent of trade barriers by the average tariffs rate weighted by trade value. The data source is the World Bank's WITS database. Data is available for sector classification ISIC revision 3 on a 4-digit level. To establish a link to the NACE revision 2 classification, we have used the Ramon correspondence tables. Newest available data year is 2017 but we report the value to weight ratio from 2015 to maintain consistency with the other indicators.
Transportability	We approximate transportability by the weight-to-value ratio of the goods produced in each sector. The data source is Eurostat's traditional international trade database *comext* for the variables *trade value* and *quantity*. Data is available for sector classification NACE revision 2 on a 4-digit level. Newest available data year is 2017 but we report the value to weight ratio from 2015 to maintain consistency with the other indicators.
Capital intensity	We approximate capital intensity by the investment rate. This measure is calculated as total investments divided by value added in each sector. The data source is Eurostat structural business statistics table sbs_na_sca_r2 variable *investment rate*. Data is available for sector classification NACE revision 2 on a 4-digit level. Newest available data year is 2015. Our reported investment rates are the weighted average over the period 2013-2015 with annual value added as weights.
Economic importance	Economic importance is not an indicator of carbon leakage, but indicates the size of the economic consequences, if industries where to move abroad. We therefore add this measure to the analysis, although it doesn't affect our evaluation of whether an industry is at risk of carbon leakage. Economic importance is approximated by the industry value added divided by total Nordic value added. Data source is Eurostat structural business statistics table sbs_na_ind_r2 variable *value added at factor*. Data is available for sector classification NACE revision 2 on a 4-digit level. Newest available data year is 2015. Our reported approximation for economic importance is the average over the period 2013–2015.

Note: The data sources contain data for Denmark, Finland, Norway and Sweden, but not Iceland.

Source: Copenhagen Economics.

2.3 List of industries at risk of carbon leakage

We start by producing the list of industries which are at risk of carbon leakage by looking at the energy intensity indicator. The indicator is calculated as energy expenditures divided by the value added in each industry. To be considered at risk of carbon leakage in our analysis, we choose a threshold value of at least 10% in at least one Nordic country. This threshold is the same as the one used in the our 2012-report on carbon leakage in Nordic countries.[14] See the list in Table 3, which reports the average energy intensity for Denmark, Finland, Norway and Sweden, and the industries' share of the total economic-wide value added in these four countries.

Table 3: List of industries in Nordic countries with high energy intensity

NACE	Sector	Energy intensity	Value added
Food products and beverages			**0.443%**
C1020	Fish	8..2%	C1020
C103	Fruit and vegetables	10.8%	C103
C104	Oil and fats	24.0%	C104
C1051	Dairy products	8.5%	C1051
C106	Grain mill and starches	13.9%	C106
C1081	Sugar	10.8%	C1081
C1085	Prepared meals	7.7%	C1085
C1091	Feeds	18.6%	C1091
C1092	Pet foods	11.6%	C1092
C1106	Malt	28.9%	C1106
Textiles, wearing apparel and leather			**0.070%**
C1310	Textile fibres	7.6%	0.001%
C1320	Weaving of textiles	8.6%	0.003%
C1330	Finishing of textiles	9.9%	0.003%
C1393	Carpets and rugs	8.3%	0.007%
C1394	Cordage, rope, twine and netting	5.2%	0.009%
C1395	Non-wovens	25.4%	0.003%
C1399	Other textiles n.e.c.	9.5%	0.002%
C1411	Leather clothes	9.6%	0.000%
C1412	Workwear	2.8%	0.005%
C1413	Other outerwear	3.7%	0.014%
C1419	Other apparel	3.6%	0.008%
C1420	Fur products	4.4%	0.001%
C143	Knitted apparel	5.0%	0.003%
C1511	Tanning and dressing of leather	8.2%	0.002%
C1512	Luggage	7.5%	0.002%
C1520	Footwear	4.1%	0.007%
Coke and petroleum			**0.024%**
C19	Coke and petroleum	33.3%	0.024%
Chemicals and chemical products (continued on next page)			**0.349%**
C2011	Industrial gasses	16.1%	0.028%
C2012	Dyes and pigments	55.4%	0.009%

[14] Copenhagen Economics (2012).

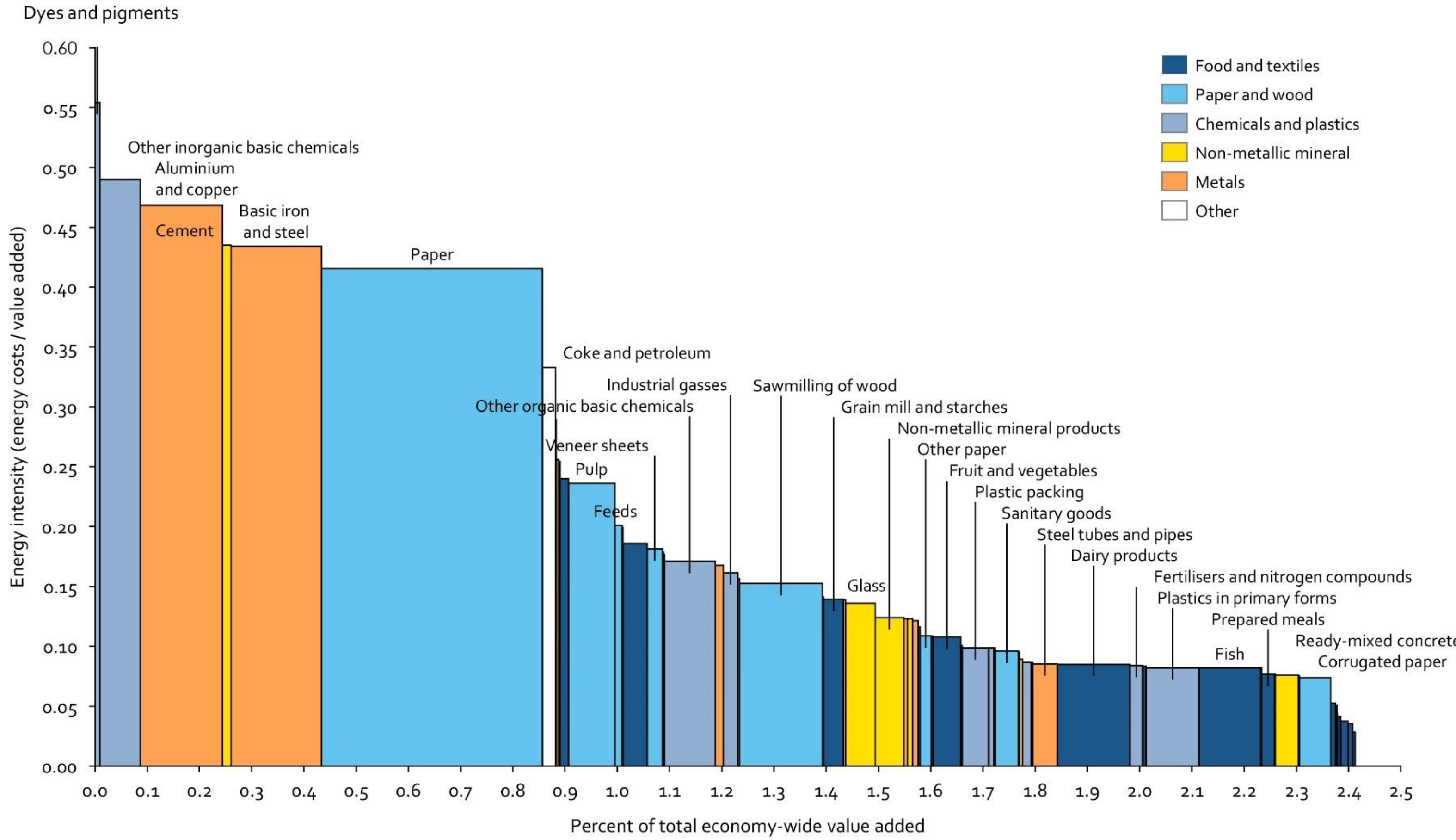
NACE	Sector	Energy intensity	Value added
C2013	Other inorganic basic chemicals	49.0%	0.078%
C2014	Other organic basic chemicals	17.1%	0.097%
C2015	Fertilisers and nitrogen compounds	8.4%	0.024%
C2016	Plastics in primary forms	8.2%	0.101%
C2017	Synthetic rubber in primary forms	19.9%	0.002%
Rubber and plastic products			**0.067%**
C2211	Rubber tyres	8.6%	0.016%
C2222	Plastic packing	9.9%	0.051%
Other non-metallic mineral products			**0.197%**
C231	Glass	13.6%	0.057%
C233	Clay building material	25.6%	0.005%
C235	Cement	43.5%	0.016%
C2363	Ready-mixed concrete	7.6%	0.045%
C2364	Mortars	12.3%	0.010%
C2365	Fibre cement	11.8%	0.000%
C2369	Other articles of cement	10.1%	0.003%
C2391	Abrasive products	8.9%	0.006%
C2399	Non-metallic mineral products	12.4%	0.055%
Basic metals			**0.420%**
C2410	Basic iron and steel	43.4%	0.173%
C2420	Steel tubes and pipes	8.5%	0.047%
C2431	Steel bars	17.6%	0.002%
C2434	Steel strips	15.6%	0.003%
C2434	Steel wires	12.3%	0.007%
C244	Aluminium and copper	46.8%	0.157%
C2451	Casting of iron	16.8%	0.016%
C2452	Casting of steel	13.9%	0.004%
C2453	Casting of light metals	12.1%	0.011%
Wood and products of wood			**0.204%**
C1610	Sawmilling of wood	15.2%	0.159%
C1621	Veneer sheets	18.1%	0.029%
C1622	Parquet floors	14.1%	0.002%
C1629	Wood products	20.1%	0.014%
Paper and pulp products			**0.638%**
C1711	Pulp	23.6%	0.089%
C1712	Paper	41.5%	0.423%
C1721	Corrugated paper	7.4%	0.060%
C1722	Sanitary goods	9.6%	0.044%
C1729	Other paper	10.9%	0.021%
Machinery and equipment n.e.c.			**0.002%**
C2891	Machinery for metallurgy	17.9%	0.002%

Note: Value added reflects the share of total economy-wide value added in the Denmark, Finland, Norway and Sweden. For categories in bold the value added is the sum of the sectors in the category on this list. We have shortened the descriptive names of the industries; see a correspondence table in the appendix Table A.2. The reason why some industries have energy intensities lower than 10% in Table 3 is because the table reports the average for Denmark, Finland, Norway and Sweden, and the energy intensity only has to be above 10% in one of the Nordic countries to be on the list. For instance, if the energy intensity in industry *x* is 15% in Sweden, but 5% in the three other countries, it is included on the list, even if the average energy intensity of all four countries is below 10%.

Source: Copenhagen Economics based on Eurostat table sbs_na_ind_r2.

Figure 8 is a visualisation of the list and shows the list ranked from the most energy-intensive to the least (from left to right), and the industries' share of total economic-wide value added in Denmark, Finland, Norway and Sweden combined.

Figure 8: Industries on the list's energy intensity and share of total value added in the Nordic countries



Source: Copenhagen Economics based on Eurostat table sbs_na_ind_r2.

The visualisation of the list in Figure 6 reveals that two industry categories stands out as particularly energy intensive and large in the Nordic countries: metals and paper. The three industries *aluminium and copper; basic iron and steel;* and *paper* have energy intensities above 40% and each account for more than 0.15% of the total value added in the Nordic countries. The paper industry is the single largest industry of all on the list, and accounts for 0.42% of the total value added in the Nordic countries.

The significance of these industries highlights the importance of looking at energy intensity instead of CO_2 intensity. As shown in subchapter 2.1, these industries use more biofuels and electricity than their European competitors. *First*, using CO_2 intensity involves debatable assumptions about the CO_2 content in electricity. The European Commission uses an average CO_2 content across the EU which is much smaller than the marginal and actual CO_2 content. Thereby, they underestimate the risk of carbon leakage in industries using electricity. *Second*, using biofuels would in the European Commission's view decrease the risk of carbon leakage. However, the price of biofuels is affected by CO_2 prices, since biofuels and fossil fuels are substitutes in many purposes (for instance power generation). Therefore, the price of biofuels will be affected if prices of fossil fuels increase.

2.3.1 Changes since the 2012 report

The list in Table 2 is comparable to the *gross list* in the 2012 report on carbon leakage in the Nordic countries,[15] and they include the same industries broadly speaking. The old list highlighted the same overall industry categories as important: *Food products, textiles and leather, wood and wood products, paper and pulp, refined petroleum products, basic chemicals and plastics, non-metallic mineral products, basic metals* and *machinery and equipment*.

There are, however, new industries in Table 3 which were not on the old list, and some industries on the old list have been excluded because of changes in energy intensity. We account for them one by one here:

- Within *Food products and beverages*, the sector *Distilled potable alcoholic beverages* was one the old list, but not on the new list. This is because this sector's energy intensity has dropped below the 10% threshold.
- Within *Textiles, weaving apparel and leather*, several sectors have been added because their energy intensity has increased above the threshold of 10% in one

[15] Copenhagen Economics (2012).

Nordic country since 2012. These are *Carpets and rugs*; *Cordage, rope, twine and netting; Other textiles n.e.c.; Workwear; Other outerwear; Other apparel; Fur products; Luggage; and Footwear*. Many of these have low energy intensities on a Nordic level, which reflects the fact that they are on the list, because the energy intensity is above 10% in *one* Nordic country, which is in many cases Sweden.

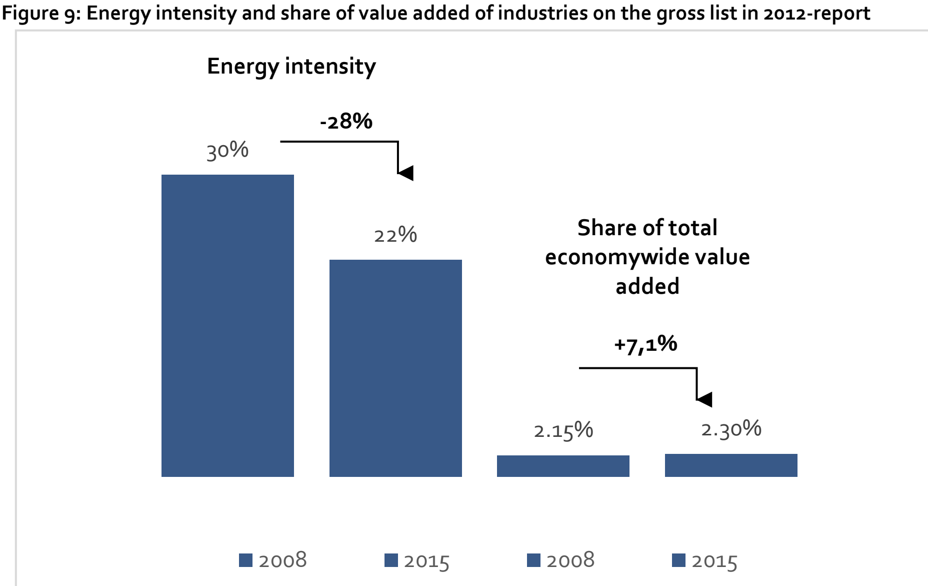
- Within *Paper and pulp*, two industries have been added: *Corrugated paper* and *Other paper*. They have been added because their energy intensity has increased above the threshold of 10%.
- Within *Chemicals and chemical products*, the industry *Basic pharmaceutical products*, which was on the old list, is not included on the new list, because of low energy intensity. It was energy-intensive industry in Finland which secured its place on the old list, however the new data from Eurostat has no data entries for Finland in the period 2013–2015.
- The new list includes a new industry category *Rubber and plastic products* with two industries *Rubber tyres* and *Plastic packing*. These industries have had increasing energy intensity above the 10% threshold.
- Within *Non-metallic mineral products*, the new list includes five new sectors because of increasing energy intensity above the 10% threshold. These are *Ready-mixed concrete; Mortars; Fibre cement; Other articles of cement;* and *Abrasive products*.

The old list and the list in Table 3 are based on two different versions of the NACE industry classifications, which make a like-for-like comparison a little more difficult. The old list was based on version 1.1 of the NACE industry classifications, whereas the new list is based on version 2. This means that the industry numbers are different. For instance, in version 1.1 of NACE the *Manufacture of pulp* industry had number C2111, but in version 2 it has the number C1711. Further, sometimes industries have been split up, renamed and/or regrouped.

Adding to the difficulty of comparing the two lists, it has been necessary to choose different levels of aggregation (3 or 4-digit industry levels) in the new list because of data confidentiality. Therefore some differences between the old and the new list is solely due to a new chosen level of aggregation. For instance, on the old list we had *Aluminium production*, *Copper production* and *Other non-ferrous metal production* in three separate categories. In the new list, we have had to group these together (in *Aluminium and copper*) as we would lose too much data if we looked at them individually.

Comparing over time, many industries have significantly improved their energy intensity. Since 2008 the average energy intensity of the industries on the 2012 list has dropped 28%. This has happened while they have maintained (and actually increased) their share of the total economy-wide value added in the Nordic countries (see Figure 9).

Figure 9: Energy intensity and share of value added of industries on the gross list in 2012-report



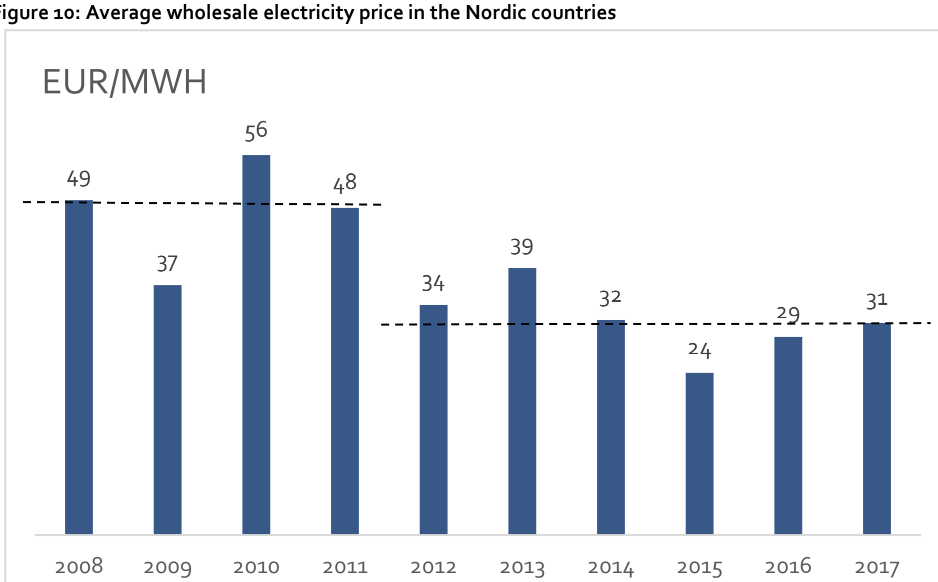
Source: Copenhagen Economics based on Eurostat table sbs_na_ind_r2.

One of the main drivers of the reduction in energy intensity is the paper industry, which has reduced its energy intensity by almost 40% since 2008. This has mainly happened because of two reasons. *Firstly*, the paper industry is producing a different mix of products today as production of for instance printing paper is declining (because of reduced demand), and production of cardboard is increasing. The change has on average decreased the average energy intensity of the products.[16] *Secondly*, the paper industry has invested heavily in energy efficiency. In Finland, the government offers a voluntary energy efficiency agreement for energy-intensive industries supporting such investments. In the period 2008–2016, Finnish paper industries invested a total of EUR 230 million, which has led to total energy savings of 5.4 TWh.[17] Besides reducing the

[16] Based on personal communication with Finnish Forest Industries.
[17] Data provided by the Finnish Forest Industries.

energy consumption, these incentives have also contributed to the fact that the share of fossil fuels in the forest industries has dropped from 26% in 2005 to 15% in 2017.[18] Another driver of the improved energy intensity is lower electricity prices in the Nordic region. In the period 2008–2011, the average electricity price was EUR 48/MWh, but this has decreased to EUR 32/MWh in the period 2012–2017 (see Figure 10). Lower electricity prices have a direct impact on the calculated energy intensity of electricity-intensive industries as it lowers their energy expenditures. Further, lower electricity prices improve these industries' competitiveness, which has a dampening effect on the risk of carbon leakage. Lower electricity prices in the Nordic region is among other things driven by the deployment of renewable energy (with marginal costs close to zero), increasing total supply which pushes down average electricity prices.

Figure 10: Average wholesale electricity price in the Nordic countries



Note: The figure shows the average of electricity prices in DK2, SE3 (SE before 2011), Oslo and FI.

Source: Copenhagen Economics based on data from Nord Pool Spot market data.

[18] Source: Statistics Finland.

2.4 The level of carbon leakage risk

To evaluate the level of carbon leakage risk, we go through the approach outlined in Figure 7. The calculation method for each indicator is outlined in Table 2. We have chosen some threshold values for each indicator in order to determine whether an industry moves on to another step in the approach. These are:

- Trade intensity: If an industry has a trade intensity above 10%, the industry is deemed at high risk of carbon leakage. Before the European Commission changed its methodology to evaluate carbon leakage risk, they also used 10% as a threshold value. Further, in our 2012 report we used roughly the same threshold.
- Weight-to-value ratio and trade tariffs: If an industry has a weight-to-value ratio below 10 kg/EUR (the average for the industries in Table 3) and has import tariffs lower than 10%, then the industry is deemed at medium risk of carbon leakage, because we consider such industries close to the tipping point for which foreign competitors can enter the market. This criterion is only relevant for industries which did not have a trade intensity higher than 10%.

The results are shown in Table 4.

Table 4: The level of risk of carbon leakage for the industries deemed at risk of carbon leakage

NACE	Sector	Risk
Food products and beverages		
C1020	Fish	High risk
C103	Fruit and vegetables	High risk
C104	Oil and fats	High risk
C1051	Dairy products	Low risk
C106	Grain mill and starches	High risk
C1081	Sugar	High risk
C1085	Prepared meals	High risk
C1091	Feeds	Low risk
C1092	Pet foods	Low risk
C1106	Malt	High risk
Textiles, wearing apparel and leather (continued on next page)		
C1310	Textile fibres	High risk
C1320	Weaving of textiles	High risk
C1330	Finishing of textiles	High risk
C1393	Carpets and rugs	High risk
C1394	Cordage, rope, twine and netting	High risk
C1395	Non-wovens	High risk
C1399	Other textiles n.e.c.	High risk
C1411	Leather clothes	High risk
C1412	Workwear	High risk
C1413	Other outerwear	High risk

NACE	Sector	Risk
C1419	Other apparel	High risk
C1420	Fur products	High risk
C143	Knitted apparel	Medium risk
C1511	Tanning and dressing of leather	High risk
C1512	Luggage	High risk
C1520	Footwear	High risk
Coke and petroleum		
C19	Coke and petroleum	High risk
Chemicals and chemical products		
C2011	Industrial gasses	Low risk
C2012	Dyes and pigments	High risk
C2013	Other inorganic basic chemicals	High risk
C2014	Other organic basic chemicals	High risk
C2015	Fertilisers and nitrogen compounds	High risk
C2016	Plastics in primary forms	High risk
C2017	Synthetic rubber in primary forms	High risk
Rubber and plastic products		
C2211	Rubber tyres	High risk
C2222	Plastic packing	High risk
Other non-metallic mineral products		
C231	Glass	High risk
C233	Clay building material	High risk
C235	Cement	High risk
C2363	Ready-mixed concrete	Low risk
C2364	Mortars	Low risk
C2365	Fibre cement	Low risk
C2369	Other articles of cement	High risk
C2391	Abrasive products	High risk
C2399	Non-metallic mineral products	High risk
Basic metals		
C2410	Basic iron and steel	High risk
C2420	Steel tubes and pipes	High risk
C2431	Steel bars	High risk
C2432	Steel strips	High risk
C2434	Steel wires	High risk
C244	Aluminium and copper	High risk
C2451	Casting of iron	Medium risk
C2452	Casting of steel	Medium risk
C2453	Casting of light metals	Medium risk
Wood and products of wood		
C1610	Sawmilling of wood	High risk
C1621	Veneer sheets	High risk
C1622	Parquet floors	High risk
C1629	Wood products	High risk
Paper and pulp products		
C1711	Pulp	High risk
C1712	Paper	High risk
C1721	Corrugated paper	Medium risk
C1722	Sanitary goods	High risk
C1729	Other paper	High risk

NACE	Sector	Risk
Machinery and equipment n.e.c.		
C2891	Machinery for metallurgy	High risk

Source: Copenhagen Economics based on Eurostat and WITS.

The results show that most industries are deemed at *high risk* of carbon leakage. This is because they have quite high trade intensities. For the *Cement* industry, we have manually set the risk at high, even though the current trade intensity is low, and that it has a very high weight-to-value ratio. This is because the most energy-intensive part of the cement manufacturing process (producing clinkers) is easier to transport, and therefore at risk of carbon leakage.

The industries at *medium risk* of carbon leakage are *Knitted apparel; Corrugated paper; Casting of iron; Casting of steel*; and *Casting of light metals*. For these industries, the current trade intensity is low, but the weight-to-value ratio and import tariffs indicate that they are tradable products. For instance, *Corrugated paper* has a trade intensity of 6%, but has no import tariffs and a weight-to-value ratio of 6.6 kg per euro, which is in the lower end of the spectrum for these industries. Therefore, this industry does not seem to have structural barriers preventing or severely restricting international trade.

The industries at *low risk* of carbon leakage are *Dairy products; Feeds; Pet foods; Industrial gasses; Ready-mixed concrete; Mortars;* and *Fibre cement.* They all have low trade intensities, and weight-to-value ratio indicates that the products are quite expensive to transport.

2.4.1 How does this list compare to the European Commission's preliminary list?

The European Commission is currently updating the list of industries which they deem at risk of carbon leakage (see Box 0.1). At the time of writing, they have concluded the first round and produced a preliminary list. The list is reproduced in Table 5.

Table 5: The European Commission's preliminary list of manufacturing industries at risk of carbon leakage

NACE	Description
C1041	Manufacture of oils and fats
C1062	Manufacture of starches and starch products
C1081	Manufacture of sugar
C1106	Manufacture of malt
C1310	Preparation and spinning of textile fibres
C1395	Manufacture of non-wovens and articles made from non-wovens, except apparel
C1411	Manufacture of leather clothes
C1621	Manufacture of veneer sheets and wood-based panels
C1711	Manufacture of pulp
C1712	Manufacture of paper and paperboard
C1910	Manufacture of coke oven products
C1920	Manufacture of refined petroleum products
C2011	Manufacture of industrial gases
C2012	Manufacture of dyes and pigments
C2013	Manufacture of other inorganic basic chemicals
C2014	Manufacture of other organic basic chemicals
C2015	Manufacture of fertilisers and nitrogen compounds
C2016	Manufacture of plastics in primary forms
C2017	Manufacture of synthetic rubber in primary forms
C2060	Manufacture of man-made fibres
C2311	Manufacture of flat glass
C2313	Manufacture of hollow glass
C2314	Manufacture of glass fibres
C2319	Manufacture and processing of other glass, including technical glassware
C2320	Manufacture of refractory products
C2331	Manufacture of ceramic tiles and flags
C2351	Manufacture of cement
C2352	Manufacture of lime and plaster
C2399	Manufacture of other non-metallic mineral products n.e.c.
C2410	Manufacture of basic iron and steel and of ferro-alloys
C2420	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
C2431	Cold drawing of bars
C2442	Aluminium production
C2443	Lead, zinc and tin production
C2444	Copper production
C2445	Other non-ferrous metal production
C2446	Processing of nuclear fuel
C2451	Casting of iron

Note: We have only included C-industries here, i.e. industries in the manufacturing sector. Note that descriptions vary from our descriptions, since these are official descriptions, and we have shortened them, see a correspondence table in the Appendix Table A.2.

Source: DG Climate Action (2018).

There are many similarities between our list of industries at risk of carbon leakage and the European Commission's, although there are some important differences. We account for the most important differences here:

- Within the *Food product and beverages* category, there are several differences:
  - The European Commission does not include the *Fish* industry (C1020), which our list does. In the European Commission's analysis, the emission intensity of this sector is too low to be included. We do, however, find that the energy intensity in Denmark is rather high (on average 14% in the period 2013–2015). For the other Nordic countries energy intensity in this sector is low.
  - The European Commission does not include any industries in the category *Fruit and vegetables* (C103), which we deem at high risk of carbon leakage. It is in particular the processing of potatoes that is energy intensive.
  - The European Commission does not include *Prepared meals* (C1085), an industry which is energy-intensive in Denmark in particular.
- Our list includes a large number of industries in the *Textiles, wearing apparel and leather* category. The European Commission's list includes only *Textile fibres (C1310)*, *Non-wovens (C1395)*, and *Leather clothes (C1411)*. In our analysis, many industries within this category are deemed energy-intensive, but have energy intensities in the lower end of the spectrum.
- Within the *Paper and pulp* category, our list includes two additional industries compared to the European Commission's list: *Sanitary goods (C1722)* and *Other paper (C1729)*. These are energy-intensive enough to be on our list, but have intensities in the lower end of the spectrum.
- The two industries we have in the *Rubber and plastic product* category is not on the European Commission's list. These are energy-intensive enough to be on our list, but have intensities in the lower end of the spectrum.
- Within the *Other non-metallic mineral products* category, we have included *Abrasive products* which is energy-intensive enough to be on our list, but has an intensity in the lower end of the spectrum.
- Within the *Basic metals* category, there are two main differences:
  - For the *Steel bars (C2431); Steel strips (C2432);* and *Steel wires (2434)* industries, the European Commission only includes the first one, which in our analysis is also the most energy and trade-intensive of the three. However, the two other industries are only a little less energy-intensive than the first one, which is why we include them on our list.
  - For the *Casting of iron (C2451); Casting of steel (C2452);* and *Casting of light metals (C2453)* industries, the European Commission includes only the first one, because the latter two have low trade intensities. However, in our

analysis we find that all three industries are very tradable products (low weight-to-value ratio and low tariffs), which is why we include them on our list at medium risk of carbon leakage.

- The European Commission does not include the industry *Machinery for metallurgy (C2891)*, which is an energy-intensive industry in Sweden. The emission intensity is too low, although we see a relatively high energy intensity of 24% in Sweden.

2.5 Carbon leakage that may materialise in the longer run

The last step in our numerical assessment of the industries at risk of carbon leakage is to evaluate whether the risk is short or long run. If an industry is capital-intensive, it will most likely not react to extra carbon costs until investments have been depreciated. Because of this the risk of carbon leakage can be a long-term issue for some industries.

We evaluate this question by looking at the capital intensity of the industries. If an industry has a capital intensity higher than 15%, then the risk of carbon leakage is a long-term risk. If the capital intensity is lower than 15%, then the risk of carbon leakage is a short-term risk. The 15% threshold was also used in the 2012 report.

The result is shown in Table 6.

Table 6: Industries at risk of carbon leakage in the long run

NACE	Sector
C103	Fruit and vegetables
C104	Oil and fats
C1051	Dairy products
C106	Grain mill and starches
C1091	Feeds
C1092	Pet foods
C1106	Malt
C1610	Sawmilling of wood
C1711	Pulp
C1712	Paper
C1722	Sanitary goods
C19	Coke and petroleum
C2011	Industrial gasses
C2013	Other inorganic basic chemicals
C2014	Other organic basic chemicals
C2015	Fertilisers and nitrogen compounds
C2017	Synthetic rubber in primary forms
C2222	Plastic packing
C235	Cement
C2365	Fibre cement
C2399	Non-metallic mineral products
C2410	Basic iron and steel
C2420	Steel tubes and pipes
C2434	Steel wires
C2452	Casting of steel

Source: Copenhagen Economics based on Eurostat table sbs_na_sca_r2.

The implication is that for these industries the risk carbon leakage may be strong even though we have not witnessed it yet.

2.6 Deep dive into the aluminium industry

Aluminium is one of the most important non-ferrous metals (i.e. it does not contain iron), and it is used in everything from transportation vehicles and buildings (because of its high strength-to-weight ratio) to electrical equipment and food packaging. It is made by crushing and smelting the rock bauxite in a highly electricity-intensive process (primary production), but can also be recycled, which requires less energy (secondary production). Globally, the vast majority of aluminium is produced in China (57%).[19] In the Nordic countries, most of the aluminium production takes place in Norway and in

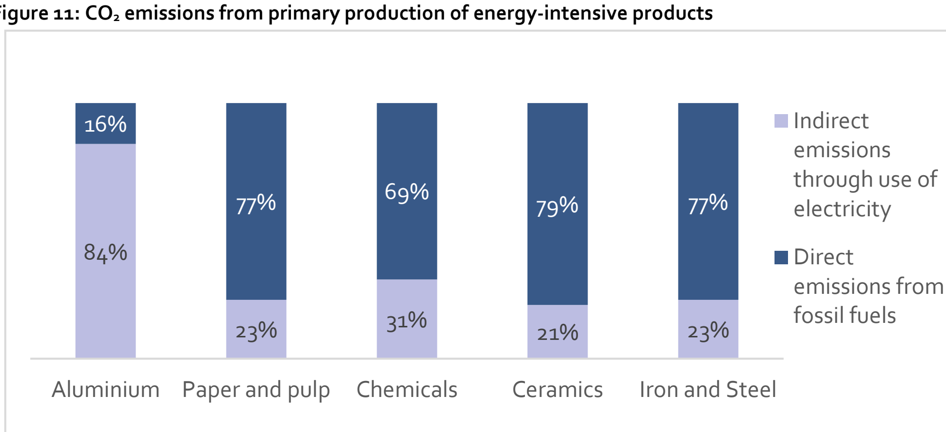
[19] Source: World Aluminium.

Iceland. And in Iceland aluminium production is by far the predominant energy-intensive industry accounting for almost 80% of the energy consumption in the industry. These characteristics make aluminium an interesting case study.

2.6.1 *Electricity costs are a main production cost component which make indirect emission costs important*

The production of aluminium is very electricity-intensive, and the cost of electricity accounts for a very large share of production costs. Around one-third of the production costs are cost of electricity.[20] This means that most of the CO_2 emissions caused by aluminium production happens through generating the electricity used in aluminium production (indirect CO_2 emissions). In the production of primary aluminium, indirect CO_2 emissions account for 84%, where CO_2 emissions through direct consumption of fossil fuels only account for 16%. The share of indirect CO_2 emissions in aluminium is thus much higher than in other energy-intensive industries (see Figure 11).

Figure 11: CO_2 emissions from primary production of energy-intensive products



Source: Ecofys (2015).

The importance of indirect CO_2 emissions makes indirect CO_2 costs critical for the competitiveness of the aluminium industry. The price of aluminium is *global* (set at the London Metal Exchange), whereby local producers cannot pass on extra cost to consumers. We estimate that an increase in the ETS price of EUR 30/tonne and EUR 50/tonne will increase production costs by 13 and 27% respectively through its upward

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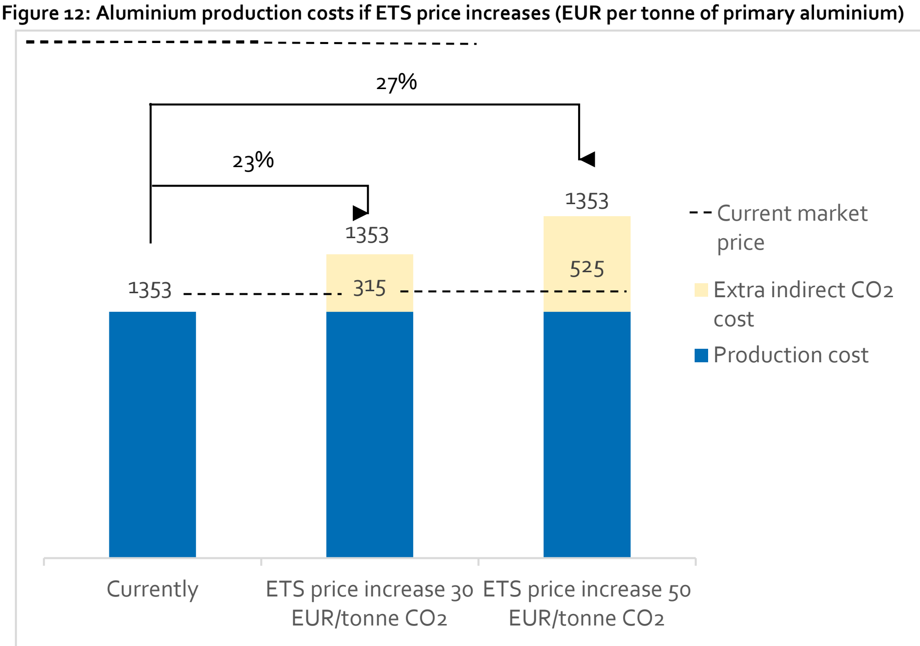
[20] Own calculations based on numbers from CRU international.

pressure on the electricity price (see Figure 12). Such an increase would exceed the current market price of aluminium, potentially placing European aluminium producers at a competitive disadvantage.

Figure 12: Aluminium production costs if ETS price increases (EUR per tonne of primary aluminium)



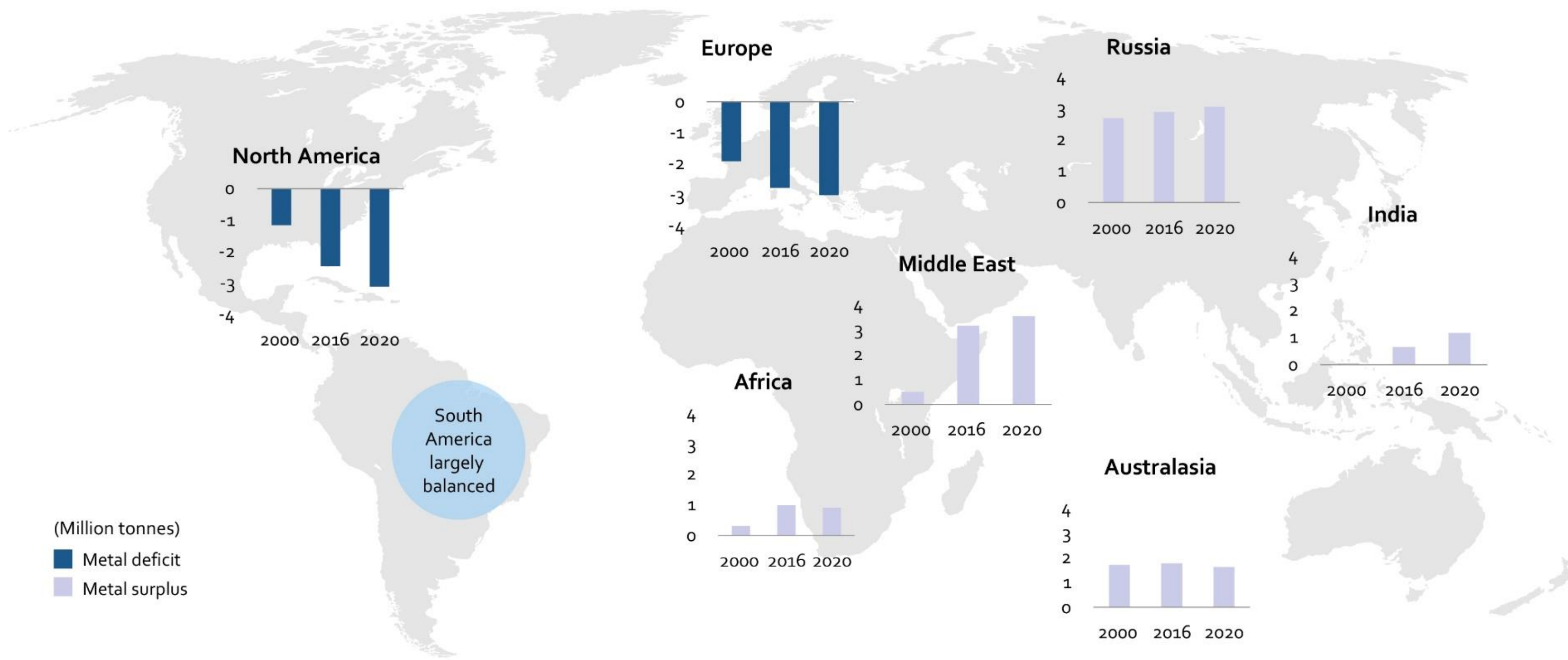
Note: "Currently" and "Current market price" is the average of 2012 and 2013, source: JRC (2016). We assume an electricity intensity of 15 MWh per tonne of aluminium, source CEPS (2013), and a marginal CO_2 content in electricity of 700 g/kWh.

Source: Copenhagen Economics based on CEPS (2013) and JRC (2016).

2.6.2 EU is becoming more import-dependent

Trends in the production and consumption of primary aluminium show that Western countries like the United States and countries in Europe are increasingly becoming dependent on imports. The market deficit (consumption minus production) in Europe is currently almost 3 million tonnes, meaning that consumption exceeds production by 3 million tonnes (see Figure 13). This highlights the international competitive pressure existing in the aluminium industry, and underscores how extra CO_2 costs could intensify this trend.

Figure 13: Production and consumption of primary aluminium in selected regions



Note: The market balance is defined as the difference between consumption and production. China is not included.

Source: Hydro based on CRU International.

2.7 Deep dive into the nitrogen fertilizer industry

The fertilizer industry is an interesting case because its position as carbon leakage exposed briefly was drawn into question by a study suggesting high pass-through rates. In this deep dive, we show that the industry is nonetheless severely exposed to carbon leakage risk.[21]

All crops need a combination of different nutrients to grow. Nitrogen fertilizers are by far the most important fertilizer, accounting for 70% of total nutrient consumption in the Nordic countries.[22] Further, the Nordic region is home to one of the largest manufacturers in the world, Yara, measured on revenue.[23]

The production of nitrogen fertilizers is a very GHG-intensive production process. Most nitrogen fertilizers are made from ammonia, which is made by extracting CO_2 (and other chemicals) from a carbon-based feedstock (typically natural gas). Thus, in this process CO_2 emissions is an unavoidable by-product. On the European Commission's preliminary list of industries at risk of carbon leakage, the fertilizer industry is in the top 10 of industries with the highest CO_2 intensities. Fertilizers are heavily traded on international markets (trade intensity is almost 30%), which further adds to this industry's risk of carbon leakage.

2.7.1 Fertilizer costs are significantly affected by carbon prices

Whether costs are significantly affected by increased carbon prices depend on two elements. *Firstly*, that GHG emissions per value added are high, meaning that extra CO_2 costs would significantly increase production prices and, *secondly*, that options to mitigate GHG emissions, e.g. through energy efficiency, are limited or very costly. In this section, we argue that nitrogen fertilizers are in fact very emission-intensive and that there is limited potential to reduce emission intensity further.

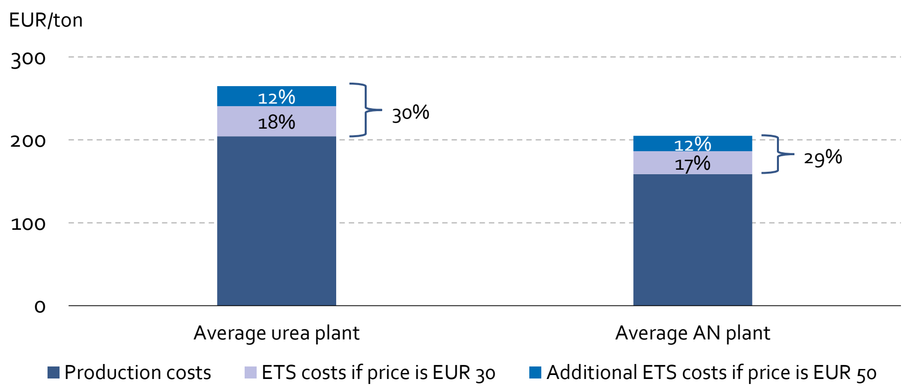
A higher cost of CO_2 will substantially raise the cost of producing fertilizers in the EU. For instance, if the carbon price is EUR 50, the extra cost will amount to a 30% increase for the two types of nitrogen fertilizers urea and ammonium nitrate (AN), see Figure 14.

[21] This deep dive is based on Copenhagen Economics (2015).

[22] Based on data from the International Fertilizer Industry Association.

[23] Yara (2017)

Figure 14: Higher EU ETS price will significantly raise cost of fertilizer production



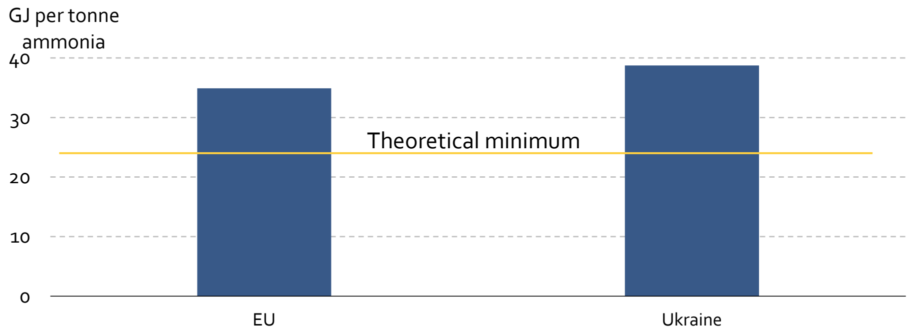
Note: The production cost is based on urea and AN production, respectively, and is calculated as an average plant. The figure does not include free allowances in order to show the "raw impact" of the ETS price. Urea is more expensive than AN per tonne, as there is a higher nutrient value in one tonne of urea than AN.

Source: Copenhagen Economics (2015).

The chemical production process of producing fertilizers requires a minimum energy inflow, since fuels are not just used to drive energy processes, but also as a feedstock to be converted to ammonia. In fact, two thirds of natural gas consumption in this industry is for feedstock, and the remaining third is to provide an energy source. To reduce emissions, producers thus have two options: 1) use less carbon-intensive feedstock and 2) increase energy efficiency in the energy process. As for the first option, EU producers already use the most carbon efficient feedstock,[24] namely methane, where e.g. Chinese producers typically use coal, which emits significantly more carbon per tonne of ammonia. As for the second option, EU fertilizer producers have already reduced their energy use substantially and are currently well below other fertilizer producing countries. The theoretical minimum for the feedstock is 18.6 GJ/t and when the theoretical minimum for the necessary energy is added, the total absolute theoretical minimum is 23 GJ/t.[25] See Figure 15 which compares European producers' energy use to Ukrainian producers.

[24] Other carbon feedstock such as biomass could also be used, but this is not deemed a realistic option as it is currently neither technically possible, reliable in a sufficient scale nor realistic in terms of costs, see Vivid Economics (2014).
[25] Copenhagen Economics (2015).

Figure 15: There is little room for further energy reductions



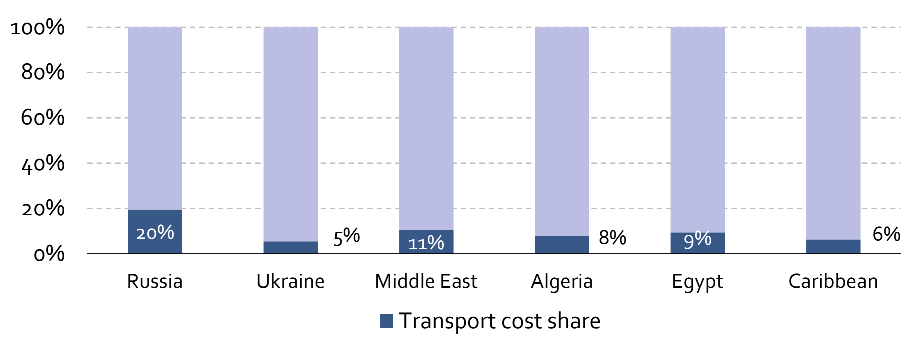
Note: The columns show that energy intensity for an average European and Ukrainian plant in 2013.

Source: Copenhagen Economics (2015).

2.7.2 Nitrogen fertilizers are transportable

Transporting nitrogen fertilizers to the European market is relatively cheap compared to the value of the product. In fact, it is below 10% for most of the regions in question, especially the regions where the goods are transported by sea. This picture suggests that non-European production could be cost-competitive with European production for relatively small cost differentials. For fertilizers, the transport cost as a share of product value ranges from 20% in Russia to 5% in Ukraine, see Figure 16. Notice that the low relative cost in Ukraine reflects the current very high cost of natural gas in Ukraine.

Figure 16: Transport costs as a share of production costs are low for nitrogen fertilizers



Note: The calculation is based on urea. The transport cost share is calculated as the cost of transporting to Europe relative to the value of the product measured by an EXW price of EUR 250 per tonne. Rail to EU border has been used for calculations of transport costs from Russia and Ukraine. For the other regions, transport costs have been estimated based on dry bulk ocean freight.

Source: Copenhagen Economics (2015).

3. Effective policy framework to deal with carbon leakage

3.1 An effective policy is to combine a carbon price with compensation to trade exposed industries

A cost-effective policy instrument to reduce CO_2 emissions is to put a price (e.g. a tax) on these emissions. By letting the emitter pay, this regulation provides an incentive for the emitter to find ways to reduce the emissions in the cheapest way possible. However, the cost-effectiveness of a CO_2 price is only high, when all CO_2 emissions are subject to the same price; something that is very hard to do in a world with very different countries and very different tax systems. And because of globalisation and international trade, putting a CO_2 price on industries in one country might just move the CO_2 emissions to another country because of carbon leakage.

Therefore, the *second-best* policy instrument is a CO_2 price, which take into account the risk of carbon leakage by shielding trade exposed industries. This can be done by compensating the industries for their extra carbon costs with a lump-sum transfer (for instance free allowances, which is done in the EU ETS). By letting the industry pay the CO_2 price, but compensating them, they will still have the incentive to reduce their CO_2 emissions, but will not be set at a competitive disadvantage. The level of compensation should optimally reflect the risk of carbon leakage. If the industry is at high risk of carbon leakage, there should be full compensation of the higher CO_2 cost in their production. We have argued, through this report, that evaluating the risk of carbon leakage should be done by looking at a range of indicators revealing important aspects of the industries' market conditions supplemented by a qualitative assessment for those industries for which the indicators badly reflect their specific market conditions.

It is important to note that the risk of carbon leakage depends on the *relative* CO_2 prices at home and abroad. I.e. if CO_2 prices in domestic markets increase relative to CO_2 prices abroad, then the risk of carbon leakage increases. Hence the level of compensation should also increase. However, the definition of "abroad" here is key: Since foreign competitors are spread out in multiple countries, what matters is the CO_2 price in the country with the *lowest* CO_2 price. If all countries but one increase their CO_2 prices collectively, the risk of carbon leakage still persists because of that one important country. This highlights the importance of collective action on CO_2 prices.

A much-debated alternative to the compensation mechanism is the so-called border tax adjustment mechanism. Essentially, this mechanism means that domestic industries are refunded the carbon tax when they export, and/or foreign companies are subject to a carbon tax when their product is imported.[26] This necessitates an estimate of the carbon emissions inherent in the product, which is not straightforward as the inherent carbon emissions will depend on the specific production methods. Therefore, there is a risk that this mechanism does not effectively target carbon emissions. Such mechanisms have not yet been implemented, and it can prove difficult to construct such a mechanism while complying with international WTO rules. The United States' recent shift in opinion on free trade could however reduce the weight the WTO has on the world community.

3.1.1 Free allowances within the EU ETS

Within the framework of the EU ETS, compensation is dealt with by allocating free CO_2 emissions allowances to industries deemed at risk of carbon leakage. As a concept, this is very reasonable as it ensures that European industry faces a price on emitting CO_j while also compensating the industries exposed to competition.

Nonetheless, the free allowance system has been heavily criticised over the years. One of the main reasons for the critique is that the amount of free allowances has been too high. Indeed, the current list of industries at risk of carbon leakage covers 97% of EU industrial emissions. Hence, the historical low price of allowances has often been attributed to an "over supply" of free allowances[27] largely as a result of the financial crisis, credits from JI/CDM and probably a lenient interpretation of what it means to be at risk of leakage. Consequently, the "natural" response suggested has been to limit the amount of free allowances.

We argue that this is an inappropriate response. It is important to distinguish between a general oversupply of allowances and whether allowances are given out for free as leakage compensation or auctioned out at a price. We argue that an appropriate response would instead be to increase the ETS price by reducing the total amount of allowances while ensuring that industries truly facing a risk of leakage remain compensated by receiving these allowances for free.

3.2 Implementation of Paris is an important step to prevent risk of leakage between EU and non-EU countries

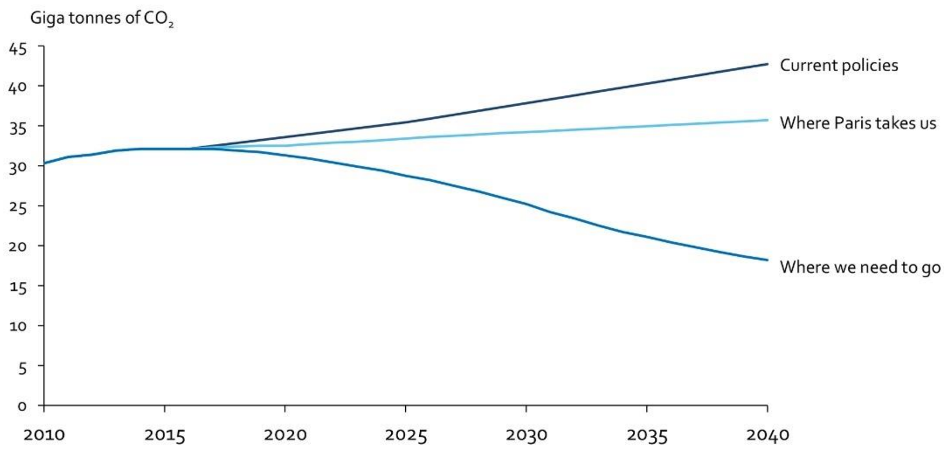
Collective global action on climate change is key to limit the risk of carbon leakage. The most significant step forward in this respect is the Paris Agreement within the United Nations Framework Convention on Climate Change (UNFCCC) from 2015. In this agreement most countries have submitted so-called *nationally determined contributions* (NDC), which specifies each country's targets for limiting CO_2 emissions. When all countries move and take actions to reduce CO_2 emissions, single regions will not be left with a competitive disadvantage if they were to impose stricter climate policies on their own.

[26] See Copenhagen Economics (2012).

[27] See for instance EEA (2017).

However, the ambitions and actions in the Paris Agreement is not sufficient to reduce CO_2 emissions enough to limit the increase in global temperatures to 2 degrees. In 2040 the Paris Agreement will have only reduced global energy-related CO_2 emissions by 16% compared to where current policies will take us. This compares to a required reduction of almost 60%, if we want to be in line with the 2-degree target (see Figure 17).

Figure 17: Future global energy-related CO_2 emissions is crucially dependant on ambitious policies



Note: *Current policies* are IEA's current policies scenario (CPS), *Where Paris takes us* is their new policies scenario (NPS) and *Where we need to go* is their sustainable development scenario (SDS).

Source: IEA (2017).

Even though the Paris Agreement is a collective step forward, countries have not necessarily moved equally far. For a collective action to eliminate the risk of carbon leakage, CO_2 prices (direct or indirect) should be equal in all countries. The NDC's are difficult to compare in terms of the *strictness* of the targets as they are defined in different ways (for instance some countries have CO_2 reduction targets below a historical year, e.g. 1990, and some have reduction targets below a baseline scenario). Comparing them therefore needs a rigorous analysis based on energy-economic modelling. One such comparison done by a Harvard professor shows that the European Union has taken the furthest step. Table 7 shows such a comparison showing that the EU's efforts are twice the United States' and that China's and Russia's NDC's do not amount to any cost in terms of GDP.

Table 7: Ex ante assessment of the economic cost of CO_2 mitigation efforts in NDCs in the Paris Agreement

Country/region	Mitigation costs per GDP (per cent)
European Union	0.82
United States	0.39
China	~ 0
Russia	~ 0

Source: Aldy et al. (2016).

In 2017 the Trump administration announced that the United States would withdraw from the Paris Agreement, which increases the risk of carbon leakage for Nordic and European industries. By withdrawing from the agreement, the difference between EU and US mitigation efforts increases, which, all else equal, places EU industries at a competitive disadvantage. It also means that the US mitigation cost of 0.39% of GDP in Table 7 is now 0%, which leaves the EU as the only region of the four willing to accept an economic cost of reducing CO_2 emissions.

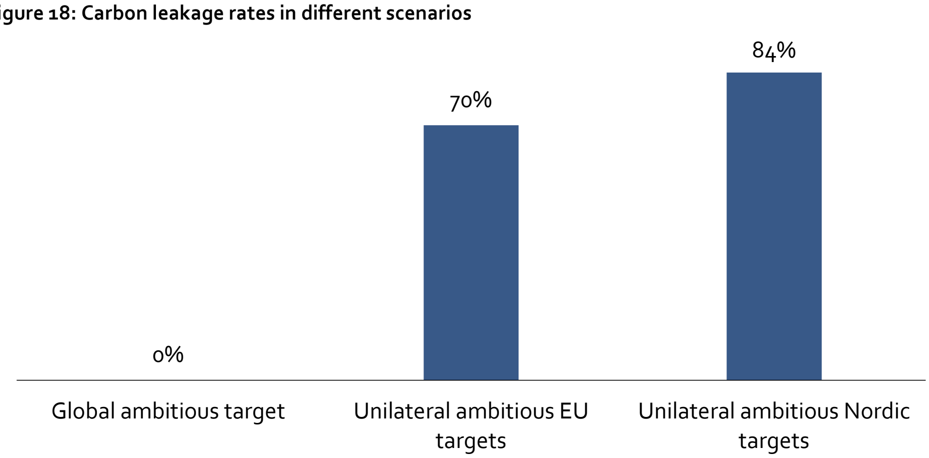
3.2.1 Carbon leakage can be reduced by true collective action

In order to show how unilateral versus collective action on CO_2 mitigation efforts affects the degree of carbon leakage, we have simulated the effect of different climate policy scenarios in our carbon leakage CECEM.[28]

In a situation where all countries apply binding carbon emission targets, there will be no carbon leakage on the economy as a whole on the margin as any increase in production in one sector, will have to be met with a decrease in production in another.[29]

However, we find that if the EU unilaterally moves too far ahead, leakage rates for the energy intensive industries can be as high as 70% in the long run. This implies that for every 100 ton of CO2 saved in the EU 70 ton are created in another country. If the Nordic region were unilaterally to adopt stricter ambitions the leakage rate could even be as high as 84%.

Figure 18: Carbon leakage rates in different scenarios



Source: Copenhagen Economics based on CECEM model. See appendix for technical description.

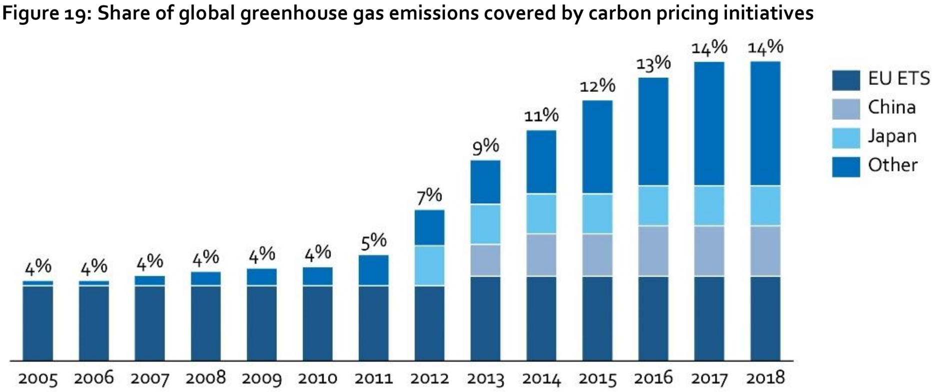
[28] The model is a global computable general equilibrium (CGE) model based on the GTAP model, built to model energy systems globally. The main purpose of the model is to analyse long-run economic impacts of climate policies.
[29] Some sectors can still be exposed to carbon leakage, but the overall effect is zero at the margin.

We base this modelling exercise on the assumptions and information about future policies around the world from the IEA's *World Energy Outlook 2017* projections. We construct four scenarios each representing different CO_2 mitigation efforts in different world regions. The scenarios use all the same assumptions although differ on CO_2 prices:

- *Reference scenario*: This scenario is in line with the IEA's *new policies scenario*, which includes the Paris agreement although not for the United States. As a general rule, the *new policies scenario* includes all implemented and announced policies (for instance CO_2 emission reduction targets).
- *Unilateral Nordic action*: In this scenario, Nordic countries implement stricter policies than those included in the reference scenario. More specifically, CO_2 prices are increased to be equal to IEA's *sustainable development scenario*, which is in line with limiting global temperature increases to 2 degrees.
- *Unilateral EU action*: In this scenario, all countries in the EU implements stricter policies than those included in the reference scenario. More specifically, CO_2 prices are increased to be equal to IEA's *sustainable development scenario*, which is in line with limiting global temperature increases to 2 degrees.

Carbon pricing initiatives at both national and sub-national levels have become increasingly widespread in the past decade. In 2008, 4% of global GHG emissions were covered by carbon pricing initiatives mostly due to the EU ETS. By 2017 this number had risen to 14% as a large range of countries and sub-national regions have introduced carbon pricing (see Figure 19). A large part of the increase stems from Japan's carbon tax covering all fossil fuel use in Japan. In 2017 China officially launched their plans for a national ETS although the year of implementation is still uncertain. So far, China has implemented regional pilot ETS's. In the United States, several states have implemented their own ETS (California, Washington and Massachusetts) and other states are currently considering the same (Virginia and Oregon).

Figure 19: Share of global greenhouse gas emissions covered by carbon pricing initiatives



Note: Only the introduction or removal of a carbon pricing initiative is shown. Emissions are stated as a share of GHG emissions in 2012. China covers pilot ETS.

Source: The World Bank, Carbon Pricing Dashboard.

3.3 Compensation for direct emissions through free allowances works but could be improved

In order to compensate industries for so-called direct emission costs,[30] the ETS operates with a harmonised and institutionalised system of allocating some of the emission allowances for free. By allocating the allowances for free, the manufacturing sector is facing an incentive to reduce CO_2 emissions, because the allowances can be sold in the market, but it does not put the industry at a competitive disadvantage. Therefore, the system of allocating allowances freely works from a theoretical point of view.

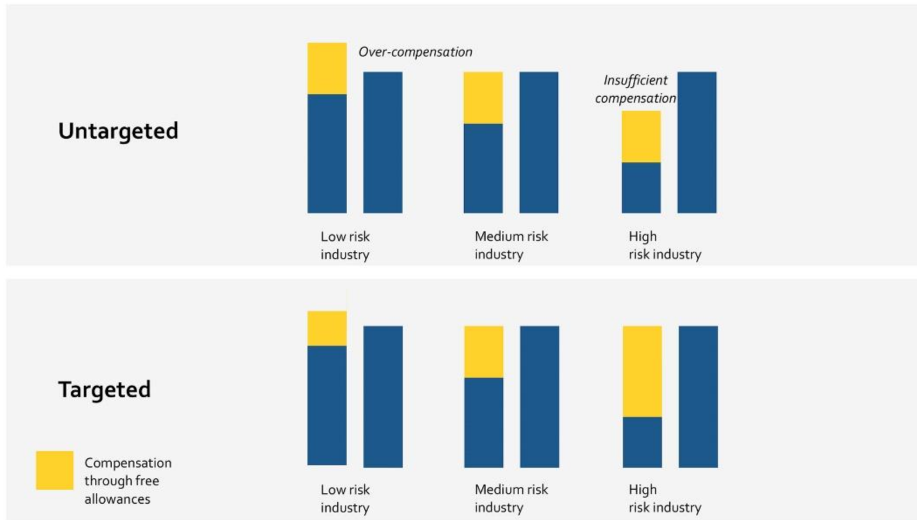
However, we argue that this approach faces two major drawbacks in terms of preventing carbon leakage:

Firstly, all industries/processes on the carbon leakage list obtain a lower amount of compensation than they need because only some of them are allocated for free. This amount will decline over time. In 2013 the manufacturing industry received 80% of its allowances for free, but this share is decreasing to 30% in 2020. The rest is allocated by auction. This is problematic, because if an industry truly is at risk, a too low compensation will not be effective in preventing leakage. Theoretically, there is no argument for why industries at high risk should not face full compensation for the imposed CO_2 costs. Moreover, the idea that the free allowances should decline over time seems contrary to the purpose as ETS prices are indeed likely to increase going forward. Instead, the amount of free allowances could be determined with a look towards main competitors and how these countries impose climate costs to their industries.

Secondly, industries/processes on the carbon leakage list facing relatively low (potential) foreign competition will receive the same compensation treatment as industries on the list facing high (potential) foreign competition. Consequently, free allowances are relatively equally spread out across industries, leaving industries at high risk "undercompensated" and industries at low risk "overcompensated" (see Figure 20).

[30] Direct emissions are the emissions resulting from either combustion of fossil fuels or process emissions from fossil fuels. This is in contrast to indirect emissions, which are emissions resulting from electricity consumption that ultimately leads to emissions when generating electricity.

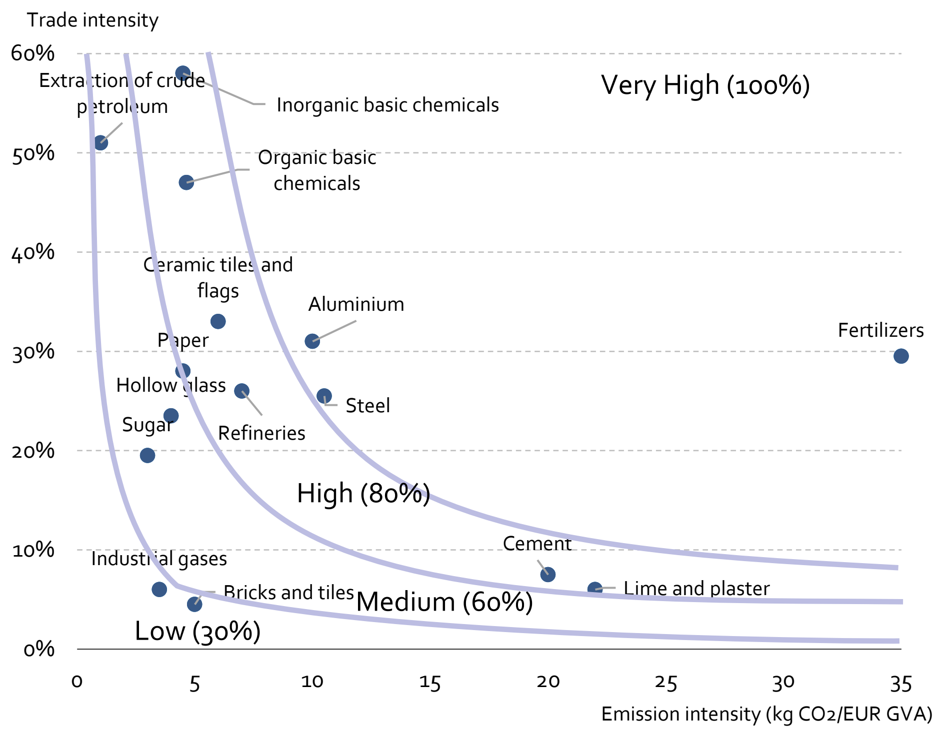
Figure 20: Illustration of targeted and untargeted compensation



Source: Copenhagen Economics.

This problem was indeed recognised in the Impact Assessment done by the Commission in 2015. Here it is recommended to adopt a tiered approach to leakage compensation, differentiating between industries at high, medium and low risk (see one way of determining the tier in Figure 21). However, there was no political appetite to adopt this change at that time.

Figure 21: An approach to differentiating between industries at varying degrees of risk



Source: Copenhagen Economics based on Figure 13 in European Commission (2015).

3.4 Compensation for indirect carbon emissions through State aid has major shortcomings

Where direct carbon emissions are compensated through an institutionalised EU-based setup through the free allowances system, compensation for indirect emissions is done in a significantly different – and less encompassing – way. Here, Member States can decide whether or not to compensate their own industries as long as they adhere to the EU State aid rules. The current State aid rules allow partial compensation of the indirect costs, declining from 85% for the period 2013–2015, to 75% for the period 2019–2020.[31] In this connection, the existence of State aid rules does ensure some degree of consistency between the countries.

Initially, EU Member States dealt with this compensation on an ad hoc basis, deciding whether or not to grant aid to a particular industry/process. However, in recent years, several countries have adopted more clear compensation practice guidelines. Currently, at least 10 countries have some sort of compensation mechanism approved

[31] EC (2017).

by the European Commission: United Kingdom, Germany, Belgium, the Netherlands, Greece, Lithuania, Slovakia, France, Finland and Spain.[32] Not all of these have yet paid out compensation. While most apply the maximum allowed compensation of up to 85% compensation, some have lower limits. In Finland, for example, compensation is only granted up to 40% of the indirect costs. Moreover, and importantly, all of the adopted schemes are only approved for the current EU ETS phase three ending in 2020, making compensation after 2021 highly uncertain. This is also linked to the current State aid guidelines being in force until 2020.[33]

This approach to compensation has several drawbacks, including the following:

- Uneven compensation distorts competition between countries. Identical electricity-intensive producers located in two different countries may experience massively different compensation and therefore business cases thereby distorting the internal market.
- The differences between compensating through free allowances and through State aid gives unequal treatment of otherwise similar plants sourcing electricity from the grid and plants generating electricity onsite, e.g. through coal or gas-fired turbines (thereby causing direct emissions instead of indirect).
- Compensation is only partial, and at quite low levels. Similarly, to the case for direct emissions if anti-leakage measures should be effective, industries at high risk of leakage should obtain full compensation (meaning there is neither under nor over-compensation).
- Compensation will directly influence public budgets and is granted by national finance ministries. This creates an incentive for Member States to avoid paying compensation.
- As national compensation schemes are national prerogative, compensation schemes are easier to change for example with changing governments – unlike the free allowance system which is more institutionalised. This creates a large uncertainty for the industry.

3.5 The political process determining climate ambitions and leakage compensation should be more integrated

The political process determining climate ambitions and carbon leakage compensation should be more integrated. Measures to increase carbon pricing are often met with opposition from industry organisations, as this is seen as reducing EU competitiveness, thereby risking closing down domestic production simply to see an increased production abroad. Opposed to this view often stand green parties and environmentalists arguing that the risk of leakage is not real or negligible. The view has

[32] See EC (2017) and Ecofys (2016).

[33] A process to update the current State aid guidelines is expected to commence in 2018.

also been presented by national Ministries of Finance in response to the question of national compensation of indirect carbon costs (see above).[34]

The problem is that political discussions of strengthening of the EU ETS and compensation of carbon leakage happens in different rooms and not simultaneously. First, politicians negotiate how to strengthen the EU ETS. Secondly, politicians negotiate how to deal with carbon leakage through state aid guidelines. Industry will understandably be reluctant to support strengthening the ETS if they cannot be guaranteed a proper leakage compensation, which could hinder the political process. In order to muster support from the industry and achieve an effective ETS with much higher carbon prices – which is needed – leakage compensation and ETS reform must be treated as a full policy package.

3.6 Specific policy recommendations

Based on the identified challenges in this chapter, we draw the following conclusions for policy change:

Include leakage compensation (both free allowances, State aid guidelines, and in the energy taxation directive) in negotiations of overall climate ambitions including ETS reform. The industry would be more constructive in embracing high overall climate ambitions, if they are ensured certainty about leakage compensation mechanisms going forward.

The current approach of determining the risk of leakage through carbon intensity has drawbacks, which are particularly relevant for the Nordic industry using biomass. The price of biomass is linked to the price of the alternatives namely fossil fuels, and an increase in the price of fossil fuels is likely to spill over to the price of biomass. Consequently, an industry being fully reliant on biomass – thereby having a carbon content of zero – can still be exposed to leakage.

Similarly, as industries invest in more energy efficiency equipment and/or switch from fossil to renewable fuels, the carbon intensity will be reduced but capital/production costs are likely to increase (as long) as energy efficiency equipment is more expensive than less energy efficient equipment and renewable fuels are more expensive than fossil fuels (without any climate-related cost, e.g. ETS). Consequently, the production costs of EU industry will be higher than non-EU competitors due to EU climate policies – even though the carbon content of the EU industry is low – and industry can be at risk of leakage.

In order to truly capture the risk of leakage, each industry should be assessed by identifying main global competitors and the total climate-imposed costs to these industries in their country of origin. By total climate-imposed costs, we mean both costs from, e.g., the ETS but also increased capital costs by mandating more climate-friendly production equipment.

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[34] See, e.g., several Nordic governments' responses to the consultation document behind the State aid guidelines for environment and energy.

With respect to the *free allowance mechanism* there are several challenges that inhibit its effectiveness of preventing leakage. We propose a number of improvement options to be considered, with the ultimate aim of mobilising industry support for a more effective ETS:

- Decouple the discussion of the low ETS price due to – among others – the current oversupply of allowances from the discussion of how to compensate industry at risk. A strengthened ETS will be a prerequisite for a cost-efficient EU climate policy, but that can be done without diluting its instrument to safeguard competitiveness of the industries truly at risk.
- Allow for 100% of free allowances for select industries/processes deemed at high carbon leakage risk. If industries are truly at high risk, less-than-full compensation will not be effective in preventing leakage.

With respect to the *compensation for indirect emissions*, there are several structural challenges with the system that should be addressed. The upcoming review of the State aid guidelines would be a good opportunity to consider this. We propose the following number of improvement options, with the ultimate aim of mobilising industry support for both a more effective ETS and for any potential national or regional increases in the electricity price (e.g. as done in the UK through its carbon price floor):

- Ensure stability and credibility in granting leakage compensation, e.g. by introducing a common EU-based mechanism decoupled from the national public finances. One approach would be to include industries at risk of leakage through high indirect emissions in the free allowance system.
- Alternatively, and as a minimum, improve nationally based mechanisms by increasing the level of compensation up to the ceiling given in the State aid guidelines and making the mechanisms time indefinite.
- Raising the allowed compensation in the State aid guidelines to more than 85% for industries at high risk of leakage while minimising risk of under and over-compensation.

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Sammenfatning på dansk

Risikoen for carbon leakage er et ofte diskuteret problem i Den Europæiske Union (EU) og i Norden. Carbon leakage er en situation hvori policy-skabte reduktioner af indenlandske CO_2-reduktioner blot fører til forøgede udledninger i udlandet. Hvis klimapolitik øger produktionsomkostningerne for indenlandske industrier, kan dette forværre deres konkurrenceevne over for udenlandske industrier. Som et resultat heraf vil indenlandsk produktion og CO_2-udledninger formindskes mens udenlandsk produktion og CO_2-udledninger forøges. Globale CO_2-udledninger bliver dermed ikke reduceret, men blot flyttet fra én region til en anden.

Debatten om hvordan man løser problemet med carbon leakage føres primært i Bruxelles, og gøres i relation til den Europæiske Unions "Emissions Trading System" (ETS), EU's flagskib inden for klimapolitiske redskaber. For at undgå carbon leakage gives energi-intensive industrier udsat for direkte konkurrence fra udenlandske virksomheder ofte frie udledningstilladelser. Det er dog ikke helt ligetil at udpege industrier som bør tildeles frie udledningstilladelser grundet forøget risiko for carbon leakage. I øjeblikket afgøres dette af Europa-Kommissionen gennem forskellige kriterier på et Europæisk niveau, hvilket potentielt kan lede til at regionale forskelle overses. Spørgsmålet er fra et Nordisk perspektiv, hvilke industrier der er i fare for at opleve carbon leakage, og hvorvidt der er specifikke Nordiske perspektiver som bør introduceres i EU-debatten?

Vores vurdering af risikoen for carbon leakage tager udgangspunkt i markedskarakteristika

En analyse af *risikoen* for carbon leakage skal være en fremadskuende analyse. En specifik industri kan være i fare for carbon leakage selv hvis carbon leakage ikke er til stede under de nuværende markedsforhold. Dette kan fx skyldes at den nuværende regulering måske ikke er streng nok til at igangsætte carbon leakage, og/eller at der er tilstrækkelig kompensation for de højere omkostninger, men hvis CO_2-reguleringen strammes kan carbon leakage opstå. Der er ikke i litteraturen endnu fundet empirisk evidens for, at carbon leakage har fundet sted på betydeligt plan, men det er vigtigt at anerkende, at dette ikke afspejler risikoen for carbon leakage i fremtiden.

Vores analytiske tilgang til risikoen for carbon leakage fokuserer derfor på indikatorer som fremhæver vigtige aspekter af markedsforholdene, som industrierne opererer under. De vigtigste aspekter er implikationerne for produktionsomkostninger og hvorvidt de er udsat for internationalt konkurrencemæssigt pres. Det er ikke nok blot at kigge på hvor meget et givent produkt handles internationalt for at forstå det underliggende internationale konkurrencemæssige pres. Et produkt kan være afskærmet fra international konkurrence af høje transportomkostninger eller importtold som gør udenlandske omkostninger højere end indenlandske produktionsomkostninger. Imidlertid kan en forøgelse af indenlandske CO_2-priser dog flytte denne balance og forøge den internationale konkurrence og derigennem omfanget af carbon leakage.

Nordisk metal- og papirindustrier er især i fare for carbon leakage

Vi har konstrueret en liste af de nordiske industrier som er i fare for carbon leakage, baseret på en række numeriske indikatorer (se figuren på næste side). De væsentligste industrier på listen er *aluminium og kobber; jern og stål*; og *papir*, som både er meget energiintensive (energiintensivitet er over 40 %), og som samtidigt udgør store andele af værdiskabelsen i de Nordiske lande.

Nordiske industrier har forbedret deres energiintensitet betydeligt over tid. Siden 2008 er den gennemsnitlige energiintensitet blandt carbon leakage-udsatte industrier faldet med 28 %. En af de primære bidragere til denne udvikling er papir-industrien, som har reduceret energiintensiteten med næsten 40 % siden 2008. Dette har været drevet af blandet andet store investeringer i energieffektivisering understøttet af staten. I Finland har staten eksempelvis tilbudt frivillige energieffektiviseringsaftaler for energiintensive industrier som støtter disse investeringer. I perioden 2008-2016 investerede den finske papir-industri i alt 230 EUR millioner hvilket har ført til energibesparelser på samlet set 5.4 TWh.2

Nordiske industrier er mere elektricitets- og biobrændselsintensive end i EU

De energiintensive industrier i de Nordiske lande bruger mere elektricitet og biobrændsel sammenlignet med industrier i EU. For alle industrielle sektorer gælder det, at 68 % af energiforbruget i industrien i de Nordiske lande dækkes af enten elektricitet eller biobrændsel og kun 25 % fra fossile brændsler. I EU er de tilsvarende tal 39 % og 53 %. De største forskelle mellem sammensætningerne i forbruget af brændsler ses i papir- og papirmasseindustrien hvor 59 % af energien kommer fra biobrændsel i de Nordiske lande sammenlignet med kun 38 % i EU.

Det mere intensive forbrug af elektricitet og biobrændsel i de Nordiske lande har vigtige policy-implikationer.

For det første, kompensationssystemet for højere priser på elektricitet som følge af EU's ETS (såkaldte *indirekte omkostninger)* bruges ikke systematisk og centraliseret. Frem for en mekanisme på tværs af hele EU, kan nationale medlemsstater selv beslutte hvorvidt de vil kompensere deres egne industrier, kun begrænset af EU's regler om statsstøtte som kun tillader delvis kompensation. Dette skaber ujævn konkurrence mellem de europæiske lande (selvom eksistensen af statsstøttereglerne sikrer et vist niveau of konsistens mellem lande). Da elektricitetsintensiteten er højere i Nordiske lande er dette problem mere presserende for Nordiske industrier.

For det andet, brug af biobrændsel behandles som værende CO_2-neutralt, således at man fejlagtigt kunne konkludere at en industri som bruger biobrændsel ikke vil påvirkes af EU's ETS, og at carbon leakage derfor ikke er en risiko for denne industri. I takt med at omkostninger ved brug af fossile brændsler forøges (på grund af øget pris på CO_2) vil efterspørgslen efter biobrændsel også forøges således at prisen herpå også vil stige (alt andet lige). Derfor kan industrier som benytter biobrændsel også være i fare for carbon leakage. Denne pointe er ekstra vigtig for papir- og papirmasseindustrien (en af de største industrier i Norden), som bruger biomasse, ikke bare som brændsel, men også som rå input i produktionen. Herigennem vil en højere pris på biomasse påvirke produktionsomkostningerne for papir- og papirmasseindustrierne og gøre dem højere.

Eksisterende tiltag for at forhindre carbon leakage kan forbedres

Som en del af rammerne for EU's ETS er kompensationen for højere CO_2-omkostninger givet i form af uddeling af gratis CO_2-udledningstilladelser til de industrier som vurderes at være i fare for at opleve carbon leakage. Som koncept er dette fornuftigt, da det sikrer at europæiske industrier oplever en pris på udledning af CO_2 samtidig med at industrier udsat for konkurrence kompenseres herfor. Til trods for dette er systemet med fri uddeling af CO_2-udledningstilladelser blevet kritiseret gennem årene, blandet andet fordi det menes at have bidraget til de lave ETS-priser. Som konsekvens er det blevet fremført, at man begrænsede det samlede antal gratis tilladelser. Vi konkluderer, at dette ikke er en korrekt reaktion. Det er vigtigt at skelne mellem et generelt overudbud af tilladelser, og hvorvidt tilladelser er uddelt gratis som en del af carbon leakage-kompensation eller solgt gennem auktioner. Vi argumenterer for, at en passende reaktion i stedet vil være at øge ETS-prisen ved at reducere det samlede antal tilladelser, imens man samtidig sikrer, at de industrier som har reel carbon leakage risiko forbliver kompenseret ved at modtage udledningstilladelserne gratis.

Vi argumenterer i denne rapport for, at kompensationsmekanismen for direkte udledningsomkostninger (direct carbon costs) har to markante ulemper. For det første, at alle industrier/processer på carbon leakage-listen modtager mindre kompensation end deres samlede klimaomkostning. Dette er problematisk, for hvis en industri virkelig er i fare for carbon leakage, vil en for lille kompensation ikke være effektiv til at forhindre leakage. I stedet bør antallet af frie tilladelser fastsættes uden loft, og gerne ved at se på primære konkurrenter og hvordan disse lande påfører klimarelaterede omkostninger på deres industrier. For det andet, så vil industrier/processer på carbon leakage-listen som oplever begrænset udenlandsk konkurrence modtage den samme kompensationsprocent, som industrier på listen der møder høj udenlandsk konkurrence. Det betyder, at høj-risiko-industrier er "underkompenserede", mens lav-risiko-industrier er "overkompenserede".

Hvor direkte CO_2-udledninger er kompenserede gennem et institutionaliseret EU-setup gennem frie tilladelser, sker kompensation for *indirekte udledninger* (indirect carbon costs) gennem en markant anderledes – og mindre ensartet – metode. Som nævnt herover kan nationale medlemslande vælge at kompensere deres egne industrier så længe de overholder EU's regler omkring delvis kompensation. I øjeblikket har mindst 10 lande en form for kompensationsmekanisme godkendt af Europa Kommissionen. Hvor de fleste er i overensstemmelse med den maksimalt tilladte kompensation på op til 85 %, tildeler nogle lande markant mindre. Finland kompenserer eksempelvis kun op til 40 % af omkostningerne. Det er derudover vigtigt, at alle disse benyttede systemer kun er godkendt under det nuværende statsstøttedirektiv som udløber i 2020, hvilket gør kompensation efter 2020 særdeles usikker.

Den politiske proces som fastsætter klimaambitionerne og carbon leakage-kompensation bør være mere integreret. Tiltag som skal øge carbon-priser mødes ofte med opposition fra industrien, da dette anses som en reduktion af EU's konkurrencedygtighed. En primær grund til industriens tøven med at støtte ambitiøse klimapolitiske tiltag er manglen på afklaring omkring carbon leakage-kompensation. Problemet er at den politiske diskussion omkring styrkelsen af EU's ETS og kompensationen for carbon leakage ikke sker som del af samme proces. Nøgleproblemer som fastlæggelsen af leakage-listen og leakage-kompensationen i statsstøttereglerne er afkoblede fra generelle diskussioner om hvordan EU's ETS styrkes, hvorfor den leakage-udsatte industri kan anse det som risikabelt at støtte ambitiøse klimapolitiske tiltag, før de ved hvordan leakage-kompensationen bliver. Så længe denne problematik ikke adresseres, risikerer man at blokere for en reel mulighed for en styrkelse af ETS og andre klimatiltag.

Kollektiv global handling er vigtigt for at reducere risikoen for carbon leakage. Det mest signifikante step fremad i denne henseende er Parisaftalen inden for UNFCCC fra 2015 på trods af usikkerhed om implementering og USA's tilbagetrækning fra aftalen. Når alle lande agerer og handler for at reducere CO_2-udledninger vil enkle regioner ikke efterlades med en ufordelagtig konkurrencemæssig situation hvis de indfører strengere klimaregulering selv. Gennem modelsimulationer finder vi, at carbon leakage ratioen kan være helt op mod 85% for de energiintensive erhverv, hvis de nordiske lande vælger unilateralt at gå længere end verdenssamfundet.

Appendices

Appendix A: Detailed information on indicators

Table A.1: Detailed information on indicators

NACE	Sector	Energy intensity	Trade intensity	Weight-to-value ratio	EU tariffs	Capital intensity
Food products and beverages						
C1020	Fish	8.2%	46.8%	2.79	4.4%	13.9%
C103	Fruit and vegetables	10.8%	18.4%	9.01	13.3%	15.2%
C104	Oil and fats	24.0%	31.7%	16.30	2.1%	16.9%
C1051	Dairy products	8.5%	7.2%	6.78	22.6%	19.0%
C106	Grain mill and starches	13.9%	10.6%	16.32	10.9%	22.3%
C1081	Sugar	10.8%	14.3%	28.58	27.8%	5.9%
C1085	Prepared meals	7.7%	21.3%	3.11	3.4%	8.5%
C1091	Feeds	18.6%	4.5%	16.24	37.2%	40.9%
C1092	Pet foods	11.6%	9.7%	7.58	37.2%	26.4%
C1106	Malt	28.9%	26.0%	26.14	0.0%	23.6%
Textiles, wearing apparel and leather						
C1310	Textile fibres	7.6%	41.9%	2.33	3.4%	10.8%
C1320	Weaving of textiles	8.6%	55.2%	1.06	3.4%	9.3%
C1330	Finishing of textiles	9.9%	55.2%	1.06	5.5%	3.1%
C1393	Carpets and rugs	8.3%	32.0%	2.68	0.0%	7.4%
C1394	Cordage, rope, twine and netting	5.2%	41.3%	4.50	0.0%	11.7%
C1395	Non-wovens	25.4%	34.6%	2.57	0.0%	14.4%
C1399	Other textiles n.e.c.	9.5%	27.2%	1.56	0.0%	4.4%
C1411	Leather clothes	9.6%	71.0%	0.13	2.3%	6.5%
C1412	Workwear	2.8%	30.6%	0.55	6.5%	2.9%
C1413	Other outerwear	3.7%	59.4%	0.63	6.5%	4.4%
C1419	Other apparel	3.6%	91.1%	0.41	6.5%	5.5%
C1420	Fur products	4.4%	85.8%	0.05	1.8%	3.2%
C143	Knitted apparel	5.0%	8.9%	0.31	0.0%	9.7%
C1511	Tanning and dressing of leather	8.2%	75.4%	0.83	2.3%	9.0%
C1512	Luggage	7.5%	75.4%	0.46	3.9%	9.0%
C1520	Footwear	4.1%	59.8%	0.45	10.0%	3.8%
Paper and pulp products						
C1711	Pulp	23.6%	46.8%	17.15	0.0%	25.8%
C1712	Paper	41.5%	22.0%	13.09	0.0%	22.1%
C1721	Corrugated paper	7.4%	5.9%	6.59	0.0%	11.1%
C1722	Sanitary goods	9.6%	13.3%	3.98	0.0%	20.3%
C1729	Other paper	10.9%	21.9%	3.48	0.0%	6.9%
Coke and petroleum						
C19	Coke and petroleum	33.3%	26.9%	23.31	1.2%	17.9%
Chemicals and chemical products (continued on next page)						
C2011	Industrial gasses	16.1%	3.8%	40.98	0.0%	27.7%
C2012	Dyes and pigments	55.4%	45.8%	3.47	0.0%	12.0%
C2013	Other inorganic basic chemicals	49.0%	46.6%	15.78	0.0%	16.1%
C2014	Other organic basic chemicals	17.1%	40.3%	7.08	0.0%	21.6%
C2015	Fertilisers and nitrogen compounds	8.4%	28.6%	35.57	0.0%	42.0%

NACE	Sector	Energy intensity	Trade intensity	Weight-to-value ratio	EU tariffs	Capital intensity
C2016	Plastics in primary forms	8.2%	33.4%	6.27	0.0%	11.8%
C2017	Synthetic rubber in primary forms	19.9%	52.4%	5.83	0.0%	45.0%
Rubber and plastic products						
C2211	Rubber tyres	8.6%	32.3%	2.38	3.2%	11.6%
C2222	Plastic packing	9.9%	13.1%	3.22	4.0%	24.9%
C2211	Rubber tyres	8.6%	32.3%	2.38	3.2%	11.6%
C2222	Plastic packing	9.9%	13.1%	3.22	4.0%	24.9%
Non-metallic mineral products						
C231	Glass	13.6%	23.0%	7.66	4.0%	9.6%
C233	Clay building material	25.6%	23.3%	26.24	2.6%	10.0%
C235	Cement	43.5%	8.2%	138.25	0.8%	18.0%
C2363	Ready-mixed concrete	7.6%	0.1%	237.00	0.0%	14.9%
C2364	Mortars	12.3%	3.1%	38.56	0.0%	10.7%
C2365	Fibre cement	11.8%	8.2%	19.98	0.0%	18.0%
C2369	Other articles of cement	10.1%	20.0%	19.72	0.0%	10.5%
C2391	Abrasive products	8.9%	43.5%	1.16	0.8%	12.0%
C2399	Non-metallic mineral products	12.4%	17.0%	8.20	0.9%	15.8%
Basic metals						
C2410	Basic iron and steel	43.4%	26.3%	14.69	0.4%	18.6%
C2420	Steel tubes and pipes	8.5%	43.5%	5.69	0.9%	16.9%
C2431	Steel bars	17.6%	71.2%	6.81	0.9%	11.9%
C2432	Steel strips	15.6%	31.7%	8.52	0.9%	10.5%
C2434	Steel wires	12.3%	19.9%	9.24	0.9%	18.4%
C244	Aluminium and copper	46.8%	38.2%	2.10	0.9%	10.3%
C2451	Casting of iron	16.8%	4.4%	5.22	0.9%	5.4%
C2452	Casting of steel	13.9%	4.4%	1.31	0.9%	15.7%
C2453	Casting of light metals	12.1%	4.4%	4.32	0.9%	8.6%
Machinery and equipment n.e.c.						
C2891	Machinery for metallurgy	17.9%	22.7%	1.56	1.5%	8.0%

Source: Copenhagen Economics based on Eurostat and WITS.

Table A.2: NACE sector descriptions

NACE	Our description	NACE official description
C1020	Fish	Processing and preserving of fish, crustaceans and molluscs
C103	Fruit and vegetables	Processing and preserving of fruit and vegetables
C104	Oil and fats	Manufacture of vegetable and animal oils and fats
C1051	Dairy products	Operation of dairies and cheese making
C106	Grain mill and starches	Manufacture of grain mill products, starches and starch products
C1081	Sugar	Manufacture of sugar
C1085	Prepared meals	Manufacture of prepared meals and dishes
C1091	Feeds	Manufacture of prepared feeds for farm animals
C1092	Pet foods	Manufacture of prepared pet foods
C1106	Malt	Manufacture of malt
C1310	Textile fibres	Preparation and spinning of textile fibres
C1320	Weaving of textiles	Weaving of textiles
C1330	Finishing of textiles	Finishing of textiles
C1393	Carpets and rugs	Manufacture of carpets and rugs
C1394	Cordage, rope, twine and netting	Manufacture of cordage, rope, twine and netting
C1395	Non-wovens	Manufacture of non-wovens and articles made from non-wovens, except apparel
C1399	Other textiles n.e.c.	Manufacture of other textiles n.e.c.
C1411	Leather clothes	Manufacture of leather clothes
C1412	Workwear	Manufacture of workwear
C1413	Other outerwear	Manufacture of other outerwear
C1419	Other apparel	Manufacture of other wearing apparel and accessories
C1420	Fur products	Manufacture of articles of fur
C143	Knitted apparel	Manufacture of knitted and crocheted apparel
C1511	Tanning and dressing of leather	Tanning and dressing of leather; dressing and dyeing of fur
C1512	Luggage	Manufacture of luggage, handbags and the like, saddlery and harness
C1520	Footwear	Manufacture of footwear
C1610	Sawmilling of wood	Sawmilling and planing of wood
C1621	Veneer sheets	Manufacture of veneer sheets and wood-based panels
C1622	Parquet floors	Manufacture of assembled parquet floors
C1629	Wood products	Manufacture of other products of wood; manufacture of articles of cork, straw and plaiting materials
C1711	Pulp	Manufacture of pulp
C1712	Paper	Manufacture of paper and paperboard
C1721	Corrugated paper	Manufacture of corrugated paper and paperboard and of containers of paper and paperboard
C1722	Sanitary goods	Manufacture of household and sanitary goods and of toilet requisites
C1729	Other paper	Manufacture of other articles of paper and paperboard
C19	Coke and petroleum	Manufacture of coke and refined petroleum products
C2011	Industrial gasses	Manufacture of industrial gases
C2012	Dyes and pigments	Manufacture of dyes and pigments
C2013	Other inorganic basic chemicals	Manufacture of other inorganic basic chemicals
C2014	Other organic basic chemicals	Manufacture of other organic basic chemicals
C2015	Fertilisers and nitrogen compounds	Manufacture of fertilisers and nitrogen compounds
C2016	Plastics in primary forms	Manufacture of plastics in primary forms
C2017	Synthetic rubber in primary forms	Manufacture of synthetic rubber in primary forms
C2211	Rubber tyres	Manufacture of rubber tyres and tubes; retreading and rebuilding of rubber tyres

NACE	Our description	NACE official description
C2222	Plastic packing	Manufacture of plastic packing goods
C231	Glass	Manufacture of glass and glass products
C233	Clay building material	Manufacture of clay building materials
C235	Cement	Manufacture of cement, lime and plaster
C2363	Ready-mixed concrete	Manufacture of ready-mixed concrete
C2364	Mortars	Manufacture of mortars
C2365	Fibre cement	Manufacture of fibre cement
C2369	Other articles of cement	Manufacture of other articles of concrete, plaster and cement
C2391	Abrasive products	Production of abrasive products
C2399	Non-metallic mineral products	Manufacture of other non-metallic mineral products n.e.c.
C2410	Basic iron and steel	Manufacture of basic iron and steel and of ferro-alloys
C2420	Steel tubes and pipes	Manufacture of tubes, pipes, hollow profiles and related fittings, of steel
C2431	Steel bars	Cold drawing of bars
C2432	Steel strips	Cold rolling of narrow strip
C2434	Steel wires	Cold drawing of wire
C244	Aluminium and copper	Manufacture of basic precious and other non-ferrous metals
C2451	Casting of iron	Casting of iron
C2452	Casting of steel	Casting of steel
C2453	Casting of light metals	Casting of light metals
C2891	Machinery for metallurgy	Manufacture of machinery for metallurgy

Source: Copenhagen Economics.

Appendix B: Carbon leakage model documentation

The Copenhagen Economics Global Climate and Energy model (CECEM) is a multisector and multiregional CGE model with bilateral trade flows, taxes and carbon accounting. The base model is a static general equilibrium models calibrated for the years 2030, 2040 and 2050. The model is based on the GTAP model and database, and features the entire world. Each country is featured with input/output-tables describing sectoral supply and demand consistent with trade flows. The model presented here is built based on the GTAP model, though some features such as the banking sector and consumer preferences are modelled differently.[35]

The model features bottom-up technologies for transportation and electricity generation. It also features a combination of Armington and Heckscher-Ohlin trade formulation for select manufacturing sectors. Aside from accounting carbon emissions by sector, the model is particularly well suited to analyse impacts on carbon leakage and effects of different global climate policies (e.g. emission allowance trading schemes). The model is written in GAMS/MPSGE and solved with the PATH solver. The version used in this report features 21 regions and 14 industries.

Table A.3: Regions and sectors in the CECEM model

Regions	Market sectors
Nordic countries	Agriculture and animal products
Great Britain and Ireland	Food products
Baltics	Natural gas
Germany	Electricity and heat distribution
Poland	Electricity production
France	Refined oil
Benelux	Crude oil
Eastern Europe	Solid fuels
Southern Europe	Metals
USA	Minerals
Russia	Energy intensive goods
India	Transportation (freight)
China	Transportation (private)
Australia and New Zealand	All other goods
Canada	
Brazil	
Mexico	
South East Asia	
Africa	
South and Central America	
Japan	

Note: In addition to the depicted sectors, there are also four sectors producing private consumption goods, government consumption goods and investment goods.

Source: Copenhagen Economics

[35] See Lanz and Rutherford (2016) for a more thorough documentation of the base model.

The private transportation services are demanded by the private consumer and features four different technologies of which two are active in the baseline.[36] Each transport technology is in perfect competition with other transport technologies.

The electricity generation is in demand from all sectors as well as private consumption. The model features ten active technologies of which eight are active in the baseline.[37] As with the private transportation, the electricity generation technologies are in perfect competition with other electricity generation technologies. As with the transportation technologies, electricity is produced by a mix of inputs consisting of capital, fossil fuels (emitting CO_2) and existing capacity.

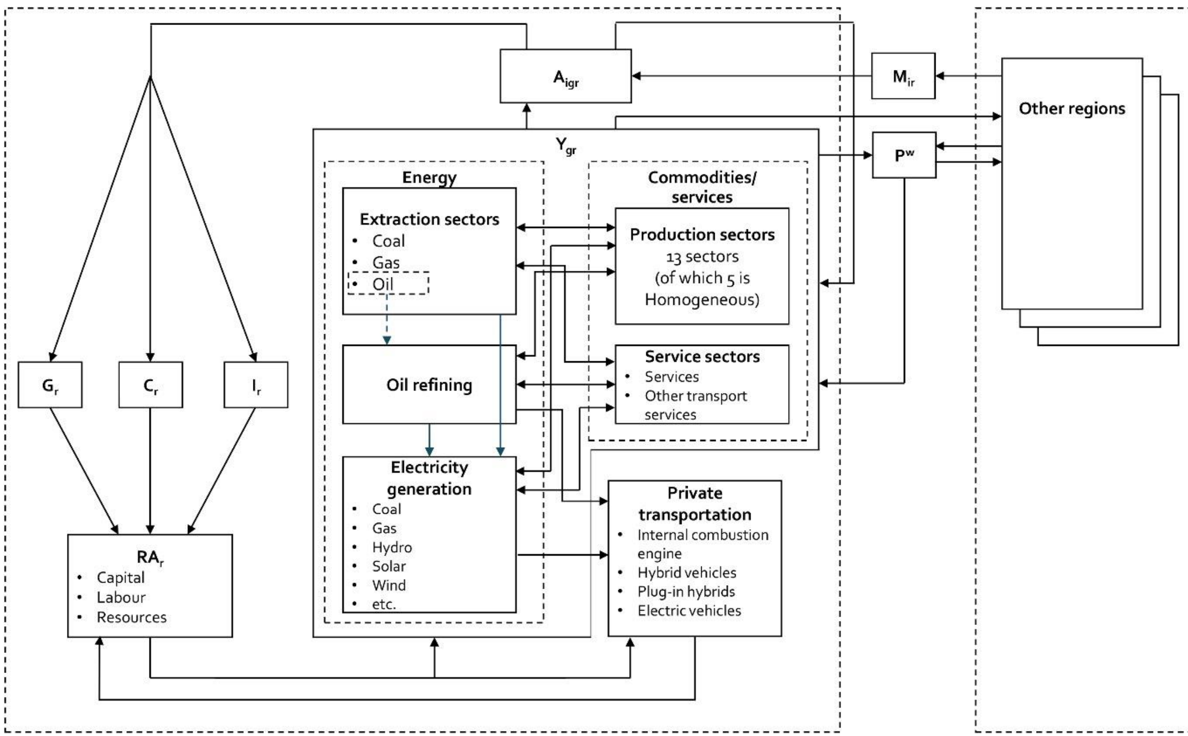
Economic flows

Figure A.4 below shows the economic flows in the model. In this illustration, taxes, subsidies, tariffs etc. are not shown in an effort to try to focus on the overall flows.

Each country has a representative agent that has an initial endowment of labour, capital and resources. The agents sell their endowment to the production sectors. Each production sector produces one type of good from intermediate input and value-added (labour, capital and resources). The output of the production is either exported to other countries or sold on the domestic market. The Heckscher-Ohlin sectors export to the world market, which only features one price. The domestic and foreign market creates the total market supply faced by all sectors. The market supply is demanded by the production sectors and the "conversion" sectors. The conversion sectors are the three sectors that produce government goods, investment goods and consumption goods. These goods are demanded by the representative agent, who pays for the goods with their endowment.

[36] Internal combustion engine, Hybrid electric vehicle, Plug-in hybrid vehicle and Electric vehicles.
[37] Coal, Oil, Natural gas, Nuclear power, Hydroelectric power, Other renewables, Wind, Solar, Coal CCS and Natural gas CCS.

Figure A.4: Economic flows in the model



Note: Taxes, subsidies and tariffs are not shown. G: Public consumption, I: Investment consumption, C: Private consumption, RA: Representative agent, A: Armington aggregate, Y: Production, M: Imports, P^w: World price

Source: Copenhagen Economics

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Carbon leakage in the Nordic countries

Carbon leakage is a situation in which a policy-induced reduction in CO_2 emissions domestically is followed by increased emissions abroad. We investigate from a Nordic perspective what industries are at risk of carbon leakage.

We find that aluminum and copper, basic iron and steel and paper, all having energy intensities over 40 per cent, have the highest risk of carbon leakage.

The policy of giving free emissions allowances to industries at risk of carbon leakage is relatively equally spread out, leaving industries at high risk "undercompensated" and industries at low risk "overcompensated". We find that the leakage rates for the energy intensive industry from unilateral ambitious EU targets could be as high as 70%, and even as high as 85% if the Nordic countries unilaterally adopt more ambitious targets. The key to limit the risk of carbon leakage is collective global action.

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