Carbon intensities of energy-intensive industries

A top-down country comparison

CE Delft

Committed to the Environment

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CE Delft
Committed to the Environment

Through its independent research and consultancy work CE Delft is helping build a sustainable world. In the fields of energy, transport and resources our expertise is leading-edge. With our wealth of know-how on technologies, policies and economic issues we support government agencies, NGOs and industries in pursuit of structural change. For 40 years now, the skills and enthusiasm of CE Delft's staff have been devoted to achieving this mission.

Content

1 Introduction

1.1 Background

Greenpeace has requested CE Delft to perform calculations of the carbon intensities of sectors participating in the EU ETS from public data.

In principle, such information should be available by the European Commission that has set the benchmarks for use in the EU ETS during 2009-2010. In this benchmarking exercise, a few thousands of installations have been rated on their relative efficiency, defined as CO_2 emissions per unit of output. Over 50 relevant outputs have been defined for the most energy-intensive sectors under the EU ETS. Based on this information, the European Commission has set a benchmark (CO_2 emissions per unit of physical output) reflecting the efficiency level that the 10% most efficient installations in the EU would meet.
Annex A to this report gives an overview of the relevant benchmarks that have been defined in the EU ETS for the various sectors and the benchmark levels that have been identified by the European Commission.

However, no information so far has been released on the performance of individual installations to the benchmark. Therefore, while information on the performance level is available at the European Commission (and most likely also at the executive bodies, like the *Nederlandse Emissieauthoriteit*), this is not available for analysis on the relative performance of industrial companies.

Therefore, to compare the carbon intensities of sectors from public data, one has to refer to Eurostat, or to studies that have addressed this issue.
This background paper gives an overview of two types of analysis:
1. An analysis of the carbon intensity from Eurostat data.
2. An analysis of the carbon intensity from data inherent in the Exiobase model.

This background paper provides information about the methodological choices that have been made and the results that have been obtained by the two methods that have been employed here.

1.2 Methodological approach and delineation

We limit the analysis here to four sectors:
1. Refineries (NACE 4 code: 1920).
2. Fertilisers (NACE 4 code: 2015).
3. Petrochemical industries (NACE 4 code: 2014).
4. Iron and Steel (NACE 4 code: 2410).

These sectors are, together with cement production, the most carbon emitting sectors in the EU ETS.

As stated above we have followed two routes for calculating the carbon intensity:
1. An analysis of the carbon intensity from Eurostat data.
2. An analysis of the carbon intensity from data inherent in the Exiobase model.

Below these are being described in more detail.

1.2.1 Carbon intensity method of Eurostat

The carbon intensity of each sector has been determined using the following formula:

$$CI_{j,t} = \frac{ETS\ verified\ emissions_{j,t}}{Turnover_{j,t} * PPI_{j,t} * EU\ ETS\ Share_{j,t}}$$

where:

- CI implies the carbon intensity of sector j in year t;
- ETS verified emissions gives the verified emissions from the EU ETS Registry;
- $\text{Turnover}_{j,t}$ reflects the nominal production value of a country's sector j in year t;
- $PPI_{j,t}$ reflects the producer price index of a country's sector j in year t;
- $EU\ ETS\ Share_{j,t}$, the share of a country's ETS companies in the total production of sector j in year t.

For the different terms of the Emission Performance Index, the calculation and the data sources used are explained in detail in the following way:

ETS Verified Emissions

Eurostat does not provide detailed estimates of CO_2 emissions at the NACE-4 sectoral classification. Therefore, we have taken information from the EU ETS. All companies participating in the EU ETS have been submitting information about their verified emissions that are published in the EUTL, the European Union Transaction Log. Based on information from the EUTL augmented with own analysis, we have mapped 99% of emissions under the EU ETS to a corresponding NACE-4-code. This database has been used to determine the CO_2 emissions from a sector.

One should notice that emissions in the iron and steel industry do not contain emissions from waste gasses in the EUTL, because these have been allocated to electricity production if they are being used for electricity production. We have not corrected for this issue in this study.

Real production value (in 2010 prices) per sector and country at NACE-4 ($Turnover_{j,t}$ * $PPI_{j,t}$)

1. The nominal production values are taken from the Eurostat Structural Business Statistics dataset (Annual detailed enterprise statistics for industry; NACE Rev. 2, B-E; sbs_na_ind_r2; V12120).
2. Real production values (in 2010 prices) have been derived by the applying the Producer Price Index from the Eurostat Short-term Business Statistics (Producer prices in industry, total - annual data; 2015 = 100; sts_inpp_a) to the 2015 nominal production values.

The real production value thus indicates the value of the product in 2015 prices.
This implies that the indicator can be regarded as a value. This implies that the indicator can be regarded as a proxy for physical production. If e.g. 1 metric tonne of steel in 2015 was sold for 400 euros (average), then it would imply that with a production value of 4 billion euros, the total amount of steel sold would be equivalent to 10 Mt. Now suppose that in 2016 the total production value would increase to 4.4 billion euros in prices of steel 2015, this would imply that the production would have been increased to 11 Mt. So in principle, this indicator could be indicative of the development of physical production in a sector.

If steel prices are similar across all countries in Europe (and to some extent this is true), the indicator could also be indicative of the differences in physical production between countries.

For the sectors under consideration, there is no information available on the production value of the refineries sector in the Netherlands due to confidentiality issues. Therefore, this sector has not been investigated using this method.

EU ETS Share

This calculation needs to be corrected for the share of companies that fall under the EU ETS in this particular sector. If in country A the majority of companies does not fall under the EU ETS, the production value in this country will be relatively much higher than for a country B where all companies are under the EU ETS. This will thus influence the carbon intensity in an unintended manner: the carbon intensity of country A will be much lower than the carbon intensity of country B.

However, there is no information on how to correct for this. An initial analysis undertaken for the European Commission showed that in the sectors refineries, fertiliser and petrochemical around 100% of the production value in most European countries is generated within the EU ETS firms. However, for the sector iron and steel (NACE 2410) this seems not to be the case and a considerable amount of production value is also generated by companies that do not take part in the EU ETS. However, in the absence of quantitative information we have not been able to correct for that. Therefore, the figures from the iron and steel industry should be treated with some care in this method.

1.2.2 Carbon intensity method of Exiobase

Exiobase is a global, detailed Multi-regional Environmentally Extended Supply and Use / Input Output database. It was developed by harmonising and detailing input and output tables for a large number of countries, estimating emissions and resource extractions by industry, and adding physical dimensions to the monetary units from trade data. Exiobase thus describes relations between industry and final consumption product groups not only from a monetary basis but also on a physical basis.

Part of the information available in Exiobase are the carbon dioxide emissions and the output in weight (tonnes) of a certain industry. They can be combined to an indicator of carbon intensity:

$$CI_{j,t} = \frac{CO2\ emissies\ Exiobase_{j,t}}{Dry\ matter_{j,t}}$$

CO_2 emissions

The CO_2 emissions from Exiobase are basically derived from the EMEP/EEA emission factors that have been applied and made consistent with other data. The resulting CO_2 emissions diverge somehow from the EU ETS data that have been used in the other approach:
- CO_2 emissions in the iron and steel industries include emissions from waste gasses;
- CO_2 emissions in the fertiliser industries do not contain the CO_2 that is embodied in the product.

Moreover, we observed further differences of about 15% of emissions in the refineries and iron and steel industries for which no explanation could be found. Within the context of this explorative study, we have not been able to further delve into potential explanations for these differences.

Dry matter

Dry matter is an indicator in Exiobase that describes the physical output of the sectors and deliveries of one sector to another sector. We have chosen for the following outputs for the three sectors that we have been investigating using Exiobase:

Iron and Steel

Output: Tonnes of basic iron and steel and of ferroalloys and first products thereof.
The output of blast furnace gas has not been allocated as an output to the iron and steel industry.

Refineries

Outputs: Tonnes of Motor Gasoline; Aviation Gasoline; Gasoline Type Jet Fuel; Kerosene Type Jet Fuel; Kerosene; Gas/Diesel Oil; Heavy Fuel Oil; Refinery Gas; Liquefied Petroleum Gases; Refinery Feedstocks; Ethane; Naphtha; White Spirit & SBP; Lubricants; Bitumen; Paraffin Waxes; Petroleum Cokes; Non-specified Petroleum Products; Crude Oil products.

Petrochemical and extractive industries may also have outputs in these categories but only the outputs that in the Exiobase are linked to the sector “Petroleum Refinery” have been taken into account.

N-fertiliser

Outputs: Tonnes of N-fertiliser.

2 Comparison of carbon intensities

2.1 Introduction

This chapter gives an overview of the carbon intensities in the various countries.
In Paragraph 2.2 we will present an overview using the data of Eurostat. In Paragraph 2.3 we present an overview of the data using Exiobase.

2.2 Carbon intensity using deflated monetary data

2.2.1 Approach

As Eurostat statistics on the production value at NACE-4-level have become relative scarce (many sectors are now confidential), we could only assess the carbon intensities for three sectors:
1. Petrochemicals.
2. Fertiliser.
3. Basic Iron and Steel.

Because producer prices tend to differentiate quite substantially over time, it was decided to opt for an average value over several years as most reliable indicator. For the iron and steel industries, this was not possible, as 2009 was the only data for which the Netherlands provided information.

2.2.2 Results

Table 1 gives information on the carbon intensity of the Dutch petrochemical industry in comparison with other countries in the EU.

Table 1 - Average carbon intensity (kgCO_2/€$_{2015}$) of the petrochemical industry (NACE: 2014) for the years 2011-2015

Country	kgCO_2/€
Germany	0.29
Sweden	0.42
EU28 average	*0.44*
Netherlands*	**0.45**
Belgium*	0.48
France	0.49
Italy	0.52
Spain	0.61

* Values have been deflated using Eurozone Producer Prices for the sector because no information on the country specific producer prices was available.

It appears that the Dutch carbon intensity is just around the EU average and slightly lower than the industries in Belgium/France. The German petrochemical industry has the lowest carbon intensity.

Table 2 gives the carbon intensities in the fertiliser industries. We have opted for an average for the years 2013-2015 because of scope changes in the EU ETS.
This would imply that carbon emission data in the EUTL between 2012 and 2013 are showing a break in series.

Table 2 - Average carbon intensity (kgCO_2/€$_{2015}$) of the fertiliser industry (NACE: 2015) for the years 2013-2015

Country	kgCO_2/€
Italy	0.69
France	1.09
Spain	1.28
Germany	1.61
EU28	*1.82*
Netherlands	**2.58**

Here we clearly see that the Netherlands is having a much higher carbon intensity than those industries in other countries. However, there is an important caveat here. Fertiliser industry in the Netherlands is virtually only based on N-fertiliser, which is more carbon-intensive according the scope and definition of carbon emissions in the EU ETS, than fertilisers based on phosphates or potassium. Therefore, the high figure for the Netherlands can be explained by reference to the exact product mix in producing fertiliser.

Table 3 provides information about the relative efficiency of the iron and steel industry in the Netherlands against other countries. Because of data limitations, this table only applies for the situation in the year 2009.

Table 3 - Average carbon intensity (kgCO_2/€$_{2015}$) of the iron and steel industry (NACE: 2410) for the year 2009

Country	kgCO_2/€
Italy	0.53
Spain	0.57
Sweden	0.62
Belgium	0.66
Greece	0.94
Austria	1.18
Finland	1.29
France	1.42
Hungary	1.43
Poland	1.47
Netherlands	**1.59**
United Kingdom	2.37
Romania	2.41

Again, we see that the Dutch iron and steel industry is more carbon-intensive than those in other countries, with the exception of the United Kingdom and Romania. However, this may also be because most steel produced in the Netherlands is through the carbon-intensive BOF (Basic Oxygen Furnace) route. Electric Arc Furnaces (EAF) can produce steel against much lower carbon costs. This may explain the relatively good position of the Southern European countries in this overview, as the EAF is mostly applied there while the Netherlands and the United Kingdom have more specialised in the BOF.

2.2.3 Interpretation

The results show that the Dutch industry is in comparison with other countries more carbon-intensive, especially for the fertiliser and iron and steel industries. This can most likely be explained, at least partly, by the fact that the Dutch industry has been specialising on the most carbon-intensive products within these subsectors.

Can these results be interpreted as a sign that the Dutch industry is less carbon-efficient than other industries? That is difficult to answer and largely depends on the definition of "efficiency". If efficiency is determined as the amount of energy used in a specific installation producing a specific product, these data are too inaccurate to determine the efficiency of the specific Dutch installations. Installations making steel using the Basic Oxygen Furnace technique in other countries may be more or less efficient than the Dutch installations. For that to conclude, much more research should be conducted at the level of individual installations.

However, if efficiency is to be interpreted in a more loose sense, as the amount of carbon we put in the production that is being sold on international markets, then it is obvious that the Dutch industry is less efficient in this process. Industries in the Netherlands use relatively high amounts of CO_2 to make products and in a world of growing carbon prices, and a growing trend to internalise external costs, this may pose Dutch industry in a competitive disadvantage on global markets.

2.3 Carbon intensity using Exiobase

2.3.1 Approach

A second source of information that has been employed in this study is Exiobase. Which indicators we have used from Exiobase is being described in Section 1.2.2. The sectoral classification in Exiobase follows the old NACE-classification, so the results may not entirely be comparable to the analysis in the previous paragraph. From Exiobase we primarily focussed on results for the fertiliser, refineries and iron and base chemical sectors as these sectors would allow us for a straightforward analysis of the amount of products sold in weight.

For comparison, we have selected the EU28 countries plus China, the United States, Japan, South Korea and Canada. In Exiobase all countries tend to have (some) part of production allocated to these sectors, but the amount of production is sometimes relatively small. Countries that had CO_2 emissions (including waste gasses) less than 1 Mt for iron and steel and refineries or 0.1 Mt for N-fertiliser were omitted from the analysis.

We have used the Exiobase 3.0 that expresses data for the year 2011.

2.3.2 Results

Table 4 gives information on the carbon intensity of the Dutch refinery sector in comparison with other countries. The Dutch refineries are in the Exiobase database slightly less carbon-intensive than average value of the whole sample but are more carbon-intensive than e.g. refineries in the Scandinavian countries or China.

Table 4 - Average carbon intensity (kgCO_2/kg output) of the refinery sector in 2011 according to Exiobase

Country	kgCO_2/kg output
Japan	0.06
Sweden	0.07
Norway	0.07
Belgium	0.08
South Korea	0.08
Italy	0.08
Finland	0.11
China	0.11
France	0.12
Netherlands	**0.13**
Hungary	0.13
Germany	0.13
Canada	0.14
Lithuania	0.14
Spain	0.15
United Kingdom	0.15
Bulgaria	0.15
Portugal	0.15
United States	0.15
Switzerland	0.16
Croatia	0.17
Poland	0.19
Slovakia	0.21
Austria	0.23
Romania	0.24

Table 5 presents the results for the production of nitrogen fertiliser. This table shows again that the Dutch fertiliser production is about the same position in the carbon intensity ranking: just a bit better than the average of the sample and slightly better than in China, but less efficient than Belgium and Germany. Because this table only concerns N-fertiliser production, it is more accurate than the sectoral classification using Eurostat data in Paragraph 2.2.2 where the Dutch industry was least efficient. Correcting for the production mix in the fertiliser industry thus indeed does improve the relative position of Dutch fertiliser industry in their carbon intensities, but does not make them on the top.

Table 5 - Average carbon intensity ($kgCO_2$/kg output) of the fertiliser sector in 2011 according to Exiobase

Country	$kgCO_2$/kg output
Belgium	0.14
South Korea	0.15
Germany	0.17
Austria	0.18
Slovakia	0.18
Hungary	0.19
Netherlands	**0.19**
China	0.20
Finland	0.21
Norway	0.22
Canada	0.23
Japan	0.24
Bulgaria	0.28
Portugal	0.28
Lithuania	0.32
Romania	0.35
United Kingdom	0.36
France	0.37
Italy	0.39
United States	0.40
Spain	0.41
Poland	0.42
Czechia	0.47

One should also notice that the carbon emissions in Exiobase for fertiliser production are different from those measured in the EU ETS, because within the EU ETS the carbon content of the fertilisers is taking into account as “emissions”, whereas the table in Exiobase only includes emissions directly emitted in the sector itself. Therefore, the information in this table cannot be compared to e.g. the benchmarking values that have been expressed within the EU ETS.

Table 6 presents the overview of carbon intensities in the iron and steel industry according to the data in Exiobase.

Table 6 - Average carbon intensity (kgCO_2/kg output) of the iron and steel industry in 2011 according to Exiobase

Country	kgCO_2/kg output
Austria	1.02
South Korea	1.05
Sweden	1.06
Belgium	1.06
Finland	1.07
Canada	1.21
Slovakia	1.21
Japan	1.24
Netherlands	**1.26**
Italy	1.27
Germany (until 1990 former territory of the FRG)	1.29
Norway	1.39
France	1.48
China	1.55
Czechia	1.58
United States	1.65
Hungary	1.67
Romania	1.75
United Kingdom	1.81
Spain	1.92
Poland	1.92

Again, the position of the Dutch industry is just slightly better than the average figure but not necessarily the best carbon intensity in the world. Comparing this table against Table 3 in Section 2.2.2 it again appears that providing carbon intensity using physical data does improve the relative position of Dutch industry but does not make them the most carbon-intensive in the world. One should also notice that the carbon intensities in Table 6 do include emissions due to waste gasses (in contrast with the carbon intensities that were calculated in Section 2.2.2).

2.3.3 Interpretation

The results show that the carbon intensity of the Dutch industry in comparison with other countries is just slightly lower, compared to industries in other countries, but certainly not among the best in the world. For each of the chosen product groups there are a number of countries where industry seems to have lower carbon intensities.

The question if this is indicative for efficiency is again a matter of defining efficiency. A measure comparing the kilograms output is a better measure than monetary output for measuring efficiency, but it is not free from limitations either. There is no correction made for the various products that are being produced within a sector. For refineries, e.g., the relative mix of various fuels may affect the efficiencies and this measure does not take that into account. In addition, one may notice that the factual data basis of Exiobase is not always very transparent and that the spread in intensities is quite large. Moreover, a model does not seem to provide an answer to why the intensities differ so much. To answer that question, more detailed analysis at the level of individual installations may be needed.

3 Conclusions

This study has investigated carbon intensities of four industrial sectors (refineries, petrochemical industry, fertiliser industry and iron and steel) from a top-down perspective. These sectors make up the largest part of industrial emissions in the Netherlands. This study has compared the carbon intensities of these sectors in the Netherlands with other countries.

This study has started with the notion that carbon intensities could, in theory, be easily calculated with data available at the regulatory bodies that are dealing with the EU ETS. However, this data is confidential and cannot be used by us. We identified two options to calculate these carbon intensities:
1. An analysis of the carbon intensity using monetary data from Eurostat.
2. An analysis of the carbon intensity using physical data from Exiobase.

The first approach resulted in the insight that the Dutch industry is in general about average carbon-intensive in the petrochemical sector and more carbon-intensive than average in the fertiliser and iron and steel sector. This can most likely be explained, at least partly, by the fact that the Dutch industry is specialized in the most carbon-intensive products within these subsectors.

The second approach showed that the Dutch industry is just slightly less carbon-intensive than the average of a sample of European countries plus United States, Canada, China, Japan and South Korea.

Can these results be interpreted as a sign that the Dutch industry is less carbon-efficient than other industries? That is difficult to answer and largely depends on the definition of "efficiency". If efficiency is defined as the amount of energy used in a specific installation producing a specific product, these data are too inaccurate to measure the efficiency of the specific Dutch installations. Installations in the steel industries in other countries making hot rolled coils may be more or less efficient than installations in the Netherlands making hot rolled coils, but this cannot be determined on the basis of this study. For that to determine, much more research should be conducted at the level of individual installations and products.

However, if efficiency is interpreted in a more loose sense, as the amount of carbon we put in the production of manufactured products (such as steel) that is being sold on international markets, then it is obvious that the Dutch industry is not among the most efficient industries globally. Industries in the Netherlands use relatively high amounts of CO_2 to make products (especially when measured in monetary terms) and are thus less efficient than industries in other parts of the world. This may not only be a climate problem, but can also pose an economic problem: in a world of growing carbon prices and a growing trend to internalise external costs, the carbon intensity of Dutch industries may constitute a competitive disadvantage in the long run.

Finally we recommend more research on the area of industrial efficiency. Detailed information on industrial efficiency is available within the system of the EU ETS. However, this data is not available to the public and therefore cannot be used. Making more information that is being collected in the EU ETS available to the public is recommended for future work in this area.

A Benchmarks in the EU ETS

The following table provides an overview of the most important product benchmarks in the EU ETS. For each of these products, a method approved by the EU is available on the basis of which the efficiency of every company participating in the EU ETS can be compared to each other. However, this information is not publicly available

Sector	Principal NACE	Benchmark product	Description
Refining	19.20	Refinery products	Mix of refinery products with more than 40% light products (motor spirit (gasoline) including aviation spirit, spirit type (gasoline type) jet fuel, other light petroleum oils/ light preparations, kerosene including kerosene type jet fuel, gas oils) expressed as CO_2 weighted tonne (CWT).
Cement	23.51	Grey cement clinker	Tonne of grey cement clinker
		White cement clinker	Tonne of white cement clinker (as 100% clinker)
Iron and Steel	24.1	Hot metal	Tonne of hot metal
Paper and Cardboard	17.12	Coated carton board	Air Dried Tonnes (Adt)
		Coated fine paper	Air Dried Tonnes (Adt)
		Newsprint	Net saleable production in Adt (Air Dried Tonnes)
		Testliner and fluting	Net saleable production in Adt (Air Dried Tonne)
		Tissue	Net saleable production of parent reel in Adt (Air Dried Tonne)
		Uncoated carton board	Net saleable production of parent reel in Adt (Air Dried Tonne)
		Uncoated fine paper	Net saleable production of parent reel in Adt (Air Dried Tonne)
Ammonia	20.15	Ammonia	Tonne of ammonia produced as saleable (net) production and 100% purity.
Bulk Chemicals	20.14	Aromatics	CO_2 weighted tonne
		E-PVC	Tonne of E-PVC (saleable product, 100% purity)
		Ethylene oxide (EO)/ethylene glycols (EG)	Tonne of EO-equivalents (EOE), defined as the amount of EO (in mass) that is embedded in one mass unit of any of the specific glycols defined under the next heading.
		Phenol/acetone	Tonne of phenol, acetone and the by-product alphamethyl styrene (saleable product, 100% purity)
		S-PVC	Tonne of S-PVC (saleable product, 100% purity)
		Steam cracking (high value chemicals)	Tonne of acetylene, ethylene, propylene, butadiene, benzene and hydrogen
		Styrene	Tonne of styrene (saleable product)
		Vinyl chloride monomer (VCM)	Tonne of vinyl chloride (saleable product, 100% purity)
Ferrous metals	24.1	EAF carbon steel	Tonne of crude secondary steel ex-caster
		EAF high alloy steel	Tonne of crude secondary steel ex-caster
		Iron casting	Tonne of liquid iron
Hydrogen and synthetic gas	20.11	Hydrogen	Tonne of hydrogen (100% purity as net saleable production)
		Synthesis gas	Tonne of synthesis gas referred to 47% hydrogen as net saleable production
Primary aluminium	24.42	Aluminium (primary)	Tonne of unwrought non-alloy liquid aluminium
Nitric acid	20.15	Nitric acid	Tonne of HNO_3 of 100% purity