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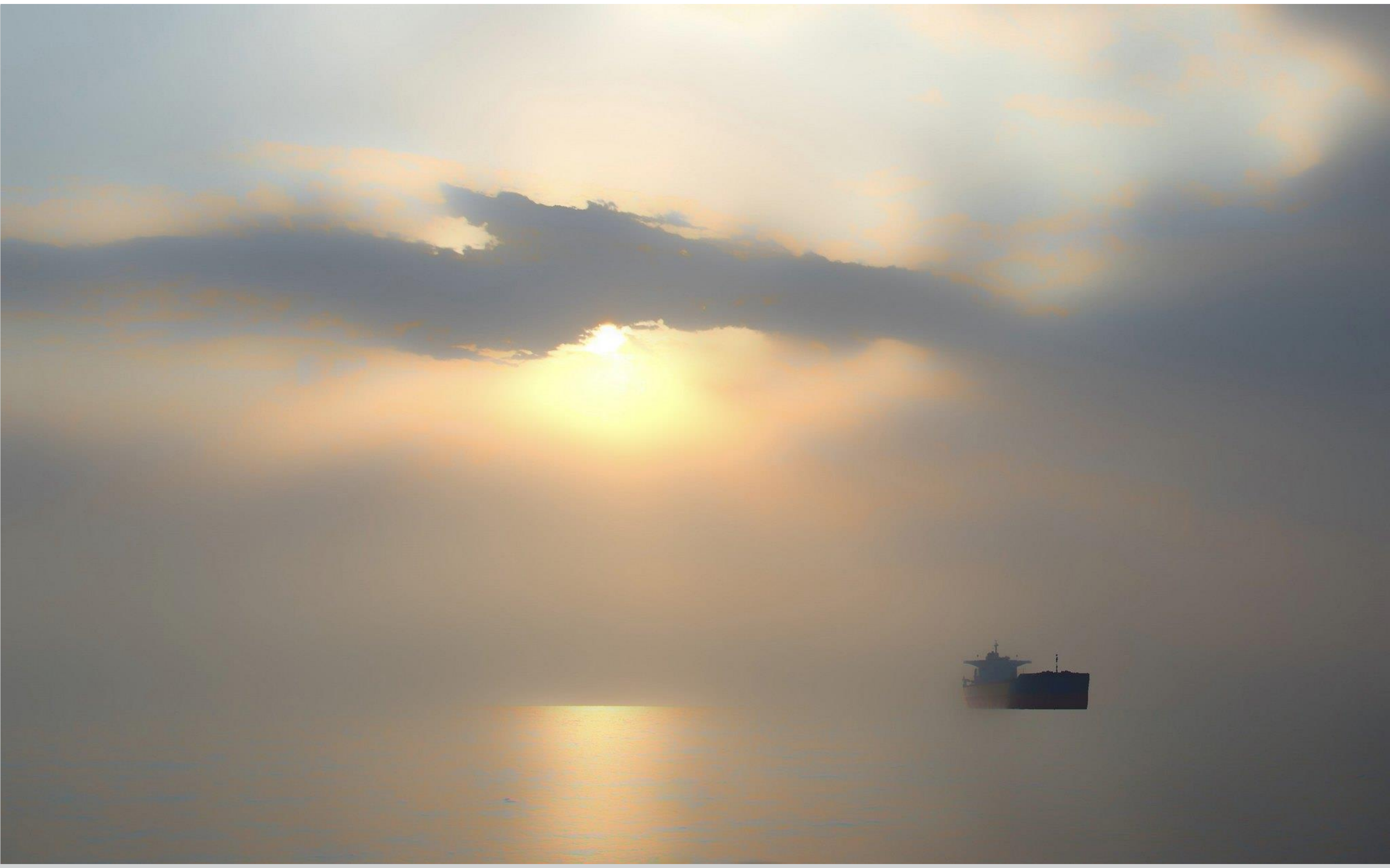
Emissions outsourcing in the EU

A review of potential effects on industrial pollution

March 2020



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Contents

Summary

The European Environment Agency (EEA) recently reported that emissions of industrial pollutants have significantly declined in Europe over the past decade as a result of effective European regulation. However, there are concerns that aversion to environmental regulations can lead to industries relocating outside of Europe, which would represent emission outsourcing.

The main goal of this study is to understand whether the reduction in industrial emissions in Europe may be linked to the relocation of industry abroad (i.e. away from Europe). Atmospheric emission trends of selected industrial pollutants (PAH, SO_x, B(a)P, PCB, Pb, Zn and Ni) for direct and embodied emissions were established based on available data in the EXIOBASE environmentally extended multiregional input-output (EE-MRIO) tables. The EE-MRIO system contains data on domestic production and trades between economic sectors and regions, as well as a record of emissions of industrial pollutants associated with economic activity. The potential role of environmental regulation in emissions outsourcing is also explored through a literature review.

This report looks at the chemical sector and mining of copper (Cu), lead (Pb), zinc (Zn) and tin (Sn). The results demonstrate that the overall emissions of pollutants from industrial activities have been decreasing in Europe from 1995 to 2011. Direct emissions of industrial pollutants decreased, and emissions embodied in imports increased at various rates between 1995 and 2011 in the selected industrial sectors, despite the increase in their production output (measured in monetary terms). Relatively high, and increasing, import to production ratios for these sectors further indicated that the changes in European demand for these products were mainly met through imports from outside of Europe. This resulted in a significant increase in emissions embodied in imports. While this does not per se indicate absolute industrial relocation in these sectors (in the sense of production shutting down in Europe to be relocated abroad), it could be a possible indicator of emission outsourcing. Increased demand could have been met by increased domestic output, rather than through imports, even though such an increase in domestic production would be subject to potential constraints, including natural resource availability and opportunity to expand production capacity.

This behaviour could not be observed in the data for sectors downstream of the chemical and mining sectors described above. Manufacturing of rubber and plastic products, manufacturing of machinery and equipment, and manufacturing of electrical machinery and apparatus had relatively low import to production ratios indicating that changes in European demand for these products were mainly met by domestic production. Coupled with generally decreasing domestic emission trends in these sectors this implies the effectiveness of emissions control measures to reduce industrial emissions including the application of best available techniques (BAT) under the EU Industrial Emission Directive (IED).

Environmental regulations have different effects on industrial activities depending on the characteristics of industries. Evidence from the literature shows that environmental regulations in Europe may not impose a high enough cost to impact international competitiveness. In other words, the additional costs of more stringent environmental standards are a small fraction of total costs (e.g., labour and resources), and as a result they do not affect international competitiveness.

According to the literature, environmental regulations in home countries (origin of industry) are not considered to be a strong driving force for industries to relocate but - once the decision to relocate is

made based on production cost and accessibility to resources - the degree by which environmental regulations are enforced in host countries can significantly affect the decision of industries on where to relocate to. Future studies should focus more on specific environmental regulations and their impacts on a specific industry, in order to provide a more factual assessment on the impact of environmental regulations on emission outsourcing.

1 Introduction

1.1 Background

Globalisation has connected countries worldwide and ushered in a new era of economic prosperity, opened up channels of development and facilitated the global flow of resources, goods and services. It has led to a massive exchange of knowledge among nations and rapid technological development. Globalisation has been characterized as the rapid increase in worldwide connections driven mainly by open markets, cost reduction and competition. Market drivers include common costumer needs, government drivers influence trade barriers and a shift towards open and more accessible markets and cost advantages provide access to human capital and resources, which result in low-cost production through outsourcing and import. Competitive drivers increase the trade between nations through increases in foreign direct investment (FDI), which subsequently lead to interdependence among countries.

Despite all its benefits, the negative environmental and societal impacts of globalisation have been of concern (Shapiro and Walker, 2015). Less industrialised countries, for example, serve as constant suppliers of raw materials and natural resources to meet global demands. The relocation of industrial processes from more industrialised regions to less industrialised regions and locations where appropriate environmental protection policies and standards may not be in place may lead to an uneven distribution of industrial environmental burden (Breivik et al., 2011; Abbasi et al., 2019; Shahbaz et al., 2015).

This report reviews trends in industrial emissions in Europe and industrial emissions attributed to European consumption outside of Europe as an indicator of the relocation of industrial activities away from Europe. It further examines whether differences in the rigor of environmental regulation may be a driver in this respect.

1.1.1 Industrial emissions in Europe

Data from the Emissions Database for Global Atmospheric Research (EDGAR) show that key air pollutants, such as nitrogen oxides (NO_X), particulate matter (PM_{10} and $PM_{2.5}$) and sulphur dioxide (SO_2), from European industrial sources have steadily decreased in the period 1970-2012 (Crippa et al., 2018).

Data for a more recent period 2007-2017 shows that gross value added (GVA) across the EEA-33 has increased by more than 11 % (Eurostat, 2019). Over the same period, the emissions to air for selected contaminants have decreased between 12 % (CO_2) and 77 % (SO_x). Overall, the industrial sector is responsible for >50 % of the emissions of carbon dioxide (CO_2), non-methane volatile organic chemicals (NMVOCs), sulphur oxides (SO_x), lead (Pb), mercury (Hg) and cadmium (Cd) and the energy supply industries are the largest source of Hg and SO_x to air. It should be noted, however, that non-industrial sources are the largest single source of Cd, Pb, NO_x, NMVOCs, PM_{10} and CO_2 emissions to air. Regarding the emissions to water, these have also decreased in the same period by approximately 4 % for total nitrogen and up to 50 % for Cd, Hg, Pb and Ni. The chemical industries together account for 51 % of these emissions and also contribute to the 21 % that passes through wastewater treatment facilities before discharge. Of all the discharges to soils and sediments, 30 % are heavy metals and a further

28 % are mineral oils. The largest component of the non-hazardous waste transfers is from the energy supply industry followed by the extractive industries. Of the total waste transfers, only 16 % are classed as hazardous and these are produced mainly by the chemical industry. These transfer rates have remained essentially static for the past decade (EEA, 2019a).

1.1.2 From industrial relocation to emission outsourcing

The relocation of industry appears to be associated with economic factors such as lower cost of operation, abundancy of (cheap) labour and access to resources (Xu et al., 2017; Wang et al., 2019). A study by the European Parliament refers to industry relocation as closing or scaling down of firms' activities in the domestic market (home country) and shifting production or parts of production chain abroad (host country) (European Parliament, 2007). The same study however only found limited evidence of relocation of industry away from Europe. It is important to note that relocation of industry can lead to the relocation of industrial pollution, which is known as emission outsourcing (see Box 1). The scale of emission outsourcing largely depends on the type of industrial activity. However, other factors such as level of governance, environmental capacities and social awareness are also influential (Xu et al., 2017). Understanding the effects of industrial activities and emission relocation is crucial for devising effective emission control measures on a global scale.

To date, it is not clear to what extent emission outsourcing as a result of industrial relocation occurs. From an environmental policy perspective, the potential role of environmental regulation is of particular interest. Environmental regulation and any potential associated cost of compliance may raise production costs which could in turn be a driving factor of relocation. However, there is no consensus among environmental economists as to whether relocation has been a result of stringent environmental regulation or a combination of other motives and economic factors such as those listed above (inter alia (Leiter et al., 2011; Jaffe and Palmer, 1997).

Box 1: Outsourcing, leakage, offshoring, and relocation

There is no single definition for emissions outsourcing. In this report, emissions outsourcing refers to the emissions occurring abroad as a result of a transfer of economic activities away from the European Union. In the context of the climate debate the term carbon leakage is used to indicate the relocation of carbon intensive activities abroad to decrease domestic carbon emission accounts. From a business perspective, outsourcing implies the sourcing of a good or service from outside of the firm. Goods or services may originate from either a domestic or foreign market, with the term offshoring used to imply sourcing from abroad.

1.1.3 The role of environmental regulation

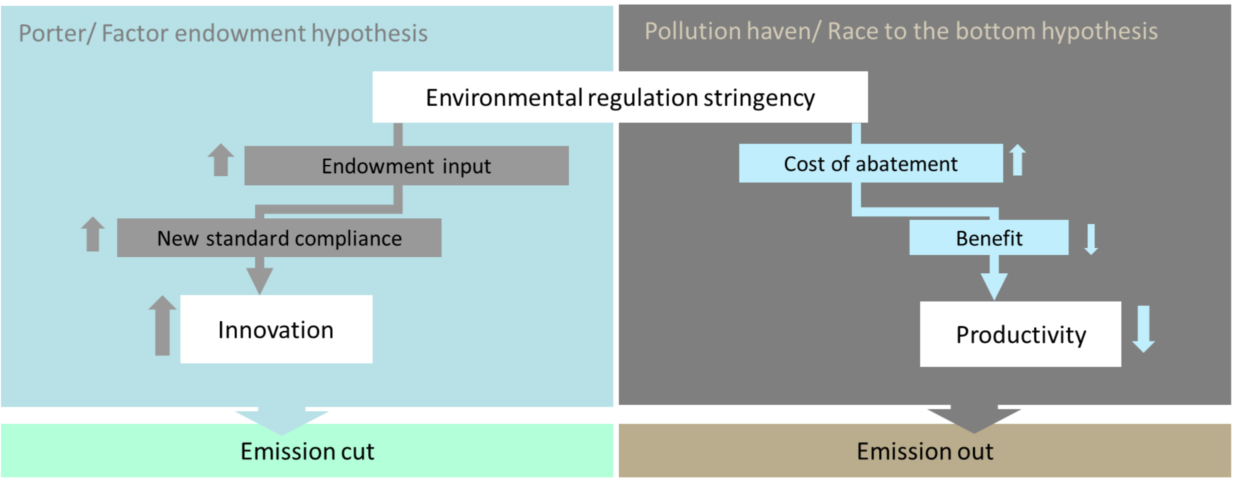
In the literature, the potential consequences of stringent environmental regulation have been discussed under two main categories of hypotheses: i) The Porter/ Factor Endowment Hypothesis and ii) The Pollution Haven/Race to the Bottom Hypotheses.

The Pollution Haven Hypothesis purports that the enforcement of environmental regulations leads to relocation of heavily polluting industries to countries with less stringent environmental regulations and/or lax enforcement mechanisms. Similarly, the 'Race to the Bottom' hypothesis suggests that industries will continue to relocate to where the environmental standards are lower and/or jurisdictions are willing to lower their environmental standards to attract industrial activities (Mulatu et al., 2010). Under these hypotheses, stringent regulations could impose higher costs for industries, forcing them to (re-)locate (new) industrial activity abroad, thus affecting domestic investment. The development of domestic investment is therefore an indicator of interest in studying potential emission outsourcing, even though the correlation between domestic investment trends and environmental regulation stringency may be difficult to establish empirically.

In contrast, the Factor Endowment Hypothesis argues that industries may accept more stringent regulations to profit from an abundancy in input factors (e.g. land, capital and labour) (Copeland and Taylor, 2004), which would lead to better environmental performance. Similarly, the Porter hypothesis also suggests that properly designed environmental policies that stimulate innovation and the application of new technologies would enhance the competitiveness of industries (Porter and van der Linde, 1995). This holds for industries that have a high dependency on input factors and are concerned about the quantity and quality of relevant inputs (factor endowments). As such, industries would react positively if the availability of input factors such as capital, labour and/or environmental resources positively associates to proposed regulations. In addition, the Porter hypothesis stipulates a positive impact of regulations on investment, which is explained by industries' incentives to reduce compliance costs by implementing innovative technologies. In this case, a positive relationship between environmental protection expenditures and taxation on an industry's investments could reflect the effectiveness of such regulations in improving industrial practices (Leiter et al., 2011).

Figure 1 demonstrates a conceptual model of the impacts of environmental regulations under the two different categories of hypotheses described above. Regional reduction in emissions is expected under both hypotheses, either by improving innovation and abatement technology or by outsourcing emissions. However, under the Porter hypothesis the investment and domestic implementation of abatement technologies would result in emission reduction without causing emission outsourcing. Emissions reductions under the pollution haven hypothesis are achieved by shifting the emission sources of pollutants to other regions.

Figure 1: Consequences of environmental regulations under different hypotheses



In order to provide a more detailed examination of the above hypotheses in response to environmental policies and regulatory actions, several indicators were identified as measures of industrial performance and relocation in the literature. In general, the impact of environmental regulation can be assessed using as indicators (a) industry total expenditure on environmental protection, and (b) revenue from environmental taxation. In turn, industrial performance can be assessed using as indicators (a) implementation of best available techniques (BAT) and (b) industry productivity rate.

According to the reviewed literature, the assessment of industrial responses to environmental regulation is based on industrial activities. As such, industries are classified as either upstream or downstream industries ([1]). In addition, manufacturing and non-manufacturing sectors are classified as (a) heavily-polluting industry, (b) toxic-good industry and (c) non heavily-polluting industry. Heavily-polluting industry applies to energy intensive industries, while toxic-good industry refers to those industries that emit toxic chemicals as final product or during the production phase. Non heavily-polluting industry refers to those industries that neither consume energy intensively nor produce toxic substances. As environmental regulation can impact different industries in various ways, we have selected industries that represent each industrial category stated above for the purpose of this study (see section 2.2.1).

1.2 About this report

1.2.1 Goal

The main goal of this study is to understand whether the reduction in industrial emissions in Europe in the past decades (EEA, 2019a; Crippa et al., 2018) may be linked to the relocation of industry abroad (i.e. away from Europe). Towards this goal, we review evidence of the occurrence of emissions outsourcing in Europe. The potential role of environmental regulation in emissions outsourcing is also explored.

([1]) The categorisation of an industry as upstream or downstream depends on the reference point of view in the value chain. Here, upstream industries refer to the sectors supplying material inputs needed for production, while downstream industries refer to production and manufacturing sectors before distribution.

1.2.2 Scope

The goal is approached by using an environmentally extended multi-regional input-output (EE-MRIO) system as well as by reviewing scientific literature. EE-MRIO systems contain a record of regional economic activity (inputs and outputs) and associated pollutant emissions (commonly referred to as environmental extensions) within regions, as well as records on trade of goods and services between regions (thus allowing a multiregional perspective). EE-MRIOs can be used to quantify the emissions associated with the imports of goods and services into Europe, so-called embodied emissions. A review of data in the latest publicly available version ([2]) of the EE-MRIO system EXIOBASE (Stadler et al., 2018) is used to address the question on emissions outsourcing in Europe. EXIOBASE was chosen as it is the only publicly available high resolution MRIO system that provides both air pollutants as an environmental extension and is available as a time series ([3]). The database extraction is limited to the period 1995-2011 as this is the time period available in EXIOBASE. The emissions to air of selected heavy metals (Pb, Zn and Ni), polycyclic aromatic hydrocarbons (PAH) polychlorinated biphenyl (PCB), benzo(a)pyrene (B(a)P) and sulphur oxides (SO_X) were analysed for the EU-28 as a single region by aggregating the EXIOBASE system. In addition to European trends, some results are presented for the United States, Republic of China and Rest-of-the-World to provide a comprehensive picture of industrial activities outside of Europe (see section 3.1).

The EXIOBASE analysis is supplemented by a literature review on the potential role of environmental regulation in emissions outsourcing (within and outside Europe) to address the impact of environmental regulation. This review also covers literature discussing measures of industrial performance in response to regulatory actions. Such measures include, for example, total expenditure on environmental protection and environmental taxation.

1.2.3 Structure of this report

This report consists of five chapters: this **Introduction** (Chapter 1); **Methods** (Chapter 2), which describes in more detail the dual approach of utilising an EE-MRIO system and a structure of literature review; **Results** (Chapter 3), which presents emissions trends observed in the EE-MRIO data as well as the outcome of literature review; **Discussion** (Chapter 4), in which the results are contextualized and limitations of this study are discussed; and **Conclusions** (Chapter 5), summarizing the key findings.

([2]) As of January 2019, EXIOBASE3.4 was the latest publicly available version on www.exiobase.eu

([3]) Examples of other MRIO systems include World Input-Output Database (www.wiod.org), Eora (www.worldmrio.com), and OECD inter-country input output tables (http://www.oecd.org/sti/ind/inter-country-input-output-tables.htm).

2 Methods

This Chapter presents the dual approach to the central goal of this study. First, Section 2.1 describes how input-output models may be used as to establish historic trends in emissions embodied in trade as an indicator for industrial relocation and emissions outsourcing. Second, Section 2.2 addresses the potential role of environmental regulation in emissions outsourcing through literature review.

2.1 Historic trends in embodied emissions as an indicator for emissions outsourcing

2.1.1 Input-output models as a tool

In the late 1930s, Wassily Leontief developed an input-output model for analysis of inter-industry relationships within the national economy. His work was recognized in 1973 with a Nobel Prize in Economic Sciences (Miller and Blair, 2009). In the 1960s, the input-output (IO) framework was extended by many researchers, including Leontief himself to account for emissions of pollution to the environment (Leontief, 1970; Miller and Blair, 2009). This model has been used as the foundation for EE-MRIO systems including EXIOBASE (Stadler et al., 2018; Wood et al., 2015).

EXIOBASE contains data that describe the complex relationships between global economies and their environmental consequences (see Box 2). In particular, EXIOBASE aims at addressing sustainability questions within the EU while considering the environmental footprint of European consumption on trading partners as well as major global economies through analysis of sector-based cross-country comparison for environmental impacts (Stadler et al., 2018). A number of studies used EE-MRIO databases to address the environmental footprints of nations using either carbon (Moran and Wood, 2014; Södersten et al., 2018) or resources such as material, land and water (Tukker et al., 2016; Lenzen et al., 2012). Recently, EXIOBASE has been successfully applied to assess the environmental footprint of consumption and trade among nations (Wood et al., 2018; Beylot et al., 2019), as well as the environmental footprint of regions in Europe (Ivanova et al., 2017).

Box 2: EXIOBASE 3.4

The EXIOBASE 3.4 MRIO system covers 44 countries and 5 Rest-of-the-World (RoW) regions. Each regional economy is disaggregated into 200 product groups or 163 economic sectors (commonly referred to as industries, see Annex 2 for a full list), and covers a time series from 1995 to 2011. In addition to the monetary accounts, EXIOBASE 3.4 contains over 1000 environmental extensions. As such, it provides a starting point for the analysis of both emissions occurring during production in a certain region as well as emissions embodied in trade between regions.

The availability of time series of IO tables in a multiregional framework, including environmental extensions provides the key elements for studying emissions outsourcing with EXIOBASE. First, emissions associated with domestic economic activity over time can be extracted from the system, at regional (EU-28) and sectoral level. Second, as trade between sectors and regions is included, data on the direct emissions embodied in trade can be used to establish temporal trends of emissions embodied in imports. Note that we take a sectoral perspective where only emissions directly associated with the production sector are included. A full 'emissions footprint' associated with European demand for imported goods would include both direct and indirect emissions (see Box 3).

2.1.2 Key assumptions

Following assumptions were made in this study:

a) Decreasing domestic emission trends that are not accompanied by declining domestic production output (in monetary terms) are an indicator of **improving emission intensities in Europe**.
b) Decreasing domestic emission trends along with increasing direct emissions embodied in imports are indicators of **potential emission outsourcing in Europe**.

2.1.3 Approach taken in this study

In this report, EXIOBASE 3.4 was used to investigate the relationship between industrial activities in the EU-28, associated emissions of pollutants within the EU-28 and trends in emissions embodied in imports from outside the EU-28.

2.1.3.1 Pollutants covered

This report covers emissions of heavy metals (Pb, Zn and Ni), PAH, PCB, B(a)P and SO_X to air as a result of industrial activities. For each of the 163 sectors, a time series of pollutant emissions associated with production in the EU-28 and a time series of emissions embodied in EU-28 imports was extracted from the EE-MRIO system, using a dedicated extraction package (Stadler, 2015) customized to provide the relevant data. For each time series, trend analysis was performed to determine whether or not a statistically significant upwards or downwards trend can be observed using a Mann-Kendall trend test ([4]) (Mann, 1945). A significant upward or downward trend was identified using a significance level of 0.01. All time-series of emissions data were indexed to the base year of 1995 to facilitate the comparison of emission trends across sectors.

2.2 Literature review

Databases used for the literature review in this report were Web of Science, Science Direct and Google Scholar. Search keywords of 'environmental regulation' and 'industry relocation' or 'industrial activities' were used to identified indicators of industry relocation. We further investigated those references of selected literature that were relevant to the report. The primary results of the literature review were used as a basis for further data analysis.

Box 3: Embodied emissions

We distinguish between so-called *direct* and *indirect* emissions. *Direct* emissions are those emissions that occur from an economic activity, for example the production of a good or service. *Indirect* emissions refer to those emissions associated with economic activity occurring along the upstream value chain (e.g. emissions associated with electricity generation for electricity used in a production process). When goods or services are traded, they can be considered to have embodied these emissions. The combination of direct and indirect emissions plays an important role in the establishment of emissions accounts based on economic consumption of a region, as opposed to the more traditional emissions accounts based on production in a region.

In the context of emissions outsourcing in this report, we are interested in the emission trends of specific sectors. Therefore, only *direct* emissions embodied in imports are investigated. Results cannot be interpreted as the full environmental pressure or 'footprint' occurring abroad as a result of European consumption, as this perspective covers both direct and indirect emissions.

([4]) A Mann-Kendall trend test is commonly used as a non-parametric test to assess the significance of trends in time series based on a null hypothesis that data are independent and do not have an upward or downward trend in time.

2.2.1 *Selection of sectors*

According to the literature, industries have different responses to regulatory action from their associated downstream industries (Franco and Marin, 2017). Moreover, the impact of regulations can vary significantly based on the characteristics of industries, such as manufacturing and non-manufacturing, multinational and national firms or heavy-polluting and non-heavy-polluting industries. With these factors in mind, we selected industries from EXIOBASE and identified candidates for emissions outsourcing for those sectors that exhibited a statistically significant downward trend in emissions associated with production and statistically significant upwards trends in emissions embodied in imports. In addition, only those sectors were selected, for which production emissions and embodied emissions in imports were of the same order of magnitude. Consequently, the **chemical sector** (as an example of industries that might manufacture toxic-goods) and various **mining activities** (copper (Cu), lead (Pb), zinc (Zn) and tin (Sn)) were selected for further analysis in this report.

Note that these sectors are examples of upstream and heavy-polluting industries and therefore may have a different response to regulatory action than industries that are further down the value chain and with a less polluting profile. Therefore, we also selected downstream manufacturing industries that use a significant amount of either chemicals or Cu, Pb, Zn, and Sn as primary raw materials. The following sectors were selected to exemplify downstream behaviour: **manufacturing of machinery and equipment**, **manufacturing of electrical machinery and apparatus,** and **manufacturing of rubber and plastic products**.

2.2.2 The role of environmental regulations in emission outsourcing

In order to rationalize the underlying drivers of observed emission trends, we reviewed evidence of industrial performance and activities in response to regulatory measures in the existing scientific literature. We also compared our results to empirical data available in natural geological archives([5]) in Europe and Asia.

To structure the literature review, we developed the conceptual model presented in Figure 2. It accounts for various impacts of environmental regulations on industries' performance, which in turn can determine the level of emissions outsourcing. We identified a number of indicators that are used in the literature as a measure of industrial performance.

In general, indicators for environmental regulation are considered to be:

- Industry total expenditure on environmental protection
- The level of and revenue from environmental taxation

Industrial performance or productivity in response to environmental regulations can be considered to be a measure of:

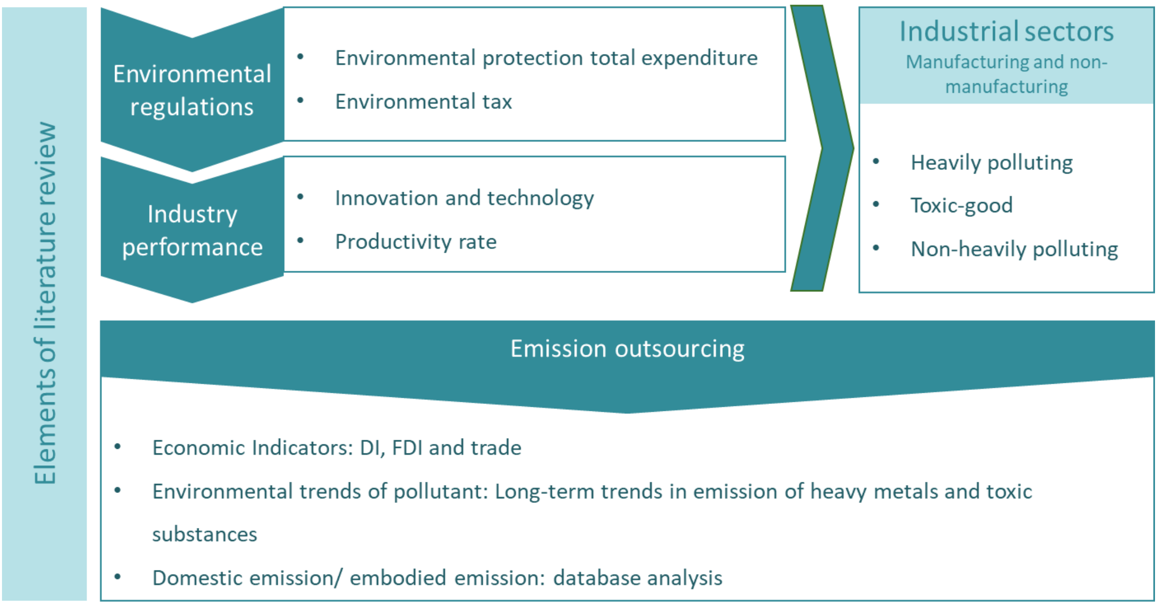
- Implementation of Best Available Techniques (BAT)
- Industry productivity rate

([5]) natural geological archives (e.g. ice fields and peats) are sites that act as a natural record for atmospheric transport and deposition of pollutants. They are extensively used to study the historical impact of anthropogenic activities through release of pollutants to the natural environment.

Economic parameters that are used in the literature as measures of industrial relocation were defined as:

- Domestic investment (DI),
- Foreign direct investment (FDI)
- Trade

Figure 2: Conceptual model of parameters and indicators used in the literature review



In addition, we reviewed long-term trends in the concentrations of industrial pollutants in different compartments (e.g. soil, water or air) of the environment in Asia and Europe to investigate whether empirical data provide evidence of the industrial relocation and thus emission outsourcing (see section 3.3).

3 Results

This chapter consists of three sections covering

a) results from the database extraction (Section 3.1) as well as
b) findings from the literature on the impacts of environmental regulations on trade and potential emission outsourcing (Section 3.2) and on
c) findings from the literature on pollution trends in the environment as a result of industrial activity (Section 3.3).

3.1 Trends in production emissions and emissions embodied in imports

This section first gives an overview of emission trends in the EU-28, aggregated for all economic sectors, and subsequently presents the results for the individual sectors identified as a case study in Chapter 2. The trends observed for associated downstream industries are presented in Section 3.1.3.

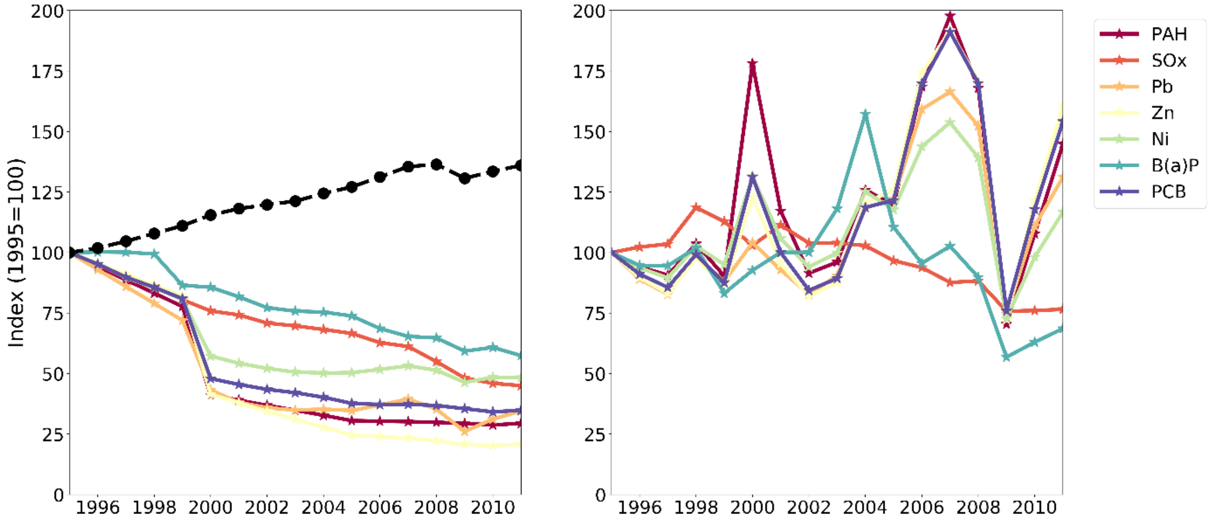
3.1.1 Overall emission trends in the EU-28

Figure 3 shows the trends in emissions of selected pollutants for the EU-28 extracted from EXIOBASE for the period of 1995-2011. The left panel depicts the trends in production emissions, i.e. emissions occurring within the EU-28 as well as the increase in GVA (in chain-linked volumes, 1995 = 100) (Eurostat, 2019). It demonstrates that despite the substantial increase in GVA in Europe from 1995 to 2011, emissions of the pollutants covered here (PAH, SO_X, Pb, Zn, Ni, B(a)P and PCB) decreased at different rates. Emissions of heavy metals, PAH and PCB decreased considerably around the turn of the century, possibly as a result of, or in anticipation of, international agreements such as the 1998 Aarhus protocols on Heavy Metals and POPs (UNECE, 1998b, 1998a), the 2001 Stockholm convention on Persistent Organic Pollutants (UNEP, 2001) and the 2001 EU directive on the limitation of certain air pollutants from large combustion plants (EU, 2001a). As such, the overall emissions intensity, the amount of emissions per unit GVA of the European economy, has decreased in this period.

The temporal trends of emissions embodied in EU-28 imports are presented in the right hand panel of Figure 3. This demonstrates an increase in the embodied emission of Pb, Ni and Zn by 25-50 % in the period 1995-2011 as a result of European demand for imported products, while embodied SO_X and B(a)P emissions decreased by approximately 25 %.

While it is of value to investigate pollutant emissions at the EU-28 aggregate level, it is not possible from the aggregate values to distinguish between relocation of industries as a driving factor, or other factors such as changing demands for different products and corresponding changes in emissions levels. To understand the impact of specific industrial sectors to the overall emissions of industrial pollutants, a sectoral approach was applied.

Figure 3: Total industrial pollutant emissions and direct emissions embodied in imports between 1995 and 2011; (left panel) emissions for selected pollutants and growth of GVA (chain-linked volume, 1995=100), (right panel) emissions embodied in imported products and services



Sources: EXIOBASE3.4 and Eurostat (2019).

3.1.2 Trends for individual sectors

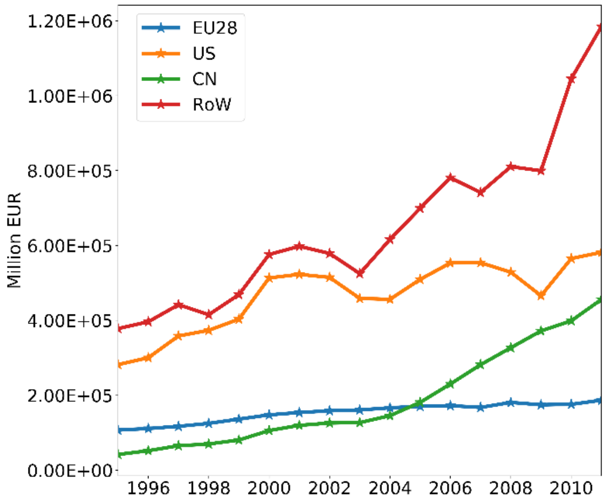
As described in Chapter 2, sectors that simultaneously exhibited a decreasing trend in pollutant emissions associated with production in the EU-28 and an increasing trend in emissions embodied in imports were selected as the opposing trends may imply outsourcing of industrial emissions. In addition, we investigate the trends in sectoral output and regional imports in monetary terms .

The following subsections discuss the sectoral results for the case study sectors outlined above (see section 2.1.3.2), namely the chemical sector (section 0), mining of Cu ores and concentrates (section 3.1.2.1), and the mining of Pb, Zn and Sn ores and concentrates (section 0).

Chemicals sector

Figure 4 shows the monetary output of the chemicals sector in four different regions: the 28 Member States of the European Union (EU-28), the United States (US), People's Republic of China (CN), and the Rest-of-the-World (RoW) as extracted from EXIOBASE 3.4. Increasing trends were observed for all four regions. The global production of chemicals has increased significantly during the period 1995-2011, assuming that the monetary output is an indicator for physical production volume. The largest increase of output was recorded in the RoW and mainly driven by production in Japan and the rest of the Asia and Pacific region.

Figure 4: Sectoral output (in monetary terms) of the chemicals sector in four different regions

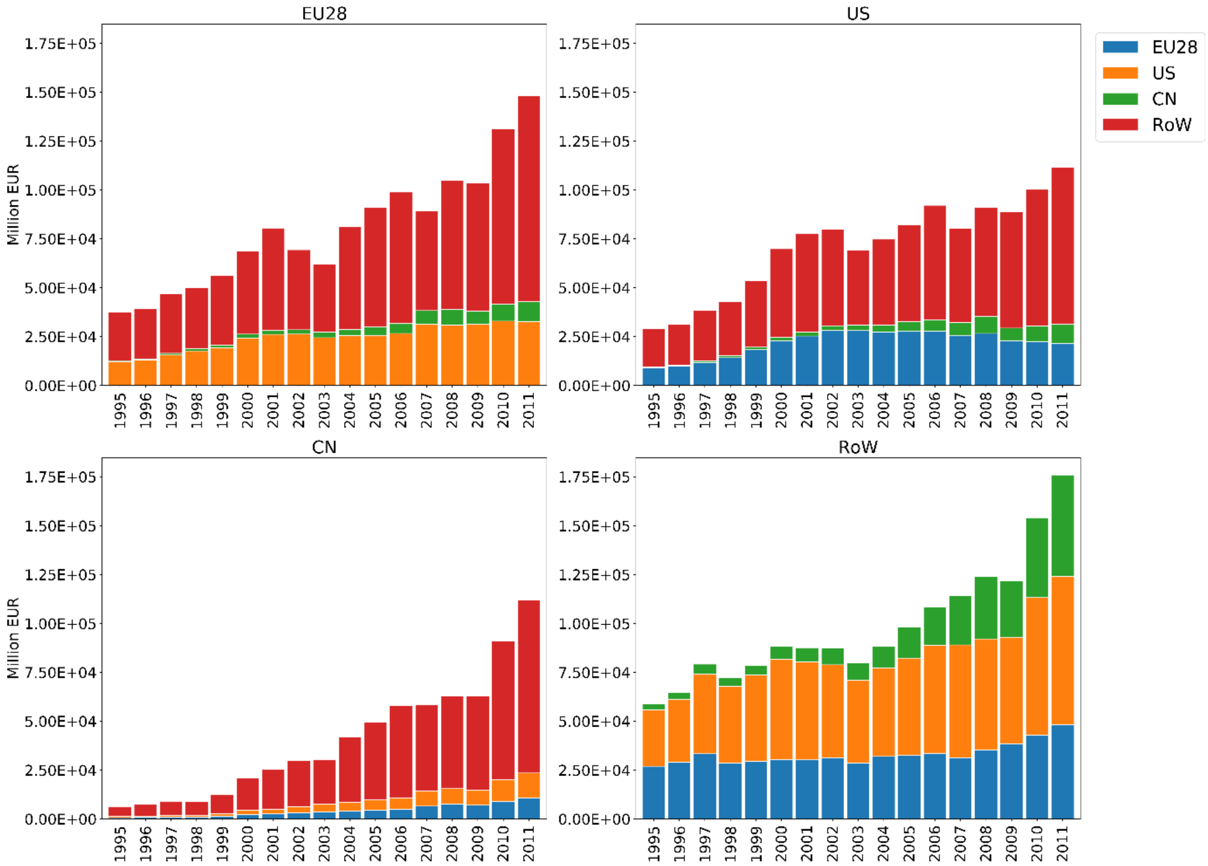


Source: Author's compilation based on EXIOBASE3.4.

The trends in the monetary value of import of chemicals per region is broken down by source region in Figure 5. Note that Figure 5 also gives an overview of bilateral trade in chemical sectors between the regions. For example, the import of chemicals into the European Union from the United States is equal to the export of chemicals from the United States to the European Union.

Figure 5 shows that the value of imports of chemicals is steadily increasing in all regions. The majority of European imports is sourced from the US and the RoW, even though the majority of growth in imports after 2006 appears to be sourced from the RoW and China (top left panel). US imports of chemicals from Europe have decreased since the early 2000s while overall imports from China and the RoW have increased (top right panel). Chinese imports of chemicals have increased significantly, with growing value of imports from all regions, though most of the growth can be attributed to imports from the RoW (bottom left panel). Finally, export of chemicals from the EU-28, US and China to the RoW have increased in the period 1995-2011, and particularly Chinese export of chemicals increased significantly relative to 1995 (bottom right panel).

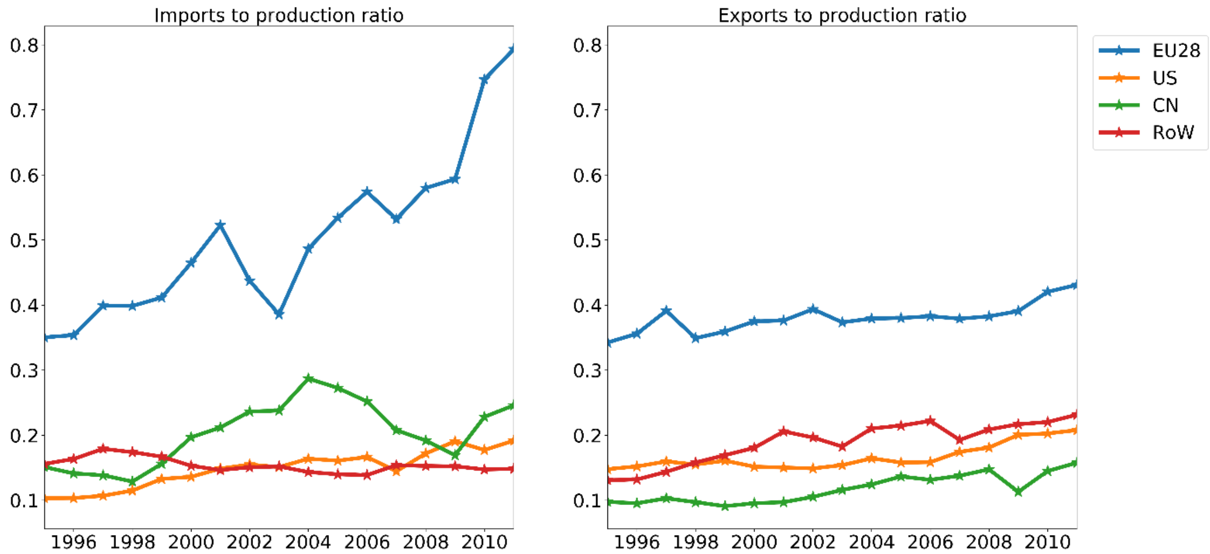
Figure 5: The monetary value of imports from chemical sectors broken down by source region. The MRIO system was aggregated to four regions: European Union (EU-28), United States (US), Republic of China (CN) and the Rest-of-the-World (RoW)



Source: Author's compilation based on EXIOBASE3.4.

The ratio between the (monetary value of) import, export and production for the four different regions are shown in Figure 6. The higher value of import to production ratio is an indicator of the extent by which a region can satisfy demand for chemicals from external markets. However, the higher export to production ratio indicates a large proportion of domestic production is exported. For both import and export we can observe upwards trends in the respective ratios for Europe. In addition, ratios are generally lower in the other three regions than EU which indicates that the size (measured in terms of monetary output) of the European chemicals sector is relatively small. This is also indicated in Figure 4 where the output of the Chinese chemical sector becomes larger than European output around 2005. The strong increase in the import to production ratio for Europe relative to the slower increase in the export to production ratio implies that the increase in European demand was partially met by import from outside of Europe.

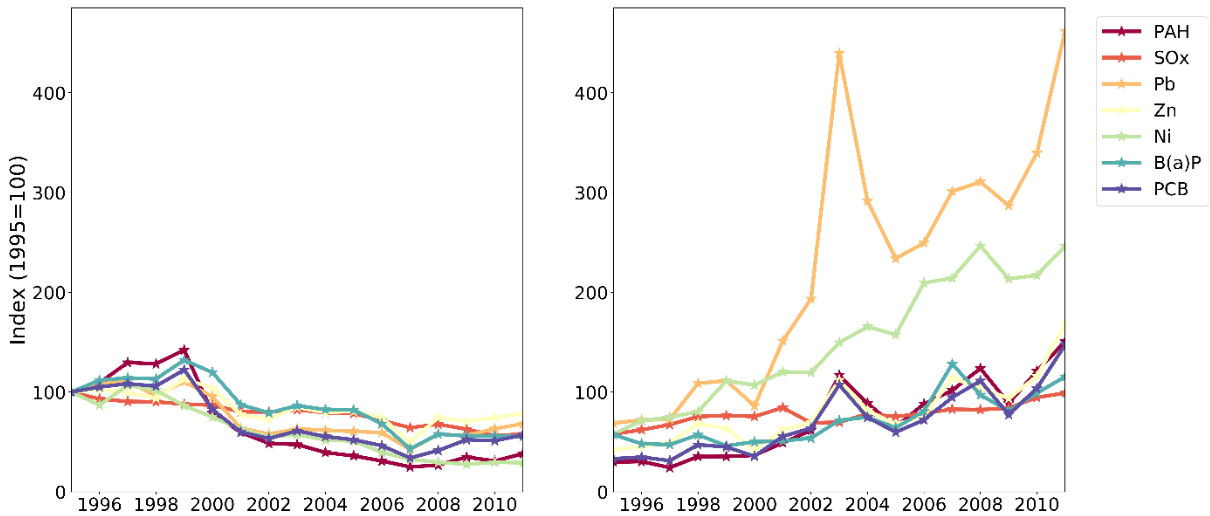
Figure 6: Ratio of the monetary value of imports or exports to production output for four regions



Source: Author's compilation based on EXIOBASE3.4.

The emission trends of PAHs, SO_X, Pb, Zn, Ni, B(a)P and PCBs as a result of European production of chemicals and European imports of chemicals are presented in Figure 7. The results show decreasing trends in pollutant emissions from the European chemicals sector, despite the increase in production volume (depicted in Figure 4). Simultaneously, the direct emissions embodied in imported chemicals increased over the period of 1995-2011. In addition, for all pollutants except SO_x, we can observe that the emissions embodied in imports are smaller than emissions from production in 1995, but gradually grow to exceed production emissions.

Figure 7: Direct emissions from production (left) and embodied emissions in imports (right) of industrial pollutants of the chemicals sector. For each pollutant, emission values are indexed to 1995 production levels

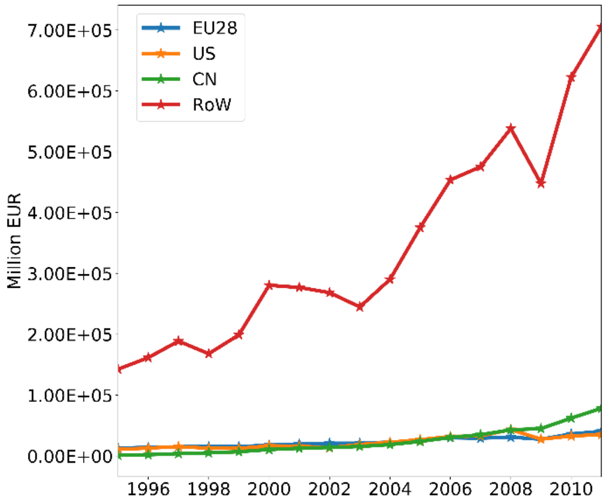


Source: Author's compilation based on EXIOBASE3.4.

3.1.2.1 Mining of Cu ores and concentrates

Figure 9 shows the monetary output of the sector “Mining of Cu ores and concentrates” in four different regions of EU-28, US, CN and RoW. Increasing trends were observed for all four regions. Assuming that the monetary output is an indicator for physical production volume, we can conclude that the global production of Cu ores and concentrates has increased significantly during the period of 1995-2011. The most rapid increase can be observed in RoW. Based upon the source data in EXIOBASE, this can be further broken down in the regions South America (26 % of RoW output, excluding Brazil), Middle East (20% of RoW output), Africa (25% of RoW output) and Asia and Pacific (14% of RoW output).

Figure 8: Sectoral output (in monetary terms) of the sector “mining of copper ores and concentrates” in four different regions

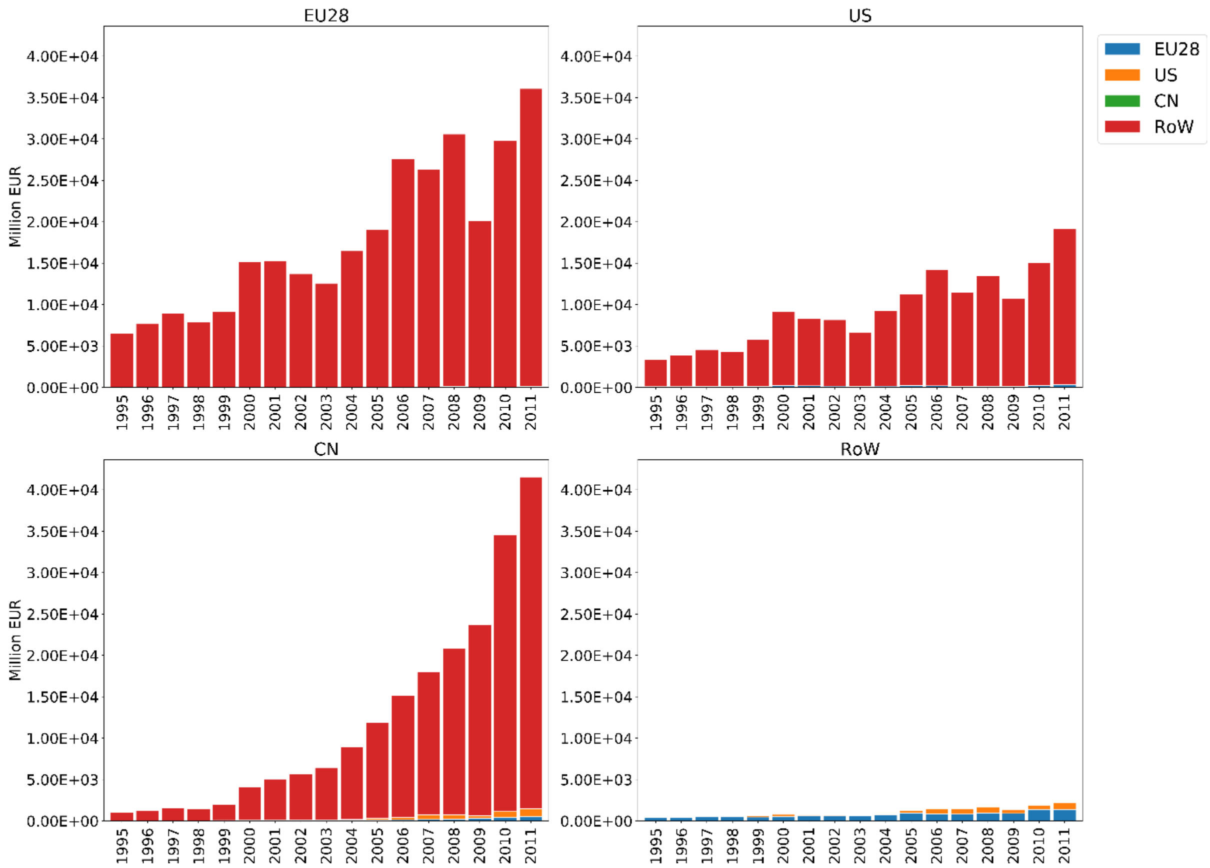


Source: Author’s compilation based on EXIOBASE3.4.

Figure 9 shows temporal trends of the monetary value of Cu ores and concentrates imports, broken down by exporting region. The imports (in monetary terms) are increasing for all regions and virtually all imports from both EU-28 and US are sourced from the RoW (top left and top right panel). However, the EU-28 and US export a relatively small amount of Cu ores and concentrates to China and the Rest-of-the-World (bottom left and bottom right panel).

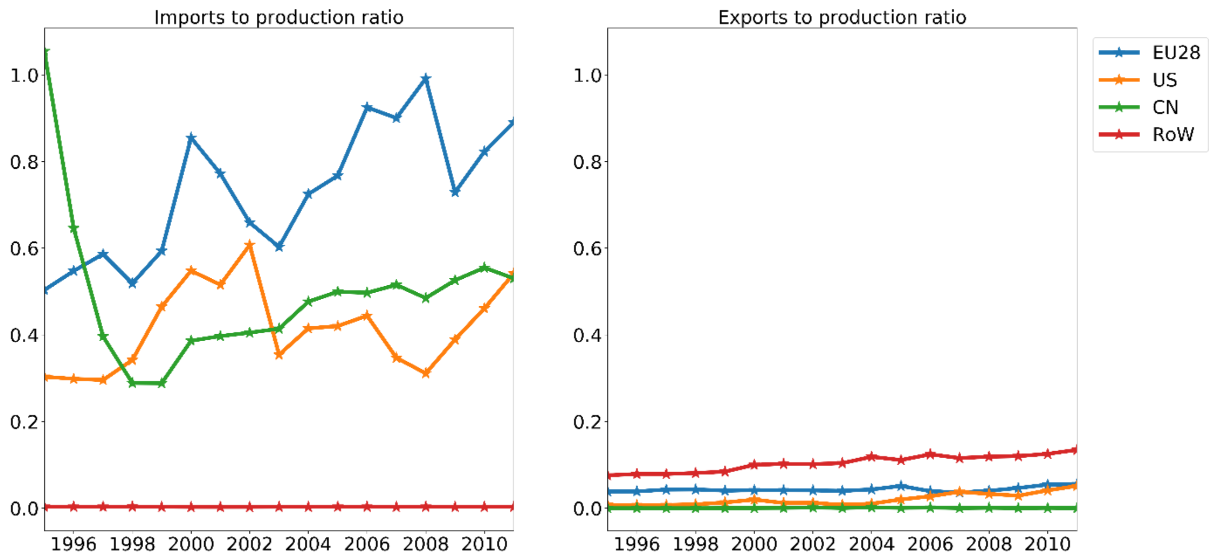
The ratio between (the monetary value of) import, export and production are shown in Figure 10 for the four different regions. For the EU-28, the increased import-to-production ratio shows the reliance of European Cu ore and concentrate demand on imports, as exports-to-production ratio remain at a relative constant level. For China, large variations in imports-to-production ratio can be observed. In 1995 the value of imports exceeded that of domestic production, decreasing rapidly in the subsequent years as production started to increase. Despite the continued increase in Chinese production of Cu ores and concentrates after 2000 (see Figure 9), an increase in import-to-production ratio can be observed. As a main exporting region, imports to the RoW are low compared to production output. More generally, export-to-production ratios are low for all four regions which indicates that most domestic production is intended for domestic demand. The production and import trends for the mining of Cu ores and concentrates implies that the European, US and Chinese demand for these products were partially met by imports from the Rest-of-the-World.

Figure 9: The monetary value of Cu ore and concentrates imports broken down by source region. The MRIO system was aggregated to four regions: European Union (EU-28), United States (US), Republic of China (CN) and the Rest-of-the-World (RoW)



Source: Author's compilation based on EXIOBASE3.4.

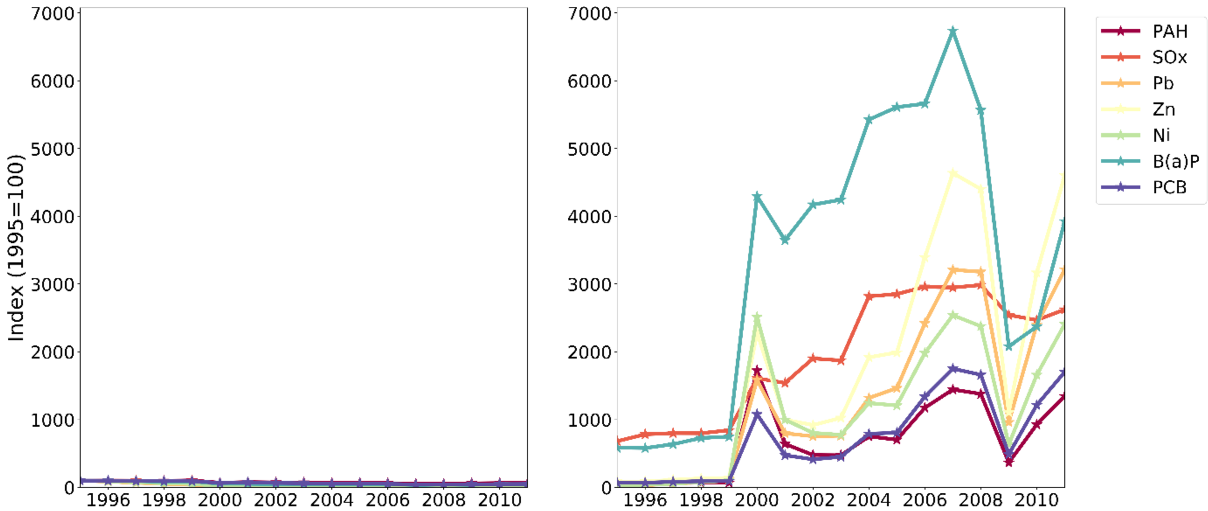
Figure 10: Ratio of the monetary value of imports or exports to production for four regions



Source: Author's compilation based on EXIOBASE3.4.

The emission trends of PAH, SO_X, Pb, Zn, Ni, B(a)P and PCBs as a result of production and imports of mining of Cu ores and concentrates in the EU-28 are presented in Figure 11. The data show that emissions associated with production have been decreasing at a rate of approximately 3-5 % per year (not distinguishable due to the scale of Figure 11), despite (monetary) output of the sector increasing (Figure 9). As such, the emissions intensity (per unit value) for all assessed pollutants has decreased significantly in this period. However, emissions embodied in imports of Cu ores and concentrates to Europe increased at significantly higher rates, following the approximately six-fold increase in the monetary value of imports (see Figure 9). No clear explanation was found for the initial peaking of embodied emissions in 2000. Despite the value of imports being lower than the value of production the emissions embodied in imports are more than one order of magnitude larger than emissions associated with domestic production. This implies that the emissions intensity (per unit value) of Cu ores and concentrates produced in the RoW is far larger than the domestic emissions intensity.

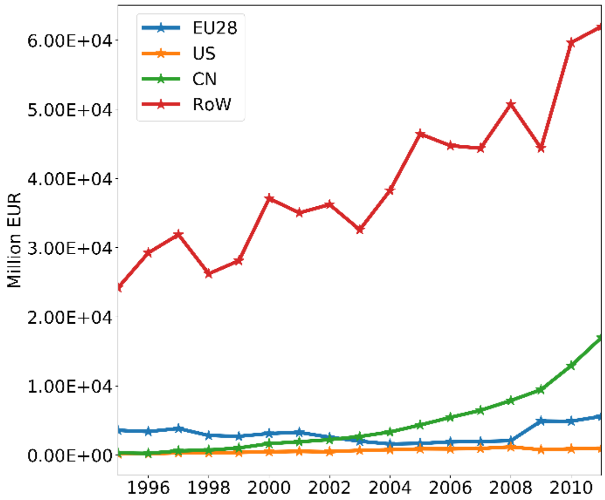
Figure 11: Direct emissions from production (left) and embodied emissions in imports (right) of industrial pollutants of mining of Cu ores and concentrates. For each pollutant, emission values are indexed to 1995 production levels



Source: Author’s compilation based on EXIOBASE3.4.

Mining of Pb, Zn and Sn ores and concentrates. Figure 12 shows the monetary output of the sector of Mining of Pb, Zn and Sn ores and concentrates in four different regions of EU-28, US, CN and RoW extracted from EXIOBASE 3.4. Increasing trends were observed for CN and the RoW. The global production of Pb, Zn and Sn ores and concentrates has increased significantly in the period of 1995-2011, assuming that the monetary output is an indicator for physical production volume. Trend analysis shows no significant trend in the volume of European production in mining of Pb, Zn and Sn ores and concentrates over the period of 1995-2011, mainly due to decreasing production from 2000 to 2008, followed by a significant increase after 2008. As it was the case for Cu ores and concentrates, the most rapid increase can be observed in RoW. This can be further broken down into India (25 % of RoW output) and the regions South America (20% of RoW output excluding Brazil), and mino0 contributions (10% of RoW output) of other RoW regions in EXIOBASE.

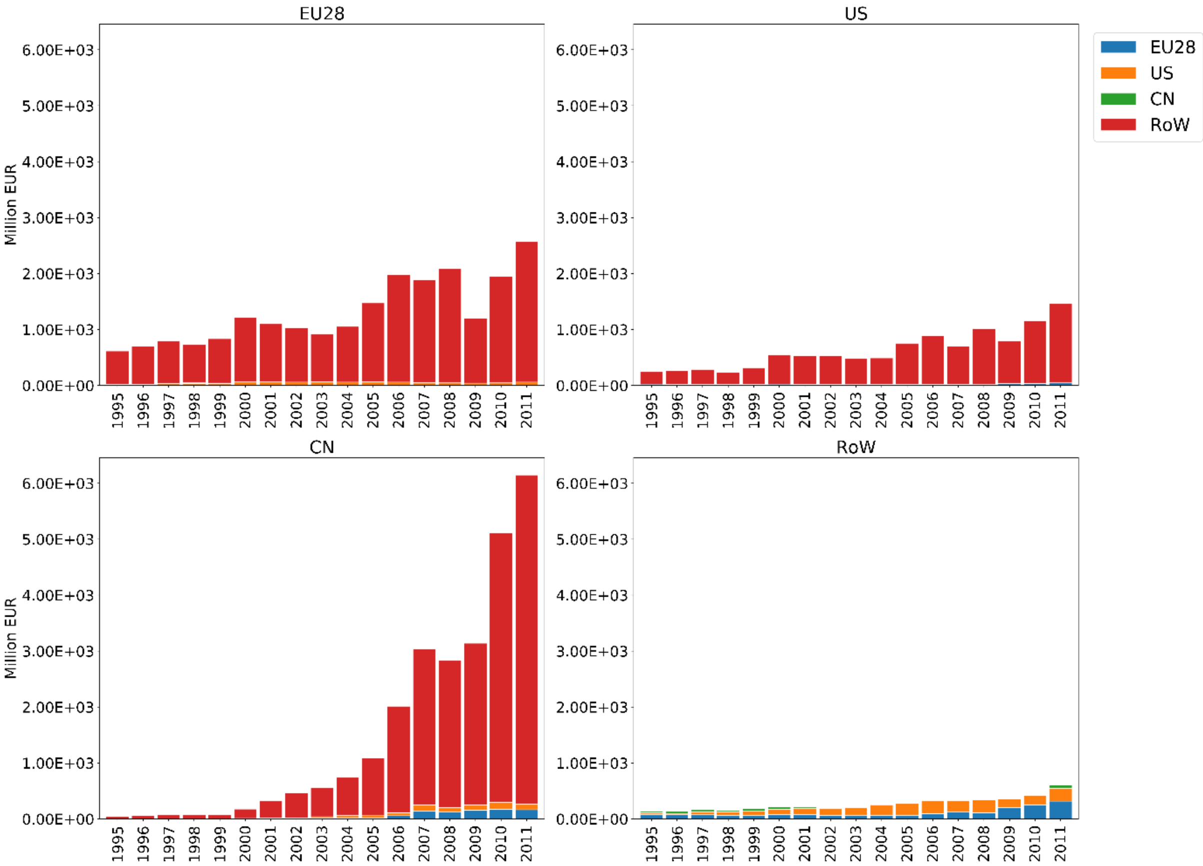
Figure 12: Sectoral output (in monetary terms) of the sector "Mining of Pb, Zn and Sn ores and concentrates" in four different regions



Source: Author's compilation based on EXIOBASE3.4.

Figure 13 shows temporal trends of the monetary value of Pb, Zn, and Sn ores and concentrate imports, broken down by exporting regions. The imports (in monetary terms) are increasing for all regions and that most imports from EU-28, US and CN are sourced from the RoW (top left, top right and bottom left panel). However, the EU-28 and US do export a relatively small amount of Pb, Zn and Sn ores and concentrates to CN and the RoW (bottom left and bottom right panel).

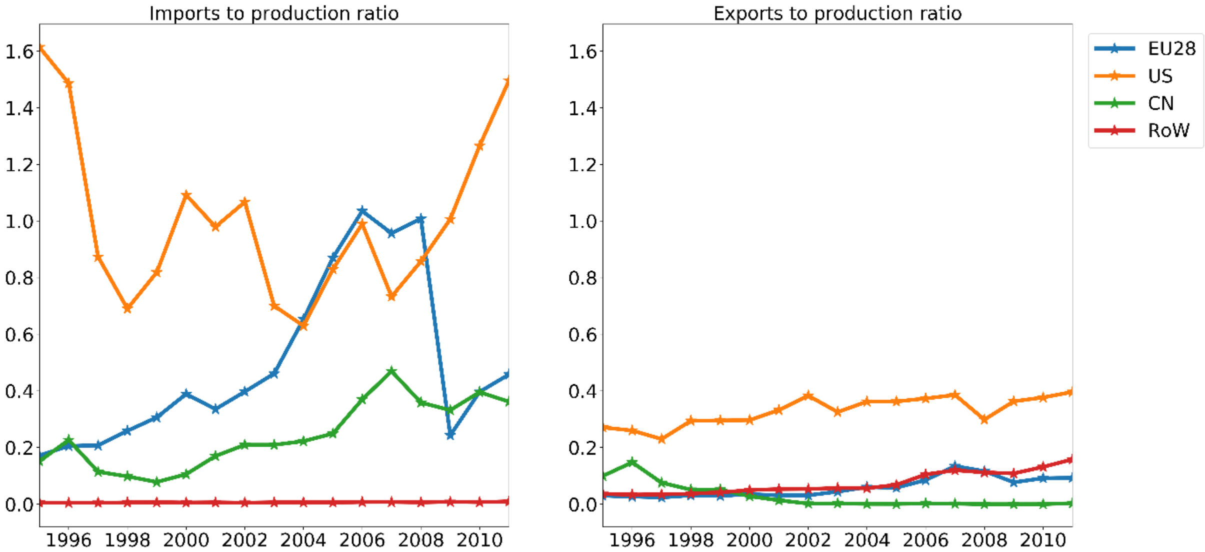
Figure 13: The monetary value of imports from the mining of Pb, Zn, and Sn ores and concentrates sectors, broken down by source region. The MRIO system was aggregated to four regions: European Union (EU-28), United States (US), Republic of China (CN) and the Rest-of-the-World (RoW)



Source: Author's compilation based on EXIOBASE3.4.

Figure 14 shows the value of imports and exports relative to the production for all four regions. For the EU-28, the value of imports volume of Pb, Zn, and Sn ores and concentrates exceeded domestic production from 2006 to 2008. The subsequent drop in imports to production ratio in 2009 may be linked to the financial crisis as well as a significant increase in domestic output compared to 2008 (see Figure 12). The highest import-to-production ratio can be observed for the US, possibly due to the relatively small size of the total production output (see Figure 12). The high increase of imports of Pb, Zn and Sn ores and concentrates in China is reflected in the import-to-production ratio, despite the significant increase in domestic production.

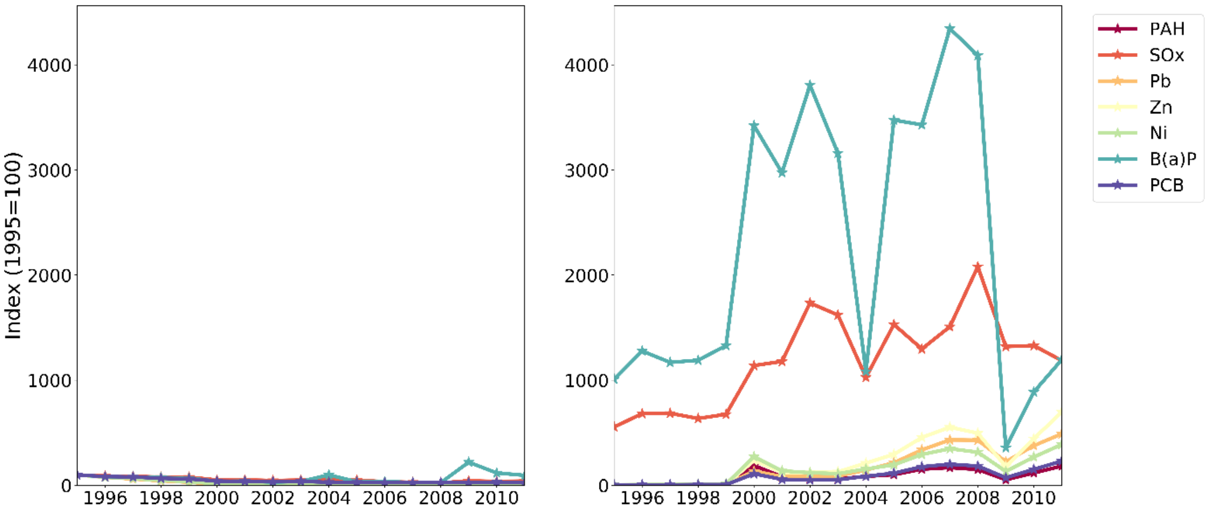
Figure 14: Ratio of the monetary value of imports or exports to production for four regions



Source: Author's compilation based on EXIOBASE3.4.

The emission trends of PAH, SO_X, Pb, Zn, Ni, B(a)P and PCBs as a result of production and imports of mining of Zn, Pb and Sn ores and concentrates are presented in Figure 15. Overall downward trends from production were observed for all pollutants except B(a)P. The trends in emissions embodied in imports exhibited general upward trends in the period of 1995-2011, again with the exception of B(a)P with a large variation in the annual emissions values. The increase in the production volume of mining of Zn, Pb and Sn ores and concentrates, did not result in increasing emissions of pollutants in Europe from 1995 to 2011, which can be indicative of the decreased emissions intensities (per unit value of production).

Figure 15: Direct emissions from production (left) and embodied emissions in imports (right) of industrial pollutants of mining of Zn, Pb and Sn ores and concentrates. For each pollutant, emission values are indexed to 1995 production levels

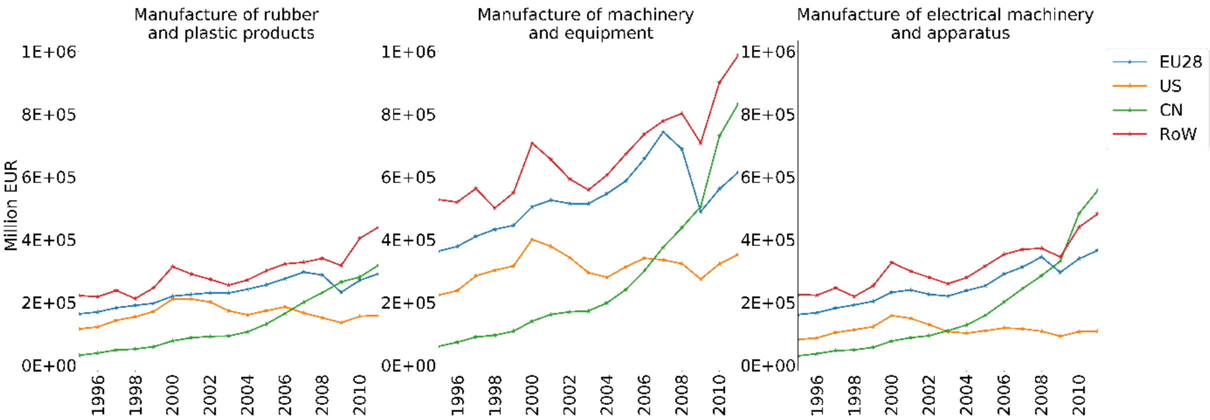


Source: Author's compilation based on EXIOBASE3.4.

3.1.3 Trends in downstream industries

It is of interest to investigate the trends in industries downstream of the sectors discussed in the previous sectors. Those manufacturing industries that consume chemicals, Cu, Pb, Zn, and Sn as primary raw materials were selected for discussion here (see section 2.2.1).

Figure 16: Sectoral output (in monetary terms) for three downstream sectors in four different regions.

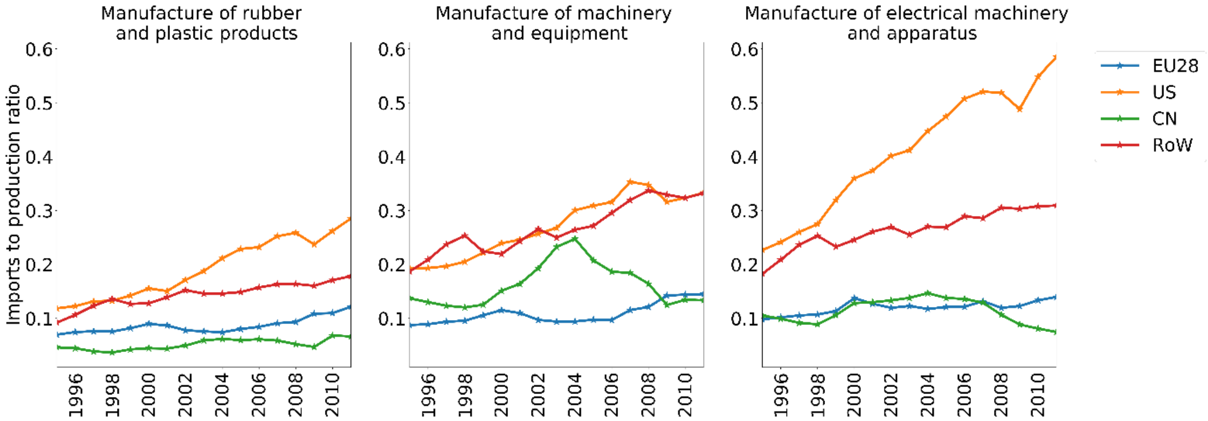


Source: Author’s compilation based on EXIOBASE3.4.

Figure 16 shows the sectoral output (in monetary terms) for all three downstream sectors. An upwards trend can be seen for all sectors for most regions except the US. Most rapid growth is registered in China. The economic downturn at the later part of the decade is clearly visible for the EU-28, US and RoW, but not so for China, showcasing its role as a manufacturing hub for both domestic and foreign markets. Note also that in terms of economic output the EU-28 is the second largest manufacturer of these three product groups, only to be overtaken by China after the financial crisis. Judging by the rebound in output in the period 2009-2011 however, it is unlikely that losing this position is the result of industrial relocation from the EU.

Figure 17 shows the import to production ratio for the three sectors, which is increasing in the period of 1995-2011 for most regions, except China. The largest increase in import to production ratio is observed for the US. This reflects in part the growing value of imports as well as the low growth or constant production output of these sectors in the US. The value of imports from these three sectors to the EU-28 increased steadily in the period of 1995-2011, even though the value of imports relative to the industrial output of these sectors is relatively low. Despite growth in imports and increasing ratio of imports to production the absolute growth rate of production exceeds the growth rate of imports suggesting that increases in European demand for products from these three sectors was mainly met by European production.

Figure 17: Import to production ratio for three downstream sectors in four different regions

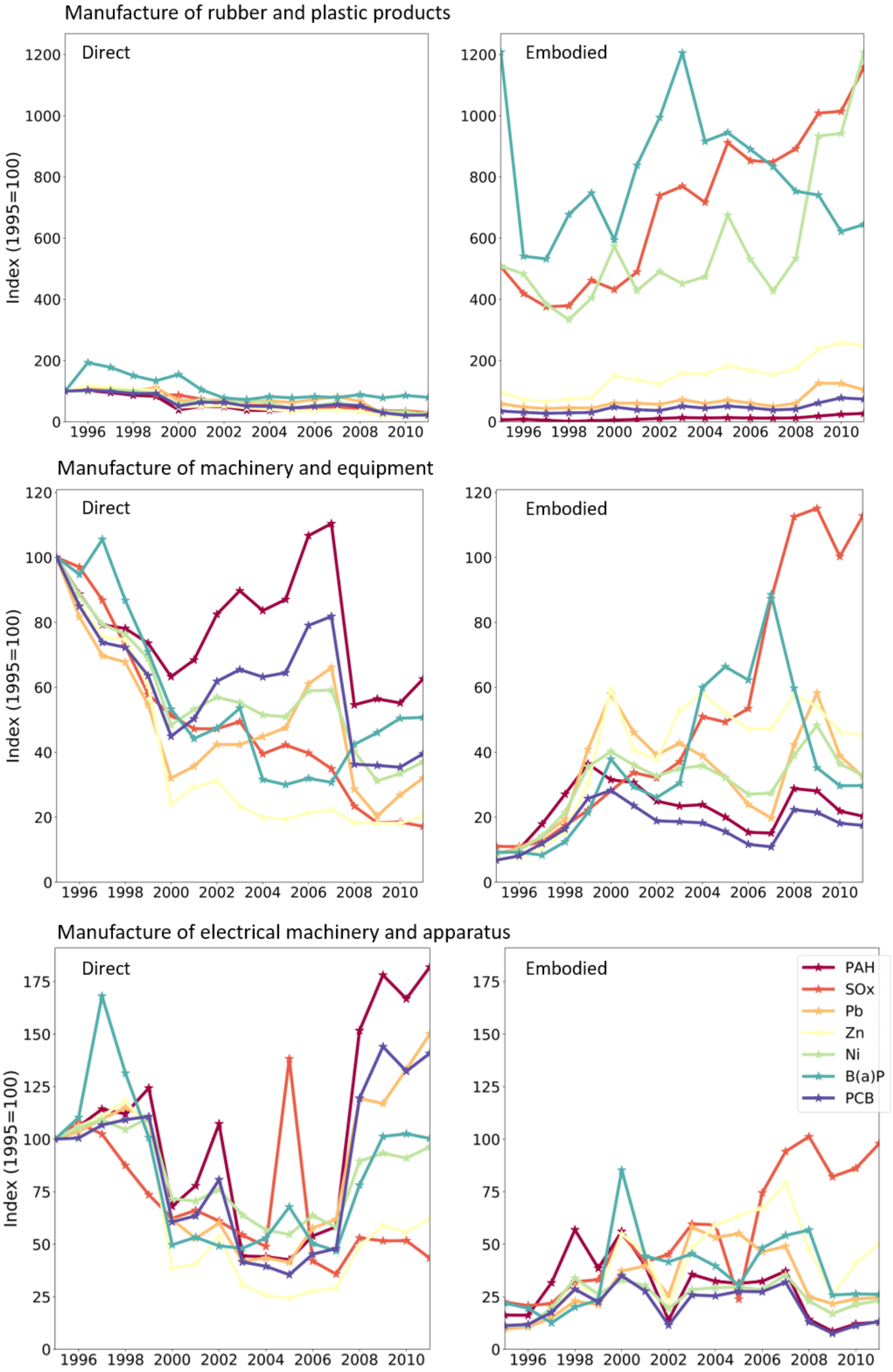


Source: Author's compilation based on EXIOBASE3.4.

Figure 18 shows the pollutant emissions in the EU-28 from these three sectors as well as emissions embodied in imports. Emissions associated with the manufacture of machinery and equipment and manufacture of rubber and plastics products decreased in the period of 1995-2011, though no significant trend was established for PAH in the former, and B(a)P in the latter sector. Considering the increase in output, emissions intensities (in monetary terms) decreased. No clear downwards trend was established for emissions from the manufacturing of electrical machinery and apparatus sector, except for emissions of SO_x.

Contrastingly, the emissions embodied in imports of these three sectors show a mixed picture. For the manufacture of rubber and plastics there is a clear upwards trend in emissions embodied in imports for all studied pollutants except B(a)P. In addition, note that the emissions embodied in imports of SO_x and Ni are many times larger than the emissions occurring in the EU-28, despite the value of imports ranging approximately 7-12 % of European value of production (see Figure 17). For the other two sectors only upwards trends in emissions embodied in imports were established for SO_x and Zn. Over the full period of 1995-2011, emissions of B(a)P embodied in machinery and equipment imports also increased, but from 2007 emissions started to decrease.

Figure 18: Direct emissions from production and embodied emissions in imports of industrial pollutants for three downstream sectors in EU-28. For each pollutant, emission values are indexed to 1995 production levels of the respective sector.



Source: Author’s compilation based on EXIOBASE3.4.

3.2 The potential role of environmental regulations in emission outsourcing

In this section, the role that environmental regulations may play in relocation of industries and consequent emission outsourcing is discussed on the basis of the reviewed literature. Most available literature addresses this role through the use of various economic indicators. Since emission outsourcing is one of the main outcomes of industrial relocation, literature focusing on **domestic investment**, **foreign direct investment and trade** as indicators of industrial relocation is reviewed in order to understand to what extent environmental regulations may result in emission outsourcing (see Section 2.2 for a description of the conceptual model behind this analysis).

Box 4: Environmental regulations relevant to the EU

Environmental protection policies were first introduced by the European Council at the Paris Summit 1972 in response to increasing pollution (EU 1972). In 1996, the EU promulgated the Integrated Pollution Prevention and Control (IPPC) directive (EU 1996) to determine a framework of reference for Integrated Environmental Authorization of industrial activities for Member States. The IPPC directive was later replaced by the Industrial Emission Directive (EU 2010), which aims at protecting human health and environment by reducing harmful industrial emissions across the EU, in particular through application of Best Available Techniques (BAT).

The Convention on Long-range Transboundary Air Pollution (LRTAP) was signed in 1979 and entered into force in 1983. It was the first international treaty aiming to reduce and control air pollution. The convention established international cooperation for air pollution abatement and an institutional platform for science and policy interaction. The European co-operative program for monitoring and evaluation of the long-range transmission of air pollutants (EMEP) also reports monitoring data under the LRTAP Convention for a number of air pollutants. The review of data is performed jointly with the data reported by Member States under the National Emission Ceilings Directive (EU 2001b) The European Environment Agency in 2019 reported that emissions of air pollutants had declined significantly since 1990 as a result of these collective efforts and the introduction of abatement techniques (EEA 2019a).

The Aarhus protocols on heavy metals and persistent organic pollutants (POPs), as well as the Stockholm convention on POPs all have had considerable impact on the release of heavy metals and POPs to the environment.

3.2.1 Domestic investment

The impact of environmental regulation stringency ([6]) in 21 European countries on four types of country-industry-specific ([7]) investment ([8]) suggested that environmental regulations as a measure of environmental expenditures and revenues from environmental taxation is positively related to all types of domestic investment as it increases incentive for innovation and thus perhaps the use of Best Available Techniques (BAT) by industries (Leiter et al., 2011). The same study also observed that the positive effects of environmental regulation diminishes with tighter restrictions depending on the costs of compliance with stricter environmental regulation. For a reasonable range of environmental regulation, however, such regulation is positively associated with country-industry-specific investment. The positive impact could indicate a relative advantage emerging from the efficient use of natural resources, which supports both the Factor Endowment and Porter hypotheses, presented in Section 1.1. However, the negative impacts for strict regulation could indicate that neither of these hypotheses holds if the environmental cost of compliance with environmental standards are relatively higher than industries' financial benefits. In contrast, stringent environmental regulations have been previously shown to hinder the industrial investment in the US, especially in the manufacturing sector since the 1990s (Greenstone, 2002).

Jaffe and Palmer (Jaffe and Palmer, 1997) also argue that the Porter hypothesis can have a different outcome depending on the types of industrial activities and environmental regulations. They investigate the possible outcome of the Porter hypothesis under weak, strong and narrow scenarios.

The weak scenario fosters specific types of innovations that can constrain the profit-maximizing behaviour of firms. In this case, a positive but not significant relationship is expected between pollution abatement cost and innovation rate. The degree to which the positive effect is related to environmental regulation varies among industrial sectors in different countries. It has been shown that drivers of the positive effect may not necessarily be related to technological innovation but the involvement of government in a specific sector — which is known as the crowding out effect ([9]) — compared to other types of innovation investment can also be a driver of such positive effects (Kneller and Manderson, 2012; Carrión-Flores and Innes, 2010).

The strong scenario involves estimating the effects of environmental regulations on the economic performance of firms, sectors and/or countries. In this case, both processes and productivity of firms are affected by environmental regulations and thus they may not follow a profit maximizing behaviour. For instance, the positive impacts of environmental regulations in Japan's manufacturing sectors have

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([6]) stringency can be defined as the strength of the environmental policy signal – the explicit or implicit cost of environmentally harmful behaviour, for example pollution (http://www.oecd.org/economy/greeneco/How-stringent-are-environmental-policies.pdf).

([7]) Nine manufacturing industries were included in the referenced study: food products, beverages and tobacco; textiles and textile products, leather and leather products; wood and wood products; pulp, paper and paper products; coke, refined petroleum products and nuclear fuel; chemicals, rubber and plastic products; other non-metallic mineral products; basic metals and other manufacturing.

([8]) (1) gross investment in tangible goods, (2) gross investment in construction and alternation of buildings, (3) gross investment in machinery, (4) productive investment, defined as the difference between gross investment in tangible goods excluding investment in abatement technologies.

([9]) In economics, crowding out occurs when increased government involvement in a sector of market economy substantially affects the remainder of the market, either supply or demand.

been caused by positive effects on research and development (R&D) (Hamamoto, 2006). However, despite an immediate negative relationship between environmental regulations and productivity manufacturing industries in Canada, a positive impact was detected later on when delayed influencing parameters (e.g., long-term positive effects of innovation or BAT on productivity) were considered in the analysis (Lanoie et al., 2008).

Under the narrow scenario, the innovative effects of flexible policy instruments, such as environmental taxes are compared with technology standards, which may provide limited options for firms and potentially not allow them to choose the most cost-effective methods. This may result in increasing innovation from the implementation of performance standards rather than technology-based standards (Lanoie et al., 2011).

3.2.2 Foreign direct investment

Environmental regulations have also been recognized as influencing factors for foreign direct investments (FDI). FDI provides direct capital financing and generates positive externalities through technology transfer, spill-over effects, productivity gains and the introduction of new processes and technical and managerial skills (Lee, 2013). Despite its significant role in economic growth, FDI has been inversely related to CO_2 emissions in G20 ([10]) countries (Lee, 2013). The environmental costs of FDI have been extensively discussed in the context of the pollution haven hypothesis that purports that industries tend to relocate to countries with lax environmental regulations or where non-enforced regulations are in place (Mulatu et al., 2010). In the US, the enforcement of Clean Air Act Amendments (CAAA) has led to the substitution of domestic production with foreign production locations by multinational corporations (Hanna, 2010).

Other studies argue that the compliance costs of environmental regulations are considerably lower than the cost of establishing new plants in new locations and thus environmental regulations do not play important roles on firms' FDI (Levinson, 1996). To examine whether the environmental regulations lead to relocation of industries, Eskeland and Harrison (2003) examined the FDI pattern using industry level data from four developing countries ([11]) after controlling country-specific factors (openness, market concentration, market size, wage, etc.). They found weak evidence of relocation despite the tendency of data points towards polluting sectors.

Considering that many manufacturing plants were relocated to Asia in the past three decades, Yoon and Heshmati (2017) argued that neglecting the distinction between the (polluting) production part and non-production part may provide biased and confounded effects on the relationship between FDI and the pollution haven hypothesis. They classified industrial activities into production and non-production processes to investigate the relationship between FDI and manufacturing and non-

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([10]) The G20 is a group of heads of government or state from 20 leading economies, 19 countries plus the European Union, including Argentina, Australia, Brazil, Canada, China, France, Germany, India, Indonesia, Italy, Japan, South Korea, Mexico, Russia, Saudi Arabia, South Africa, Turkey, the United Kingdom, and the United States. Collectively, the G20 economies account for more than 80 percent of the gross world product, 80 percent of the world trade, and 62 percent of the world population (World Bank).
([11]) The four countries are Cote d'Ivoire (1977-1987), Mexico (1984-1990), Morocco (1985-1990) and Venezuela (1983-1988).

manufacturing industries. Their results show that when FDI is not classified separately for production, results can falsely be interpreted as having no effect of environmental regulations on FDI. However, differentiating between foreign investments targeted specifically at the production parts of industrial activities would lead to opposite conclusions as multinational firms tended to move production investment where environmental regulations are lax and thus supporting the pollution haven hypothesis.

In addition to environmental regulation being a potential factor for FDI in host countries, an opposite relationship between FDI and environmental regulations may exist. This implies that host countries may adjust environmental regulation or the degree of enforcement under the prospective of FDI (Cole et al., 2006). Mulatu et al. (2010) found a stronger correlation between labour supply and FDI than environmental regulatory laxness. However, when the most polluting sectors are considered, less stringent environmental regulations play an important role in industries' decision on where to relocate to (Mulatu et al., 2010). This effect was also seen for French manufacturing industries that have chosen to relocate in countries with more lax environmental regulations (Ben Kheder and Zugravu, 2012).

3.2.3 Trade and other approaches

Recently, Hille (2018) found evidence of the pollution haven effect for heavy-polluting sectors for EU-28 countries in response to climate policies using the World Input-Output Database (WIOD) (Dietzenbacher et al., 2013). However, no support for the stronger pollution haven hypothesis was found, which suggests that the cost associated with climate policies did not incentivise relocation of heavy-polluting industries. Thus, climate policies seem to be just one of several factors that are influencing the trade flows and are not considered as main driving factor of emission outsourcing.

The relocation of industries and changes in the industrial activities can be also projected in emission source transfer via increasing international trade since 1990 (Peters et al., 2011). The response of net imports to changes in climate policy stringency for US manufacturing and sector-specific energy prices over the period of 1974 to 2009 showed that energy-intensive manufacturing industries are more likely to experience decrease in production and increases in net imports than less energy-intensive industries (Aldy and Pizer, 2015). Likewise, an analysis of an international dataset covering bilateral trade flows of 42 countries and 62 manufacturing sectors between 1996 and 2011 reveals that rises in energy prices result in a larger increase of imports for energy-intensive sectors, which suggests that the differences in energy prices are marginal drivers of trade flows (Sato and Dechezleprêtre, 2015). To the contrary, limited evidence exists on how carbon prices, implemented by the EU Emission Trading Scheme, affect trade flows. No significant effect on net imports was observed due to carbon pricing in the energy-intensive steel and cement industries in Europe from 1999 to 2005 (Branger et al., 2017). Similar results were also observed for imported intermediate materials of Belgian manufacturing sectors from 1995 to 2007 (Michel, 2013). Due to the characteristics of the database used in this study, energy-intensive industries could not be differentiated for the analysis.

By classifying industrial activities based on energy-intensive and toxicity indices in Europe, Cave and Blomquist (Cave and Blomquist, 2008) demonstrated an increasing trend in energy-intensive industry imports from less industrialized countries. Despite evidence of increased EU imports of toxic goods from lower-income Organisation for Economic Cooperation and Development (OECD) and non-EU

European countries, they did not find an increasing trend in the import of toxic goods once these industries were heavily regulated. In contrast, the demand of toxic goods from lower-income countries was reduced in Europe. This has also been the case for industrial organic contaminants (IOUCs), such as PCB and PBDEs. They came into use as a result of demands in industrialized regions. Once their use has been restricted or regulated in industrialized regions, their production transferred to less industrialized regions and subsequently products and waste containing these chemicals have been spread out globally (Breivik et al., 2011; Abbasi et al., 2019). Furthermore, the trade of waste containing these chemicals and inappropriate handling of waste containing these chemicals significantly contributed to the global emissions of these harmful chemicals (Breivik et al., 2016; Breivik et al., 2014). Such transfer in source regions of IOUC emission have been also observed for other industrial chemicals such as perfluoroalkyl substances (Wang et al., 2014), and short-chain chlorinated paraffin (Glüge et al., 2016).

A study by Franco and Marin (2017) demonstrated that environmental regulations have different impacts on upstream and downstream industries in Europe. They used country and year-specific WIOD data from manufacturing sectors of eight European countries to account for the benefits that sectors may have gained from upstream and downstream associated industries when complying with environmental regulations (Franco and Marin, 2017). By measuring direct and indirect effects of environmental taxes on patents and productivity of sectors, they showed that the strongest effects on both patent and productivity could be ascribed to downstream taxes. This in turn induces corresponding upstream sectors to innovate and generate new intermediate goods that can consequently improve the energy efficiency and environmental performance of the downstream sectors. These types of taxes also have an extremely strong effect on productivity. While downstream regulation generates opportunities for innovation and may create markets for new and improved intermediate goods, upstream regulation acts as a constraint which can negatively affect innovation and even more strongly, productivity. It should be considered that the sector-specific measure of regulation may have no effect on patents but a positive and significant effect on productivity. Various sectors tend to react to direct environmental regulations by other means than innovations, which may not be effectively evaluated by measure of patents, such as process innovations (e.g. energy efficient machinery) or organizational innovations (Franco and Marin, 2017).

3.3 Environmental trends

In this section, we present the results of a literature review on trends of heavy metal pollutants in the environment as a potential indicator of outsourcing of industrial emissions.

At the beginning of the 19th century, mercury (Hg) concentrations in air increased globally due to emissions from production of Hg and gold and silver mining activities. From the 1940s to 1970s, a steep increase in emission of Hg indicated increasing consumption of Hg containing products in the Europe and North America (Horowitz et al., 2014). After a distinct decrease in 1980s as a result of reduction measures and strategies in the 1980s, Hg concentrations in air return to its maximum levels at the beginning of the 2000s due to increased Hg emissions mainly from coal in central Asia Europe (Eyrikh et al., 2017).

The accumulation of trace metals in sediment cores were widely used to establish temporal trends of industrial emissions (Bao et al., 2017). The correspondent enrichment factors ([12]) of heavy metals in sediments can indicate whether the origin of heavy metals is the local crustal or an industrial source. The accumulation rate and enrichment factors of As, Cd, Pb, Sb and Zn in sediment cores from coastal wetlands in Eastern China demonstrated an increasing pollution trend from industrial sources in parallel with economic development in the region, especially in the past 20 years (Bao et al., 2017). Dated sediment cores taken from rivers in industrial zones in China have also demonstrated sharp increases in the flux of industrial pollution to adjacent water bodies from 1993 to 2003, which can be a result of economic growth, urbanization and rapid industrialization (Gao et al., 2017). The increasing trend of Cd and Sb pollution in alpine sediment cores from Southwest China in the period of mid-1980s until the 2000s was also attributed to regional non-ferrous metal smelters and impact of regional and sub-regional industrial activities (Lin et al., 2018).

On the contrary, the time trend analysis of heavy metal concentrations in the Greenland icecap revealed concentrations of Pb, Zn, Cd and Cu have increased in the 1960s and 1970s due to industrial activities before decreasing significantly in the 1990s (Candelone et al., 1995). A long-term European moss survey provided valuable information on concentrations of 10 heavy metals (As, Cd, Cr, Cu, Fe, Hg, Ni, Pb, V, Zn) in naturally growing mosses. Based on isotopic ratios, their results demonstrated that the concentrations of heavy metals in moss follow changes in anthropogenic sources including gasoline combustion and shifting major industrial emission sources from Western to Eastern Europe (Rühling and Tyler, 2004; Rosman et al., 1998). In general, the concentration of Pb and Cd in mosses decreased in Europe between 1990 and 2000 with a faster decline for Pb in comparison with Cd (Harmens et al., 2008).

The temporal trends in environmental concentrations of heavy metals in Asia show an upward trend while they are environmental concentrations are decreasing in Europe. It is however not possible to conclude whether the observed downward trends of heavy metals in Europe were the outcome of abatement strategies following the use of BAT or relocation of polluting industries outside of Europe because it may have been the result of relocation of polluting industries to Asia. On the other hand, increasing concentrations of heavy metals in the Asian environment may have been the result of rapid domestic urbanization and associated industrial activities. It is therefore not possible to conclude to what extent local and/or European demand contribute to the increasing trends of pollutants in Asia based on the evidence provided in this section.

([12]) The enrichment factor is calculated based on concentrations of minerals in comparison to their average occurrence of that mineral in the Earth's crust.

4 Discussion

The report at hand studied emissions outsourcing using data from EXIOBASE combined with a literature review on the potential role of environmental regulation. In the following sections we will discuss the results presented in Chapter 3.

4.1 Evidence for emissions outsourcing?

By using EXIOBASE, we investigated trends in emissions of industrial pollutants due to production in the EU-28 and associated emissions embodied in European imports. Based on national accounts and a range of other data sources, data in EXIOBASE reflects the changing process and technology mix in this period, even though there may be differences in the specific type of processes and technologies within each sector. The main indicator for selecting industrial sectors for potential emissions outsourcing was assumed to be a decreasing trend in domestic emissions together with an increasing trend in direct emissions embodied in imports. To account for improvements in the emissions intensity of sectors, the production output (in monetary terms), trend in the value of imports, and import-to-production and export-to-production ratios were presented for the selected sectors.

At EU-28 aggregate level, we observed a decrease in the overall domestic emissions of industrial pollutants and an increase in emissions embodied in imports for some pollutants (see Figure 3). It should be noted that the aggregated level of the entire EU-28 economy did not provide satisfactory evidence to distinguish between relocation of industrial activities or more general changes in both demand for products and technological improvement in production processes.

At the sectoral level, despite the increase in production, the emissions of selected industrial pollutants from production in chemical sector decreased over the period of 1995-2011. However, the embodied emissions in imports of chemical sector increased significantly over this time period. The higher ratio of import-to-production than export-to-production value in the chemicals sector shows that a large proportion of European demand for products from the chemical sector was met by imports from outside of Europe, which consequently resulted in a significant increase in emissions embodied in those import.

Contrary to our results, Cave and Blomquist (2008) demonstrated that the import of toxic goods (e.g., toxic chemicals) to Europe did not increase from 1970 to 1999. Further, the reduction in European production and imports of regulated toxic chemicals, e.g. PCB and PBDEs, have been demonstrated in previous studies (Breivik et al., 2011; Abbasi et al., 2019). Although these studies have used certain toxic chemicals as an indicator of toxicity measures of industrial processes, their results cannot overall be compared with our findings since the chemical sector encompasses far more products.

Despite the slight increase in production value of mining of Cu, Zn, Pb and Sn ores and concentrates from 1995 to 2011, the emission trends of industrial pollutants decreased, while the embodied emissions increased significantly for the same time period. Although a lower value of imports than production was observed for these industries, the emission intensity was significantly higher in imports. This can indicate that the same unit of production leads to less emissions in Europe than outside of Europe. Less effective and more pollution intensive means of production can result in higher emission intensities in less industrialized countries in comparison with more industrialized countries

(Shapiro and Walker, 2015; Malik and Lan, 2016). However, it should be noted that in the past decade substantial changes in environmental regulations have led countries to significantly improve the environmental performance of industrial activity, something not reflected by the EXIOBASE dataset due to its limited temporal scope. In addition, the above assumes that the sectors covered in EXIOBASE have a homogenous production structure across regions, while this does not necessarily need to be the case. Note that the sector description 'Mining of Cu ores and concentrates' covers a range of activities and there may be considerable differences between the processes employed and products produced in Europe and abroad leading to differences in environmental performance.

Energy and carbon prices are shown to influence the activities of energy-intensive industries worldwide (Aldy and Pizer, 2015; Sato and Dechezleprêtre, 2015). However, no effects of carbon pricing have been observed for steel and cement industries in Europe (Branger et al., 2017). Mining and production of raw materials, such as Cu, Pb and Zn, can be considered energy-intensive industrial processes and our results cannot confirm relocation of these industries as the value of sectoral output increased slightly in Europe over time, indicating continued operation in Europe. The increasing trends in embodied emissions, however, together with the increasing value of imports, imply that an increasingly large portion of emissions associated with European demand occurred outside of Europe.

Differences in responses of downstream and upstream industries to environmental regulation have been shown previously in Section 3.2. While upstream regulation appears to hinder innovation and consequently production, downstream regulation creates more opportunities for innovation which can create a market for new and improved goods (Franco and Marin, 2017). Our results demonstrated that unlike upstream industries, the output of selected downstream industries in Europe (manufacturing of rubber and plastic products, machinery and equipment and electrical machinery and apparatus) increased significantly over the period of 1995-2011. Import-to-production ratios of these industries indicated that the European demand of these industries was mainly met by domestic production. The domestic emissions of most industrial pollutants decreased over this time indicating improved environmental performance.

The observed trends in this study are in accordance with previous studies. Many industrialized countries reported a decline in domestic or territorial greenhouse gas emissions, whereas embodied emissions in imported products increased rapidly since 1980 (Peters et al., 2011). By using the Emission Database for Global Atmospheric Research (EDGAR), Crippa et al. (2018) demonstrated that the emission trends of CO, SO_2, NO_X and $PM_{2.5}$ have been decreasing in the EU and USA since 1970, while still increasing in China to this day. Thus, the success story of declining industrial pollution in developed countries could have been achieved in part due to a transfer of emission sources to other regions (Moran et al., 2018; Breivik et al., 2011).

In this study, emissions outsourcing is defined as the occurrence of emissions abroad as a result of a transfer of economic activities away from the European Union. This concept was used to define as an indicator for potential emissions outsourcing the opposite trends in sectoral domestic emissions and emissions embodied in imports. However, throughout the analysis it is shown that for all sectors presented in section 3.1.2, economic output in the EU-28 increased between 1995 and 2011 alongside an increase in both the value of imports and emissions embodied in imports. Thus, European demand for products from these sectors is increasingly satisfied by production, and corresponding emissions, abroad. Though not the result of industrial relocation, this is an example of effective outsourcing of emissions. The question remains whether the EU-28 would have had both the natural resource availability (in the case of the mined products) and capacity to scale up production activities commensurate with increases in demand in a competitive and increasingly freer trade environment.

4.2 Environmental regulation, relocation and emission outsourcing

The literature discussing emissions outsourcing is diverse. Most researchers approach this topic with a combination of modelling and empirical data at various levels of detail. Overall, environmental regulation can have both positive and negative effects on the domestic investment and subsequent industrial activities and is therefore a factor in relocation of industry. If properly devised, environmental regulations can increase the use of BAT and encourage research and development. For more information on policies and practises, experiences and other discussions of BAT we refer to the OECD BAT project (see Box 5). This consequently can promote innovation and patenting for implementing better environmental practices by industries. The negative effect is expected when the cost of compliance is higher than industries' profits, which may subsequently result in relocation and potentially emission outsourcing. Similar effects may occur for environmental taxation in downstream sectors. An indirect effect of this taxation may induce corresponding upstream sectors to innovate and generate new intermediate goods that can consequently improve the energy efficiency and environmental performance of the downstream sectors.

There is some evidence that the levels of FDI are associated with the level of environmental regulation stringency in host countries. The high cost of relocation for industries can impede relocation, but this effect can vary greatly among heavily polluting industries. When the decision to relocate is reached (regardless of reason), multinational firms may choose to relocate their production sector to where environmental regulations are lax and/or not strictly enforced, and some evidence is indicative of the pollution haven effect (Mulatu et al., 2010). As such, the impact of environmental regulations on relocation must be investigated at a sector-specific level of industries, especially in relation to labour costs, availability of natural resources, and other commercial considerations of firms. In addition, the type of environmental regulation or standard may be of influence. On a process level, the EU framework is largely based on the adoption of BATs, whereas other countries have adopted approaches setting legally binding performance standards (see Box 6). Despite the lack of evidence on *how* the environmental regulations influence the relocation of industries, the lack of stringent environmental regulations or lax enforcement of environmental regulations in host countries play important roles in attracting FDI and industries' new locations. (OECD, 2017, 2018a, 2018b)

Summarizing, the relocation of industries is a complex and multi-faceted issue. Firms' decisions to relocate, or add new capacity abroad instead of domestically, are shaped by multiple driving factors, of which the laxness or stringency of environmental regulation is one of many.

Box 5: OECD's Best Available Techniques project

The OECD Joint Meeting of the Chemicals Committee and Working Party on Chemicals, Pesticides and Biotechnology, approved a major project on Best Available Techniques (BAT) to assist governments by sharing experience regarding controlling and regulating industrial emissions (*). The first three activities have been completed and focused on (i) the collection of information on the policies and practices that use BAT (or similar concepts) across the world (OECD 2017); (ii) a review of the experience with developing BAT (OECD 2018b) and (iii) an evaluation of the policies and practices that use BAT (OECD 2018a). A further set of activities have been defined for the period 2019-2021, namely (iv) to develop guidance on determining BAT, BAT-associated environmental performance levels and BAT-based permit conditions; (v) to conduct a study on value chain approaches to determining BAT for industrial installations and (vi) to carry out inter-country comparisons of BAT and BAT-associated emission levels for selected sectors. This major project is producing an extensive evidence base on BAT policies and practices, illustrated with specific examples from different industries in 10 countries/regions worldwide (Chile, EU-28, India, Israel, Kazakhstan, Korea, New Zealand, People's Republic of China, Russian Federation and the United States).

*See for further information: https://www.oecd.org/chemicalsafety/risk-management/best-available-techniques.htm

Box 6: Environmental Regulation and Standards – Differences Worldwide

The processes and procedures involved in the development of environmental regulation and control of industrial processes vary significantly across the world. Europe uses a system based on the concept of Best Available Techniques (BAT) that offers flexibility to apply a case-by-case analysis to determine permit conditions to impose on individual operators. Other countries, such as the United States and India, have opted for different approaches. The legislation and mechanisms used in a selection of countries are summarised below, based on the information collated in a recent OECD study (2018b).

	Industrial emissions legislation	**Implementation Mechanisms**
EU	Industrial Emissions Directive (2010)	Legally binding emission limit values in integrated environmental permits based on Best Available Techniques and Associated Emission Levels (BAT-AELs)
India	Pollution Control Law Series (2010)	Minimal National Standards (MINAS) and sector-specific guidelines or Comprehensive Industry Documents Series (COINDS)
New Zealand	Resource Management Act (1991)	National Environmental Standards (NES) and Best Practical Options (BPO)
PR China	Administration Regulations for Revisions of Environmental Protection Standards (2017); the Directives for the Development of Guidelines of Pollution Prevention & Control Available Techniques (2018); Implementation Plan for Controlling Pollutant Discharge Permit System (2016).	Legally binding emission limit values in integrated environmental permits (not based on BAT), environmental quality & emission standards; Guidelines on Available Technologies of Pollution Prevention & Control (GATPPCs)
Russian Federation	Federal Law on Environmental Protection (2014) and related legislative acts.	Legally binding emission limit values in integrated environmental permits, based on BAT-AELs
US	Clean Air Act (1970); Clean Water Act (1972); Pollution Prevention Act (1990).	A variety of legally binding technology-based performance standards and medium specific environmental permits.

An important operational factor is the level of implementation and enforcement taking place and there is some evidence to suggest that this can vary widely between different countries. For example, in EU countries the Industrial Emissions Directive is generally well implemented and enforced though permits and inspections. The EU Network for the Implementation and Enforcement of Environmental Law (www.impel.eu) also facilitates the exchange of best practice between its members comprising environmental authorities in 36 countries.

However, implementation and enforcement in other countries is sometimes more difficult. For example, a recent study reviewed the process for setting industry specific emission standards in India (Shakti, 2016). It was found that although significant progress had been made in developing emission standards, discussions with key stakeholders and the authors' observations of real-world practice, identified some of the significant challenges faced; these included resource constraints (skills and manpower) in some key institutions, opportunities to improve the clarity of the process and the variable quality of the evidence base used in developing standards in different sectors. There is a premise that legislative and regulatory differences may be leading to the outsourcing of some industrial processes from the EU to other countries where the environmental legislation is less stringent. It is not possible within the scope of this work to prove or disprove this premise. Decision-making on industrial relocation is generally a corporate decision within individual industrial companies and will typically include factors such as costs of labour, cost of resources, size and location of markets, transportation costs, tax regimes, in addition to any consideration of favourable environmental legislation and/or regulations.

4.3 Limitations and uncertainty

Analysis of emissions outsourcing as a result of environmental regulation does not provide conclusive evidence for supporting one hypothesis of emissions outsourcing over the other. The existing evidence often addresses general patterns as detailed firm level data is not available to researchers at a sufficient scale to draw robust conclusions in support of the hypotheses. In addition, the difference between existence of environmental regulation, its legislation and implementing mechanism, and enforcement of environmental regulation is often not discussed in the context of industry (re-)location and emissions outsourcing. Environmental regulations cause various differing responses from similar industrial sectors. For instance, innovation and patents were extensively used as measure of responses to environmental regulations. However, the response of industries in the form of process improvement (e.g. energy efficiency) or organizational innovations inhibit evaluation of industrial behaviour. This in turn can obstruct the factual assessment of the impact of environmental regulations.

In general, the conflicting evidence in the literature regarding the impact of environmental regulations on industrial activities are attributed to:

(i) Inconsistent or lack of measures for polluting industries. There is no agreement in literature on the definition of polluting industries. Thus, different studies use various scales to identify polluting or heavy polluting industries and the degree by which their industrial activities lead to environmental pollution.

(ii) Lack of consistent approaches to measure efforts by industries to comply with environmental regulations. The measure of industries' compliance with environmental regulations vary greatly in literature. For instance, environmental taxation, environmental expenditure and/or the use of BAT were discussed widely in literature, whereas the study of each measure could have led to inconsistent outcome.

(iii) There is a major difference in resolution between studies adopting a sectoral approach (such as this study and most of the literature reviewed in it) and in changes in industrial processes as a result of the adoption of Best Available Techniques or end-of-pipe regulations that relate to the type of plants or processes used.

(iv) The literature may provide a snap-shot of a long-term cause and effect relationship as the long-term consequences of innovation on the productivity of firms could have been neglected due to the time-scale of studies. For instance, applying innovation might impose significant cost upon industries, however, it will increase the long-term benefits from improved productivity.

(v) Possible false correlation between environmental stringency and their potential impact on industrial performance. Different studies use various indicators to investigate the impact of environmental regulations on industrial performance. This might have introduced bias in the overall conclusion drawn by each study. Furthermore, several driving factors are usually involved to the relocation industries and the response of different industrial sectors to environmental stringency varies significantly among different sectors . As such, it is not possible to conclude to what extent environmental stringency can influence the occurrence of emission outsourcing.

The results of this EXIOBASE analysis are limited in both time and scope. EXIOBASE is one of the most detailed environmentally extended MRIO systems. However, it is a known issue that there can be differences between EXIOBASE and other EE-MRIO systems such as Eora (Lenzen et al., 2013) and WIOD (Dietzenbacher et al., 2013). In part, these differences are due to the adoption of different approaches in the construction of EE-MRIO systems. Differences are introduced by selection of the source data and the choice of sector classification or regions. In addition, tables need to be balanced and missing information may be added and approaches and methods differ between different MRIO systems (Owen et al., 2014). In theory, an analysis involving multiple MRIOs would increase the robustness of results, but this is impeded by differences in sectoral and regional resolution, as well as the common availability of environmental extensions for the individual MRIOs. A thorough analysis of the environmental extensions in EXIOBASE in relation to other available data sources, such as EDGAR (Crippa et al., 2018) and data reported to the Convention on Long-range Transboundary Air Pollution (LRTAP, 2019) will be beneficial in future studies.

5 Conclusions

This study provided an overview of selected industrial pollution trends in Europe, emissions embodied in imports and possible drivers of these trends. The results show that the emission of industrial pollutants as a result of industrial activities decreased between 1995 and 2011 in Europe, while embodied emissions in imports increased. However, a great variation in the decrease and increase rates was observed based on the characteristic of each industry. The analysis of upstream industries (chemical sectors and mining of Cu, Zn, Pb and Sn) demonstrated that despite the reduction of pollutants from these industries, increasing imports of associated products in Europe led to a considerable increase of embodied emissions of pollutants, which could potentially offset the objectives of (local) emission abatement on a global scale. The increase in downstream industrial activities in Europe (manufacturing of plastic and machinery) did not result in an increase of direct emissions in Europe. The lower import to production ratio of downstream industries implies that domestic production was adequate to absorb increases in European market demand.

The responses of industries to environmental regulations vary greatly among industries. More detailed studies on the impact of specific environmental regulations on particular industrial sectors will provide stronger evidence on whether or not emission outsourcing is occurring in response to environmental regulation at the sectoral level. Overall, evidence from the literature shows that environmental regulations in Europe may impose lower cost compared to other driving factors such as access to labour and resources to impact international competitiveness. In other words, the additional cost of more stringent environmental regulation is a small fraction of the total cost and does not affect international trade competitiveness. Even though environmental regulation per se may not be considered a driving force, the degree to which environmental regulation is enforced in host countries can significantly affect the decision of industries on where to relocate. In order to assess to what extent the environmental regulations drive the emission outsourcing, future studies should focus on specific environmental regulations and their impacts on particular industries and consider the broader commercial and financial factors affecting decision-making in individual firms.

6 References

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Annex 1
Results of trend tests.

Table A1: Mann-Kendall test results of production and import trends of chemical sector, mining of Cu ores and concentrates and mining of Zn, Pb, and Sn ores and concentrates.

Sector	Production		Import	
	Trend	Slope	Trend	Slope
Chemical	Upward	4 795	Upward	5 887
Mining of Cu ores and concentrates	Upward	1 548	Upward	1 686
Mining of Zn, Pb, Sn ores and concentrates	No trend	45	Upward	100

Table A2: Mann-Kendall test results of emission trends of industrial pollutants from production and embodied emissions in imports pollutants from chemical sector, mining of Cu ores and concentrates and mining of Zn, Pb, and Sn ores and concentrates.

Pollutants	*sector*	*Production*		*Import*	
		Trend	*P-value*	*Trend*	*P-value*
PCB	Chemicals	Downward	6.E-04	Upward	2E-05
PCB	Mining of Cu ores and concentrates	Downward	4.E-06	Upward	2.E-05
PCB	Mining of Pb, Zn and Sn ores and concentrates	Downward	1.E-05	Upward	2.E-05
Pb	Chemicals	Downward	1.E-03	Upward	5.E-06
Pb	Mining of Cu ores and concentrates	Downward	2.E-06	Upward	2.E-05
Pb	Mining of Pb, Zn and Sn ores and concentrates	Downward	2.E-06	Upward	7.E-07
Ni	Chemicals	Downward	5.E-07	Upward	2.E-07
Ni	Mining of Cu ores and concentrates	Downward	1.E-05	Upward	4.E-04
Ni	Mining of Pb, Zn and Sn ores and concentrates	Downward	5.E-05	Upward	5.E-05
B(a)P	Chemicals	Downward	5.E-05	Upward	6.E-05
B(a)P	Mining of Cu ores and concentrates	Downward	2.E-04	Upward	2.E-03
B(a)P	Mining of Pb, Zn and Sn ores and concentrates	No trend	1.E-01	No trend	2.E-01
Zn	Chemicals	Downward	2.E-03	Upward	5.E-05
Zn	Mining of Cu ores and concentrates	Downward	5.E-06	Upward	2.E-05
Zn	Mining of Pb, Zn and Sn ores and concentrates	Downward	7.E-07	Upward	8.E-06
SO_X	Chemicals	Downward	8.E-08	Upward	5.E-05
SO_X	Mining of Cu ores and concentrates	Downward	5.E-06	Upward	5.E-05
SO_X	Mining of Pb, Zn and Sn ores and concentrates	Downward	2.E-05	Upward	4.E-03
PAH	Chemicals	Downward	9.E-05	Upward	4.E-06
PAH	Mining of Cu ores and concentrates	Downward	6.E-05	Upward	8.E-04
PAH	Mining of Pb, Zn and Sn ores and concentrates	Downward	3.E-05	Upward	4.E-04

Table A3: Manufacturing and import trends of rubber and plastic, electrical machinery and apparatus and machinery and equipment

Sector	*Production*		*Import*	
	Trend	*Slope*	*Trend*	*Slope*
Rubber and plastic	Upward	7 712	Upward	1 217
Electrical machinery and apparatus	Upward	12 099	Upward	1 886
Machinery and equipment	Upward	16 763	Upward	3 323

Table A4: The emission trends of industrial pollutants from production and embodied emissions in imports pollutants from manufacturing of rubber and plastic products, machinery and equipment and electrical machinery and apparatus.

Pollutants	*sector*	*Production*		*Import*	
		Trend	*P-value*	*Trend*	*P-value*
PCB	Manufacturing of rubber and plastic products	Downward	2.E-05	Upward	4.E-04
PCB	Manufacturing of machinery and equipment	Downward	6.E-03	No trend	4.E-01
PCB	Manufacturing of electrical machinery and apparatus	No trend	7.E-01	No trend	6.E-01
Pb	Manufacturing of rubber and plastic products	Downward	6.E-04	Upward	4.E-03
Pb	Manufacturing of machinery and equipment	Downward	3.E-03	No trend	9.E-02
Pb	Manufacturing of electrical machinery and apparatus	No trend	8.E-01	No trend	5.E-02
Ni	Manufacturing of rubber and plastic products	Downward	2.E-05	Upward	3.E-03
Ni	Manufacturing of machinery and equipment	Downward	1.E-04	No trend	1.E-02
Ni	Manufacturing of electrical machinery and apparatus	No trend	9.E-02	No trend	4.E-01
B(a)P	Manufacturing of rubber and plastic products	No trend	1.E-02	No trend	6.E-01
B(a)P	Manufacturing of machinery and equipment	Downward	5.E-03	Upward	3.E-03
B(a)P	Manufacturing of electrical machinery and apparatus	No trend	2.E-01	No trend	5.E-02
Zn	Manufacturing of rubber and plastic products	Downward	2.E-06	Upward	1.E-05
Zn	Manufacturing of machinery and equipment	Downward	4.E-06	Upward	9.E-05
Zn	Manufacturing of electrical machinery and apparatus	No trend	9.E-02	Upward	5E.-03
SOx	Manufacturing of rubber and plastic products	Downward	7.E-07	Upward	8.E-06
SOx	Manufacturing of machinery and equipment	Downward	1E.-07	Upward	2.E-07
SOx	Manufacturing of electrical machinery and apparatus	Downward	2.E-04	Upward	2E.-05
PAH	Manufacturing of rubber and plastic products	Downward	3.E-05	Upward	9.E-05
PAH	Manufacturing of machinery and equipment	No trend	1.E-01	No trend	5.E-01
PAH	Manufacturing of electrical machinery and apparatus	No trend	8.E-01	No trend	0.97

Annex 2
Sectoral resolution EXIOBASE 3.4

Number	Name
1	Cultivation of paddy rice
2	Cultivation of wheat
3	Cultivation of cereal grains nec
4	Cultivation of vegetables, fruit, nuts
5	Cultivation of oil seeds
6	Cultivation of sugar cane, sugar beet
7	Cultivation of plant-based fibres
8	Cultivation of crops nec
9	Cattle farming
10	Pigs farming
11	Poultry farming
12	Meat animals nec
13	Animal products nec
14	Raw milk
15	Wool, silk-worm cocoons
16	Manure treatment (conventional), storage and land application
17	Manure treatment (biogas), storage and land application
18	Forestry, logging and related service activities (02)
19	Fishing, operating of fish hatcheries and fish farms; service activities incidental to fishing (05)
20	Mining of coal and lignite; extraction of peat (10)
21	Extraction of crude petroleum and services related to crude oil extraction, excluding surveying
22	Extraction of natural gas and services related to natural gas extraction, excluding surveying
23	Extraction, liquefaction, and regasification of other petroleum and gaseous materials
24	Mining of uranium and thorium ores (12)
25	Mining of iron ores
26	Mining of copper ores and concentrates
27	Mining of nickel ores and concentrates
28	Mining of aluminium ores and concentrates
29	Mining of precious metal ores and concentrates
30	Mining of lead, zinc and tin ores and concentrates
31	Mining of other non-ferrous metal ores and concentrates
32	Quarrying of stone
33	Quarrying of sand and clay
34	Mining of chemical and fertilizer minerals, production of salt, other mining and quarrying n.e.c.
35	Processing of meat cattle
36	Processing of meat pigs
37	Processing of meat poultry

Number	Name
38	Production of meat products nec
39	Processing vegetable oils and fats
40	Processing of dairy products
41	Processed rice
42	Sugar refining
43	Processing of Food products nec
44	Manufacture of beverages
45	Manufacture of fish products
46	Manufacture of tobacco products (16)
47	Manufacture of textiles (17)
48	Manufacture of wearing apparel; dressing and dyeing of fur (18)
49	Tanning and dressing of leather; manufacture of luggage, handbags, saddlery, harness and footwear (19)
50	Manufacture of wood and of products of wood and cork, except furniture; manufacture of articles of straw and plaiting materials (20)
51	Re-processing of secondary wood material into new wood material
52	Pulp
53	Re-processing of secondary paper into new pulp
54	Paper
55	Publishing, printing and reproduction of recorded media (22)
56	Manufacture of coke oven products
57	Petroleum Refinery
58	Processing of nuclear fuel
59	Plastics, basic
60	Re-processing of secondary plastic into new plastic
61	N-fertiliser
62	P- and other fertiliser
63	Chemicals nec
64	Manufacture of rubber and plastic products (25)
65	Manufacture of glass and glass products
66	Re-processing of secondary glass into new glass
67	Manufacture of ceramic goods
68	Manufacture of bricks, tiles and construction products, in baked clay
69	Manufacture of cement, lime and plaster
70	Re-processing of ash into clinker
71	Manufacture of other non-metallic mineral products n.e.c.
72	Manufacture of basic iron and steel and of ferro-alloys and first products thereof
73	Re-processing of secondary steel into new steel
74	Precious metals production
75	Re-processing of secondary precious metals into new precious metals
76	Aluminium production
77	Re-processing of secondary aluminum into new aluminum
78	Lead, zinc and tin production
79	Re-processing of secondary lead into new lead, zinc and tin

Number	Name
80	Copper production
81	Re-processing of secondary copper into new copper
82	Other non-ferrous metal production
83	Re-processing of secondary other non-ferrous metals into new other non-ferrous metals
84	Casting of metals
85	Manufacture of fabricated metal products, except machinery and equipment (28)
86	Manufacture of machinery and equipment n.e.c. (29)
87	Manufacture of office machinery and computers (30)
88	Manufacture of electrical machinery and apparatus n.e.c. (31)
89	Manufacture of radio, television and communication equipment and apparatus (32)
90	Manufacture of medical, precision and optical instruments, watches and clocks (33)
91	Manufacture of motor vehicles, trailers and semi-trailers (34)
92	Manufacture of other transport equipment (35)
93	Manufacture of furniture; manufacturing n.e.c. (36)
94	Recycling of waste and scrap
95	Recycling of bottles by direct reuse
96	Production of electricity by coal
97	Production of electricity by gas
98	Production of electricity by nuclear
99	Production of electricity by hydro
100	Production of electricity by wind
101	Production of electricity by petroleum and other oil derivatives
102	Production of electricity by biomass and waste
103	Production of electricity by solar photovoltaic
104	Production of electricity by solar thermal
105	Production of electricity by tide, wave, ocean
106	Production of electricity by Geothermal
107	Production of electricity nec
108	Transmission of electricity
109	Distribution and trade of electricity
110	Manufacture of gas; distribution of gaseous fuels through mains
111	Steam and hot water supply
112	Collection, purification and distribution of water (41)
113	Construction (45)
114	Re-processing of secondary construction material into aggregates
115	Sale, maintenance, repair of motor vehicles, motor vehicles parts, motorcycles, motor cycles parts and accessories
116	Retail sale of automotive fuel
117	Wholesale trade and commission trade, except of motor vehicles and motorcycles (51)
118	Retail trade, except of motor vehicles and motorcycles; repair of personal and household goods (52)
119	Hotels and restaurants (55)
120	Transport via railways
121	Other land transport

Number	Name
122	Transport via pipelines
123	Sea and coastal water transport
124	Inland water transport
125	Air transport (62)
126	Supporting and auxiliary transport activities; activities of travel agencies (63)
127	Post and telecommunications (64)
128	Financial intermediation, except insurance and pension funding (65)
129	Insurance and pension funding, except compulsory social security (66)
130	Activities auxiliary to financial intermediation (67)
131	Real estate activities (70)
132	Renting of machinery and equipment without operator and of personal and household goods (71)
133	Computer and related activities (72)
134	Research and development (73)
135	Other business activities (74)
136	Public administration and defence; compulsory social security (75)
137	Education (80)
138	Health and social work (85)
139	Incineration of waste: Food
140	Incineration of waste: Paper
141	Incineration of waste: Plastic
142	Incineration of waste: Metals and Inert materials
143	Incineration of waste: Textiles
144	Incineration of waste: Wood
145	Incineration of waste: Oil/Hazardous waste
146	Biogasification of food waste, incl. land application
147	Biogasification of paper, incl. land application
148	Biogasification of sewage sludge, incl. land application
149	Composting of food waste, incl. land application
150	Composting of paper and wood, incl. land application
151	Waste water treatment, food
152	Waste water treatment, other
153	Landfill of waste: Food
154	Landfill of waste: Paper
155	Landfill of waste: Plastic
156	Landfill of waste: Inert/metal/hazardous
157	Landfill of waste: Textiles
158	Landfill of waste: Wood
159	Activities of membership organisation n.e.c. (91)
160	Recreational, cultural and sporting activities (92)
161	Other service activities (93)
162	Private households with employed persons (95)
163	Extra-territorial organizations and bodies

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