THE TRUE COST OF THE CEMENT, STEEL AND CHEMICAL INDUSTRIES

Final report
July 2021

THE GREENS/EFA
in the European Parliament

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Authored by

True Price™

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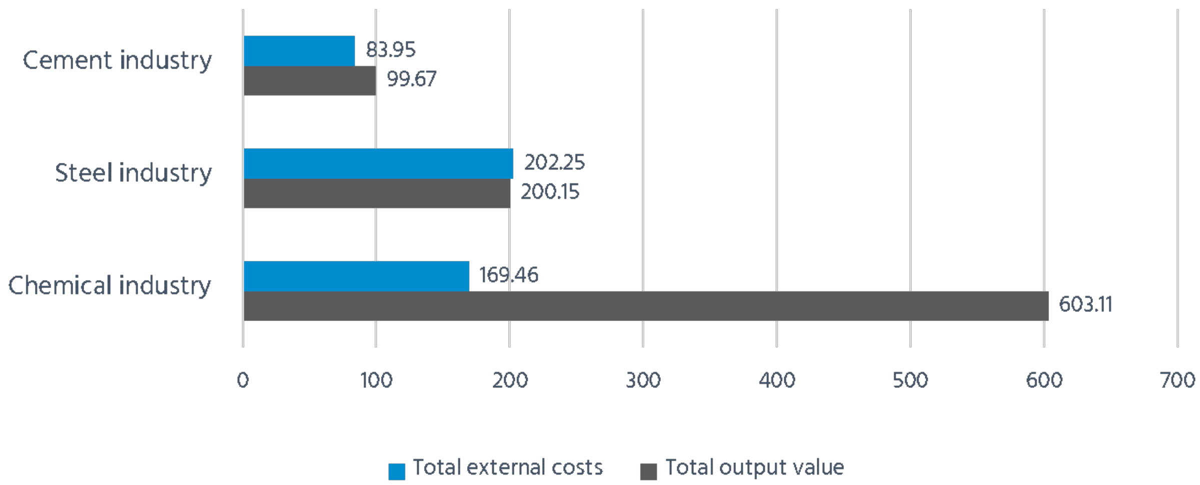
1. SUMMARY

In the current economic system, the EU27's cement, steel and chemical industries provide many products to the EU27 economy, such as materials used in construction and the automotive sector. Simultaneously, the energy-intensive cement, steel and chemical industries cause large damages to people and our planet. Contrary to the 'polluters pay' principle, the costs of these social and environmental damages are not paid for by the industries (CE Delft, 2021). Rather, social and environmental costs caused by the EU's cement, steel and chemical industries are born by society and future generations.

In this report Commissioned by the Greens/EFA group in the European Parliament (Greens/EFA), True Price performs a true cost assessment of the EU27's cement, steel and chemical industries for the year 2019. The report looks at both the industries at large and their direct and upstream impacts. Moreover, this report dives into the main polluting value chain step of each industry to further grasp the industries' external costs to society and the environment in the current economic system.



Total external costs and total output value of EU27's cement, steel and chemical industries in 2019 (in billion euros)

True Price finds that the EU's cement, steel and chemical industries accounted for €84, €202 and €169 billion in damages to society, respectively, in 2019[1]. The industries' contribution to climate change, depletion of fossil fuels and air pollution account for a large share of these external costs. Comparatively, the steel industry contributes the largest share in damage to society, mainly through air pollution. The external costs due to air pollution differ per country with the most populous countries -Germany, France, Italy and Spain- contributing most. On average, the external costs of EU27 countries and their cement, steel and chemical industries is €0.84, €2.01 and €2.52 in terms of impact per euro product, respectively. External costs represent damage to people and planet through, for example, negative effects on human health and biodiversity loss.

Diving further into the value chains of the EU's cement, steel and chemical industries highlights the unfair advantaged which polluting companies face in these industries[2]. Environmentally friendly cement producers in Italy would be able to ask up to €400 per tonne cement and still be able to offer a cheaper product than conventional cement producers (given the 2019 market price of €109/tonne cement) if the external costs of producing cement were included. Similarly, green steel producers may ask up to €1,900 for a tonne of steel and still be cheaper than conventional steel with a market price of €470/tonne steel when including external costs of producing steel. For the chemical industry, environmentally friendly plastics could cost up to 50% more and still be cheaper when including environmental costs.

The results of this report illustrate that our current economic system is unable to meet societal needs. It focuses on financial and economic gains and fails to value and prioritise human rights, the environment and well-being over profits. This report stresses the need for us to ask ourselves: How can we adjust our economic system such that it creates value for people and planet? What is needed to move away from the polluting practices present in our current system? And how will we internalise value creation for people and planet in EU27's new economy?

Based on the findings in this report, there are multiple opportunities for improvement for EU's cement, steel and chemical industries to transition towards socially just and environmentally friendly industries. Firstly, industries should lower their energy consumption by improving production efficiency. Secondly, they should replace energy use based on fossil fuels by green energy. Thirdly, industries must optimize the use of recycled materials to minimize the use of virgin materials. Fourthly, they should eliminate the use of fossil fuels as feedstocks. Fifthly, companies in the cement, steel and chemical industries should integrate their external costs into decision-making cycles to account for and steer on both financial and non-financial profits and losses.

Furthermore, to stimulate the EU's cement, steel and chemical industries to transition towards industries which abide by EU climate goals, systemic change is needed. For example, the EU ETS-system must be updated as to support the transition towards green industries. Regulatory frameworks aiming at such change must be evaluated on a regular basis to ensure they serves their intended purpose. In its role as governing body, the European Parliament can make industries account for the external costs they cause. By making external costs transparent and letting industries pay for the external costs they cause, the European Parliament will stimulate the socio-ecological transition of its energy-intensive industries.

1 Please find the scope, assumption and limitations to the study in chapter 3 Method.

2 Price levels hold for the year 2019 and assume the external costs of production by the environmentally friendly or green producers are negligible. Simultaneously, only the external costs of air pollution and contribution to climate change are considered for these deep-dive studies. When including additional impacts (such as fossil fuel depletion), the gap will only increase further.

2. INTRODUCTION

This report assesses the environmental and social costs of EU27[3]'s cement, steel and chemical industries. The aim of this assessment is to investigate the environmental and social costs of these industries. Furthermore, the report aims to understand whether companies in these industries upholding polluting practices are presented with unfair advantage over companies which aim to produce socially just and environmentally sustainable cement, steel and chemical products.

The European production of cement is estimated to account for 61,000 direct jobs (European Commission, n.d.-a) while the European steel industry accounted for an estimated 330,000 direct jobs in 2019 (EUROFER, 2020). The chemical industry (including pharmaceuticals, rubber and plastics) of EU28 (EU27 plus United Kingdom) was estimated to directly employ 3.3 million people in 2015 (CEFIC, 2020-b). To contrast, nearly 200 million Europeans were employed in 2019 (Eurostat, 2020). An estimated 55% of them were employed in manufacturing (16%), wholesale & retail trade (14%), human health & social work (11%), education (7%), or public administration & defence (7%) (Eurostat, 2021).

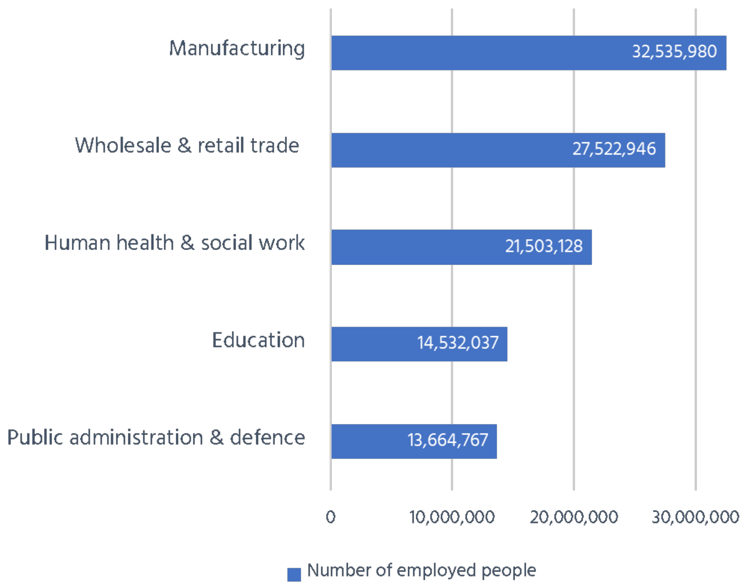


Figure 1: Number of employed EU citizens for 5 sectors with largest number of employees (Eurostat, 2021)

3 Unless explicitly stated otherwise, EU refers to EU27

While less represented in direct employment figures, the EU's cement, steel and chemical industries are strongly interlinked with other industries, making them valuable aspects of the EU27 economy. For example, the construction sector is currently designed to rely heavily on the cement and steel industries with 35% of the EU's steel consumed being used for construction. In addition, the demand for steel from the automotive sector, responsible for 7% of the EU's GDP (European Commission, n.d.-b), makes up 19% of EU steel consumption (EUROFER, 2020). The chemical industry produces over 70,000 different products for all kinds of sectors such as in health and agriculture (CEFIC, 2020). Conclusively, the EU's cement, steel and chemical industries directly or indirectly contribute in many ways to the EU economy.

Simultaneously, these energy-intensive industries are under scrutiny due to their negative impacts on people and planet. Next to being significant, contrary to the 'polluters pay' principle, these costs are born by society and future generations rather than the industries themselves. An example of such costs to society is the contribution to climate change (for example resulting from CO2eq emissions caused by the industries' large energy consumption and use of fossil fuels). A research study by CE Delft shows the EU ETS-system, used to regulate greenhouse gas emissions, fails to stimulate energy-intensive industries to reduce their environmental footprints (CE Delft, 2021). For the EU to reach its climate goals (European Commission, n.d.-c), the current practices of the EU's cement, steel and chemical industries must change. To reach the EU climate goals, societal needs must be met with a supply of goods and services provided by businesses and organisations which carry out risk-based due diligence to avoid and address adverse impacts on economic, environmental and social progress associated with their operations, supply chains and other business relationships (OECD, 2018).

The Greens/EFA group in the European Parliament (Greens/EFA) wants to understand the damages caused to people and planet by energy-intensive industries and accelerate their transition to socially responsible and environmentally sustainable industries. The Greens/EFA wish to counter the argument that sustainable production is more costly than conventional production. Once negative externalities are considered, the results clearly show that statement is false. In terms of impact on people and planet, sustainable technologies are cheaper than conventional polluting practices. This report contains an assessment of the social and environmental impact caused by the EU's cement, steel, and chemical industries to underline this argument. To grasp the impact of the cement, steel and chemical industries on people and planet, True Price has performed a true cost assessment on each of these EU industries. Furthermore, it performed deep-dive studies on the most polluting value chain step for selected products for the cement, steel and chemical industries as to support the Greens/EFA's understanding of how to transform the EU's economy.

True Pricing contributes to this transition as it is a unique method to quantify and present external costs of production. The True Pricing methodology gives quantitative insights into the direct external costs which are not part of the purchasing price of a product, but which are paid by society nonetheless – for instance by local communities (air and water pollution), by future generations (climate change) or by employees (health and safety risks). The aim of True Pricing is to minimise products' external costs. This can be done by creating transparency about external costs and showing how industries can be transformed to improve their societal impact. Complementary, governing bodies can facilitate and accelerate reduction of external costs via incentives (such as taxes and subsidies).

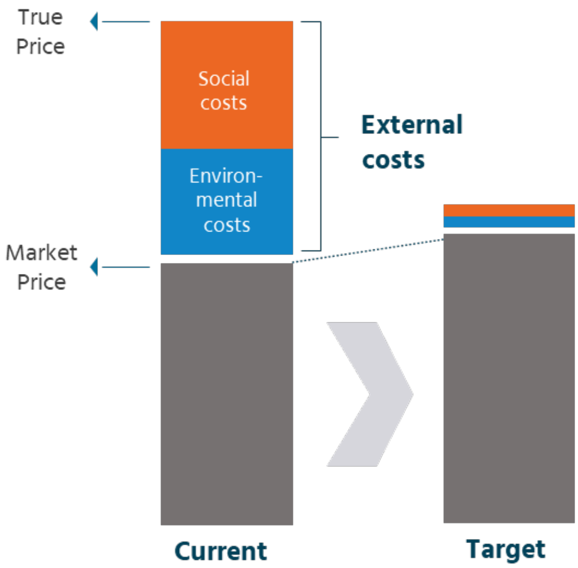


Figure 2: Explanation of external costs

Figure 3: Publications on true pricing

This information can be used to:

• Identify the largest external costs of the cement, steel and chemical industries and improvement levers for each industry;

• Draft a roadmap to transitioning the EU's energy-intensive industries towards a green and sustainable future;

• Strengthen advocacy for green alternatives by providing fact-based and tangible arguments;

• Inform policy makers and regulators on the benefits of internalising external costs.

This report allows the Greens/EFA to accelerate the transition of the EU's energy-intensive industries into green industries. Firstly, it describes the study's method, including the approach to the study, its scope, assumptions & limitations, data and methodology. Secondly, the results of the assessments are presented in chapter 4. Results. This chapter consists of two sub-chapters: One presenting the results of the baseline study and one presenting the results of the deep-dives studies. Finally, chapter 5. Recommendations discusses recommendations for establishing sustainable industries as based on the findings of this report.

3. METHOD

The goal of chapter 3. Method is to discuss the approach, scope, assumptions & limitations, main data sources, overall methodology and the costing (or: how to monetize environmental and social footprints) relevant to the baseline study and the three deep-dives. The chapter consists of three sub-chapters:

• **3.1 Approach:** Description of the steps that were taken in carrying out the four studies discussed in this document.

• **3.2 Scope, assumptions & limitations and data:** Outline of the scope and assumptions underlying each of the studies and the limitations they represent. In addition, the main data sources are discussed.

• **3.3 Methodology and costing:** Overview of the methodology applied throughout the studies, including an overview of how to monetize social and environmental footprints.

3.1 APPROACH

The true cost assessment in this report contains four complementary studies, namely one baseline study and three deep-dive studies (one for each industry). The purpose of the baseline study is to understand the full impact of the EU's cement, steel and chemical industries (both their direct impact within the EU as well as their upstream impact which may occur either within or outside of the EU).

Complementary, the deep-dive studies zoom in on selected aspects of the industries which represent value chain steps which both often occur and are highly polluting. Moreover, the deep-dive studies assess possible green alternatives to these polluting value chain steps. All studies were carried out in five steps: scoping, model building, data collection, analysis and validation, and reporting:

Step 1: Scoping

The assessment starts by scoping the boundaries of the project. These boundaries are determined together with the Greens/EFA during a scoping session.

Step 2: Model building

For each of the four studies, True Price developed a model. The deep-dives are performed using the True Price tool. This tool provides the true cost of a product and allows for converting externalities into monetary values using monetisation factors1. True Price used sector literature to map a clear value chain and customise the True Price tool to the value chain step selected for each deep-dive study.

The baseline study requires a different type of model. The data used to acquire the baseline study's result originate from the Global Impact Database (GID) version 2.4.12. The GID is a database developed by True Price and contains data on a wide variety of impacts, sectors and countries. True Price adjusted the model of the baseline study to the GID-data.

Step 3: Data collection

The third step is to collect data. For all studies (the baseline study and the three deep-dives), secondary data and literature was used to assess their impact. These secondary data sources include for example sector reports, national statistics, ReCiPe 2016/2008 and Ecoinvent 3.6 (2016) LCA data[4].

Step 4: Analysis and validation

For each of the four models, True Price performed an in-depth analysis. Regarding the baseline study, the report assessed the GID-data from a multitude of angles collecting insights including the total true cost gap of the EU's cement, steel and chemical industries, their underlying causes and indicators and the external costs per euro product. Regarding the deep-dives, the models were assessed to find the true cost gap and a comparison between conventional production and the green alternative. The analyses provide insights into the drivers of the external cost of the EU's cement, steel and chemical production. The models and analyses were validated by quality experts from True Price to ensure they are accurate and error free.

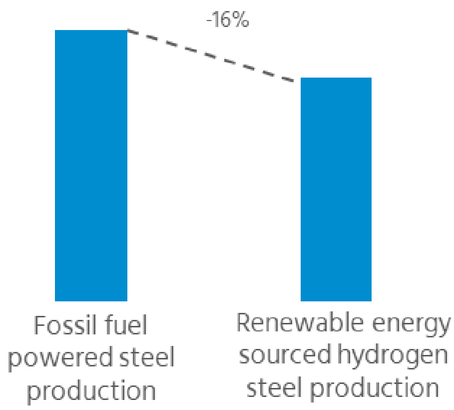


Figure 4: External costs of contribution to climate change of current production versus a green alternative – Dummy graph (values presented do not represent assessed results)

Step 5: Reporting

In the reporting step, all findings, methodologies, assumptions and limitation are documented. The report includes the external cost of selected value chain steps for selected products of the cement, steel and chemical industries and a green alternative for each industry. Moreover, the report includes insights into the levers for change in the value chain and respective recommendations.

4 Please see section 3.2.3 Main data sources for more detailed information on the main data sources used for each of the studies.

3.2 SCOPE, ASSUMPTIONS & LIMITATIONS AND DATA

3.2.1 SCOPE

The four studies discussed in this document are designed as complementary studies: one baseline and three sector deep-dives. In this section the scope of the different studies is outlined, together with the most important assumptions and limitations. For all studies, the year of measurement is 2019. This year was selected as it represents the most recent completed year to study before the influence of the COVID-19 pandemic. Studying the external costs of the year 2019 allows us to study the 'business as usual' situation.

Baseline study

The sectors in scope for the baseline study are the EU27's cement, steel and chemical industries. More specifically, these sectors are defined as set within the geographical boundaries of the EU27. This means a cement producing company based in Germany, for example, is included in the scope. The external costs of the upstream value chains of these sectors are also included in this study. To illustrate, returning to the example of a cement producing company based in Germany (or any other country in the EU27), this company may source its input products (for example, raw materials or energy) from regions outside of the EU27. These parts of the value chain which may be based outside of the EU27 are also included in the scope of the baseline study. In addition, the scope of the study is limited to the production of goods in the cement, steel and chemical industries meaning impact caused by the consumption of good and services by consumers is not in scope. The impacts in scope for the baseline study are listed and defined in table 1.

Table 1. Overview of the impacts in scope for the Baseline study[5]

Environmental impacts	Description
Contribution to climate change	The rise of the global mean temperature caused by increased emissions of greenhouse gases (GHG) due to anthropogenic activities
Scarce water use	The use of surface or groundwater (blue water) in such a way that the water is evaporated, incorporated into products, transferred to other watersheds or disposed into the sea, in areas where water is scarce
Water pollution	The impact of emissions to water contributing to ecotoxicity and human toxicity, as well as eutrophication of marine- and freshwater
Material depletion	The reduction in future availability of non-renewable materials as the consequence of the primary extraction of scarce, non-renewable material resources excluding fossil fuels, such as gold, zinc, copper and many more
Land use and biodiversity	The decreased availability of land for purposes other than the current one, through land occupancy (land occupation) and the effect on ecosystem services and the climate system of changes in land-cover (land transformation)
Air pollution	Emissions to air other than climate change, including ozone layer depletion, acidification, photochemical oxidant formation, particulate matter formation, nitrogen deposition from emissions to air, terrestrial and aquatic ecotoxicity and human toxicity from toxic emissions to air.
Fossil fuel depletion	The reduction in future availability of fossil fuels caused by the primary extraction of fossil fuels linked to fuel use, energy use and to produce other inputs

5 Section 3.3.2 Costing discusses these impacts and their costing (or why and how they are damaging) in more detail.

Social impacts	Description
Underpayment	The gap between workers' wages, the local minimum wage and the local living wage
Forced labour	Presence of forced labour in own operations and in the value chains
Child labour	Presence of child labour in own operations and in the value chains
Negative effects on employee health and safety	The occurrence of accidents in the value chain and cost of workers performing work in unsafe conditions
Gender equality	The value of the pay gap between female and male employees along the value chain

DEEP-DIVE STUDY PER INDUSTRY

The deep-dives focus on the most material value chain steps for the EU27's cement, steel and chemical industries. The study performs individual deep-dives on each industry. For each industry, it assessed the external costs of air pollution and contribution to climate change (see table 2) caused by its most polluting value chain step. The next step was to research green alternatives to these polluting value chain steps and assess the external costs of air pollution and contribution to climate change of these green alternatives as well. To illustrate, a green alternative may replace non-renewable energy by green energy. In this study, green energy is defined as energy sourced from renewable energy sources (wind power, solar power, hydroelectric power, ocean energy, geothermal energy, biomass, or biofuels) (European Parliament, 2020).

Assessing both the external costs of conventional production and the external costs of the green alternative allows for comparison between the currently dominant (and polluting) value chain step and a more environmentally friendly alternative. The scope of each deep-dive study is summarized in table 3 and will be discussed and visually presented in more detail below.

Table 2. Impacts in scope for the deep-dive studies

Environmental impact	Description
Contribution to climate change	The rise of the global mean temperature caused by increased emissions of greenhouse gases (GHG) due to anthropogenic activities
Air pollution	Emissions to air other than climate change, including ozone layer depletion, acidification, photochemical oxidant formation, particulate matter formation, nitrogen deposition from emissions to air, terrestrial and aquatic ecotoxicity and human toxicity from toxic emissions to air.

Table 3. Summary of the scope for each deep-dive study

Cement industry	Scope	Country, year
Value chain step	Calcination (the heating of input materials to create clinker) of producing Ordinary Portland cement in Italy in 2019	Italy, 2019
Green alternative	Geopolymer cement consisting of fly-ash and an alkali-solution	
Steel industry		
Value chain step(s)	Production of hot rolled coil (a flat steel product) via the Basic Oxygen Furnace-method in Germany in 2019	Germany, 2019
Green alternative	Steel production via Electric Arc Furnace using reduced iron obtained using hydrogen gas (based on a Swedish pilot study).	

Chemical industry		
Value chain step	Fossil-based steam cracking in the production of HDPE (a type of plastic) in France in 2019;	France, 2019
Green alternative	Electric steam cracker consuming only green electricity.	

DEEP-DIVE ON THE CEMENT INDUSTRY

The main cement producing countries in EU27 are Germany, Italy, Spain, France and Poland (European Commission, 2018). In close discussion with Greens/EFA, Italy was selected for the geographical scope of the deep-dive study on the cement industry. As second largest cement producer, it represents an important player in the EU cement industry. Italy was preferred over Germany for the deep-dive on the cement industry to optimize variety of countries in the geographical scopes of the deep-dives (as Germany was selected for the deep-dive on the steel industry).

The most common type of cement produced in EU27 is Ordinary Portland cement (OPC) which largely consists of clinker (European Commission, 2018). Clinker is the resulting product of crushing, blending and grinding limestone and other rocky materials (such as clay) and subsequently heating this mixture at a high temperature (European Commission, 2018). This heating step is called 'calcination' and requires heating the input products to 1,400 – 1,500 degrees Celsius (European Environment Agency, 2019). Due to its high energy demand (used for heating) and the amount of fossil fuels used for this process, the calcination step is selected for the deep-dive study on the cement industry. Figure 5 present the value chain of OPC[6].

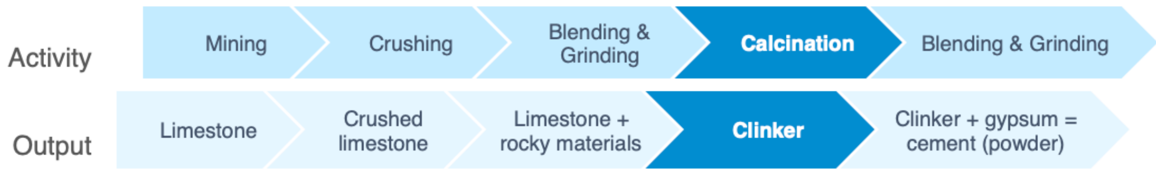


Figure 5. Simplified value chain of OPC production

After selecting the value chain step to be assessed in terms of air pollution and contribution to climate change, the study required a green alternative to the calcination-step in OPC's value chain. Research into potential alternatives led to the selection of a geopolymer cement which consists largely of industry by-product fly ash. It is used in combination with an alkali-solution to produce cement. Notably, secondary literature and data on alternative cements is not readily available in a constructive and conclusive manner. Many alternatives to OPC have been or are being researched by scientists. However, due to lack of proper use of terminology and contradicting results of studies, it was difficult to establish a green alternative to the value chain of OPC.

To clarify, this is not caused by lack of green alternatives to OPC but rather due to unclear classification and definitions of alternatives to OPC. As previously mentioned, the green alternative to OPC contains an industry by-product (fly ash) meaning this product is produced in currently existing production processes and not (or not fully) used. Therefore, industry by-products offer an environmentally friendly alternative to virgin products, such as the limestone used for OPC. Another important benefit to the green alternative cement selected for this study is that it does not require to be processed at high temperature, thereby significantly reducing its energy consumption.

6 Please note the visualisation of the value chain was simplified to make understanding it accessible to all readers. For more detailed information on the value chain of Ordinary Portland cement, please consider European Environment Agency (2019).

DEEP-DIVE ON THE STEEL INDUSTRY

Germany is the leading steel producing country in the EU27 (Eurofer, 2020). The geographical scope of the deep-dive on steel therefore looks at steel production in Germany. There are two main methods to producing steel: Using a Blast Furnace or an Electric Arc Furnace. Since the Blast Furnace method is more commonly used in EU27 (Eurofer, 2020) this method was selected for the deep-dive on the steel industry. The scope of the deep-dive was expanded slightly from one value chain step to a collection of value chain steps to match a viable green alternative (titled the 'Hybrit' method (HYBRIT, n.d.)) to this method. The steps in scope are visualized in figure 6. As depicted in the figure, both methods start with iron ore as input product and process it into (liquid) crude steel. This crude steel can henceforth be processed into steel products such as hot rolled products used in the construction and automotive sectors (Eurofer, 2020).

Figure 6 illustrates the required input products (next to iron ore) for both the Blast Furnace method and the Hybrit[7] method. The Hybrit method represents an effort of Swedish companies to work towards producing fossil-free steel (Hybrit, n.d.). Where the Blast Furnace method uses large quantities of fossil fuels to heat and process iron ore into crude steel, the Hybrit method large replaces fossil fuels with renewable and green alternative. Importantly, the Hybrit method uses hydrogen (sourced from water using green electricity) to treat the iron ore in a process called direct reduction, thereby replacing additional use of fossil fuels.

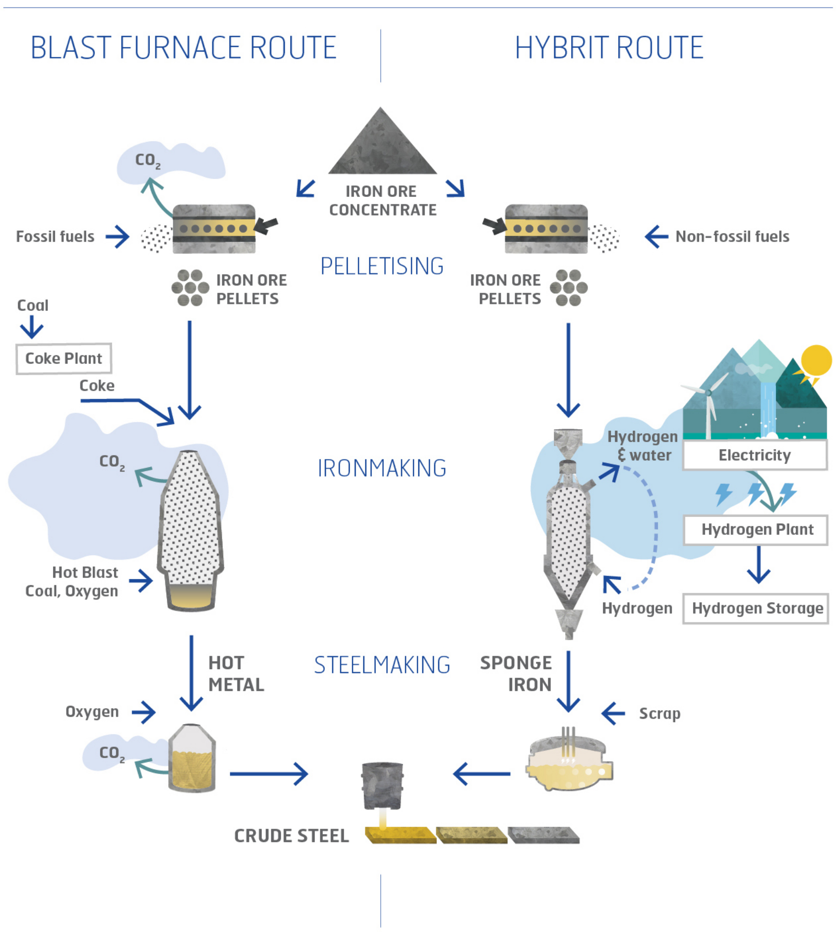


Figure 6. Selected steps of the value chain of steel production according to the Blast Furnace method and the green alternative Hybrit method (picture by Hybrit (n.d.))

7 HYBRIT is an abbreviation of Hydrogen Breakthrough Ironmaking Technology (Hybrit, n.d.).

The geographical scope of this deep-dive is Germany. Therefore, the deep-dive assumes the Blass Furnace method and the Hybrit method are both situated in Germany. For the Hybrit method assessed in this deep-dive, hydrogen is assumed to be sourced without using fossil fuels (like in Sweden). However, this represents a scenario which is currently unrealistic since 95% of hydrogen in Europe is currently sourced using fossil fuels (Hydrogen Europe, 2021). Looking towards the future, it is likely hydrogen will become more green (thus, move towards sourcing hydrogen using only green energy sources) (Hydrogen Europe, 2021). Therefore, the scenario is valuable for the current deep-dive study.

DEEP-DIVE ON THE CHEMICAL INDUSTRY

The chemical industry is an extensive industry produces a variety of products. Plastics are also produced in the chemical industry and make up a significant part of the category base chemicals which accounted for 60% of EU chemical sales in 2018 (CEFIC, 2020-b; Plastics Europe, 2020). The deep-dive study on the chemical industry therefore assesses a value chain step in the production of plastic. In 2019, the main plastic producing countries in the EU27 were Germany, Italy and France (Plastics Europe, 2020). The geographical scope of this deep-dive is limited to France.

There are different kinds of plastics, used for different purposes. Examples are plastic bottles used for drinks (which are generally made of PET), plastic supermarket bags (which may be made of HDPE (high-density polyethylene)) and plastic good containers (for example made of PP (polypropylene)) (Plastics Europe, 2020). Together, PP, PE and PET presented 57% of EU demand for plastics in 2019 (Plastics Europe, 2020). This study looks at the value chain of polyethylene (PE) (which can in turn be used to make HDPE or other PE-products). The main input product used for making plastics is crude oil (petroleum) (Plastics Europe, 2020). The deep-dive assesses the value chain step 'steam cracking' of a crude oil-based PE-product's value chain (see figure 7). Steam cracking is a common step in the value chain of many plastic products[8] which at the same time requires large quantities of fossil fuels due to the process' high temperature demand. Similar to the deep-dive on the cement industry, the green alternative to the conventional steam cracking process should be one in which it is not necessary to combust fossil fuels to generate extremely high temperatures for processing materials. There are limited cases available, but some parties are experimenting with electricity-based steam cracking (Amghizar et al., 2020). This would offer the opportunity to replace fossil fuel by renewable energy as the electricity can be sourced from renewable energy sources.

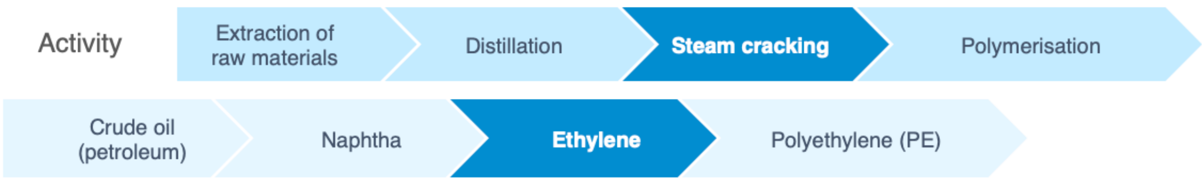


Figure 7. Simplified value chain of high-density polyethylene (HDPE) production

To assess the implications of replacing conventional steam cracking by green electricity-based steam cracking, the to-be-developed technology of electric steam cracking (Amghizar et al., 2020) was modelled as the green alternative for the deep-dive on the chemical industry.

3.2.2. ASSUMPTIONS AND LIMITATIONS

Throughout the studies assumptions have been made for feasibility, comparability, and applicability. Together with the underlying methodology (as presented in section 3.3 Methodology and costing), these present limitations to the studies to be considered when assessing the results.

8 Please see Chapter 4 Results, section 4.2.3 for more detailed information.

Table 4. Overview of the most important assumptions and limitations of the studies

Study focus	Assumption
All	Both historical impact and trade data (selected on basis of completeness, granularity and year of origin) can be used as a representative proxy and is inflated to 2019-levels when needed. To illustrate, if only emission rates per tonne product were available for the year 2017 True Price compared different sources to make a best estimate for the emission rates applicable to 2019.
Baseline study	The impact indicators of air pollution (particulate matter formation and others) do not only result in air pollution but also in –for example- water pollution. In the Global Impact Database (GID), no distinction is made between the resulting impact in terms of air pollution and other forms of pollution. All is assumed to result in air pollution as it is likely that most of the impact must be accounted to air pollution.
Steel deep-dive	This report assumes steel no scrap metal is used as input product for steel production. Rather, only virgin material (iron ore) is used. Replacing virgin materials with scrap metal might requires less energy to process the input materials into liquid steel and therefore result in lower emissions per tonne product.
Chemical deep-dive	The technology used by the green alternative in the chemical industry's deep-dive is still in its infancy. Therefore, there is no data available yet on its energy demand and emissions rates. In this report, the green alternative (electric steam cracking using only green electricity) is assumed to require the same amount of energy (in MJ) as the conventional naphtha steam cracker.
Study focus	**Limitation**
Baseline study	The baseline study is based on data from True Price's Global Impact Database (GID) (version 2.4.12). It uses data from Exiobase, Eora26, ILOSTAT and WageIndicator and estimates impact for 49 countries and 163 sectors in the global economy. This means the GID uses a top-down approach to assessing the environmental and social footprints of sectors and countries. This is a limitation since if reliable, primary data is available (for example, on the footprints of specific companies, sectors and countries), using such primary data would present a bottom-up approach and would provide a more accurate picture of the specific situation at hand.
Baseline study	Due to lack of available trade data on the year 2019, the trade data upon which the baseline study is based on stems from 2015. It is inflated to 2019 levels to reflect trade data on the year 2019.
Deep-dive studies	Due to lack of reliable data available on the emissions of fossil fuel use caused by individual value chain steps, Lifecycle Assessment (LCA) data by Ecoinvent 3.6 is used to estimate the emissions. Ecoinvent 3.6 contains robust data on the emissions of the total value chains. Using estimations of specific value chain steps' attribution factors allowed for calculating the environmental footprint of individual value chain steps.
Deep-dive studies	The Ecoinvent 3.6 LCA data used for the deep-dive studies is data specific to the European level, as opposed to country-specific data.
Deep-dive studies	To make the processes and results accessible to the public, this report sometimes simplifies terminology or present value chains in simplified manners. This is not to say the results are not accurate.
Cement deep-dive	There is limited data availability on green alternatives to OPC as most literature is research-focused with little regulation on terminologies in this field. This makes it difficult for businesses and non-academics to use their data and insights. To illustrate, there are many studies researching varying types of cements (for example, consisting of different shares of industry by-product) which are not given a name or list of main characteristics such that studies do not complement each other sufficiently for their insights to be used by businesses.

3.2.3. MAIN DATA SOURCES

There are five main data sources which are used throughout the studies. The first is ReCiPe (Huijbregts et al., 2017) which is used for the True Price methodology. Regarding the baseline study, main sources are the Global Impact Database (v2.4.12) and EXIOBASE (2016 and 2008). The deep-dive studies are largely based on Ecoinvent 3.6 (2016). Hybrit (n.d.) is used specifically to the deep-dive on the steel industry.

Table 5. Overview of the main data sources.

Source	Description
ReCiPe (2016)	ReCiPe lifecycle assessment methodology was developed by Huijbregts et al. (2017). The ReCiPe methodology is an important aspect of the True Price methodology.
Global Impact Database 2.4.12	The Global Impact Database (GID) is a database of impact-related information collected, analysed and maintained by Impact Institute. It allows us to quickly estimate the impact of an activity by quantitatively describing the global economy, estimating economic, social and environmental impacts for 49 countries with 163 sectors, making a total of 7,987 country sector combinations (version 2.4.12). The GID estimates this impact based on data on the interconnectedness of industries in various countries and their economic, environmental and social performance from global databases (mainly EXIOBASE). The output of the GID model can be used for top-down impact estimates of value chain impacts.
EXIOBASE (2016 and 2008)	EXIOBASE is a global, detailed database which was developed by harmonising and detailing supply-use tables for many countries, estimating emissions and resource extractions by industry. It is used for the analysis of environmental impacts associated with final consumption of product groups.
Ecoinvent 3.6 (2016)	The Ecoinvent database is a lifecycle inventory database which contains (LCA) data on environmental footprints of thousands of products and value chain on a European level. Ecoinvent data is used for all three deep-dive studies.
Hybrit (n.d.)	Specific to the deep-dive on the steel industry, researchers of the HYBRIT-pilot set in Sweden assessed the quantities of input and output products for both the conventional (Blast Furnace) and the green alternative (Hybrit) method. This data was used to evaluate the environmental footprint and monetized impact of the two methods.

3.3 METHODOLOGY AND COSTING

The true cost assessments of the EU's cement, steel and chemical industries are performed using the True Price methodology. Amongst others, this methodology requires data on the environmental footprint (for example, including kilograms CO2-equivalents emitted) on all parts of the assessed value chains. This section will elaborate on what the True Price methodology entails and how to get from environmental and social footprints to monetized environmental and social costs.

3.3.1 TRUE PRICE METHODOLOGY

The true cost assessments of the EU's cement, steel and chemical industries are performed using the True Price methodology.

What is the true price?

The true price is a way to make the external costs of producing and consuming a product explicit. External costs are the costs associated with negative externalities. These are the negative effects on external stakeholders who did not participate in the production or consumption of that product (or, if they did, did not do so sufficiently freely). Externalities include effects on the environment, such as climate change and water pollution, and on people, such as health and safety accidents and child labour. True price makes external costs explicit by assessing them on a per-unit basis and by monetising them—that is, expressing them in a monetary way (e.g., in euros or dollars), just as with conventional costs.

How to quantify and monetise external costs?

For each of the relevant impacts in the current study, the size of the impact in natural unit (or 'footprint') can be measured or estimated using primary or secondary sources. Examples of footprints are the emission volumes of greenhouse gases per unit product (for determining the contribution to climate change), and hours of child labour per unit product. To obtain the respective monetised value of an impact, the impact expressed in its natural units (or footprint indicators) can be multiplied by its monetisation factor.

How to determine monetisation factors?

The Principles for True Pricing defines the principle of remediation that monetisation can be based on. This is inspired by, among others, the UN Guiding Principles on Business and Human Rights and links directly to the rights-based approach (see Principles for True Pricing for more details).

The principles of remediation are implemented by identifying the four types of costs that, when appropriately combined, form the remediation cost for an impact: Restoration costs, compensation costs, prevention costs of re-occurrence, and retribution costs.

To derive monetisation factors for a given impact, the following approach is followed:

1. Firstly, the types of damage that are associated to the impact are determined based on existing literature. Damage can be either damage to people or to the environment. In some cases, the damage has already occurred (i.e. damage in the past; it is irreversible). In other cases, the future damage might occur unless it is prevented (namely, reversible future damage), or is certain to occur (namely, irreversible future damage).

2. The damage can also be assessed as severe or non-severe. We assess which of the four types of remediation cost must be applied (see Monetisation Factors for True Pricing for more details). More than one type of cost might be relevant (e.g., both Compensation costs and Prevention costs of re-occurrence). In some cases, the choice of cost may vary, depending on the country or region where the impacts take place, leading to different monetisation factors in different geographies.

3. Secondly, based on economic modelling and data available in the literature, the relevant costs are quantified in a way that can be attributed linearly to one unit of impact as measured by the footprint indicators.

4. Finally, the quantified cost(s) are summed to form monetisation factors. For impacts that have only one footprint indicator, this is a single monetisation factor. For impacts that have a set of distinct footprint indicators, there are monetisation factors for each.

BOX 1: THE FOUR TYPES OF REMEDIATION COSTS

Restoration costs

Restoration costs are the cost of bringing people's health, wealth, circumstances, capabilities, or environmental stocks and environmental qualities to the state they would have been in the absence of the social and environmental damage associated with an impact (such as the cost of ecosystem restoration). Restoration cost is applied for impacts where restoration is feasible, or feasible and more economically efficient than compensation when the damage to people or communities is not severe.

Compensation costs

Compensation costs are the cost of compensating affected people for economic and/or non-economic damage caused by the social and environmental impacts of producing or consuming a product. In the valuation literature, this is also called damage cost (e.g. compensating for denied income, or the value of lost human health). Non-economic damage can be assessed using the best available stated and revealed preference valuation techniques. Compensation costs are part of the remediation costs for impacts where restoration is not considered feasible.

Prevention of re-occurrence costs

Prevention of re-occurrence cost represents the cost that would be incurred in the future to avoid, avert or prevent the identified social and environmental impacts of a product from occurring again (e.g. the cost of introducing human rights audits in a supply chain). Prevention cost of re-occurrence is part of the remediation costs in addition to restoration or compensation when the damage is considered more severe and irreversible. Whereas the other types of costs refer to realised damage, this cost relates to the prevention of future damage. It finds its basis in, among others, the UN Guiding Principles mentioned earlier that acknowledge a responsibility to prevent reoccurrence of human rights breaches.

Retribution costs

Retribution costs are the cost associated with fines, sanctions or penalties imposed by governments for certain violations of legal or widely accepted obligations. They represent the damage to society caused by the breaking law. For impacts that correspond to the breach of a legal or a widely accepted obligation,

3.3.2 COSTING

Each impact has a 'costing' describing how the remediations costs of the impact are build up[9]. These costings are presented in table 6. Given that the costing of air pollution contains many technical terms, please see table 7 for additional information on this impact and its costing.

Table 6. Overview of the impacts in scope for the baseline study and their costing

Environmental impacts	Costing
Contribution to climate change	The restoration and prevention cost of increased emissions of greenhouse gases (GHG), expressing the cost of measures to avoid additional GHG emissions (marginal abatement cost)
Scarce water use	The restoration cost of extracting water from freshwater ecosystems in areas where it is scarce, expressing the total annualised cost of desalination
Water pollution	The compensation cost of toxic emissions, expressing the health-related, social and economic loss due to pollution AND the restoration and prevention cost of eutrophication of marine- and freshwater, expressing the average marginal cost of measures to restore nutrient levels (marginal abatement cost)
Material depletion	The compensation cost of extracting non-renewable materials, expressing the future loss of economic welfare in the society, due to increased extraction costs in the future (increased scarcity)
Land use and biodiversity	The compensation cost of land use, expressing the opportunity cost of using the land and displacing ecosystem services AND the restoration cost of land transformation, expressing the cost of ecosystem restoration projects
Air pollution	The compensation cost of toxic emissions, particulate matter formation, photochemical oxidant formation, acidification and ozone layer depletion, expressing the health-related, social and economic loss due to pollution
Fossil fuel depletion	The compensation cost of extracting non-renewable materials, expressing the future loss of economic welfare in the society, due to increased extraction costs in the future (increased scarcity)
Social impacts	**Costing**
Underpayment in the value chain	The restoration cost for wage gap, prevention costs to avoid future violations and compensation cost depending on the size of the wage gap
Forced labour	The restoration cost for existing debt and interest, cost of treatment in case of abuse and cost of reintegration, compensation cost depending on the severity of the violation and prevention costs to avoid future violations
Child labour	The restoration cost of missed education, compensation cost of loss in future earnings and prevention cost for avoiding future occurrence of child labour
Negative effects on employee health and safety	The restoration cost of medical costs, compensation cost for fatal and non-fatal incidents and prevention cost for avoiding future health & safety breaches
Gender equality	The restoration cost of the gender wage gap and compensation cost proportional to the gender wage gap

9 Please see our publication Monetisation Factors for True Pricing for further reading (True Price, 2020).

Table 7. Detailed information on selected Air pollution indicators and their consequences for human health

Indicator	Costing
Particulate matter (PM) formation	Fine Particulate Matter with a diameter of less than 2.5 μm is a mixture of organic and inorganic substances that causes human health problems as it reaches the upper part of the airways and lungs when inhaled (Huijbregts et al., 2017).
Terrestrial acidification	Acidification is a consequence of the emission to air of acidifying pollutants. This leads to acid precipitation which increases the level of acidity in the soil, which will cause shifts in a species occurrence (Huijbregts et al., 2017).
Photochemical oxidant formation	Photochemical oxidant formation, or smog formation, is the formation of ozone resulting from photochemical reactions of NOx and Non-Methane Volatile Organic Compounds (NMVOCs). Ozone is not directly emitted to the atmosphere but is a health hazard to humans since it can inflame airways and damage lunges. Ozone concentrations lead to an increased frequency and severity of respiratory distress in humans, such as asthma and Chronic Obstructive Pulmonary Diseases (COPD). Ozone can also have a negative impact on vegetation, including a reduction of growth and seed production, an acceleration of leaf senescence and a reduced ability to withstand stressors (Huijbregts et al., 2017).
Ozone layer depletion	Ozone layer depleting emissions cause to damage to the stratospheric ozone layer resulting in increased UVB-radiation on the Earth's surface. This leads to increased risk of skin cancer and cataract risks. (Huijbregts et al., 2017).

4. RESULTS

This chapter of the report discusses the results of the baseline study. The chapter first discusses the total results per industry for all impacts in scope. As the report finds that for each industry in scope, air pollution drives external costs, the next step is to zoom in on this impact. More specifically, the external costs of air pollution of each industry per country and the underlying causes of this air pollution are discussed. Finally, the report highlights the external costs for all impacts in scope for one industry (the cement industry)[10] on a product level (rather than total external costs in 2019) to properly understand differences between the results of the EU27 weighted average, Germany and France.

Complementary, sub-chapter 4.2 Deep-dive results dives further into the cement, steel and chemical industries. It discusses the results of the deep-dives on these industries. Together, these results will provide EU citizens with a deeper understanding of the social and environmental damage caused by the cement, steel and chemical industries of the EU.

4.1 RESULTS OF INDUSTRIES' TRUE COST ASSESSMENT

4.1.1 TOTAL DAMAGE IN 2019

The damage caused by the EU's cement, steel and chemical industries is estimated to be over 455 billion euros in 2019[11]. In other words, this study finds the external costs created by the EU's cement, steel and chemical industries in 2019 through social and environmental damage (for example, harming people's health by causing air pollution) would require 455 billion euros to remediate. These industries currently do not have to pay for the damage they cause to, amongst others, people's health. The 455 billion euros in damage in 2019 represents, for example, the air pollution, contribution to climate change, water pollution and biodiversity loss due to land use caused by these industries.

10 The results of the other two industries may be found in Appendix 6.1.

11 The precise amount is €455,664,830,091 in external costs in 2019.

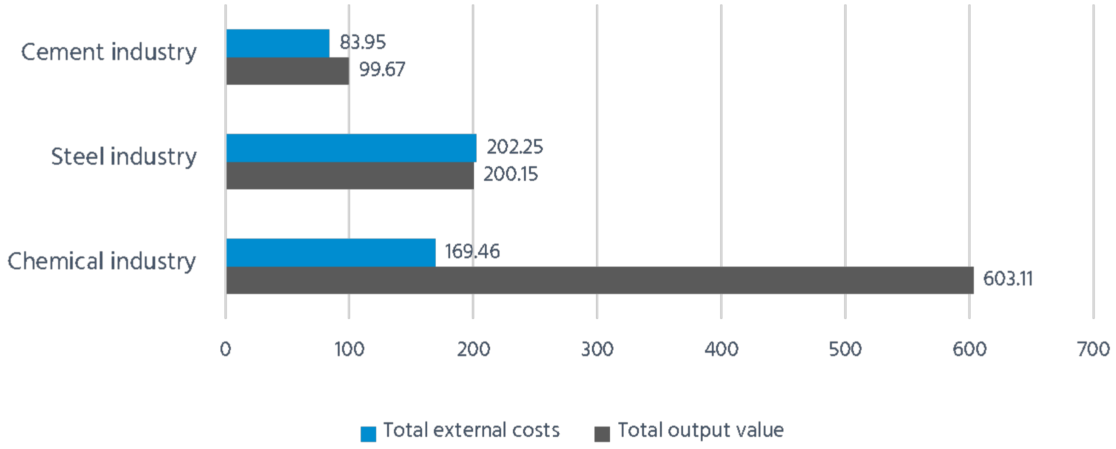


Figure 8: Total external costs and output value per EU27 industry in 2019 (in billion euros)

Figure 8 shows the EU's steel industry accounts for the largest share of the social and environmental damage caused in 2019 by the assessed industries, namely 202 billion euros. The EU's chemical and cement industries accounted for 169 and 84 billion euros in damage to people and planet, respectively.

To make these number more tangible, consider their implications. The 202 billion euros in damage to people and planet caused by steel companies in 2019, represent the amount it would take to remediate effects like the environmental pollution and the negative health effects to communities residing in the vicinity of polluting companies. To illustrate, remediating for such negative health effects means to prevent further deterioration of one's health, to treat one's current or to-be-developed condition and to compensate the person for the life years lost due to this condition. Companies do not pay for such costs of restoration, compensation or prevention of negative health effects. Nor do they pay for the loss in biodiversity or the depletion of fossil fuels resulting from their business models. It is society (and future generations) who pay for the social and environmental costs caused by these polluting industries.

True Price measured these damages by looking at both the direct impact of each industry as well as its upstream impact in 2019. The direct impact of an industry refers to the impact caused by the value chains of the industry itself while the upstream impact[12] refers to the impact caused by producing the input products used in the industry. By including both, the report ensures the measured external costs include the extraction of raw materials and run all the way until products are ready to be sold. If not stated explicitly, in this chapter the term 'impact' refers to the sum of the direct and upstream impact.

4.1.2 IMPACTS PER INDUSTRY

Figure 9 presents the external costs of all impacts in scope per industry for the year 2019. For each industry, the environmental impacts (the 7 bottom ones) overshadow the social impacts (the 5 top ones). Among the environmental impacts, air pollution, fossil fuel depletion and contribution to climate change stand out for being relatively large. The external costs of air pollution of the steel industry are three times larger than the air pollution of the chemical and cement industries (which have similar values). Moreover, the external costs of land occupation are significant for the chemical industry. Compared to the other industries, the chemical industry also has the greatest external costs of social impacts. For all three industries, land occupation and social impacts are driven mostly by the upstream impact. Generally, the cement industry has relatively low external costs for all impacts. As discussed in section 4.2.1 Cement industry, the cement industry's impact per euro product is relatively low compared to the other industries.

12 Upstream activities refer to business activities close to the exploration of natural resources and raw materials (Singer & Donoso, 2008).

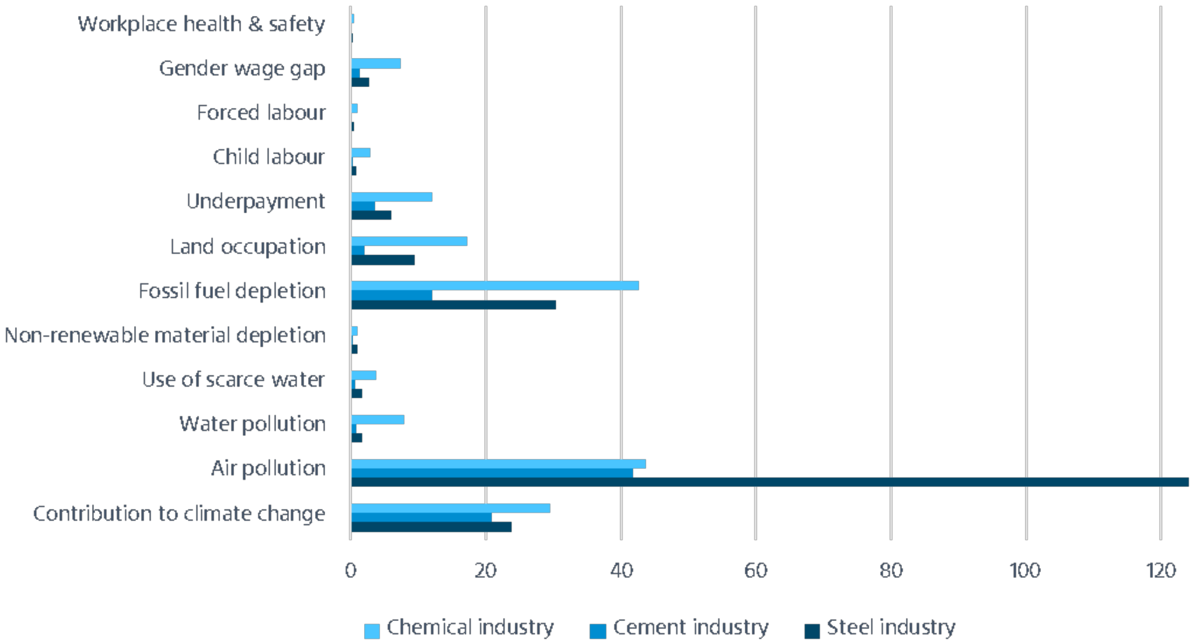


Figure 9: External cost of EU27's cement, steel and chemical industry per impact in 2019 (in billion euros)

4.1.3 AIR POLLUTION PER COUNTRY

Given the significance of air pollution in the industries, this report will dive into it further. Figure 9 shows air pollution accounted for the largest share of external costs of the cement, steel and chemical industries in 2019. The steel industry contributed greatly to this damage. Complementary, figure 10 shows the external costs due to air pollution were driven by production in Germany, Italy and France for all three industries. The EU's average external costs of air pollution caused is depicted in figure 10 as well (named 'EU-27 Average'). It represents a (unweighted) average of all EU27 countries' external costs due to air pollution. Most EU countries have external costs due to air pollution which are lower than the EU average. Countries pulling up the average in all three industries are Germany, France, Italy and Spain. These four countries have large economies and are the most populated EU countries, accounting for 58% of the EU27's population in 2019 (Eurostat, 2019).

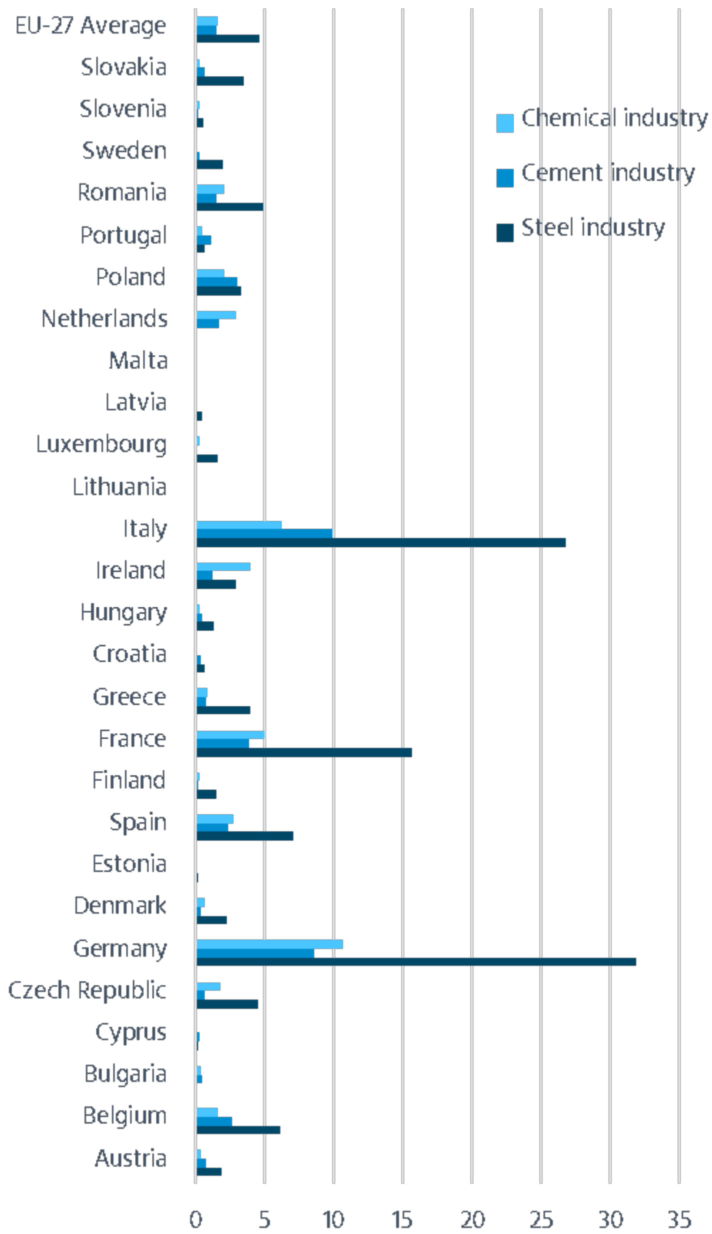


Figure 10: External cost due to air pollution per country in 2019 (in billion euros)

Whereas figure 10 shows the total external due to air pollution differs per country, the pollution rates per produced product also differ. Such rates depend on how efficient production processes are and what types of fossils are used in these processes.

The next section discusses how and why air pollution differs for the EU's cement, steel and chemical industries. It does so by showing the impact per euro product[13] and the contributions of the indicators of air pollution of the EU's cement, steel and chemical industries. The indicators of air pollution are particulate matter formation, human toxicity (carcinogenic and non-carcinogenic), terrestrial ecotoxicity, terrestrial acidification, photochemical oxidant formation, freshwater ecotoxicity and marine ecotoxicity[14]. These come about by –for example- combustion of fossil fuels and have negative effects on both the environment and people's health.

13 The impact per euro product refers to the total external costs of an entire industry (as based on the selected impacts) divided by the total value (in euros) of the industry's products.

14 For definitions of each air pollution indicator, please see Appendix 6.5.

4.1.4 AIR POLLUTION INDICATORS

Figure 11 shows the composition of air pollution according to its indicators of EU-country average for each industry in scope in 2019[15]. The unit of measurement is impact per euro product (meaning that each euro invested in an industry product results in this amount of impact). The figure shows similar trends for the cement and chemical industries. Their impact resulting from air pollution is mainly driven by particulate matter formation and terrestrial acidification both mainly resulting from combustion. As mentioned in section 3.3.2 Costing, particulate matter formation causes human health problems and acidification is damaging to soil and biodiversity.

The cement industry's air pollution accounted for €0.49 impact per euro product in 2019. Particulate matter formation accounted for €0.42 and terrestrial acidification accounted for €0.03. To compare, the chemical industry's air pollution accounted for €3.00 impact per euro product in 2019. Particulate matter formation accounted for €2.45 and terrestrial acidification accounted for €0.46. Given the large shares of particulate matter formation, these results show that, amongst others, the EU's cement and chemical industries were particularly damaging to human health in 2019.

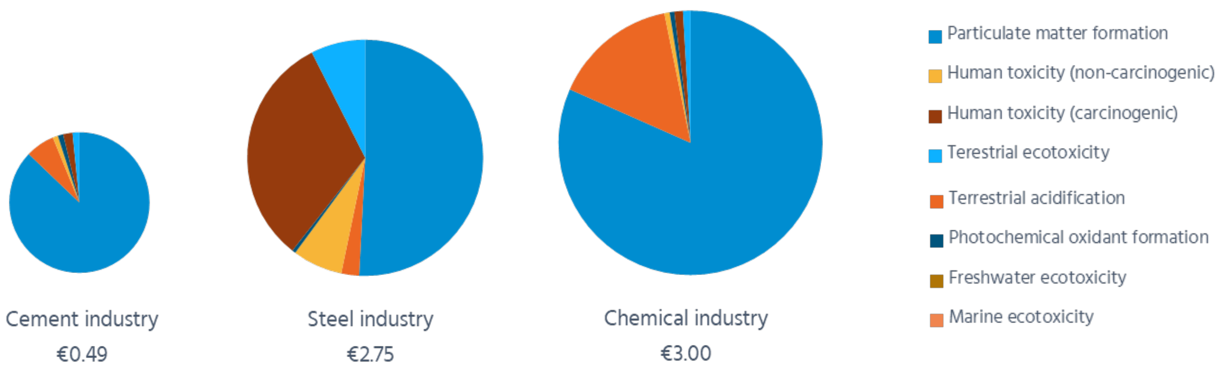


Figure 11: External cost due to air pollution per industry in 2019 (unweighted country average) (per euro product)

Figure 11 indicates the EU's steel industry does not follow the trend observed in the cement and chemical industries. Air pollution caused by the steel industry is still largely driven by particulate matter formation but also by (carcinogenic) human toxicity. Particulate matter formation in the steel industry is caused for 60% by agglomeration processes (in which the iron ore is processed into fine materials which are easy to use in a blast furnace (Küttner, n.d.)). Carcinogenic human toxicity is mostly caused by (Cr and As) emissions released in furnaces. Both particulate matter formation and (carcinogenic) human toxicity have negative effects on human health. The steel industry's air pollution accounted for €2.75 impact per euro product in 2019. Particulate matter formation accounted for €1.40 and (carcinogenic) human toxicity accounted for €0.88. On the next two pages, the report zooms out to include the impacts in scope next to air pollution as well.

4.1.5 IMPACT OF THE CEMENT INDUSTRY

Figure 12 show the impact per euro product of the cement industry for all environmental and social impacts in scope for the baseline study. The highlighted regions are the EU27 average, France and Germany (two large contributors). The cement industry's external cost of the EU is €0.84 per euro product. This is largely due to the impact on the environment (which accounts for €0.79).

The environmental impact also largely defines the external costs of France and Germany. The external cost

Please see Appendix 6.2 for a breakdown per EU country. 15

of the cement industry is €0.59 per euro product for France and €0.83 for Germany per euro product (of which €0.54 and €0.80 are due to environmental impact, respectively). These costs are driven by air pollution and contribution to climate change. The regional differences are likely caused by varying energy mixes used, differences in efficiency and in techniques used per country. On average, EU countries cause external costs of €2.01/euro steel product and €2.52/euro chemical product[16]. For all three industries, the external costs are driven by air pollution, fossil fuel depletion and contribution to climate change

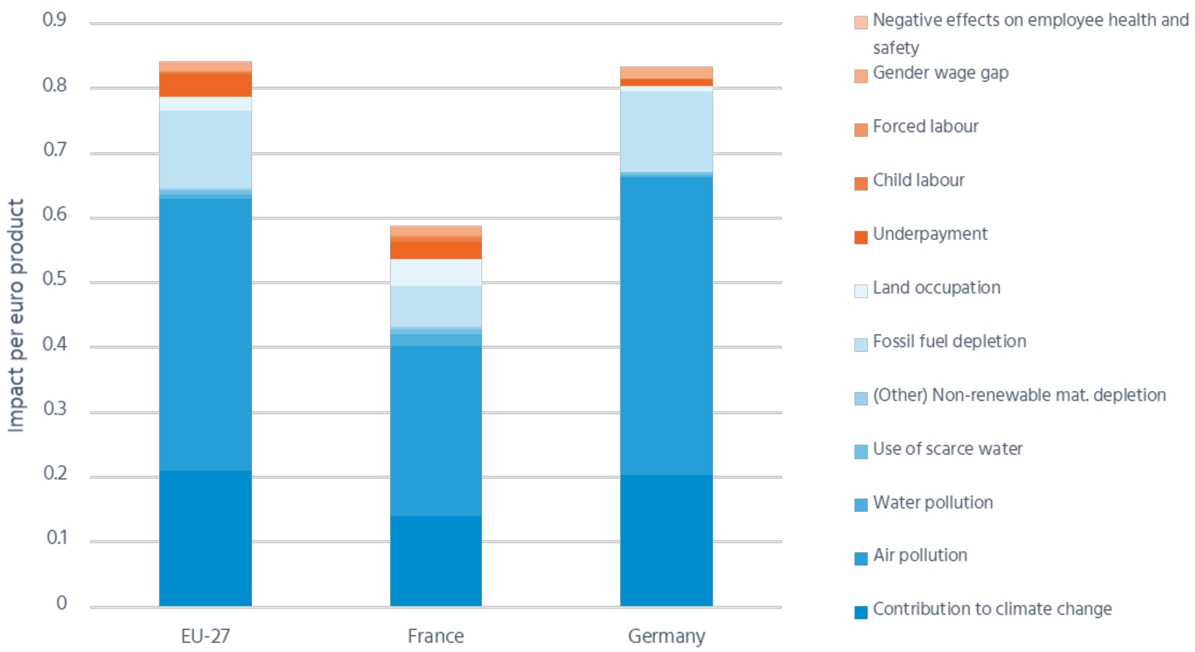


Figure 12 External costs of the cement industry in 2019 (impact per euro product)

4.1.6 DIRECT IMPACT OF THE CEMENT INDUSTRY

Figure 13 appears similar to figure 12. However, in figure 13, the upstream impact of the cement industry is excluded. This means figure 13 only presents the external costs of the direct impact of the cement industry in 2019. Examining the direct impact of an industry shows what happens within EU borders as upstream impact often also occurs outside of EU borders.

The external costs due to social impact are relatively low. For all three industries, the main contributors in terms of impact per euro product are air pollution and contribution to climate change. To illustrate, the external cost of the EU's cement industry is €0.45 of which €0.28 is due to air pollution and €0.15 is due to contribution to climate change. The main emissions of cement production in Europe are caused by chemical reactions and the burning of (fossil) fuels in kilns (European Environment Agency, 2019).

16 The results of the steel and chemical industries (both in terms of total impact and direct impact) are presented in Appendix 6.1.

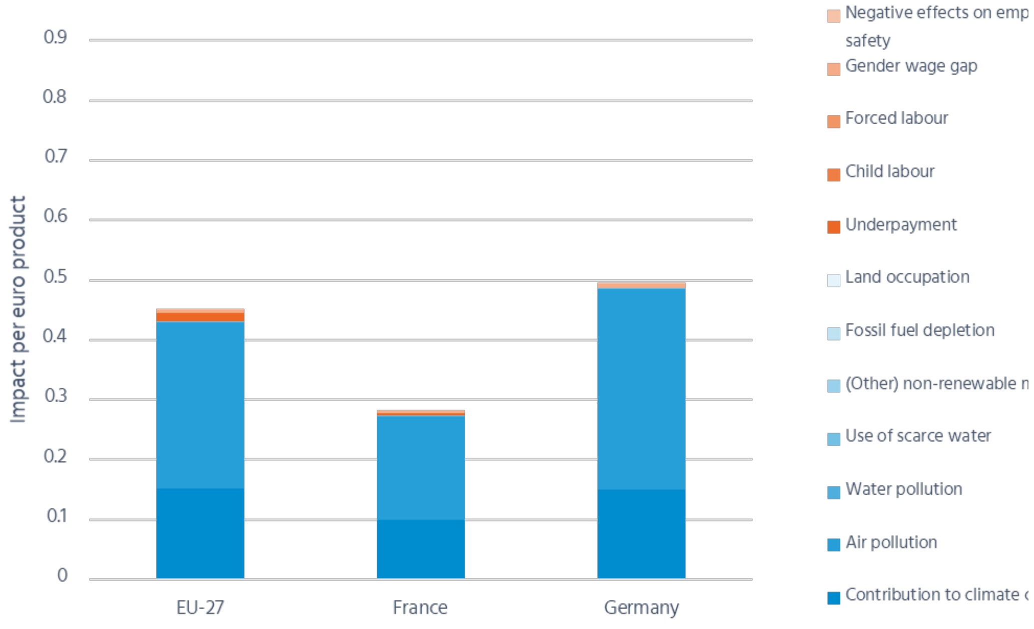


Figure 13: External costs (excluding upstream value chain impact) of the cement industry in 2019 (impact per euro product)

4.2 RESULTS OF THE DEEP-DIVES

4.2.1 CEMENT INDUSTRY

Conventional production

Based on the results from the baseline study, True Price performed a deep-dive study on the most polluting value chain step in the production of cement: The calcination-step. The calcination-step is part of the value chain of Ordinary Portland cement (OPC). In 2016, OPC represented about 83% of EU28 produced cement (European Commission, n.d.-d). OPC is dominant in the EU cement industry and consists of clinker (small rock particles) and gypsum. During OPC's calcination process, limestone is exposed to high heat in a kiln, producing calcium-oxide (an important component of clinker) and CO2. Notably, the calcination process thus produces CO2 in two ways: via the combustion of fossil fuel and via the chemical reaction in the kiln. OPC has both environmental and durability issues (Gevaudan et al., 2019). Albeit OPC is therefore much researched, it is complex to navigate through alternatives to OPC due to unclear and changing definitions of cement types and lacking information on such alternatives targeted at end-users presenting valuable opportunities for clear guidelines.

Green alternative

The alternative cement assessed in this deep-dive is a type of geopolymer cement. A geopolymer cement presents an alternative to OPC for infrastructure, construction and offshore applications and may consist of industry by-products such as blast furnace slag[17] or coal fly ash[18], alkaline reagent (a chemical substance) and water (Davidovits, 2013). The geopolymer cement in this deep-dive consists of industry by-product fly ash and an alkali-silicate solution. Since fly ash contains calcium-oxide (Fauzi et al., 2016), there is no need to calcinate this input product. Using fly ash as opposed to limestone (which is used in OPC) therefore requires less energy and offers a green alternative to OPC. Notably, OPC's clinker is sometimes mixed with fly ash to reduce its environmental footprint (Zulaiha Razi et al., 2020).

17 The residue which remains in blast furnaces due to fossil fuel combustion.

18 These are fine particles of dust or ash created by the burning of fuels such as coal or oil.

Results

The calcination-step in the production of OPC caused €222.08 per tonne OPC in external costs due to contribution to climate change and €83.03 per tonne OPC in external costs due to air pollution in Italy in 2019. To put these numbers into perspective: the United States market price of OPC was about €109 per tonne in 2019 (Statista, 2021). This means the external costs of OPC due to contribution to climate change and air pollution of calcination (not including other environmental or social costs) equal 2.8x the market price of OPC. When taking the environmental damage caused by cement products, an environmentally friendly alternative to OPC of which the market price is below €400 per tonne cement would still be cheaper than OPC (assuming the external costs of this environmentally friendly alternative are negligible).

The external costs of the calcination step in OPC production due to contribution to climate change are mainly caused by two processes occurring during calcination: The first is the chemical reaction taking place (of which CO2 is a by-product) which causes 66% of the contribution to climate change. The second is the combustion of fossil fuels which causes 27% of the contribution to climate change. A relatively small share of the external costs of contribution to climate change (7%) are due to grey electricity use.

The external costs of the calcination step in OPC production due to air pollution are largely caused by particulate matter (PM) formation (75%), photochemical oxidant formation (POF) (15%) and acidification (8%) (mostly due to NOx emissions and for a smaller share due to grey electricity use).

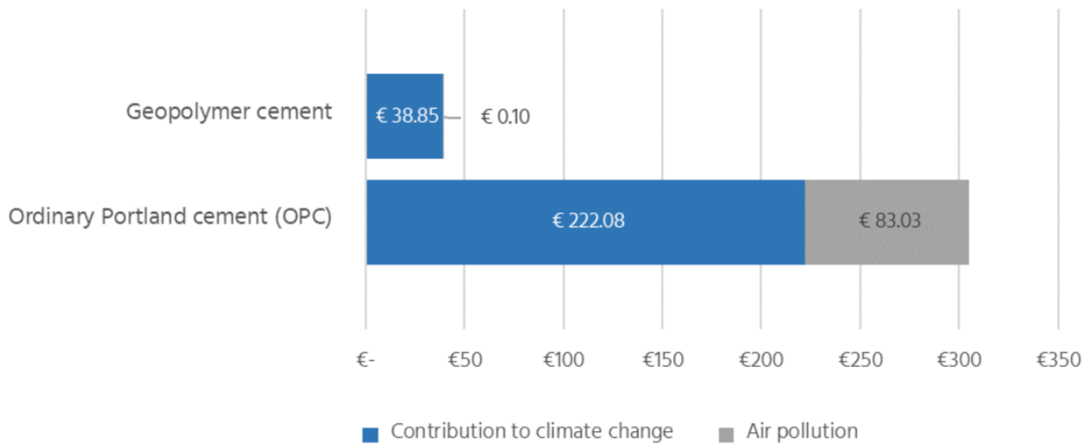


Figure 14: External costs of contribution to climate change and air pollution due to calcination in cement production in Italy in 2019 (EUR/tonne product)

The green alternative to OPC is a geopolymer cement which consists of industry by-product fly ash, water and an alkali reagent. Fly ash is produced by the burning of coal and is therefore widely produced (Basham et al., 2007). It can either be added to OPC, as a partial substitute for clinker, or be used to make geopolymer cement. The external costs of geopolymer cement are €38.85 per tonne cement for contribution to climate change (caused by the production of the alkali reagent) and €0.10 per tonne cement for air pollution (resulting from (green) electricity use).

Albeit not considered in this study, cement manufacturers who wish to reduce their environmental footprint by substituting clinker by industry by-products such as fly ash must also consider the impact of transporting fly ash to the production site (in case the site does not produce the required amount of fly ash (McLellan et al., 2011)).

4.2.2 STEEL INDUSTRY

Conventional production

Based on the results from the baseline study, the report zooms in on the most polluting part of the value chain (in terms of contribution to climate change and air pollution) of a steel product, hot rolled coil. The part of the value chain is depicted below as the Blast Furnace route. The Blast Furnace route is used at ~60% of EU steel production sites (Eurofer, 2020). It is encompassing a sinter plant, blast furnace and basic oxygen furnace and entails the heating of iron ore into pellets which are heated and treated with oxygen to obtain liquid crude steel. In this part of the value chain, combustion using fossil fuels and the required high temperature heating were expected to indicate high levels of contribution to climate change and air pollution.

Green alternative

In the search for reducing environmental impact, the Blast Furnace route is compared to the HYBRIT route (HYBRIT, n.d.). The HYBRIT route represents a pilot study set in Sweden which replaces a share of the fossil fuel used in steel production by green electricity and treats the iron ore with hydrogen gas thereby reducing the required thermal energy. It can produce the same crude steel from iron ore concentrate as the Blast Furnace route. In the HYBRIT-pilot, the hydrogen is sourced using renewable energy to avoid emissions.

Conventional production

It is important to note that –while in the current study it is assumed that the hydrogen is indeed sourced using renewable energy- this represents an unlikely scenario as 95% of hydrogen in the EU in currently obtained using fossil fuels (Hydrogen Europe, 2021). Moreover, while the HYBRIT route might have lower impact on the environment than the Blast Furnace route, both methods are based on use of iron ore (a non-renewable resource) such that neither is truly environmentally friendly.

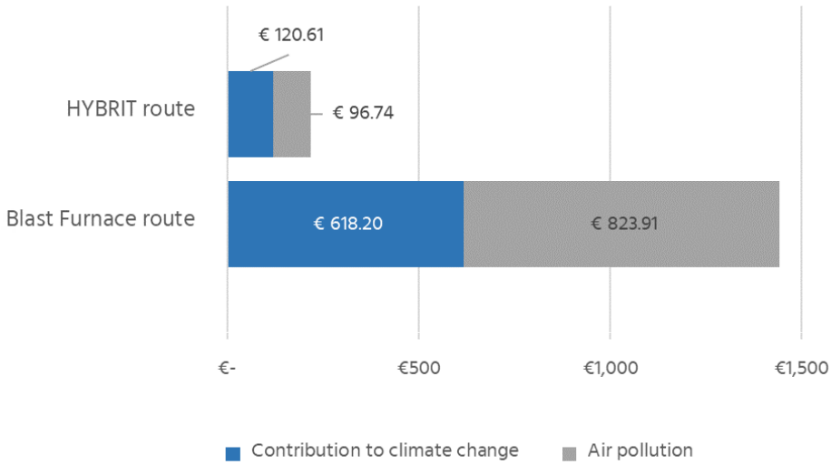


Figure 15: External costs of contribution to climate change and air pollution of partial value chain of chot rolled coil in Germany in 2019 (EUR/tonne product)

Results

Producing steel in Germany via the Blast Furnace route accounted for €618.20 in external costs due to contribution to climate change and €823.91 in external costs due to air pollution per tonne steel product in 2019. Comparatively, the European price of hot rolled coil was about €470 per tonne in 2019 (World Steel Prices, 2020). The external costs of steel production's Blast Furnace route due to contribution to climate change and air pollution alone (not including other environmental or social costs) thus equal 3.1x the market price of hot rolled coil. When taking the environmental damage caused by steel products, an environmentally friendly alternative of which the market price is below €1,900 per tonne steel product would still be cheaper than steel produced via the Blast Furnace route (assuming the external costs of this environmentally friendly alternative are negligible).

Both the contribution to climate change and air pollution of the conventional method steel production are largely caused by emissions resulting from the combustion of fossil fuels. A minor part of contribution to climate change is caused by grey electricity use. In Germany, electricity is sourced for a large part from coal and other fossil fuels making electricity use relatively polluting compared to using green electricity. Regarding the external costs of air pollution, 63% is due to particulate matter formation and 29% is due to human toxicity which both have negative effects on people's health.

In comparison, producing hot rolled coil in Germany via the HYBRIT route accounted for €120.61 in external costs due to contribution to climate change and €96.74 in external costs due to air pollution per tonne steel product in 2019. While significantly more electricity is required in this route, it is only green electricity which produces significantly less contribution to climate change and air pollution than grey electricity use. Moreover, the HYBRIT route requires less fossil fuel for combustion which reduces both the levels of air pollution and contribution to climate change when comparing to the Blast Furnace route. To further minimize the environmental costs of steel production, the industry must aim to eliminate fossil fuel use and minimize the use of non-renewable resources such as iron ore.

4.2.3 CHEMICAL INDUSTRY

Conventional production

Based on the results from the baseline study, the deep-dive study assesses the most polluting value chain step in the production of HDPE: Conventional steam cracking. HDPE, or high-density polyethylene, is a commonly used type of plastic1. An example of a product for which it is used is an HDPE construction pipe.

Plastics are produced in the chemical industry and make up a significant part of the category base chemicals which accounted for 60% of EU chemical sales in 2018 (CEFIC, 2020-b). The value chain step assessed in this deep-dive is called the 'steam cracking'-step. Many chemical products require this value chain step. To simplify, the steam cracking process entails introducing input products such as naphtha or ethane (large hydrocarbons[19]) and heating (or 'cracking') them as to obtain ethylene and other smaller hydrocarbons. Ethylene is one of world's largest produced raw materials in the petrochemical industry (in terms of volumes)[20].

Green alternative

The steam cracking-step is an energy-intensive process due to its high demand for thermal energy. Currently, the heating of this process is created by combustion of fossil fuels. To reduce CO2 emissions, companies in the chemical industry are looking for ways to reduce their environmental impact. One way of doing this is developing steam crackers which run on only (green) electricity. While this technology is still in its infancy (Amghizar et al., 2020), the current deep-dive estimates what the external costs of such an electric steam cracker are.

In the study, the required amount of energy is assumed to be the same for the conventional and electric steam cracker. For the latter, the fossil fuel used for combustion is replaced with green electricity. The results will give a better understanding of the environmental impact of the conventional steam-cracking-step.

19 Hydrocarbons are compounds which consist of the elements of carbon and hydrogen.

20 In 2014, 167 million tonnes of ethylene were produced globally (van Gijzel, 2017).

Decarbonising the chemical industry

Attempts at reducing the environmental impact of value chains in the chemical industry without addressing the impact of its feedstock (largely fossil fuels) cannot be perceived as a realistic and sincere attempt at decarbonisation of the industry. The chemical industry produces a wide variety of products for both other industries and consumers and is therefore considered an integral part of society. However, if the industry is to move towards climate neutrality in 2050, society needs it to widen its vision and look at both reducing the environmental impact of its production processes as well as decarbonising its feedstock. While the chemical industry currently uses large amounts of fossil fuels as feedstock for products such as plastics, the fossil feedstock of the HDPE construction pipe as considered in the current study may be replaced by an environmentally friendlier alternative. In fact, for many other chemical products, there are alternative feedstock opportunities such as algae and corn[21].

"The chemical industry is unique in its fossil fuels use. While most industries use fossil fuels as energy source, the chemical industry uses about half of the sector's demand as feedstock: The fossil resources are used as raw material for a variety of widely used products like plastics, fertilisers, detergents or tyres". - DENA, 2019 (German Energy Agency)

These alternative feedstocks can be used to produce –amongst others- polypropylene (PP) (the main compound of food packaging, containers, bank notes and more), polyethylene (PE) (used for shopping bags, toys and more) and PET (for example used in water bottles and soft drink bottles). Given that renewable feedstocks generally require land to be grown, using them causes environmental impact via biodiversity loss due to land use. However, alternative feedstocks do offer a valuable opportunity to lower the chemical industry's environmental footprint.

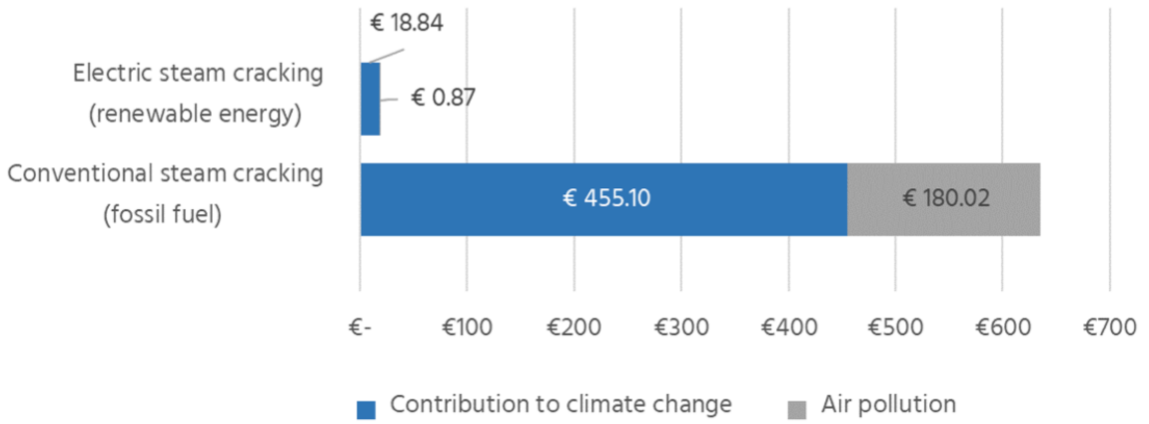


Figure 16: External costs of contribution to climate change and air pollution of steam cracking in HDPE in France in 2019 (EUR/ tonne product)

Results

The steam cracking-step in the production of HDPE construction pipes caused €455.10 in external costs due to contribution to climate change and €180.02 in external costs due to air pollution per tonne HDPE in France in 2019. To put these numbers into perspective: In 2019, the average European market price of HDPE was around €1,260 per tonne HDPE pipe (PlasticPortal, 2019). Conclusively, the external costs of HDPE production due to contribution to climate change and air pollution alone (not including other environmental or social costs) equal about half the market price of an HDPE construction pipe. When taking the environmental damage caused by HDPE products, an environmentally friendly alternative of which the market price is below €1,890 per tonne HDPE product would be cheaper than HDPE produced via the conventional steam cracker (assuming the external costs of the green alternative are negligible).

21 See Appendix 6.3 for more details on green alternatives to fossil feedstock.

Steam cracking requires heating the input product to high temperatures using large amounts of energy. The external costs of the steam cracking step in HDPE production due to contribution to climate change and air pollution are therefore caused by combustion of fossil fuels and its respective emissions to air. Electricity use accounts for a relatively small part of the external costs. The footprint of electricity use depends on the quantity of electricity use and the type of sources which are used to generate the electricity. In France, most electricity is generated using nuclear power (World Nuclear Association, 2021). Compared to coal, gas and oil, nuclear power releases little CO2-eq emissions. The external costs of steam cracking in countries where more coal, gas or oil is used to generate electricity, will therefore have higher external costs of steam cracking than France does.

In the alternative scenario, steam cracking runs on electricity. While this technology is still in its infancy, companies are currently researching such that it presents a viable alternative scenario (Amghizar et al., 2020). This study assumes all electricity is generated using renewable resources. If the steam cracker running on (green) electricity had been available in France in 2019, its contribution to climate change and air pollution would have been much lower than those resulting from the conventional steam cracker: The alternative steam cracker would have accounted for €18.84 in costs of contribution to climate change and €0.87 in air pollution costs per tonne HDPE in France in 2019.

4.2.4 TRUE COST ESTIMATES OF CEMENT, STEEL AND CHEMICAL PRODUCTS

In 2018, the Energy Transitions Commission estimated the increase in product cost of decarbonized plastic, steel and cement products will be small (up to 3%). Table 8 shows the Commission estimates the product cost (excluding external costs) of a plastic product to be less than 1% higher than the product cost of a plastic bottle when produced using conventional (polluting) techniques. For cement products, the product cost is estimated to be 3% higher while for steel products, the product cost is estimated to be 1% higher.

Table 8. Implications for product cost of decarbonized production (Energy Transitions Commission, 2018)

Industry	Product	Additional final product cost (absolute)	Additional final product cost (relative)
Cement	House (valued $500,000)	+ 15,000 USD	+ 3%
Steel	Car	+ 180 USD	+ 1%
Plastics	Bottle of soda	+ 0.01 USD	< 1%

To estimate the true cost of cement, steel and chemical products, this report combines the conclusions drawn by Energy Transitions Commission (2018) with its current findings. Specifically, the report compares the market price, external cost of contribution to climate change and external cost of air pollution[22] of conventional cement, steel and chemical products to their green alternatives[23].

22 Please remember these external cost calculations refer only to the external costs of contribution to climate change and air pollution of selected value chain steps. When assessing the full value chain of cement, steel and chemical production, the external costs will likely be higher (unless the out-of-scope value chain steps do not produce external costs). Moreover, contribution to climate change and air pollution are not the only ways in which cement, steel and chemical production may negatively affect people and planet. Examples of additional ways are biodiversity loss from land use, soil pollution and water pollution. For these current results, these impacts are out of scope. Conclusively, when including these additional ways of harming people and planet in the study, the external costs of cement, steel and chemical production are likely to increase.

23 According to Energy Transitions Commission (2018), the relative additional final product cost of plastic is <1%. Since the precise relative cost increase is unknown, the calculations used 1% for additional final product cost of plastic.

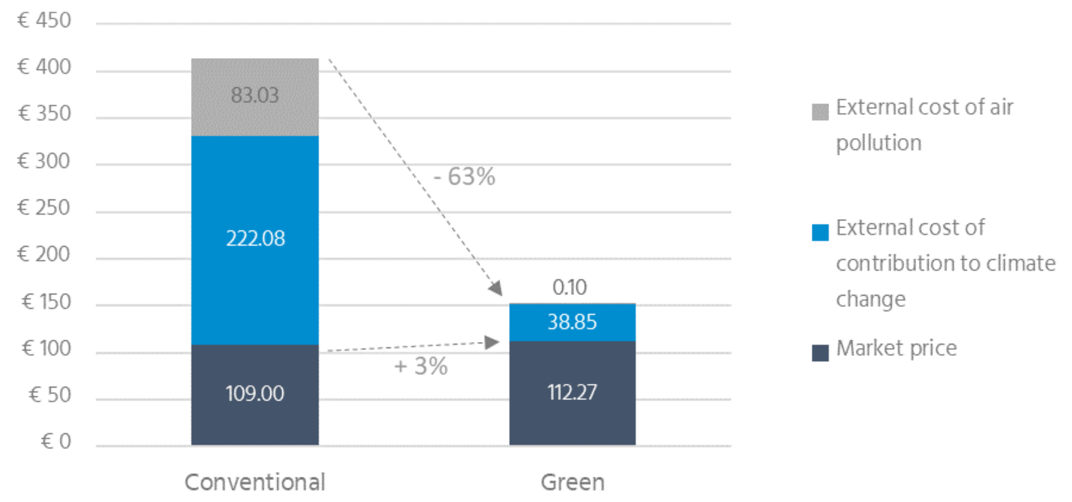


Figure 17: True cost estimate of a cement product in 2019 (EUR/tonne product)

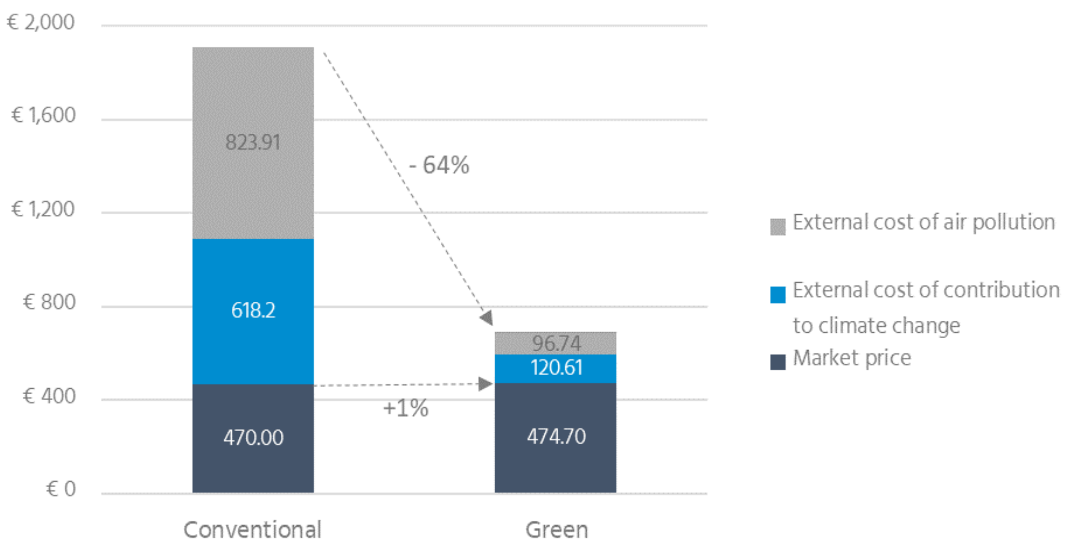


Figure 18: True cost estimate of a steel product in 2019 (EUR/tonne product)

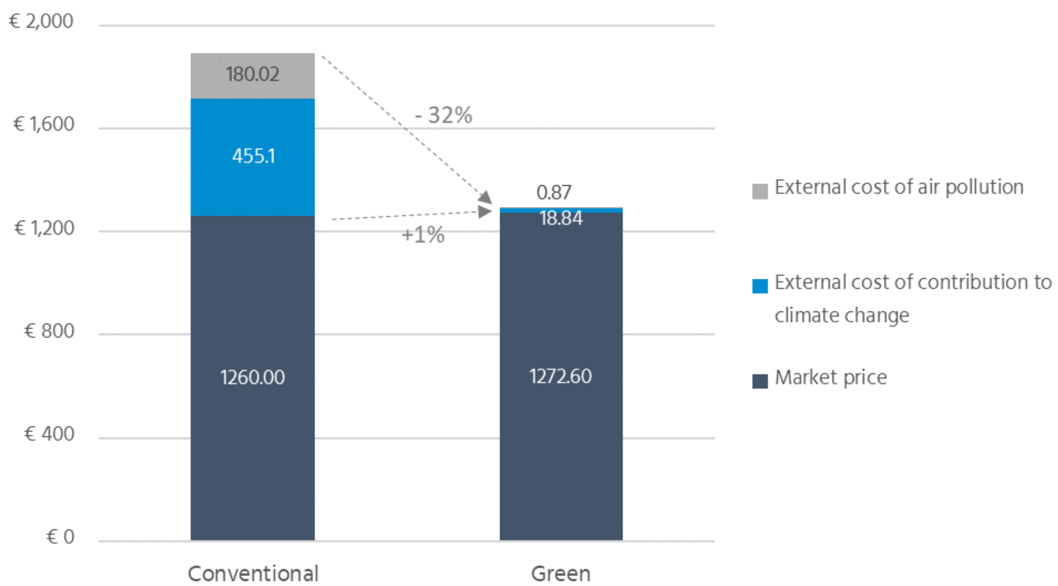


Figure 19: True cost estimate of a plastic product in 2019 (EUR/tonne product)

Figures 17, 18 and 19 show the true cost as estimated based on the results of this report and the estimated product cost increase of green alternatives to conventionally produced cement, steel and chemical products. The figures indicate that for all three sectors, the true cost estimate of the conventionally produced product is higher than the true cost estimate of the green alternative.

Regarding the cement industry, the estimated true cost of a cement product reduces by 63% when substituting conventional production methods for a green alternative. For steel products, the estimated true cost reduces by 64% when substituting conventional production by a green alternative. Finally, for plastic products (which represent a significant share of the EU's chemical industry) the estimated true cost reduces by 32% when substituting conventional production by a green alternative.

BOX 2: EXAMPLE OF INTERPRETING THE TRUE COST ESTIMATE

The true cost of a car

The true costs of products (such as cars) are often not clearly communicated to consumers. This study shows that buying a car made of steel produced by polluting techniques versus one made of steel produced by green techniques may be more expensive in terms of its true cost. To illustrate, when considering buying a new car, consumers may be interested in knowing how damaging the production of this car was to people and planet. The average car contains about 900 kg of steel (WorldSteel, 2021). For this example, we will assume the steel used in the car is virgin (not recycled) material.

The external costs of contribution to climate change and air pollution would add (0.900*€618.20 + 0.900*€823.91=) €1,297.90 to the price of the car when produced using conventional techniques. If the steel manufacturer had invested in green techniques and produced its steel in a more environmentally sustainable manner, the external costs of contribution to climate change and air pollution would add much less to the true cost of a car: The additional costs due to contribution to climate change and air pollution would add up to (0.900*€120.61 + 0.900*€96.74 =) €195.62 to the car's true cost.

5. RECOMMENDATIONS

5.1 TRANSITION TOWARDS CLIMATE GOALS

The EU's cement, steel and chemical industries provide many products often used in today's society, such as materials used in construction and the automotive sector. However, the current methods of production come at a cost. The EU's energy-intensive cement, steel and chemical industries most notably cause damage to people and our planet. These external costs are not paid for by the industries. Rather, they are born by society and future generations.

It is likely many EU citizens are not aware of the scope of this problem. External costs, especially environmental costs, are often hidden from the eye and may be difficult to grasp. Environmental are usually not explicitly stated on the price tag of products. In the current economic system, these costs are excluded from the pricing mechanism.

In its role as governing body, the European Parliament can make industries account for the external costs they cause. By making external costs transparent and letting industries pay for the external costs which they cause, the European Parliament will stimulate the socio-ecological transition of its energy-intensive industries. Research shows the current ETS-system (which aims to reduce emissions) has not only failed to reduce emissions but also contributed to financial gains of pollution companies (CE Delft, 2021). Conclusively, the current ETS-system supports these companies and their polluting practices. If the European Parliament wishes to stimulate its cement, steel and chemical industries to transition towards socially just and environmentally sustainable industries and have a change at reaching its climate goals, it must change the system.

5.2 EXTERNAL COSTS OF THE EU'S CEMENT, STEEL AND CHEMICAL INDUSTRY IN 2019

This report finds that the EU's cement, steel and chemical industries accounted for €84, €202 and €169 billion in damages to society, respectively, in 2019. The industries' contribution to climate change, depletion of fossil fuels and air pollution account for a large share of these external costs. Comparatively, the steel industry contributes the largest share in damage to society, mainly through its air pollution. Air pollution is driven by particulate matter formation and (carcinogenic) human toxicity. The external costs due to air pollution differ per country with the most populous countries -Germany, France, Italy and Spain- contributing most. On average, the external costs of EU27 countries and their cement, steel and chemical industries is €0.84, €2.01 and €2.52 in terms of impact per euro product, respectively. For all three industries, external costs are driven by air pollution, fossil fuel depletion and contribution to climate change.

5.2.1 THE CEMENT INDUSTRY

The cement industry is characterised by on-site production due to bulky, heavy materials. It is largely used in construction. The cement industry has been looking into ways to replace or improve production of the dominant type of cement (Ordinary Portland cement, or OPC) for a while, attempting to both improve the quality of the product and its environmental footprint. The report finds that there are various alternatives or partial substitutes to OPC which generate lower environmental footprints. The study finds that the calcination-step in the production of OPC caused €222.08 per tonne OPC in external costs due to contribution to climate change and €83.03 per tonne OPC in external costs due to air pollution in Italy in 2019. To put these numbers into perspective: the United States market price of OPC was about €109 per tonne in 2019 (Statista, 2021).

When taking the environmental damage caused by cement products, an environmentally friendly alternative to OPC of which the market price is below €400 per tonne cement would still be cheaper than OPC (assuming the external costs of this environmentally friendly alternative are negligible). The green alternative assessed in the deep-dive study on the cement industry is a geopolymer cement containing fly ash (an industry by-product). To compare, the external costs of geopolymer cement are €38.85 per tonne cement for contribution to climate change and €0.10 per tonne cement for air pollution. Conclusively, optimising the use of industry by-products, lowering the energy consumption by improving production efficiency and switching to green energy use has great potential to reduce the cement industry's external costs.

5.2.2 THE STEEL INDUSTRY

This report finds that producing steel in Germany via the Blast Furnace route accounted for €618.20 in external costs due to contribution to climate change and €823.91 in external costs due to air pollution per tonne steel product in 2019. Comparatively, the European price of hot rolled coil was about €470 per tonne in 2019 (World Steel Prices, 2020). When taking the environmental damage caused by steel products, an environmentally friendly alternative of which the market price is below €1,900 per tonne steel product would still be cheaper than steel produced via the Blast Furnace route (assuming the external costs of this environmentally friendly alternative are negligible).

Some companies in the steel industry are already looking into ways to make processes in its value chains more sustainable by setting ambitious goals. For example, they may use green hydrogen gas (which is obtained using only renewable energy sources) to reduce iron ore and abolish the conventional and polluting blast furnace method to making steel. While there is still quite a road ahead, it is a positive sign that companies –like the ones in the HYBRIT pilot- are experimenting in this manner.

The report finds that the alternative way of producing steel (modelled to match the HYBRIT-pilot), results in €120.61 in external costs due to contribution to climate change and €96.74 in external costs due to air pollution per tonne steel product in Germany in 2019. Given the large amount of damage to society caused by the steel industry, the EU steel industry has a great responsibility to reduce its environmental footprint. Both in terms of air pollution and contribution to climate change as well as its use of raw materials (iron ore). To satisfy society's demand for applications currently satisfied with conventionally produced steel, the economy requires more sustainable alternatives.

5.2.3 THE CHEMICAL INDUSTRY

Demand for chemical products is everywhere. It produces both products for consumers as well as many other industries. Plastics are one of main products produced by the EU's chemical industry. However, the conventional way of producing plastics is damaging to people and planet as it requires large amounts of fossil fuels. This report finds the conventional steam cracking-step in the production of HDPE construction pipes caused €455.10 in external costs due to contribution to climate change and €180.02 in external costs due to air pollution per tonne HDPE in France in 2019. In contrast, electric steam cracking (using only green electricity) would have resulted in only €18.84 in costs of contribution to climate change and €0.87 in air pollution costs per tonne HDPE in France in 2019. To put these numbers into perspective: In 2019, the average European market price of HDPE was around €1,260 per tonne HDPE pipe (PlasticPortal, 2019). When taking the environmental damage caused by HDPE products, an environmentally friendly alternative of which the market price is below €1,890 per tonne HDPE product would be cheaper than HDPE produced via the conventional steam cracker (assuming the external costs of the green alternative are negligible).

Fossil fuels are used in two ways in plastics production: As feedstock and as fuel (for example, for heating). For both feedstocks and fuels there are alternatives. The chemical industry therefore has multiple opportunities to reducing its external costs. Current attempts at introducing electric steam crackers have the potential to significantly reduce contribution to climate change and air pollution. However, for the chemical industry to work towards the EU's climate goals, attention must be paid to the industry's use of fossil feedstock. The industry must transform to welcome alternative feedstock and sustainable practices.

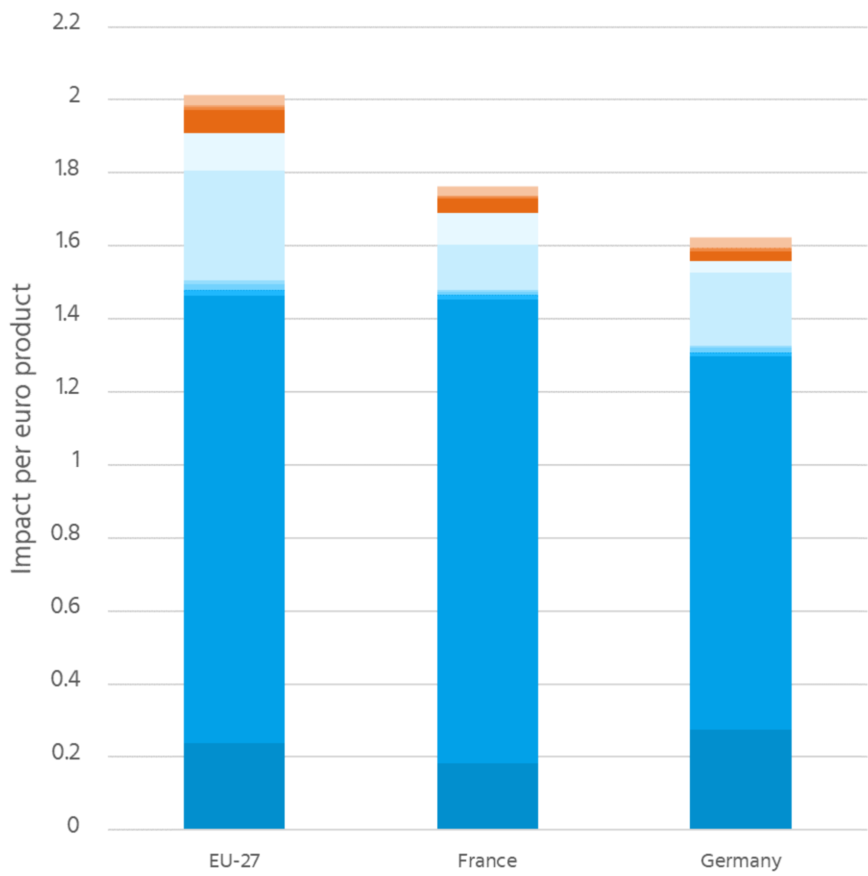
5.3 OPPORTUNITIES FOR IMPROVEMENTS

Based on the findings in this report, there are multiple opportunities for improvement for EU's cement, steel and chemical industries to transition towards socially just and environmentally friendly industries. Firstly, industries should lower their energy consumption by improving production efficiency. Secondly, they should replace energy use based on fossil fuels by green energy. Thirdly, industries must optimize the use of recycled materials to minimize the use of virgin materials. Fourthly, they should eliminate the use of fossil fuels as feedstocks. Fifthly, companies in the cement, steel and chemical industries integrate their external costs into decision-making cycles to account for and steer on both financial and non-financial profits and losses.

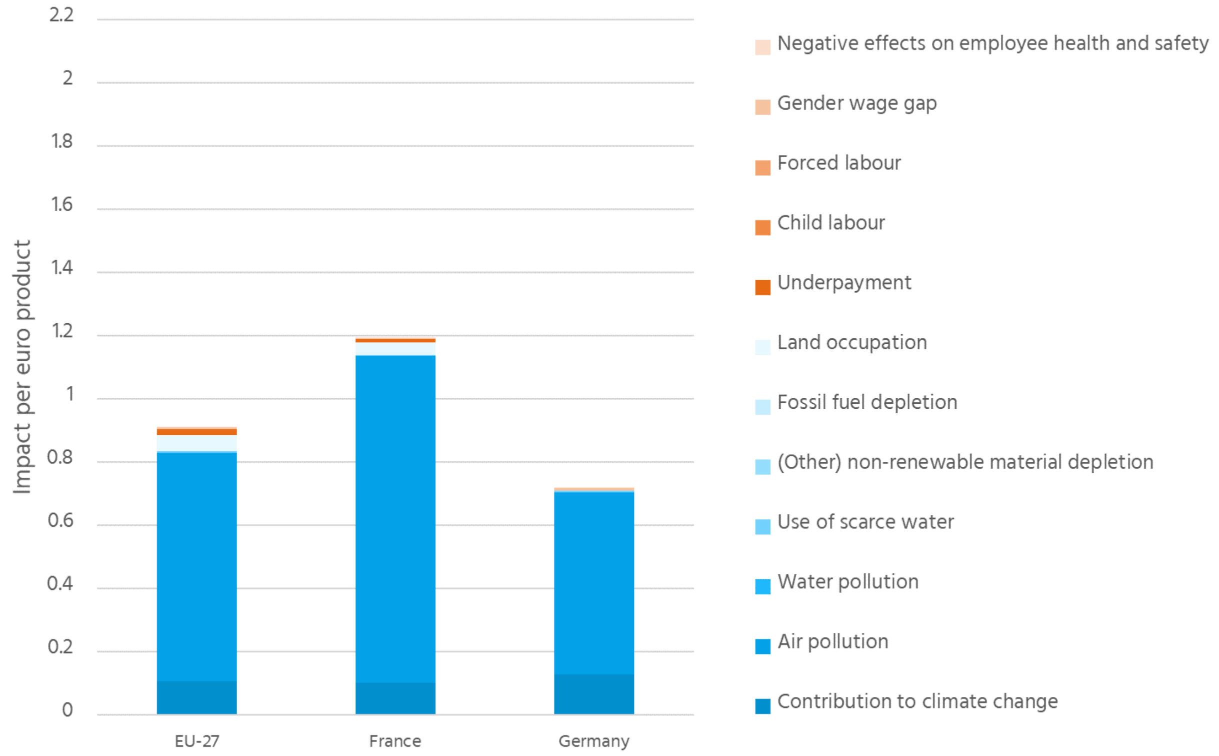
Furthermore, to stimulate the EU's cement, steel and chemical industries to transition towards industries which abide by EU climate goals, systemic change is needed. For example, the EU ETS-system must be updated as to support the transition towards green industries. Regulatory frameworks aiming at such change must be evaluated on a regular basis to ensure they serves their intended purpose. In its role as governing body, the European Parliament can make industries account for the external costs they cause. By making external costs transparent and letting industries pay for the external costs they cause, the European Parliament will stimulate the socio-ecological transition of the EU's energy-intensive industries.

6. APPENDIX

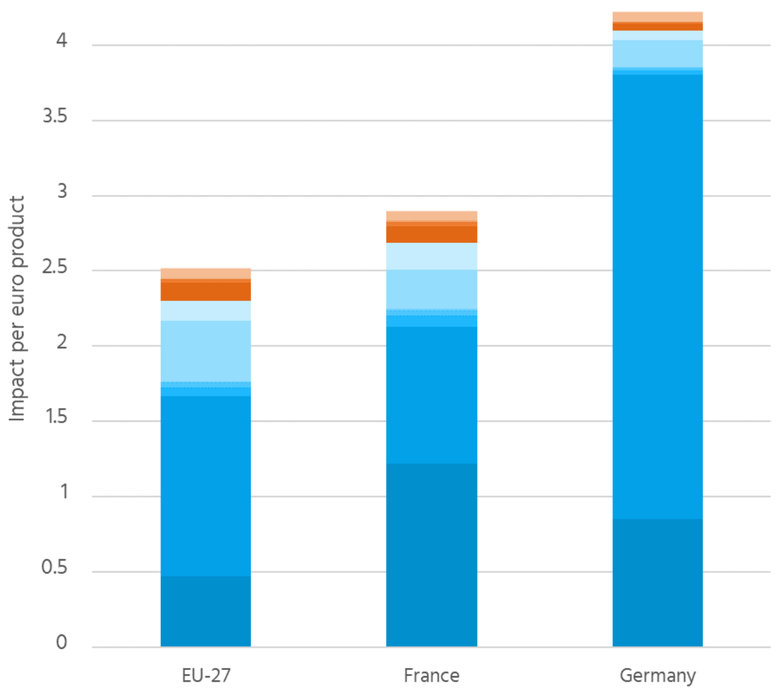
6.1 EXTERNAL COSTS PER INDUSTRY



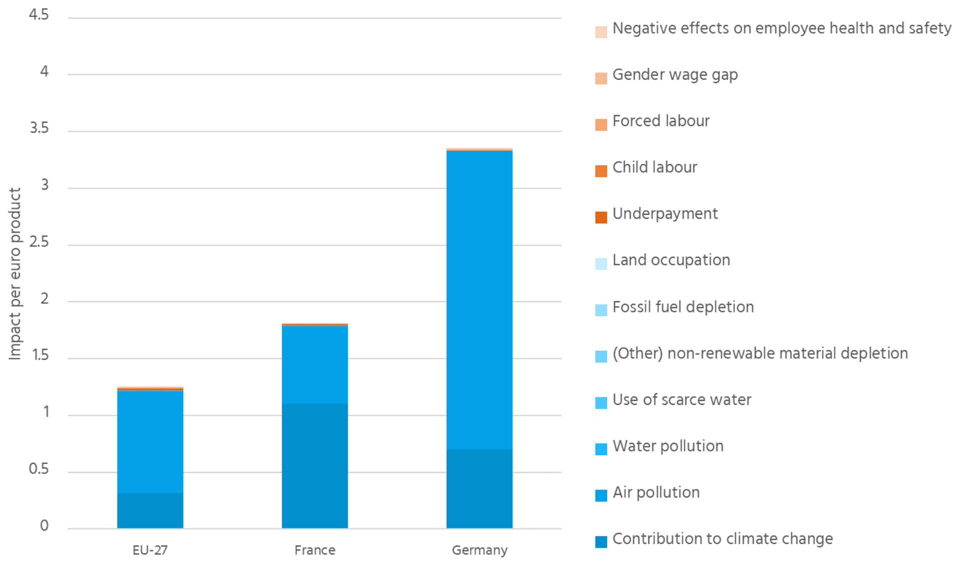
Impact of the steel industry in 2019 (impact per euro product)



Direct impact (excl. upstream value chain impact) of the steel industry in 2019 (impact per euro product)



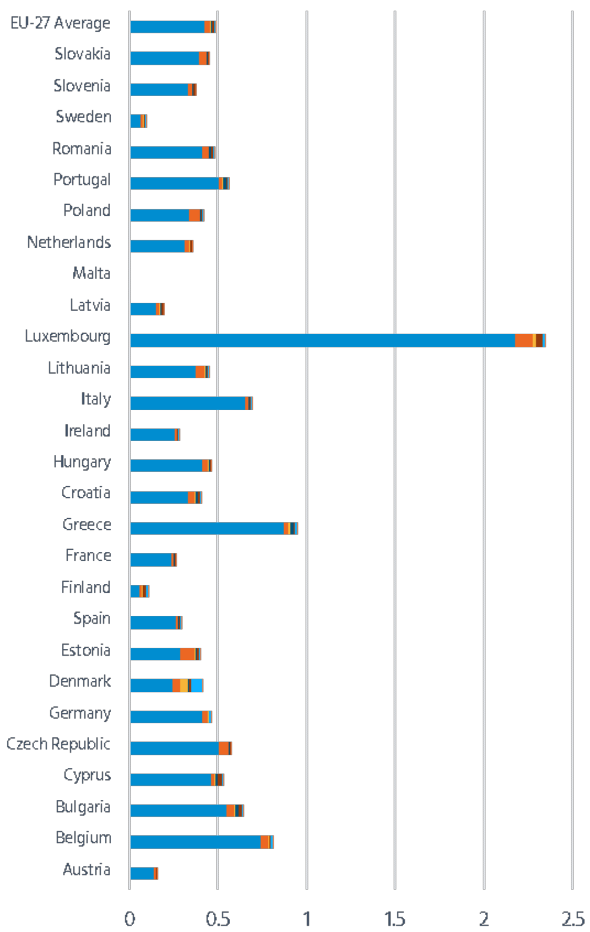
Impact of the chemical industry in 2019 (impact per euro product)



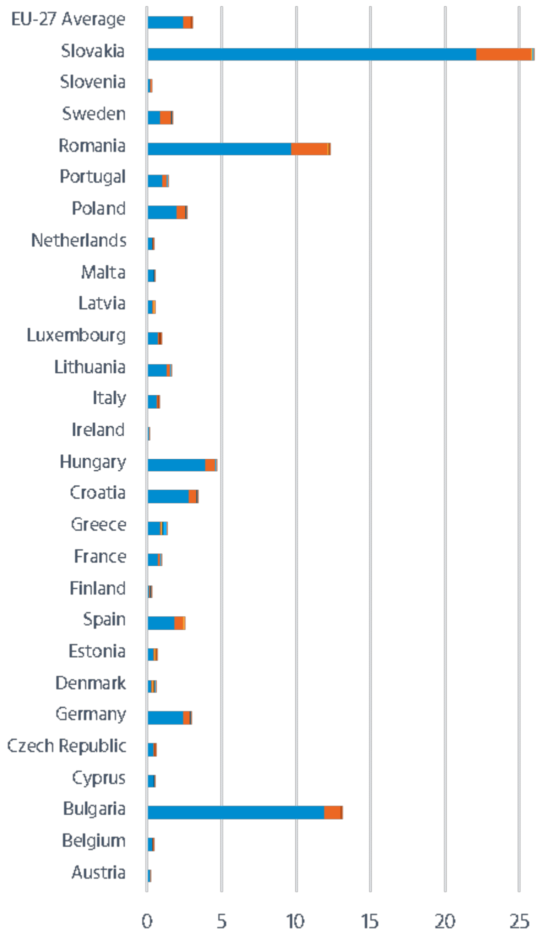
Direct impact (excl. upstream value chain impact) of the chemical industry in 2019 (impact per euro product)

	Cement industry			Steel industry			Chemical industry		
External costs (unit: impact per euro product)									
	EU27*	France	Germany	EU27*	France	Germany	EU27*	France	Germany
Total impact	**0.84**	**0.59**	**0.83**	**2.01**	**1.76**	**1.62**	**2.52**	**2.89**	**4.22**
Social impact	0.06	0.05	0.03	0.10	0.07	0.07	0.22	0.21	0.12
Environmental impact	0.79	0.54	0.80	1.91	1.69	1.56	2.30	2.69	4.10
Direct impact (excl. upstream)	**0.45**	**0.28**	**0.49**	**0.91**	**1.19**	**0.72**	**1.25**	**1.81**	**3.35**
Social impact	0.02	0.01	0.01	0.03	0.02	0.01	0.03	0.02	0.01
Environmental impact	0.43	0.27	0.49	0.88	1.18	0.71	1.22	1.79	3.33
External costs (unit: total impact in billion euros, 2019)									
	EU27	France	Germany	EU27	France	Germany	EU27	France	Germany
Total impact	**83.95**	**8.71**	**15.62**	**202.25**	**21.58**	**49.97**	**169.46**	**27.55**	**26.65**
Social impact	5.49	0.75	0.53	10.28	0.88	2.06	23.93	4.84	2.77
Environmental impact	78.46	7.96	15.09	191.97	20.71	47.91	145.53	22.71	23.89
Direct impact (excl. upstream)	**52.28**	**0.57**	**2.51**	**154.45**	**2.71**	**67.87**	**40.57**	**0.29**	**7.95**
Social impact	3.34	0.02	0.11	5.24	0.04	0.90	9.93	0.04	0.60
Environmental impact	48.94	0.55	2.40	149.20	2.67	66.97	30.64	0.25	7.35

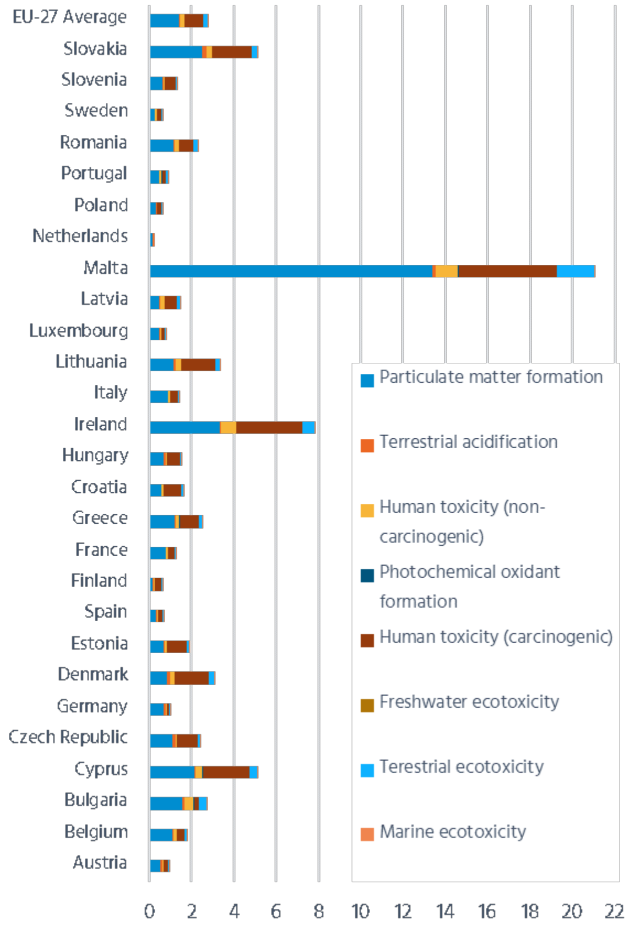
6.2 BREAKDOWN OF AIR POLLUTION INDICATORS PER INDUSTRY IN 2019



Cement industry (impact per euro product)

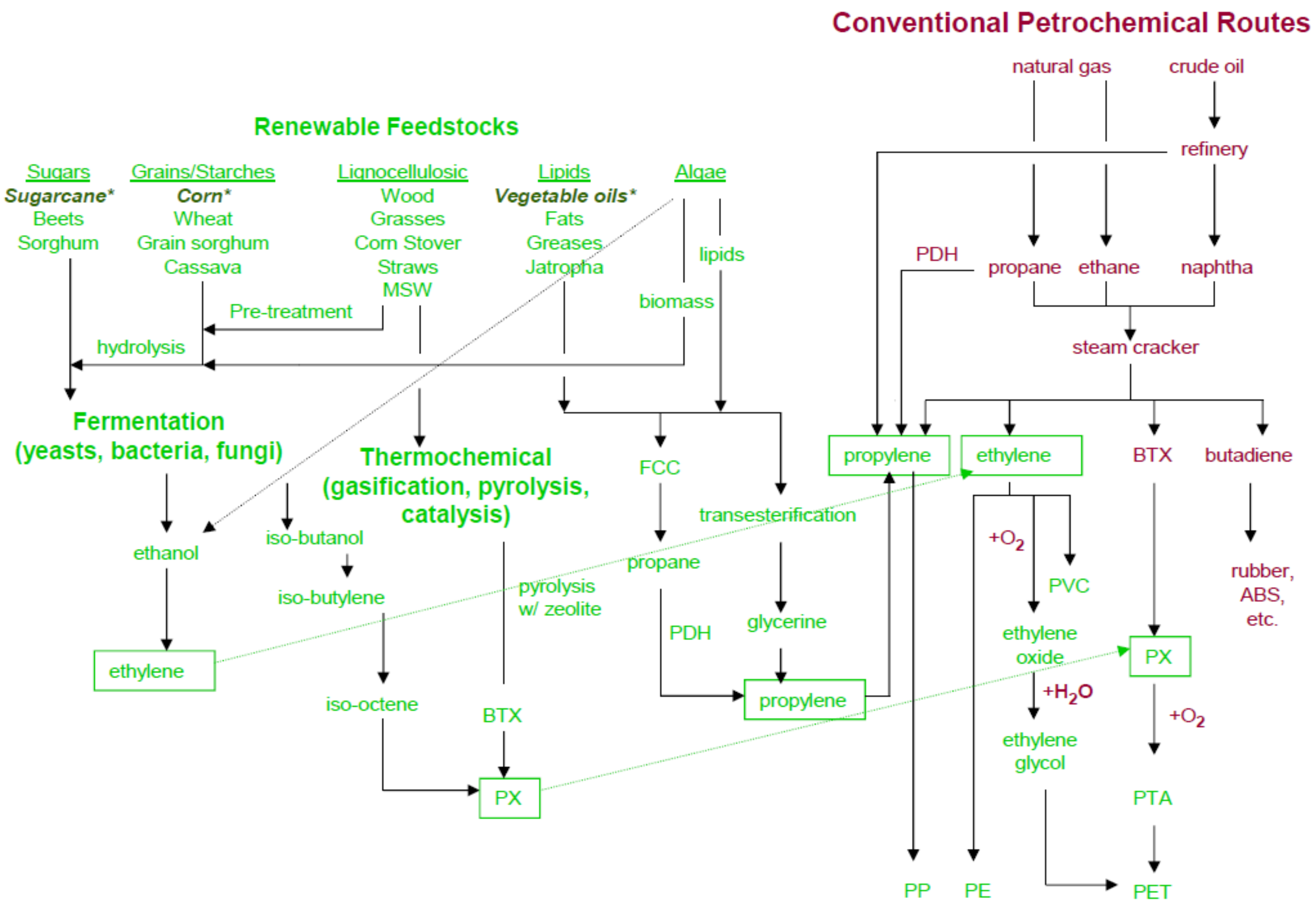


Chemical industry (impact per euro product)



Steel industry (impact per euro product)

6.3 ALTERNATIVE FEEDSTOCKS CHEMICAL INDUSTRY



Overview of various feedstocks, respective production process and applications

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