DNB Working Paper
No. 719 / July 2021

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DeNederlandscheBank
EUROSYSTEEM

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* Views expressed are those of the authors and do not necessarily reflect official positions of De Nederlandsche Bank.

Working Paper No. 719

July 2021

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What's the damage? Monetizing the environmental externalities of the Dutch economy and its supply chain

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July 2021

Abstract

The environmental externalities of economic activities, such as anthropogenic climate change and pollution, have major social, environmental and economic consequences. Monetary valuation of these externalities is a widely acclaimed approach to better account for them in economic decisions, as it provides an appropriate price level for charging a Pigouvian tax. Yet, little research exists on the monetary valuation of the environmental externalities associated with Dutch economic activities and the impact of pricing them on the profitability of different sectors. To address this gap, this paper estimates the monetary value of 30 environmental externalities associated with the activities of 13 sectors and 163 subsectors for the year 2015, based on a global environmentally extended input-output model. It then compares these environmental costs with the financial performance of the sectors to provide an appraisal of potential profit at risk. The findings show that total environmental damage costs associated with the Dutch economy amount to EUR 50 Bn or 7.3% of Dutch GDP in 2015. They also demonstrate that some sectors (energy production, waste and sewage treatment, manufacturing, transport and agriculture) do not generate sufficient profit to cover their natural resource use and pollution costs. These sectors are particularly exposed to the transition risks associated with the internalization of these costs through, for instance, taxation or stricter regulation. It is especially important for financial institutions to be aware of the presence of these risks. The analysis within this research could help to introduce and improve standards and systems, including relevant regulations aimed at internalizing the external costs of production, extraction and consumption. Moreover, these tools can also support financial institutions to inform their heat mapping exercises, the assessment of materiality and/or measurement of environmental transition risks more broadly.

Keywords: Externalities, Environment, Environmental Taxes and Subsidies, Valuation of Environmental Effects, Environmental Accounts and Accounting

JEL Classification: H23, F64, Q51, Q56

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1. Introduction

Anthropogenic greenhouse gas (GHG) emissions and environmental degradation (e.g., resource depletion, destruction of ecosystems, biodiversity loss and pollution) represent two of the most urgent threats to human well-being (IPBES, 2019). GHG emissions are estimated to have caused a 1.0 C° global warming above pre-industrial levels so far, generating long-term changes in the climate system, such as sea level rise, glacier retreat and extreme weather events, with associated impacts on human quality of life (IPCC, 2018). In addition to these physical and social impacts, both environmental degradation and global warming have potentially major economic consequences. Many studies have suggested that global warming could seriously disrupt the global economy, due to climate-related costs such as the potential need for infrastructure investments to protect against floods and droughts, the maintenance and renewal of property and critical infrastructure damaged by sea level rise and extreme weather and the negative impact on agriculture, forestry, fisheries and tourism. For instance, the OECD predicts a 10-percent reduction in the global gross domestic product (GDP) in 2100 associated with business-as-usual GHG emissions (OECD, 2019).

To better account for these environmental damages resulting from economic activities, economists have frequently argued for assigning a monetary value to them. Indeed, internalizing the environmental costs of extraction, production, and consumption activities–that is, incorporating these unaccounted costs into the budgets of households and enterprises by means of different economic interventions–is expected to accelerate the transition towards low-carbon and more circular economies. It incentivises economic actors to make better informed decisions about how they manage their environmental risk and provides them with opportunities to develop more sustainable business models and technologies in order to reduce their societal impacts in a cost-efficient way (Andersen, 2017; IPBES, 2019). The call for pricing environmental damages is most prominent for carbon emissions. According to the International Monetary Fund, for instance, carbon pricing should be front and centre in the implementation of mitigation pledges within both advanced and emerging market economies, as it increases the price of fossil energy sources, creating incentives for further mitigation (IMF, 2017). In the European Union, the European Commission is taking efforts to shift the tax burden from labour to pollution, for example by allowing Member States to reflect environmental considerations in the Value Added Tax rates (EU COM, 2019). In the Netherlands, a similar rationale underlines the Dutch government's carbon tax announcement towards companies and the circular economy action plan: according to the government, setting a price on the negative externalities a company imposes on society will encourage the adoption of circular business model innovations (IenM and EZK, 2016; Meijer, 2019). Walker et al (2009) cautions policymakers, though, that addressing climate change in isolation ignores system-wide interactions and may lead to unwanted outcomes.

Despite the alleged benefits, little research exists on the valuation of the environmental impacts of economic activities in the Netherlands. Drissen and Vollebergh (2018) analysed the monetary costs of environmental damages within the Netherlands, providing an inclusive view of environmental externalities which includes both GHG emissions and different types of air, water and soil pollution. However, the paper restricts its scope to the direct costs, excluding the indirect impacts of economic sectors along their supply chain. Wilting and van Oorschot (2017) systematically quantify the biodiversity footprints of Dutch economic sectors, including the supply-chain impacts on global biodiversity, but do not compute the associated monetary costs. The Dutch central agency for statistics, Statistics Netherlands, released a study on the environmental production footprint of the Netherlands using input-output analysis, but does not report the associated monetary costs either

(Schoenaker and Delahaye, 2016). Finally, Vollebergh et al. (2017) uses monetary pricing of several externalities, including emissions of greenhouse gases and polluting substances, to analyse how the current Dutch tax system can be reformed in order to stimulate the transition towards a more circular economy. They include supply-chain pressures and impacts, but due to the circular economy scope, the study focuses primarily on products instead of sectors and more on resource extraction, material production and use and the production of waste. Brink et al. (2020) did a similar analysis with the primary focus of comparing the results for the Netherlands with those for six surrounding countries.

To address the limitations of existing research, the aim of this study is to combine research on supply-chain-related environmental externalities of economic sectors with their monetary costs in order to analyse all economic activities covering the whole Dutch economy. It does so by analysing the potential impact of pricing 30 environmental externalities covering GHG emissions, soil, air and water pollution as well as water use on the profitability of Dutch economic sectors. First, it uses a global input-output model to calculate the environmental production footprint of Dutch economic sectors. The footprint considers all impacts associated with final demand for the domestic market as well as for export. This includes direct impacts by Dutch industry and indirect impacts related to sources upstream in their supply-chains. This footprint is then monetised to obtain the total environmental damage costs associated with the Dutch economy and with each economic sector. Finally, the potential impact of internalising these externalities on the profitability of Dutch economic sectors is computed, providing insight into the capacity of these sectors to bear the environmental damage costs should policymakers enact a direct output tax. It also provides insight into the exposure of these sectors towards transition risks related to the adequate pricing of these externalities.

The analysis shows that Dutch economic sectors generate 416 million tons of CO_2-equivalents, 6.95 million tons of polluting substances (based on unweighted substances) and use 94 trillion litres of water on an annual basis within the year 2015. The manufacturing sector has the highest associated impact across these three types of externalities. The environmental damage costs associated with these environmental externalities amount to EUR 50 billion or 7.3% of Dutch GDP. For analysing the impact, the 163 subsectors considered are aggregated to 13 main sectors to match the aggregation level of data on total sector profits. Looking at the impact of the costs on the profitability of the different economic sectors of the Netherlands, for seven out of the 13 sectors the total damage cost is more than half of their three-year average profits. This indicates that full internalisation of the externalities could have a substantial impact on the business models of these sectors.

This analysis can help firms, investors and policy makers to increase the resilience of their assets by making them better prepared for inherently hard to predict future events. Furthermore, it can serve as a basis for implementing policies focussed on the monetization of externalities. The remainder of this paper provides the related literature (Section 2), the methodology used (Section 3), the results and discussion (section 4) and some concluding remarks (section 5).

2. Related literature

2.1. Monetary valuation of environmental externalities

External effects of economic activities have been studied by economists ever since the days of Marshall and Pigou in the 1920's. Negative externalities are the unaccounted costs arising from when an action by an individual or a group impacts others (Cornes and Sandler, 1996). Discharging untreated waste into a river, for instance, imposes both health and water purification costs on society and costs associated with wider environmental degradation. Externalities are a form of market failure: the typical non-existence of a pricing mechanism for environmental goods and services underestimates their social value, even though the users of these resources are often dependent on them. This is problematic, as it can lead to the overexploitation of natural resources, the generation of unsustainable levels of pollution or other undesirable environmental consequences. Similarly, it is likely to result in underinvestment in more sustainable technologies and infrastructures (Schoenmaker and Schramade, 2019).

Considerable progress has been made in recent years in developing methods to estimate the monetary value of environmental externalities, both at national and international levels. The IPCC work for GHG estimates for the periods 1991-2000 and 2001-2010 was probably the first major undertaking regarding global warming cost estimates. In parallel, the ExternE research project series, financed by the European Union's Research Programmes, addressed the externalities of GHG releases, air pollutant and biodiversity loss related to industrial processes (e.g., energy production and transport). The methodology used in the first ExternE project has then been updated or extended over time (Stadler et al., 2018; Tukker et al., 2013, 2009). Relying on these analyses, Drissen and Vollebergh (2018) provide the most inclusive study of the monetary costs of environmental damages in the Netherlands to date, using the Pollutant Release and Transfer Register hosted by the RIVM. The authors estimated that the domestic costs of environmental pressures in 2015 (including GHG emissions and different types of air, water and soil pollution) amounted to EUR 31 billion.

The monetary valuation of environmental externalities can be performed at different geographical scales. While many efforts have focused on the supra-national or national levels (e.g. via some form of alternative indicator to GDP), a range of micro-level accounting techniques enable accountants to estimate the costs related to environmental externalities at more disaggregated layers, such as the sectoral and the organizational levels (Anas and Lindsey, 2011; Aravena et al., 2012; Georgakellos, 2010; Heine et al., 2012; Muller et al., 2011). These techniques, known as Environmental Management Accounting (EMA) identify, measure and analyse both physical information (e.g. material, energy, water and waste flows) and monetary information on environment-related earnings, costs and savings (Burritt et al., 2002; Jasch, 2003).

Within EMA, a particularly useful approach is full cost accounting (FCA; Bebbington et al., 2007; Jasinski et al., 2015). FCA stands out from other EMA tools, such as cost-benefit or material flow analysis, because it measures both an entity's direct (i.e. costs directly related to the entity's own operations) and indirect (i.e. costs related to sources along the supply chain) environmental costs, while the majority of EMA tools focus on measuring direct environmental costs only (Jasch, 2003). FCA approaches encompass various methods, such as the Sustainable Assessment Model (Frame and Cavanagh, 2009; Fraser, 2012), Forum for the Future's (FFF) sustainability accounting (Taplin et al., 2006) and monetised life cycle assessment (Antheaume, 2004; Epstein et al., 2011). The study conducted in 2013 by the agency Trucost in partnership with the UN-sponsored programme on "The Economics of Ecosystems and Biodiversity" provides an example of an FCA approach applied to industries at the global level (TruCost, 2013). Relying on an environmentally extended input-output model, it estimated the exposure of polluting industries to unpriced environmental damages, both directly and through supply chains. A similar approach is adopted in the empirical part of the current paper.

Different societal actors have a role to play in the process of internalising these externalities (Schoenmaker and Schramade, 2019). Businesses can price these externalities with the help of the aforementioned accounting techniques and incorporate them into their decisions. Non-governmental organizations can voice public concerns about externalities and spur other actors to act upon them. Investors can take environmental, social and governance factors into account when making investment decisions and consumers can purchase more sustainable goods and services. Yet, government intervention is often required to force the market to account for costs that would otherwise not be included. Among different possible interventions, market-based solutions can be distinguished from direct regulation. Market-based solutions include, among other instruments, a Pigouvian tax that reflects the external costs of the damages and cap-and-trade systems, which entail fixing a cap on the total level of pollution or emission and allocating to each market actor a tradable permit which specifies the exact amount of pollution or emission that can be generated. Carbon pricing through a carbon tax or an emissions trading system, for instance, has often been viewed in the economic literature as a first-best solution to respond to climate externalities (e.g. Baranzini et al., 2017; Jenkins, 2014; Stern, 2007). Direct regulations include environmental standards, quotas or complete bans.

2.2 Transition risks associated with pricing

Environmental degradation and climate change are sources of structural change that pose material risks for businesses and financial institutions (NGFS, 2019, Schellekens and Van Toor, 2019, Bolton et al., 2020). The likelihood of the materialisation of these risks is increasingly acknowledged by business leaders. For instance, the World Economic Forum ranked extreme weather events, natural disasters and failure to implement sufficient climate change mitigation and adaption among the top five risks most likely to occur within the next ten years (WEF, 2019). These risks fall into two categories: physical risks and transition risks. Physical risks relate to the physical impacts of environmental damages themselves. They may, for instance, result from the higher frequency and intensity of storms, flooding and droughts associated with a warmer climate, the spread of vector-borne diseases and the loss of ecosystem services (i.e. the benefits that humans freely gain from natural environments and properly-functioning ecosystems, such as forest, grassland and aquatic ecosystems; IPBES, 2019; Millennium Ecosystem Assessment, 2005; OECD, 2019). Physical risks may affect the operations of economic organisations through, for instance, direct damage to assets and indirect impacts from supply chain disruption, which can then propagate to their valuations or risk profiles via impacts on their income, cash flow or balance sheet.

Transition risks arise from the scale and speed of the adjustments made to respond to environmental crises, such as policy and technological changes or evolving consumer and investor behaviour (Carney, 2015; NGFS, 2019). These changes could prompt a reassessment of the value of a large range of assets and could potentially lead to asset stranding in the future (Caldecott et al., 2013). The pricing of externalities, such as a carbon tax, is one mechanism through which a policy change can generate risks for business and financial institutions, especially in the case of sudden, uncoordinated, unanticipated or discontinuous changes (NGFS, 2019). The transition risks increase as climate-related and environmental risks are often poorly understood, resulting in significant over-exposure to environmentally unsustainable assets throughout economic and financial systems (Caldecott et al., 2014). For instance, research on transition risks to physical assets estimates that a potential $2 trillion worth of capital expenditure may not be profitable under a 2°C transition (Fulton et al., 2015).

In the Netherlands, a transition risk stress test performed by the Dutch Central Bank showed that the impact of disruptive energy transition scenarios on the capital of financial institutions in the Netherlands could be sizeable, with losses of up to 3 percent of the stressed assets for banks, 11 percent for insurers and 10 percent for pension funds (Vermeulen et al., 2018). Another study, which analyses the potential economic impact of introducing a carbon tax of EUR 50 per tonne of carbon emitted for Dutch industries, finds that, although the impact of such a tax would be limited for the Dutch economy as a whole, with an average production cost increase of 1%, some carbon-intensive sectors would be profoundly affected, with the largest cost increases occurring for mining and quarrying (4.4%) and base metals (3.9%; Hebbink et al., 2018).

The literature shows that considerable progress has been made in developing methods to estimate the external effects of economic activities on society and the monetary value of this environmental degradation. This degradation poses material risks for businesses and financial institutions. Acting on these risks create transition risks, which arise from the scale and speed of the adjustments made to respond to environmental crises. Within the Netherlands the impact of this risk on the capital of financial institutions in the Netherlands could be sizeable. This research will contribute to this topic by showing the current exposure to these risks within the Netherlands.

3. Methodology

3.1. Data

To compute the environmental footprint of the Dutch economy, we use EXIOBASE 2015, a global, detailed Environmentally Extended Multi-Regional Input Output (EEMRIO) database (EXIOBASE, 2019; Stadler et al., 2018). EEMRIO models are usually used for the analysis of environmental impact associated with the consumption of product groups by final users (Tukker et al., 2014). In this study we follow the approach by Wilting and van Oorschot, (2017) in order to calculate the supply-chain related environmental pressures of economic sectors, also seen as production or sector footprints. The 43 countries covered in this database comprise 95% of global GDP. For each country, the database provides information about environmental externalities in the categories of I) emitted substances ii) waste supply and usage iii) land use iv) water use v) resource use disaggregated into 163 economic subsectors (see Appendix C). The remainder of the global economy is captured in in a "rest of the world" group per continent.

This study considers a total of 30 environmental externalities across three main categories: GHG emissions, air, water and land pollution and water usage (see table 1)[1]. Indeed, out of the total 35 environmental externalities covered by EXIOBASE under the categories considered in this study, 30 are covered by the available TruCost valuation data.[2] The EEMRIO analysis shows that the total amount of these missing air pollutants rank among the lowest of all air pollutants in terms of output. As their impact is not to be ignored - their respective environmental impact can still be high – the overall effect on the total damage costs computed in this study is expected to be limited. Land use transformation has been omitted due to data gaps that prevent its inclusion in the EEMRIO analysis. Admittedly, land use transformation is a key driver to biodiversity loss (IPBES, 2019) and, therefore, is likely to have a significant effect on the total environmental damage cost. In addition, there is a global data gap for the mining sector within EXIOBASE. Results associated with the mining sector and the sectors that rely heavily on the input of minerals and metals is consequently underestimated.

The use of EEMRIO models in general, and specifically EXIOBASE, entails some additional caveats. First, input-output tables do not capture all the activities within the economy. Other "off the book" activities such as for instance illegal land clearing for logging or mining activities may be excluded and can have a high environmental impact. Second, EEMRIO data allows analysis only based on the assumption of homogeneity of goods and services. The data is insufficiently granular to differentiate between different products in a sector or between different companies producing the same product, while, in

[1] Appendix B contains a more detailed overview.

[2] More specifically, for five air pollutants - benzo(a)pyrene, benzo(K)fluoranthene, Indeno(1,2,3-cd) pyrene, dioxins and furans (PCDD/F) and trisodium phosphate – no monetary valuation could be obtained.

practice, environmental externalities might differ substantially between different products and between different companies. Lastly, due to the global modelling scale of EXIOBASE, data on environmental externalities occasionally lacks consistency with other, more local sources (Ton, 2019).

To monetise these environmental externalities, we use the proprietary dataset from data provider TruCost, which provides the costs for each environmental externality. These costs are based on a monetary valuation methodology for different subsets of environmental externalities (see TruCost, 2015). Regarding GHG emissions, the valuation methodology relies on the Social Costs of Carbon (SCC), which reflects the full global costs of damages caused by GHG emissions from, for instance, changes in agricultural and forestry output, costs from changes in energy demand, property loss due to sea level rise, coastal storms and forest fires and heat related illnesses and diseases. For water consumption and pollution, the valuation methodology is based on human health and environmental impacts. The health impacts are estimated by linking the impacts associated with malnutrition due to lack of water irrigation, and the spread of deceases due to water shortages. The environmental impact of water consumption is measured based on net primary productivity (NPP). NPP is defined as the rate of new biomass production that is available for consumption and is used by TruCost as a measure for the functioning of an ecosystem. The impact of pollution on human health is calculated using the number of years lost due to illnesses, disabilities or early deaths (DALY's) associated with the discharge of chemicals to freshwater and seawater, natural, agricultural and industrial soil and rural, urban and natural air. For the calculation of the impact of pollutants on ecosystems TruCost assessed the link between biodiversity, measured species richness (IUCN, 2015) net primary activity (NPP), and ecosystem value.

The data required to compute impact ratios is obtained from Statistics Netherlands (CBS) and De Nederlandsche Bank (DNB). CBS reports yearly on the total profits of non-financial economic sectors gained over a specific year. DNB tracks the same data specifically for the financial sector of the Netherlands.

Table 1. The 30 environmental externalities considered in this study.

Externality category	Externality
Greenhouse Gas Emissions	Carbon dioxide
	Average HFCs
	Methane
	Nitrous Oxide
	Average PFCs
	Sulphur hexafluoride
Water use	Water Consumption
	Water Withdrawal
Water pollutants	Nitrogen to Water
	Phosphorus to Water
Soil pollutants	Phosphorus to Soil
Air Pollutants	Volatile organic compounds
	Nitrogen Oxides
	Particulate Matter
	Sulphur Dioxide
	Polycyclic aromatic compounds
	Arsenic
	Cadmium
	Carbon Monoxide
	Chromium VI
	Copper
	Hexachlorobenzene
	Lead
	Mercury
	Nickel
	Polychlorinated biphenyls
	Selenium
	Zinc
	Ammonia
	Benzo(b)fluoranthene

3.2. Data analysis

The methodology followed consists of three main steps. First, we determined the environmental footprint with respect to the 30 externalities considered for all 163 Dutch economic subsectors, for the sectors as well as for the whole Dutch economy in physical units (e.g., tons of CO_2-equivalents) through a global supply-chain analysis. Second, we computed a monetary value of the environmental footprints by assigning prices to each physical flow. Lastly, as a proxy of the impact of internalisation of the externalities in sectors, we determined the impact ratio. The impact ratio is the monetary value of the environmental footprint as a share of the three-year average profits of the sector. The three steps are discussed in more details in what follows.

The global supply-chain analysis conducted to compute the environmental footprint of Dutch economic sectors was performed from a production-based perspective. We determined the footprint of each of the 30 externalities for all 163 subsectors and 21 sectors using the following computation, elaborating from the approach in Wilting and Van Oorschot (2017):

$$EFP_{sector,ext} = d_{ext} \cdot (I-A)^{-1} \cdot y^{*}$$

with d_{ext} is the vector of direct environmental intensities for externality *ext* for all sectors and regions in the model, and $(I-A)^{-1}$ is the so-called Leontief inverse depicting the total output required in each sector for one unit in final demand in all sectors. The inputs of upstream sectors are obtained by making use of this Leontief inverse, a mathematical operation that calculates all the layers of dependency of different sectors within the supply-chain (Suh, 2009). For y^{*} we have two variants:

i. In case of the 163 individual subsectors: y^{*} is a vector with zeros for all regions and subsectors in the model, except for the subsector for which the environmental footprint was calculated. The value for the subsector is the total demand of all sectors, domestically and abroad, and all final demand from the specific subsector;
ii. In case of the 21 aggregated sectors, double counting must be avoided by excluding the deliveries from the subsectors to all other sectors in the same aggregated sector. For instance, when all subsectors in agriculture are aggregated to one aggregated agricultural sector, all deliveries from the agricultural subsectors to other agricultural subsectors are excluded from the y^{*} vectors since the environmental impacts from these deliveries are already in the supply chains of each agricultural subsector (via the Leontief inverse matrix).

The analysis thus considers the direct inputs into an economic sector, but also the inputs from sectors upstream in the supply-chain, both domestically and internationally. It computes the environmental footprint of economic activity associated with Dutch production, including imports.

In a similar way, the environmental footprints of the whole Dutch economy are determined:

$$EFP_{ext}^{NL} = d_{ext} \cdot (I-A)^{-1} \cdot y^{*}$$

With y^{*} the production from all Dutch sectors excluding the intermediate production to other Dutch sectors for domestic use. This is because the environmental damages associated with intermediate production are already included in the supply chains of the Dutch sectors. The environmental footprints of the Dutch economy still include the intermediate production for exports and the production for all final demand both domestically as abroad.

Based on TruCost valuation data, the total footprints of the sectors and the Dutch economy were monetised by multiplying the unit cost of a specific environmental pressure by the total flow of this pressure associated with a specific sector. This resulted in a total cost for each specific environmental pressure for all Dutch subsectors, sectors or the whole economy. The environmental damage costs (EDC) of each sector is:

$$EDC_{sector} = \Sigma_{ext}\, EDP_{ext} \cdot EFP_{sector,ext}$$

Similar, the environmental damage cost of the Dutch economy is:

$$EDC^{NL} = \Sigma_{ext}\, EDP_{ext} \cdot EFP_{ext}^{NL}$$

Lastly, we computed, for each sector, an impact ratio to get an understanding of the potential impact of pricing the externalities on their profitability. To do so, we used the three-year average profits before tax of each Dutch economic sector from 2014 to 2016, to account for annual fluctuations in profits. Due to the lower granularity of economic sectors within these datasets, the impact ratios have been determined on the level of sectors (21), rather than subsectors (163). Moreover, sectors that do not report profits (such as extraterritorial organisations) have been omitted, leading to a total number of 13 sectors considered for this study.

$IR_{sector} = EDC_{sector} / P_{sector}$

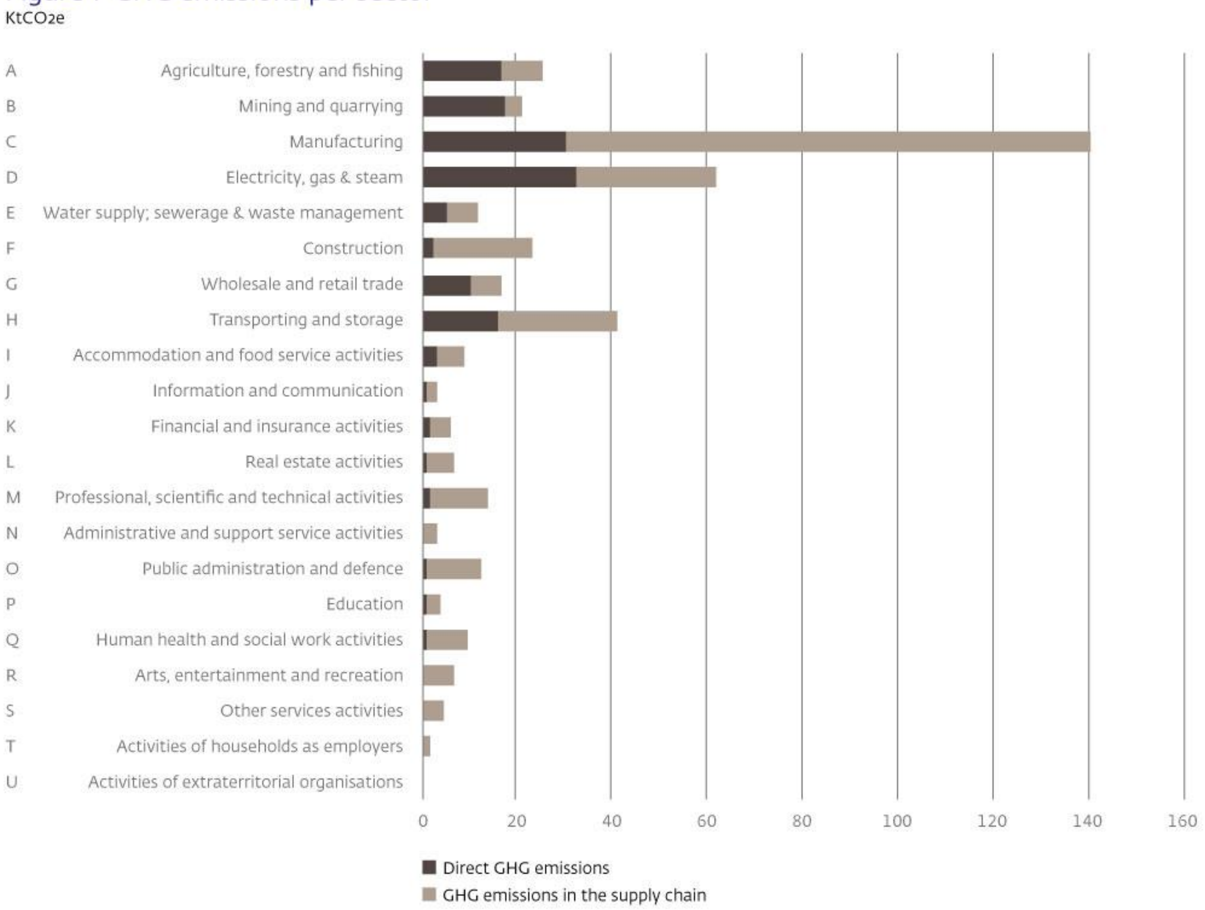
4. Results and discussion

The structure of this section follows our methodological steps, by successively presenting the environmental footprint of the Dutch economy and economic sectors (Section 4.1), the costs associated with the different environmental externalities (Section 4.2) and the impact ratio for each economic sector (Section 4.3).

4.1 The environmental footprint of the Dutch economy

The total production footprints of the Dutch economy, including their supply chains related to imports was 416 million tons of CO_2-equivalents, 6.9 million tons of polluting substances and 93.8 trillion litres of water. Looking at the individual greenhouse gases, carbon dioxide (78%) has the highest contribution in terms of volume, followed by methane (15%) and nitrous oxide (4%). Statistics Netherlands estimated the GHG footprints of Dutch production at 432 Mtonnes CO_2-equivalents in 2016 (Hanemaaijer et al., 2021), which is slightly higher than the value we calculated. We did not find studies with figures for the production footprints for polluting substances and water for comparison.

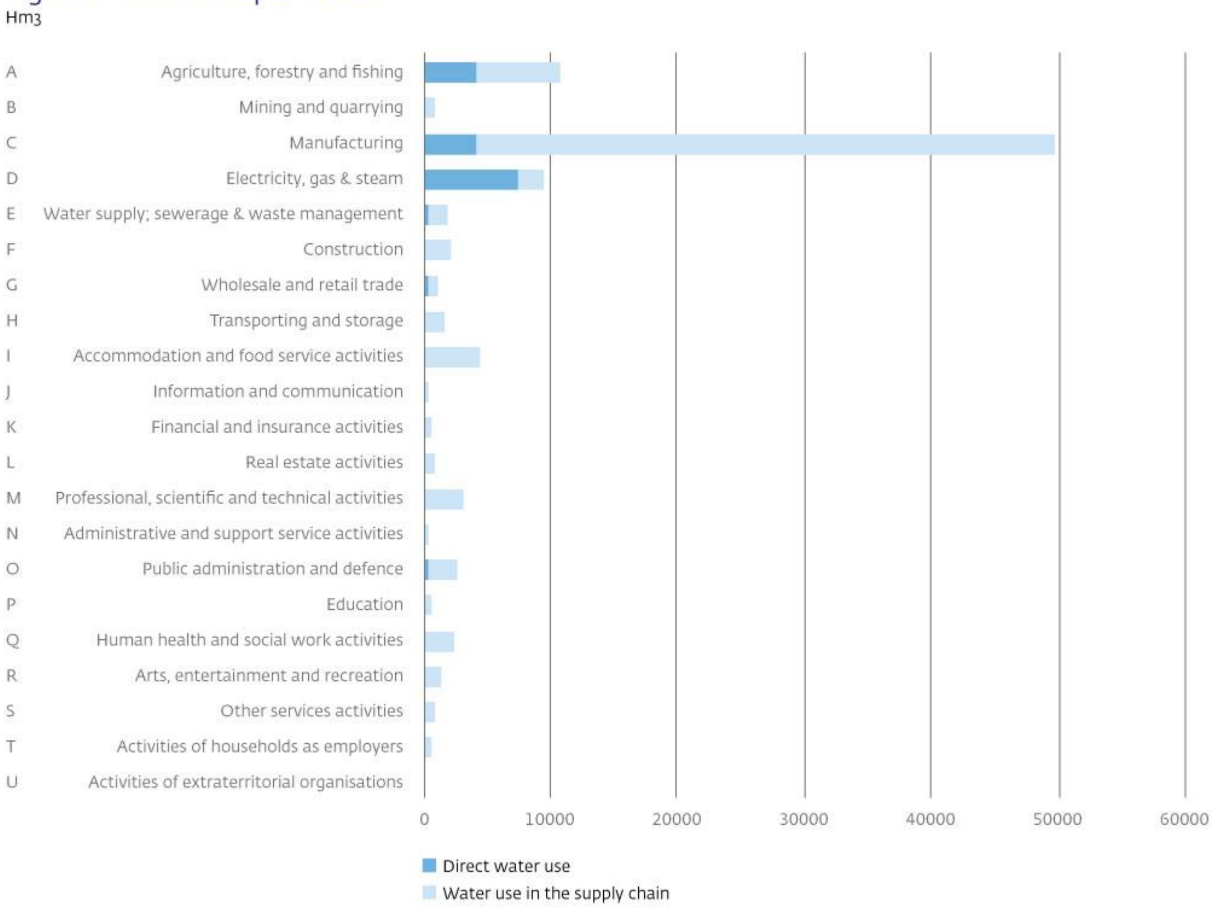
Figure 1 GHG emissions per sector



Sectors with large GHG footprints are manufacturing (140 Mtonnes CO_2-eq.), electricity, gas and steam (62 Mtonnes CO_2-eq) and transporting and storage (41 Mtonnes CO_2-eq) sectors (see Figure 1). The higher emission levels recorded in these sectors are mainly due to specialisations in carbon-intensive activities within those sectors. Within the manufacturing sector, the subsectors refineries, which covers carbon-intensive activities such as oil refining and food processing are the most prominent subsectors. The electricity, gas and steam sector covers activities such as the electricity production from fossil fuels for the direct consumption of households and other sectors. GHG emissions associated with transporting and storage are primarily attributable to the large shipping sector within the Netherlands and to a relatively large contribution from the road transport sector. About half of the total emissions are associated with the supply chain activities of these sectors, as they rely on a complex, international supply chain. The electricity, gas and steam sector is an exception, since more than half (52%) of its emissions are CO_2 emissions associated with the delivery of energy to Dutch households.

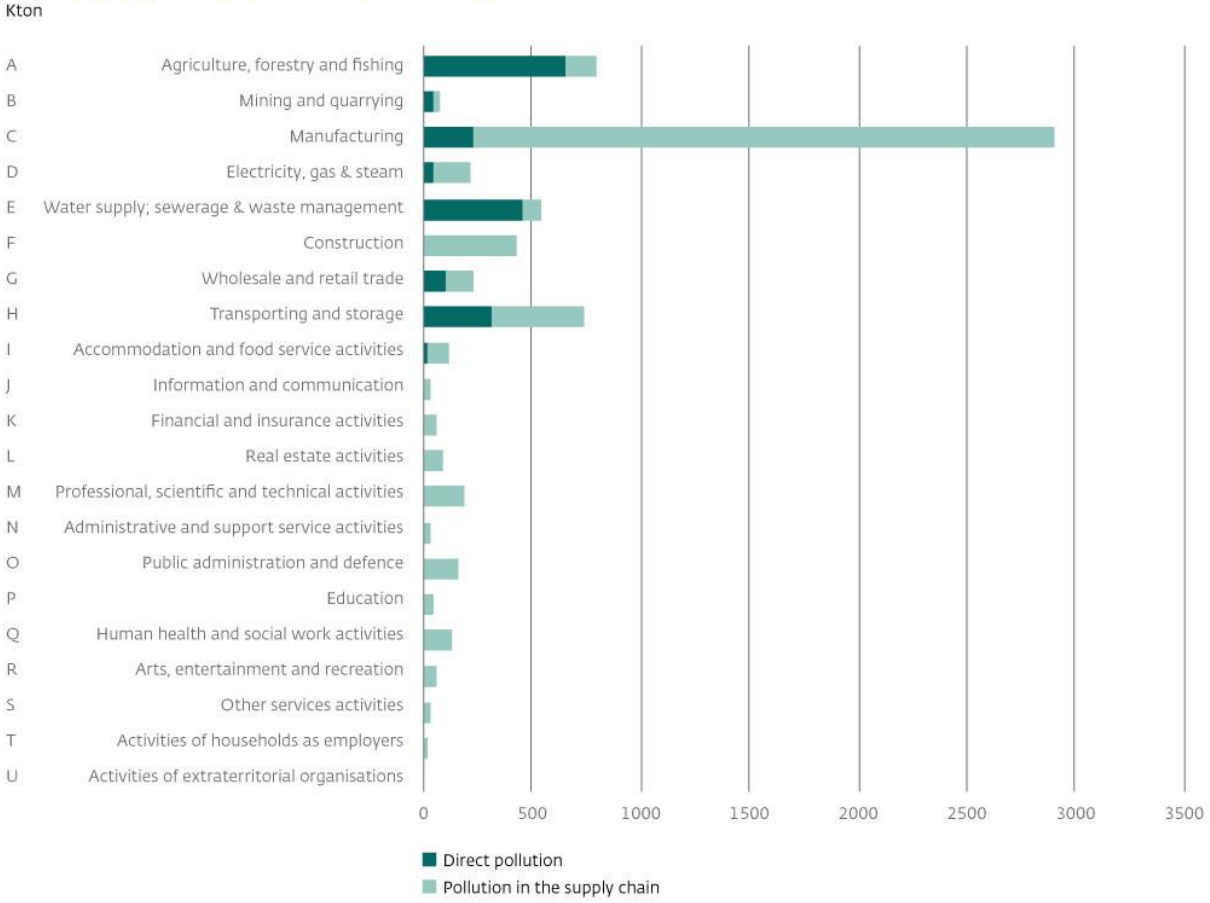
The total water footprint of the Dutch economy (98.3 trillion litres of water) is largely associated with the manufacturing sector (50 trillion litres), followed by agricultural sector (11 trillion litres) and the electricity, gas and steam production (9 trillion litres; see Figure 2). Within the manufacturing subsector, over half of the water footprint (26 trillion litres of water) is used to produce food products. The food producing sector (including all relevant upstream sectors within agriculture and manufacturing) is thus responsible for the consumption and withdrawal of 43 trillion litres of water within the Netherlands.

Figure 2 Water use per sector



The 6.9 Mtonnes of polluting substances is the aggregate of 18 substances, in which carbon monoxide (39%), nitric oxide (18.5%), ammonia (14%) and sulphur oxide (10%) rank the highest. The manufacturing sector is the biggest polluter, with an output of 2.9 Mtonnes of polluting substances, mostly polluted by the food producing subsector and the metal producing subsector. Second and third are the sectors of agriculture (0.8 Mtonnes) and transportation (750 Mtonnes) (see Figure 3). As previous studies compile different sets of polluting substances and typically do not consider the supply chain, the total level of pollution cannot be readily compared with previous analyses.

Figure 3 Air, water and land pollution per sector



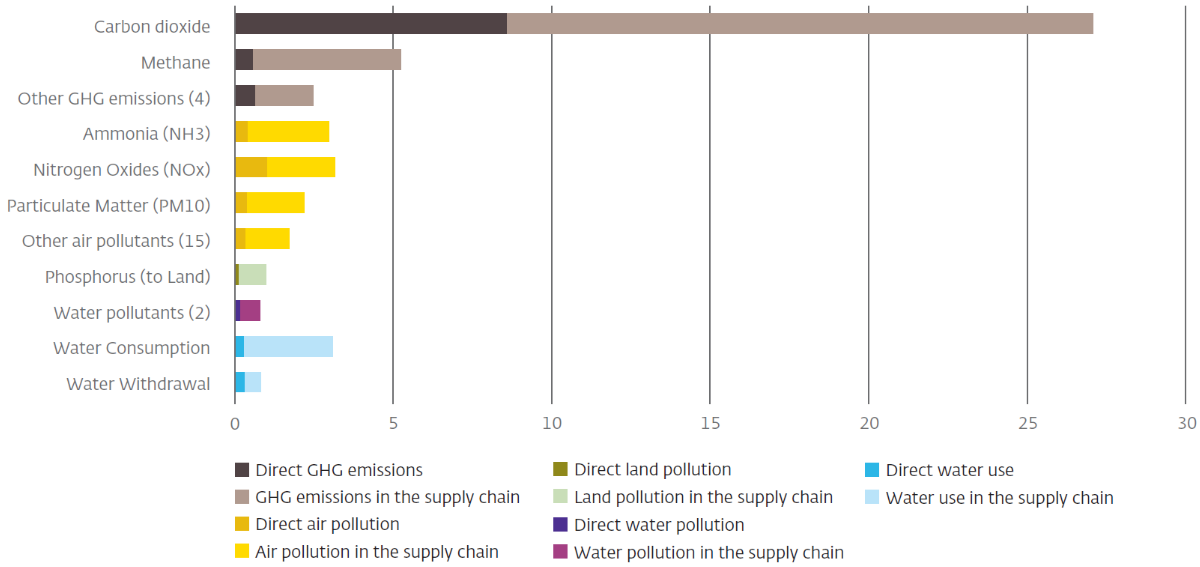
4.2 Environmental damage costs of the Dutch economy

Based on the monetary valuation of the abovementioned externalities, we estimate that the total Environmental Damage Costs (EDC's) of the Dutch economy amounts to EUR 50 Bn, or about 7.3% of Dutch GDP in 2015. This finding is somewhat lower than earlier studies such as TruCost (2013) and UNEP-FI (2011), which find that the global environmental damage costs are 13% and 11% of global GDP respectively (TruCost, 2013; UNEP-FI, 2011). The difference in EDC's is mostly related to two major differences. First, both the TruCost study and the UNEP-FI study include land use transformation within their analysis. As this study focuses on using quantifiable data, no estimates on land use transformation have been used, lowering the overall EDC's. Second, TruCost and UNEP-FI most likely also includes direct environmental pressures like for instance the impact of households, which is not within the scope of this research.

Monetising environmental damage costs in GDP terms sheds light on the extent to which economic activity causes widespread environmental damage that is not accounted for in this general measure of economic progress. Bearing in mind the conclusion of the IPCC and IPBES reports that the current level of environmental degradation cannot be sustained much longer, one could argue that Dutch economic activity forms an undue burden on natural capital. These results illustrate the need for a broader measure of welfare; explicitly considering the impact of generating financial capital on social and environmental capital (see also Schoenmaker & Schradema, 2018). Of the total environmental damage costs of the Dutch economy, a large part is associated with foreign economic activities (EUR 31 billion),(EUR 19 billion) is due to damages by Dutch economic sectors domestically. Noting this, not all the environmental damage affects Dutch wellbeing per se; a larger part of the environmental externalities impacts other countries. Naturally, these damage costs are harder to price and/or regulate. Note that the domestic and foreign environmental damage costs are additional calculations not derived directly from the main results, as supply-chain results normally also include domestic supply-chains, making no clear distinction between domestic and foreign.

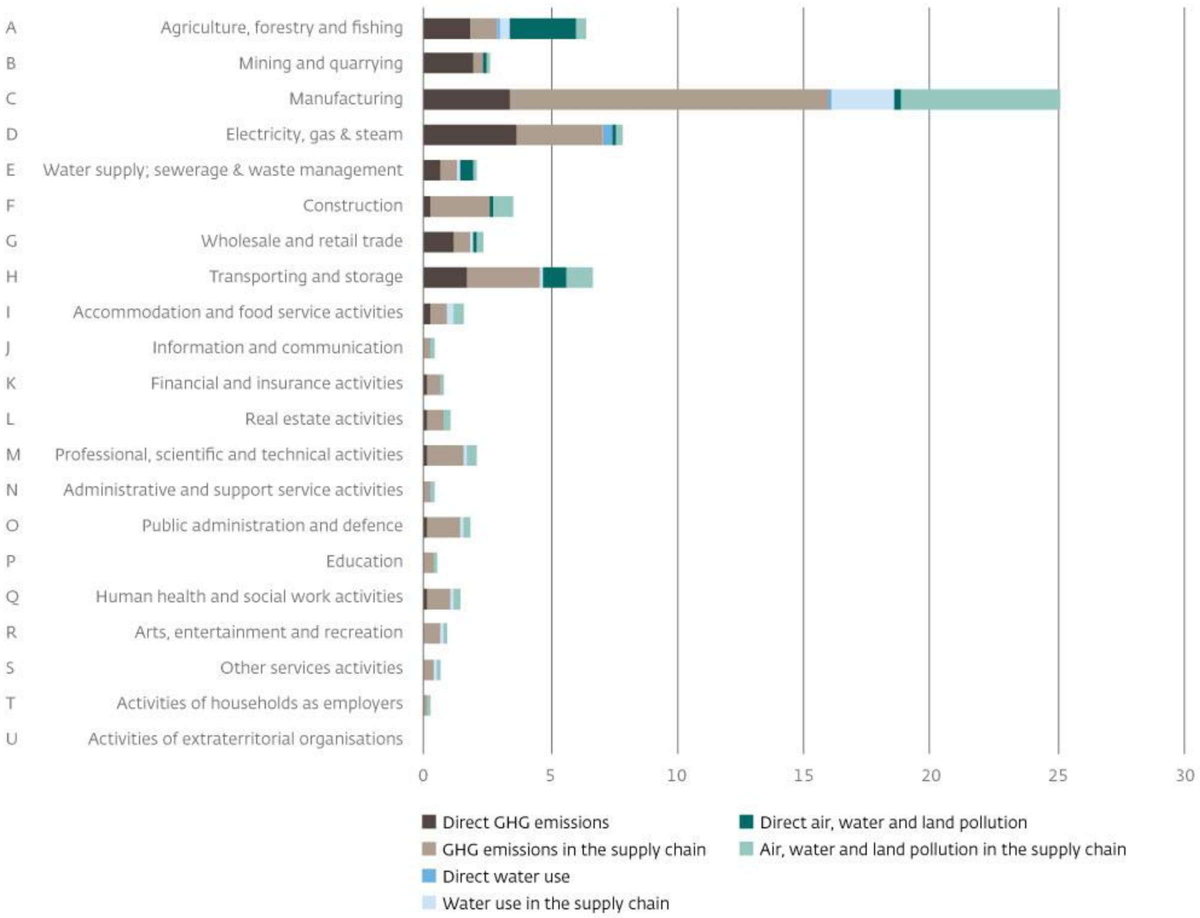
Figure 4 Environmental damage costs per environmental pressure

EUR billion



GHG emissions are the prime contributor to the total environmental damage costs, with EUR 34.7 Bn (69%; See figure 4). The total pollution generated by the Dutch economy represents EUR 11.6 Bn (23%) and the water footprint generates the smallest share of these costs, namely EUR 3.8 Bn (7.6%). Of all the externalities considered, CO_2 contributes to 54% of the total costs (27 billion euros). This finding supports the current policy focus on internalising the damage costs linked to the emissions of this substance, as discussed in the introduction. Caution is nonetheless warranted, as carbon pricing ignores close to half of the total environmental damage costs considered in this study. In an economy with profit-maximising firms, firms will implement adjustment processes that are cheaper than the carbon tax, but with pricing come potential perverse effects (Schoenmaker & Schradema, 2018; Walker et al, 2009). It cannot be excluded, for instance, that these adjustment processes carbon emissions will be substituted by other (un- or lower priced) types of emissions or pollutants. Looking at the environmental costs broken down by sector (Figure 5), three sectors stand out: manufacturing sector with a damage cost of EUR 25 Bn, the electricity, gas and steam with a total of EUR 7.9 Bn in damage costs, and agriculture EUR 6.4 Bn.

Figure 5 Environmental damage costs per sector broken down by environmental pressure
EUR billion

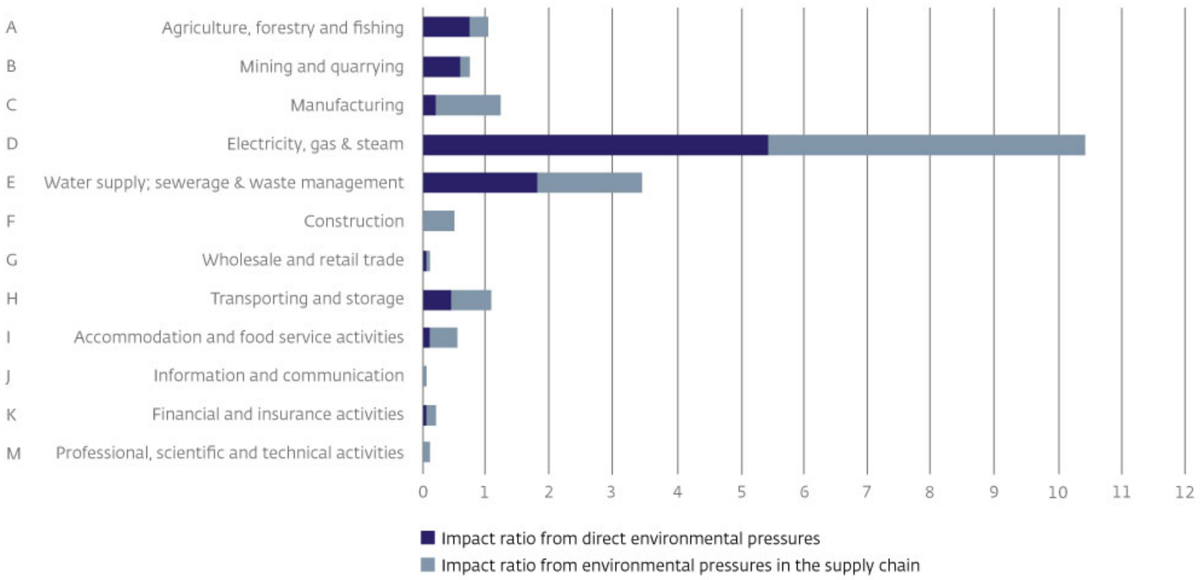


4.3 The potential impact on the different economic sectors

The calculation of impact ratios for each sector shows that, in total, 6 of the 13 economic sectors have an impact ratio above 50% reflecting that more than half of the average profits of the sectors would be, *ceteris paribus*, lost to bear their environmental damage costs, should they be internalised (see Figure 6). For five sectors the environmental damage cost exceed their average profits. The sector with the largest impact ratios include the electricity, gas and steam producing sector (1042%), the water supply, waste and sewage treatment sector (345%), the manufacturing sector (124%), the transporting and storage sector (108%), the agriculture, forestry and fishing sector (105%) and the mining and quarrying sector (74%). These sectors are likely to be particularly exposed to the transition risks related to the internalisation of these environmental damages. The water supply and sewage treatment sector display one of the highest impact ratios, despite having only relatively moderate environmental footprints and associated damage costs. An explanation might be sought in the public service provision performed by this sector, which is not necessarily profit-maximizing. By contrast, the manufacturing sector has a relatively low impact ratio, although this sector has the highest environmental footprint and the highest associated environmental damage costs. This is explained by the relatively high profit margin obtained by the many subsectors that constitute it.

Figure 6 Impact ratio per sector

in %



It should be noted, however, that the actual impact of the internalisation of these costs on the profit of individual sectors depend on other factors and, notably, the design and phasing-in of pricing mechanisms, the ability of sectors to substitute production factors with more sustainable ones as well as the price elasticity of demand (Vollebergh et al., 2017). Regarding the design and phasing-in of pricing mechanisms, transition risks in terms of stranded assets depleting wealth and generating financial instability will be greatest if pricing policies are introduced in an unexpected, inconsistent or otherwise disorderly way. By contrast, well-signalled and orderly policy responses, which allow time for the economy to adjust and for technological advances to reduce costs, likely pose lesser risk (NGFS, 2019). Regarding production factor substitution, if production costs change (as in the case of internalisation of environmental externalities), companies will likely want to adjust their production factor mix by, for instance, replacing capital with labour or by replacing their production facilities with more energy-efficient and less polluting ones. However, previous studies focusing on substitution between capital, energy and labour indicate that factor substitution elasticities across all industry sectors is low (Kemfert, 1998; Kim and Heo, 2013; van der Werf, 2008). That is, the input of capital in a given industry sector historically hardly responded to changes in energy prices by means of carbon pricing, at least in the short run. Indeed, once installed, capital has a fixed energy use and it takes time for companies to invest in more energy-efficient capital goods. Arguably, with increasing availability and the price competitiveness of more energy-efficient technologies across sectors the elasticities might be higher at present.

Regarding demand elasticity, costs increase due to the internalisation of environmental damage costs translate into higher prices, which in turn influence final domestic and international sales. However, the ability of producers to pass the costs on to their sales prices depends on the sensitivity of demand to price increases. If the sectoral price elasticity of demand is high, the decline in sales towards the new market equilibrium after a small price increase will be relatively large, while if this elasticity is low, then sales will only fall slightly. A study by DNB shows this market force specifically for carbon taxing. It gives an indication on possible effects regarding sectoral demand elasticity, as carbon emissions form a large share of the total environmental costs within the current study. The study shows that the anticipated declines of sales due relative high price elasticity are especially prevalent within the mining a quarrying sector where costs are set to increase sharply, and competitiveness will deteriorate most

(-7.5%). This is followed by the chemical sector (-4.3%), transport (-3.0%) and base metals (-2.2%). As for the economy, sales are anticipated to fall 1.2% if the carbon tax is applied to all industry sectors within the Netherlands (Hebbink et al., 2018). The full effects of the current study on possible declines of sales due to high sectoral price elasticity and the effects on the whole Dutch economy are to be determined in future research.

5. Conclusion

Environmental externalities associated with economic activities since the industrial revolution have had profound impacts on human well-being and are likely to have long-term impacts on economic growth. Economists have long called for internalisation of such externalities and the support amongst policymakers is growing steadily, most notably for carbon taxation. For 30 environmental externalities this study has computed a price for the total production footprint of the Dutch economy including its supply chain in 2015 and has presented impact ratios to estimate the level of transition risks faced by different sectors. We have used a production footprinting approach that considers final production associated with domestic final demand, and intermediate and final demand for export. This approach estimates the potential impact of enacting a Pigouvian tax, as is currently under consideration by the European Commission as part of its Zero Pollution Action Plan under the European Green Deal.

Our study has four main findings. First, we find that the total environmental damage costs of the Dutch economy amount to EUR 50 Bn (7.3% of Dutch GDP). The lion's share of these damages is associated with carbon emissions (EUR 27 Bn). Yet, other greenhouse gas emissions (EUR 7.7 Bn), pollution (EUR 11.6 Bn) and water use (EUR 3.8 Bn) are far from negligible. We, therefore, argue that policymakers should strive to consider all environmental damage costs, as well as the potential spill-over effects of partial pricing. After all, in an economy with profit-maximising firms, it cannot be excluded that businesses confronted with a carbon tax may resort to processes that substitute carbon emissions for other, unpriced and/or unregulated externalities.

Second, we find that of the total environmental damage costs of the Dutch economy the majority is associated with foreign economies activities (EUR 31 billion), with the smaller part (EUR 192.3 billion) being due to direct damages by Dutch economic sectors. An environmental tax is more likely to be effective when the production processes in which the externalities occur are directly taxed compared to a tax on a final product that incorporates embedded externalities (Vollebergh et al., 2017). For the share of environmental damages occurring due to foreign economic activities notable coordination and measurement challenges persist for environmental externalities associated with production processes outside of the Netherlands. Policymakers should strive towards global convergence of pricing of environmental damage costs and consider border adjustments as an intermediate step to level the playing field for domestic industries.

Third, based on impact ratios for each sector we show that for five sectors the average profits would, *ceteris paribus*, be insufficient to bear their environmental damage costs, should they be directly internalised. To optimize the effect of internalisation, policymakers should therefore consider time and resources needed in different sectors to adjust production processes. One mechanism to incentivize companies to make long-term investments to adjust production processes, while limiting transition risks is the phasing-in of a tax (Acemoglu et al., 2016, 2014).

Fourth, the aforementioned impact ratios show that business with high environmental damage costs relative to their profits and their investors might thus be confronted with elevated transition risks. Businesses that wait too long to adopt a more sustainable value creation model are likely to become laggards within their sector and face a gradual erosion of their market value (Fatemi & Fooladi, 2013).

Ultimately, such assets can become stranded (Caldecott et al., 2013). The current approach can support financial institutions and their supervisors to inform their heat mapping exercises, the assessment of materiality and/or measurement of environmental transition risks more broadly. For market participants to adequately consider these risks, and for financial institutions to incorporate them in their risk management practices, adequate firm-level information is a prerequisite. After all, the current study presents sector averages; an assessment at individual firms' level might reveal substantial differences between individual firms as well as pockets of risks in other than the five sectors highlighted here. International best practices for disclosing climate-related risks already include carbon footprints (TCFD, 2017). We argue that disclosure practices of both corporate and financial institutions should likewise consider all material environmental damages. After all, it has already been shown that environmental information influences asset allocation decisions (Holm & Rikhardsson, 2008). Importantly however, policymakers and industry leaders are well-advised to develop common methodologies and standards, as these are considered critical to advance the consideration by investors (Lambooy et al. 2018).

Further research could further expand the scope of environmental damages considered, for example by including land use transformation. Moreover, the effectiveness of internalisation policies, such as a direct tax, depend on, *inter alia*, the price elasticity of demand and potential impacts on competition (Hebbink et al., 2018). As these were not considered here, these could be further studied.

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Appendix A

Overview of the environmental externalities considered in this study

An overview of the environmental externalities within the main KPI categories. The KPI's which are coloured red are not considered within the analysis due to a lack of monetary units.

Category	Subcategory	Monetary Unit	Unit of analysis
Pollution	Phosphorus (to Land)	$/tonne	tonne
Pollution	Nitrogen (to Water)	$/tonne	tonne
Pollution	Phosphorus (to Water)	$/tonne	tonne
Water Use	Water Consumption	$/m3	m3
Water Use	Water Withdrawal	$/m3	m3
GHGs	Carbon dioxide	$/tCO2e	tCO2e
GHGs	Average HFCs	$/tCO2e	tCO2e
GHGs	Methane	$/tCO2e	tCO2e
GHGs	Nitrous Oxide	$/tCO2e	tCO2e
GHGs	Average PFCs	$/tCO2e	tCO2e
GHGs	Sulphur hexafluoride	$/tCO2e	tCO2e
Air Pollution	Ammonia (NH3)	$/tonne	tonne
Air Pollution	Volatile Organic Compounds (NMVOC)	$/tonne	tonne
Air Pollution	Nitrogen Oxides (NOx)	$/tonne	tonne
Air Pollution	Particulate Matter (PM10)	$/tonne	tonne
Air Pollution	Sulphur Dioxide (SO2)	$/tonne	tonne
Air Pollution	Polycyclic aromatic compounds (PAHs)	$/tonne	tonne
Air Pollution	Arsenic	$/tonne	tonne
Air Pollution	Cadmium	$/tonne	tonne
Air Pollution	Carbon Monoxide	$/tonne	tonne
Air Pollution	Chromium VI	$/tonne	tonne
Air Pollution	Copper	$/tonne	tonne
Air Pollution	Hexachlorobenzene	$/tonne	tonne
Air Pollution	Lead	$/tonne	tonne
Air Pollution	Mercury	$/tonne	tonne
Air Pollution	Nickel	$/tonne	tonne
Air Pollution	Polychlorinated biphenyls (PCBs)	$/tonne	tonne
Air Pollution	Selenium	$/tonne	tonne
Air Pollution	Zinc	$/tonne	tonne
Air Pollution	Benzo(b)fluoranthene	$/tonne	tonne
Air Pollution	Benzo[a]pyrene	*No price available*	tonne
Air Pollution	Benzo[k]fluoranthene	*No price available*	tonne
Air Pollution	Indeno [1,2,3-cd] pyrene	*No price available*	tonne
Air Pollution	PCDD/F	*No price available*	tonne
Air Pollution	TSP	*No price available*	tonne

Appendix B

Overview of NACE sectors and subsectors

Sector code	Sector	Subsector
A	Agriculture, forestry and fishing	Raw milk
		Cultivation of vegetables, fruit, nuts
		Pigs farming
		Poultry farming
		Cattle farming
		Cultivation of wheat
		Fishing, operating of fish hatcheries & farms
		Cultivation of sugar cane, sugar beet
		Meat animals N.E.C.
		Cultivation of crops N.E.C.
		Cultivation of cereal grains N.E.C.
		Forestry, logging and related service activities
		Cultivation of plant-based fibres
		Cultivation of oil seeds
		Wool, silk-worm cocoons
		Cultivation of paddy rice
		Animal products N.E.C.
		Manure treatment (conventional)
		Manure treatment (biogas)
B	Mining and quarrying	Extraction of natural gas and services related
		Quarrying of sand and clay
		Extraction of crude petroleum and services related
		Mining of chemical and fertilizer minerals, other mining and quarrying N.E.C.
		Mining of other non-ferrous metal ores and concentrates
		Mining of coal and lignite; extraction of peat
		Extraction, liquefaction, and regasification of other petroleum and gaseous materials
		Mining of uranium and thorium ores
		Mining of iron ores
		Mining of copper ores and concentrates
		Mining of nickel ores and concentrates
		Mining of aluminium ores and concentrates
		Mining of precious metal ores and concentrates
		Mining of lead, zinc and tin ores and concentrates
		Quarrying of stone
C	Manufacturing	Manufacture of machinery and equipment N.E.C.
		Manufacture of fabricated metal products, ex. machinery & equipment
		Processing of dairy products
		Chemicals N.E.C.
		Processing of Food products N.E.C.

		Petroleum Refinery
		Manufacture of cement, lime and plaster
		Manufacture of rubber and plastic products
		Plastics, basic
		Re-processing of secondary plastic into new plastic
		Manufacture of electrical machinery and apparatus
		Manufacture of other transport equipment
		Publishing, printing and reproduction of recorded media
		Re-processing of secondary aluminium into new aluminium
		Processing of meat pigs
		Manufacture of motor vehicles, trailers and semi-trailers
		Casting of metals
		Processing of meat cattle
		Re-processing of ash into clinker
		Manufacture of medical, precision (clocks) & optical instruments
		Manufacture of tobacco products
		Manufacture of furniture; manufacturing N.E.C.
		Manufacture of textiles
		Manufacture of beverages
		Manufacture of basic iron and steel & ferro-alloys
		Re-processing of secondary steel into new steel
		Paper
		Manufacture of fish products
		Re-processing of secondary wood material into new
		Manufacture of office machinery and computers
		Manufacture of coke oven products
		Re-processing of secondary paper into new pulp
		Manufacture of radio, television & comm. equipment
		Processing of meat poultry
		Sugar refining
		Other non-ferrous metal production
		Copper production
		Aluminium production
		Manufacture of bricks, tiles and baked clay construction products
		Manufacture of other non-metallic mineral products N.E.C.
		Processing vegetable oils and fats
		Manufacture of wearing apparel; dressing and dyeing of fur
		Processing of nuclear fuel
		Manufacture of wood & products of wood and cork, except furniture
		Precious metals production
		P- and other fertiliser
		Lead, zinc and tin production
		Tanning and dressing of leather
		Re-processing of secondary glass into new
		N-fertiliser
		Manufacture of glass and glass products

		Manufacture of ceramic goods
		Production of meat products N.E.C.
		Pulp
		Processed rice
		Re-processing of secondary copper into new copper
		Re-processing of secondary lead into new lead, zinc and tin
		Re-processing of secondary precious metals into new
		Re-processing of secondary other non-ferrous metals into new
D	Electricity, gas & steam	Production of electricity by coal
		Production of electricity by gas
		Manufacture of gas; distribution of gaseous fuels through mains
		Steam and hot water supply
		Distribution and trade of electricity
		Transmission of electricity
		Production of electricity by biomass and waste
		Production of electricity by petroleum and other oil derivatives
		Production of electricity N.E.C.
		Production of electricity by wind
		Production of electricity by nuclear
		Production of electricity by solar photovoltaic
		Production of electricity by hydro
		Production of electricity by solar thermal
		Production of electricity by tide, wave, ocean
		Production of electricity by Geothermal
E	Water supply; sewerage & waste management	Composting of food waste, incl. land application
		Recycling of bottles by direct reuse
		Incineration of waste: Metals and Inert materials
		Incineration of waste: Plastic
		Wastewater treatment, other
		Incineration of waste: Textiles
		Incineration of waste: Food
		Incineration of waste: Paper
		Collection, purification and distribution of water
		Recycling of waste and scrap
		Incineration of waste: Oil/Hazardous waste
		Landfill of waste: Inert/metal/hazardous
		Bio gasification of sewage sludge, incl. land application
		Landfill of waste: Food
		Wastewater treatment, food
		Incineration of waste: Wood
		Bio gasification of food waste, incl. land application
		Landfill of waste: Paper
		Landfill of waste: Wood
		Landfill of waste: Plastic
		Bio gasification of paper, incl. land application
		Landfill of waste: Textiles

		Composting of paper and wood, incl. land application
F	Construction	Construction
		Re-processing of secondary construction material into aggregates
G	Wholesale and retail trade	Wholesale trade and commission trade, except of motor vehicles
		Sale, maintenance, repair of motor vehicles
		Retail trade, except of motor vehicles; repair of personal goods
		Retail sale of automotive fuel
H	Transporting and storage	Sea and coastal water transport
		Air transport
		Other land transport
		Supporting transport activities; activities of travel agencies
		Post and telecommunications
		Transport via railways
		Inland water transport
		Transport via pipelines
I	Accommodation and food service activities	Hotels and restaurants
J	Information and communication	Computer and related activities
K	Financial and insurance activities	Financial intermediation, except insurance and pension funding
		Insurance and pension funding, except compulsory social security
		Activities auxiliary to financial intermediation
L	Real estate activities	Real estate activities
M	Professional, scientific and technical activities	Other business activities
		Research and development
N	Administrative and support service activities	Renting of machinery, equipment & household goods
O	Public administration and defence	Public administration and defence; compulsory social security
P	Education	Education
Q	Human health and social work activities	Health and social work
R	Arts, entertainment and recreation	Recreational, cultural and sporting activities
S	Other services activities	Activities of membership organisation N.E.C.
		Other service activities
T	Activities of households as employers	Private households with employed persons
U	Activities of extraterritorial organisations	Extra-territorial organizations and bodies

Appendix C

Data tables

Table of figure 1: GHG emissions per sector

Sector code	*Sector name*	*Direct GHG emissions ($ktCO_2e$)*	*GHG emissions in the supply chain ($ktCO_2e$)*
A	Agriculture, forestry and fishing	16,39	8,69
B	Mining and quarrying	17,50	3,34
C	Manufacturing	29,98	110,44
D	Electricity, gas & steam	32,00	29,97
E	Water supply; sewerage & waste management	5,34	6,35
F	Construction	1,92	20,68
G	Wholesale and retail trade	10,09	6,35
H	Transporting and storage	15,42	25,18
I	Accommodation and food service activities	2,82	5,81
J	Information and communication	0,48	2,24
K	Financial and insurance activities	1,44	4,16
L	Real estate activities	0,82	5,89
M	Professional, scientific and technical activities	1,60	12,26
N	Administrative and support service activities	0,31	2,45
O	Public administration and defence	0,90	11,43
P	Education	0,48	2,84
Q	Human health and social work activities	0,83	8,13
R	Arts, entertainment and recreation	0,31	5,77
S	Other services activities	0,26	3,69
T	Activities of households as employers	0,04	1,46
U	Activities of extraterritorial organisations	0,00	0,00

Table of figure 2: Water use per sector

Sector code	*Sector name*	*Direct water use (Hm_3)*	*Water use in the supply chain (Hm_3)*
A	Agriculture, forestry and fishing	3962,82	6618,44
B	Mining and quarrying	1,06	723,40
C	Manufacturing	4041,31	45631,07
D	Electricity, gas & steam	7287,55	2122,34
E	Water supply; sewerage & waste management	122,77	1700,58
F	Construction	8,14	2127,59
G	Wholesale and retail trade	298,17	577,01
H	Transporting and storage	20,24	1560,81
I	Accommodation and food service activities	0,00	4192,21
J	Information and communication	3,90	325,25
K	Financial and insurance activities	0,00	562,31
L	Real estate activities	0,00	695,22
M	Professional, scientific and technical activities	16,84	3037,45
N	Administrative and support service activities	1,74	237,42
O	Public administration and defence	357,42	2074,22
P	Education	0,00	517,52
Q	Human health and social work activities	0,00	2340,81
R	Arts, entertainment and recreation	0,02	1346,24
S	Other services activities	0,76	740,64
T	Activities of households as employers	0,00	589,20
U	Activities of extraterritorial organisations	0	0

Table of figure 3: Air, water and land pollution per sector

Sector code	Sector name	Direct pollution (kt)	Pollution in the supply chain (kt)
U	Activities of extraterritorial organisations	0,00	0,00
T	Activities of households as employers	0,06	25,84
S	Other services activities	1,32	37,03
R	Arts, entertainment and recreation	1,04	64,73
Q	Human health and social work activities	7,81	125,28
P	Education	1,23	40,30
O	Public administration and defence	2,74	159,96
N	Administrative and support service activities	1,18	32,36
M	Professional, scientific and technical activities	7,41	181,51
L	Real estate activities	3,27	93,24
K	Financial and insurance activities	9,85	49,19
J	Information and communication	5,30	28,13
I	Accommodation and food service activities	23,72	97,51
H	Transporting and storage	318,13	430,00
G	Wholesale and retail trade	106,27	122,68
F	Construction	13,14	420,77
E	Water supply; sewerage & waste management	456,23	83,91
D	Electricity, gas & steam	46,58	171,43
C	Manufacturing	227,39	2674,72
B	Mining and quarrying	52,50	25,79
A	Agriculture, forestry and fishing	655,95	146,14

Table of figure 4: Environmental damage costs per environmental pressure

Type	Subtype	Direct (Euro, BLN)	Supply chain (Euro, BLN)
Air Pollution	Ammonia (NH3)	0,36	2,58
Air Pollution	Nitrogen Oxides (NOx)	0,96	2,16
Air Pollution	Particulate Matter (PM10)	0,33	1,83
Air Pollution	Other (15)	0,28	1,41
GHGs	Carbon dioxide	8,53	18,52
GHGs	Methane	0,54	4,67
GHGs	Other (4)	0,60	1,85
Land Pollution	Phosphorus (to Land)	0,08	0,87
Water pollution	Other (2)	0,11	0,65
Water Use	Water Consumption	0,23	2,82
Water Use	Water Withdrawal	0,26	0,52

Table of figure 5: Environmental damage costs per sector broken down by environmental pressure

(Euro, BLN)

Sector code	*Sector name*	*Direct GHG emissions*	*GHG emissions in the supply chain*	*Direct water use*	*Water use in the supply chain*	*Direct air, water and land pollution*	*Air, water and land pollution in the supply chain*
U	Activities of extraterritorial organisations	0,0000	0,0000	0,0000	0,0000	0,0000	0,0000
T	Activities of households as employers	0,0047	0,1652	0,0000	0,0313	0,0001	0,0715
S	Other services activities	0,0298	0,4183	0,0000	0,0393	0,0017	0,0871
R	Arts, entertainment and recreation	0,0353	0,6539	0,0000	0,0714	0,0015	0,1574
Q	Human health and social work activities	0,0946	0,9207	0,0000	0,1242	0,0031	0,3333
P	Education	0,0542	0,3218	0,0000	0,0275	0,0017	0,0794
O	Public administration and defence	0,1020	1,2950	0,0190	0,1101	0,0042	0,3295
N	Administrative and support service activities	0,0351	0,2770	0,0001	0,0126	0,0023	0,0665
M	Professional, scientific and technical activities	0,1817	1,3893	0,0009	0,1612	0,0090	0,4068
L	Real estate activities	0,0929	0,6676	0,0000	0,0369	0,0031	0,1947
K	Financial and insurance activities	0,1628	0,4712	0,0000	0,0298	0,0119	0,1028
J	Information and communication	0,0547	0,2541	0,0002	0,0173	0,0026	0,0621
I	Accommodation and food service activities	0,3192	0,6576	0,0000	0,2225	0,0482	0,3241
H	Transporting and storage	1,7468	2,8526	0,0011	0,0828	0,9143	1,1070
G	Wholesale and retail trade	1,1428	0,7197	0,0158	0,0306	0,2212	0,2812
F	Construction	0,2171	2,3428	0,0004	0,1129	0,0255	0,7874
E	Water supply; sewerage & waste management	0,6051	0,7194	0,0065	0,0902	0,4884	0,2107
D	Electricity, gas & steam	3,6246	3,3951	0,3867	0,1126	0,0978	0,2753
C	Manufacturing	3,3958	12,5101	0,2145	2,4216	0,3253	6,2389
B	Mining and quarrying	1,9820	0,3789	0,0001	0,0384	0,0389	0,0525
A	Agriculture, forestry and fishing	1,8571	0,9849	0,2103	0,3512	2,5955	0,3944

Table of figure 6: Impart ratio per sector

Sector code	*Sector name*	*Impact ratio from direct environmental pressures*	*Impact ratio from environmental pressures in the supply chain*	*Total*
A	Agriculture, forestry and fishing	76,42%	28,36%	104,78%
B	Mining and quarrying	60,13%	13,98%	74,11%
C	Manufacturing	19,41%	104,40%	123,81%
D	Electricity, gas & steam	542,58%	499,53%	1042,10%
E	Water supply; sewerage & waste management	178,96%	165,99%	344,95%
F	Construction	3,33%	44,48%	47,81%
G	Wholesale and retail trade	4,84%	3,62%	8,46%
H	Transporting and storage	43,07%	65,40%	108,47%
I	Accommodation and food service activities	12,31%	40,37%	52,68%
J	Information and communication	0,88%	5,12%	6,01%
K	Financial and insurance activities	4,21%	14,54%	18,74%
M	Professional, scientific and technical activities	0,96%	9,05%	10,01%
N+S	Service activities	0,55%	8,78%	9,32%

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