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Assessing the effects of a carbon tax in industrial GHG emissions on the competitiveness of the Port of Rotterdam

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Summary

This thesis assesses the impacts that a carbon tax would have in the competitiveness of the Port of Rotterdam.

The purpose of this thesis is to provide insights for the design of policies aimed at the decarbonisation of the industrial sector in the Netherlands by assessing the applicability of both the carbon leakage hypothesis and the theory of induced innovation in the case of a carbon tax on industrial GHG. Therefore, the main research question ais: How would a carbon tax on the industrial greenhouse gas emissions affect the competitiveness of the Port of Rotterdam? The sub-questions are: What are the characteristics of the proposed carbon tax, and how would it complement the existing policy (EU ETS)? What are the determinants of port competitiveness and what are the competitive advantages of the PoR over its competitors? To what extent and under which conditions can a carbon tax enhance carbon leakage in the firms operating in the industrial cluster of the PoR? To what extent and under which conditions can a carbon tax induce technological innovation aimed at the decarbonisation of the industrial cluster of the PoR?

The research methods include interviews with experts from various sectors, background literature research, and secondary data to support and confirm findings. Background literature covers the main views and perspectives found in the academic literature about carbon leakage, induced innovation, government intervention and port competitiveness.

A higher price of CO2 emissions is required to enhance the industrial transition and investment in low-carbon technology. However, the specific mechanisms to both tackle the risk of carbon leakage and create an attractive environment for green investment are highly contested in the academic literature. Opposing stances and perspectives regarding the appropriateness and desirability of government intervention in the economy result in radically different approaches to the decarbonisation of industrial processes. This research builds on existing academic knowledge in the fields of carbon leakage, induced innovation, government intervention and port competitiveness to assess the effects of a carbon tax in the industrial cluster of the Port of Rotterdam. Based on these effects, this study assesses the foreseen implications for the competitiveness of the Port of Rotterdam in the face of a carbon tax. The assessment includes an outlook to the broader EU region and assumptions about the European Green Deal's implications to the stringency of climate policies and demand for fossil-based products. The main findings of this study put investment leakage as the main threat of a higher price of carbon. Regarding the theory of induced innovation, this research shows that there are limited readily available abatement options for facilities in the industrial cluster, at costs that keep firms from making favourable business cases from their implementation. This research finds that there is the need to scale up the existing technologies to allow for a cost reduction and facilitate their implementation. To both tackle the risk of investment leakage and enhance the scaling up of low carbon technologies, government intervention in the form of regulations, subsidies and enabling conditions is vital. This study concludes that the appropriate policy mix needs to both penalise emitters and incentivise investment in abatement technology. In this case, the Port of Rotterdam has the conditions to become a frontrunner in the implementation of low-carbon technology and clean production, enhancing its competitiveness in the ever-closer low-carbon economy.

Keywords

Competitiveness, carbon pricing policies, carbon tax, ETS, Port competitiveness, energy-intensive industries, decarbonisation of energy intensive industries, CO2 emissions mitigation, climate change policy, induced innovation, carbon leakage, political economy.

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2020

Foreword

"The difficulty lies, not with the new ideas, but in escaping the old ones."

- John Maynard Keynes

Abbreviations

IHS	Institute for Housing and Urban Development Studies
IPCC	International Panel on Climate Change
HLCCP	High-level Commission on Carbon Prices
PA	Port of Rotterdam Authority
PoR	Port of Rotterdam
IC	Industrial Cluster
EZK	The Dutch Ministry of Economic Affairs and Climate (Ministerie van Economische Zaken en Klimaat)
UNFCCC	United Nations Framework Convention on Climate Change
OECD	Organisation for Economic Co-operation and Development
EIIs	Energy-intensive industries
ETS	Emissions trading system
EU	European Union
PoR	Port of Rotterdam
BAT	Best Available Technology
CPG	Carbon pricing gap
ECR	Effective carbon rates
CL	Carbon leakage
II	Induced innovation
GI	Government intervention
PC	Port competitiveness

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Chapter 1: Introduction

1.1. Background information

To meet the goals of the Paris Agreement and keep the earth's temperature from increasing over 1.5°C by 2050 (UNFCCC, 2015), it is mandatory to reduce human-induced climate change by drastically curbing CO2 emissions (HLCCP, 2017). Studies predict that if we keep on the current CO2 emissions path, temperatures will rise over the 4°C and possibly 6°C by 2100 (Bosman et al., 2018). If serious attempts for CO2 emissions mitigation keep on being delayed, the mounting effects of climate change will become ever more frequent and intense. The impacts will not be uniform across the world; extreme weather events such as hurricanes and heat waves will devastate certain areas, while increased precipitation will produce floods and landslides in others (IPCC, 2018). Sea level rise will wipe out entire coastal urban settlements in which 630 million people are projected to live by 2100 (Kulp and Strauss, 2019), droughts will destroy ecosystem services, and along with them our ability to produce food and sustain human life (OECD, 2019). Policy actions aimed at curbing emissions from carbon-intensive sectors have a determinant role in tackling climate change (UN, 2020). It is urgent for governments – either local, national or supranational- to take action by implementing mechanisms aimed at decarbonising the economy, while enhancing a carbon-neutral growth path (OECD, 2019).

The burning of carbon-intensive fuels as a source of energy for economic activity is the primary source of CO2 emissions. This reflects a market failure, as companies and individuals are benefiting from low-cost carbon-intensive fuels at prices that do not represent the environmental damage of the resulting emissions. Furthermore, as the marginal cost of additional emissions is virtually zero, they will continue to take place – and most likely increase – as long as the cost of emitting remains lower than the benefit of the economic activity they originate from (Kennedy, 2018). The implementation of low-carbon technology in highly emitting industries has encountered many barriers, from which the costs and financing are perhaps the most important ones. This represents a second market failure, as the social benefits of implementing cleaner technology are far larger than the private benefits of the firms implementing them (Mazzucato, 2015).

According to environmental economic theory, a combination of policies is required to internalise the environmental damage of emissions, while facilitating the transition to a low-carbon economy. Carbon pricing policies are considered the first-best solution to reduce CO2 emissions; they are a cost-effective instrument that increases the price of carbon-based energy, thus decreasing demand for it (Ramstein et al. 2019, Skovgaard et al. 2019, Jenkins 2014, Aldy 2017). They stimulate emitters to seek energy efficiency, ultimately leading them to shift away from polluting fuels towards clean forms of energy (OECD, 2018). Additionally, carbon pricing policies raise revenue that adds flexibility to the fiscal policy. Carbon revenue can be reinvested in various sectors through a mechanism called *revenue recycling* (Andersen et al. 2007, Marron et al. 2015, OECD 2019). For instance, it can be invested in the development of renewable sources of energy and low-carbon technology, in the reduction of other taxes, in increasing public spending or cutting public debt, among others. There are currently 2 main carbon pricing schemes implemented around the world, covering only about 20% of the global GHG emissions (Coady et al., 2019); taxes and emissions trading system (ETS). Both instruments aim at increasing the price of carbon-based energy, resulting in higher production costs for energy-intensive firms and sectors (Aldy, 2017), changing their relative competitiveness and ultimately encouraging low-carbon innovations and preparing for a new playing field (Reinaud, 2008).

The effects on competitiveness can be analysed at different levels; firm, sector and national (Ellis et al., 2019). This study will focus on the sectoral level, in which the effects on competitiveness arise from the difference in production costs induced by the regulation in sectors competing for the same international market. When legislations implement carbon pricing policies, the domestic production of the sector subject the policy would be in a disadvantage against less-regulated regions with cheaper energy costs (Arlinghaus, 2015). This would cause *carbon leakage*, through which energy-intensive industries would relocate or divert investment to less-regulated regions damaging the local economy and potentially increasing global emissions (PMR 2015, CMW 2015, Ellis et al. 2019). However, most ex-post empirical studies find no statistically significant effects of carbon pricing policies in different dimensions of competitiveness (Ellis et al. 2019, Ferguson and Sanctuary 2019, Bolscher et al. 2013, Arlinghaus 2015), as well as no evidence of carbon leakage (CMW, 2015). On the other hand, a higher price of CO2 emissions has the potential to induce technological innovation by firms, who in the quest for cost-efficiency, could find in the implementation of CO2 abatement technology a cheaper alternative than paying for the higher price of emissions. By implementing cleaner technology, firms would gain a competitive advantage in the ever-closer low carbon economy.

Dutch enterprises emit large amounts of GHG while paying relatively little for them compared with other European countries. Also, the country’s emissions are decreasing at a considerably slower pace than the EU average. This is a consequence of the country’s high share of carbon-intensive energy consumption in the form of oil and gas, and the relatively small share of renewables and nuclear (Hebbink et al., 2018). Over 20% of the CO2 emissions of the Netherlands come from Rotterdam, particularly from the port area. The port’s industrial cluster is made up to a great extent of companies operating in the energy and CO2-intensive sectors. With more than 45 chemical companies and 6 oil refineries, the PoR is one of the world's largest oil and chemical centres (Samadi et al., 2016). The PoR is an important and strategic part of the economy of the city and the country. Considering direct and indirect employment, it currently employs over 384,500 people and provides a total added value of 45.6 billion euros to the economy. These figures represent 4.2% of total employment and 6.5% of the GDP of The Netherland’s respectively (PoR, 2019).

Some industries of the EU are covered by ETS, while others are subject to additional national carbon taxes. However, effective carbon rates are far from the low-end benchmark of 30EUR/tCO2e (OECD, 2018), that represents an underestimate of the environmental damage produced by a tonne of CO2 emitted at present (HLCCP, 2017). This *carbon pricing gap* (CGP) represents the failure in internalising the damage of CO2 emissions, resulting in a weak and insufficient price signal to curb emissions (OECD, 2019b). The Dutch Ministry of Economic Affairs and Climate (EZK) proposed the Dutch National Climate Agreement in 2019, setting reduction targets for the industry at 49% in 2030, and 95% in 2050 relative to the 1990 level (EZK, 2019). The agreement proposes a National Carbon Levy (carbon tax) on industrial GHG emissions as of 2021, that will act as a complement to the existing EU ETS, ensuring a carbon price floor of 30EUR/tCO2 in 2021 and increasing linearly to 125-150EUR/tCO2 in 2030. The carbon tax will apply to the same industries currently covered by the EU ETS (EZK, 2019). Given the ambitious goals stated in the Dutch National Climate Agreement, there is a potential deterioration of the competitiveness of several carbon-intensive sectors. The industrial cluster of the PoR consists mainly of industries operating in these sectors, which implies that the competitiveness of the port could also be affected by the introduction of a carbon tax. The extent to which the firms and the PoR would gain or lose competitiveness and the identification of the main drivers behind these counteracting forces are the focus of this study.

1.2. Problem statement

The environmental and economic goals of legislations must not be mutually contrary nor exclusive. As the effects of climate change become ever more apparent, so does the need to tackle CO2 emissions by, among other measures, shifting industries' energy and feedstocks from fossil to renewable sources. The most cost-effective mechanism to curb emissions while supporting the desired energy transition is a policy mix that, among other effects, increases the price of CO2 to levels that are high enough as to trigger investment in emissions abatement. Evidence shows that carbon pricing policies lead to substantial emissions reductions even though the prices remain modest (Narassimhan et al., 2017). However, claims regarding the potential loss of competitiveness, carbon leakage and negative economic effects in carbon-intensive sectors have resulted in an extremely low-stringent implementation of carbon pricing to date. On the other hand, a higher price of carbon has the potential to induce technological innovation in firms as it provides a market signal that incentivises firms to invest in low-carbon technologies. This would, in turn, increase firms' competitiveness in an ever-closer low-carbon economy.

Given the ambitious goals for GHG reduction in The Netherlands and the urgent need to decarbonise industrial sectors, it is important to assess the drivers behind each of these counteracting forces and understand how they relate and weigh against each other. By identifying the drivers of carbon leakage and induced innovation, climate policies can be more effectively designed. In the wider European context, assessments and research are undergoing about impacts and implications of the European Green Deal in various economic sectors. This illustrates the need to obtain more insights about the specific mechanisms by which climate regulation can increase its stringency while enhancing economic development.

1.3. Relevance of the study

With the ever more evident effects of climate change in the environment, economic activity, and society, the urgency of curb CO2 emissions is widely accepted and the mechanisms to do it have been at our disposal for decades. International agreements have been signed by the most powerful countries in the world and large academic efforts have been made, from policymaking to technology development, to accomplish the agreed GHG emissions reduction targets. Nevertheless, no significant progress has been achieved, at least relative to the emission reduction goals set to prevent an environmental catastrophe. Therefore, it is important to analyse why the mechanisms to abate CO2 emissions are not being implemented in their full capacity. Furthermore, is it crucial to investigate whether and to what extent, the forces preventing them from being fully implemented find ground on the empirical evidence.

The research topic is highly relevant both for The Netherlands and for other countries with carbon-intensive sectors evaluating the implementation of carbon pricing policies either as part of a policy mix or in isolation. The Netherlands aims at taking the lead by being a model in tackling climate change, reducing GHG emissions and shifting the industrial processes towards less emitting, more sustainable ones (EZK, 2019). Therefore, the policy measures that the country takes and how it deals with their alleged consequences could be used as an example and guide for other legislations in Europe and across the world. If successfully addressed, the economic concerns that are currently keeping legislations to adopt more ambitious climate policy can be either discarded or overcome, depending on the regulatory context of each country and the specific characteristics of its industries. This study aims at assessing the foreseen effects of a higher price of carbon in energy-intensive industries and the Port of Rotterdam (PoR) as a strategic actor of the local and national economy. Therefore, this research is also relevant to the Port of Rotterdam Authority (PA), whose business model is to a great extent linked to its industrial cluster.

The innovative contribution that this study adds to the existing body of literature comes from the assessment of both the carbon leakage hypothesis and the theory of induced innovation applied to a suitable case study. Although the amount of literature covering these concepts separately is large, the direct assessment of both in one single research applied to a case study constitutes an innovative approach that allows obtaining realistic and practical implications of their foreseen impacts in the competitiveness of key sectors of the economy.

1.4. Research objectives

The research objective is to provide insights for the design of policies aimed at the decarbonisation of the industrial sector in the Netherlands by investigating the conditions under which the carbon leakage hypothesis and the theory of induced innovation would take place. The research focuses on the industrial cluster of the PoR as a case study and assesses the foreseen effects that the carbon tax on industrial GHG emissions proposed in the Dutch National Climate Agreement would have in its competitiveness. This is done by analysing both the risks of carbon leakage (C) and the opportunities for the implementation of low-carbon technology (D) in the processes of the firms operating in the industrial cluster of the PoR. Furthermore, this research aims at discovering and explaining the relationships between these concepts and identifying the policy mechanisms that could prevent from carbon leakage while enhancing the implementation of low carbon technology, accelerating the industrial transition, and gaining competitive advantages in the future low-carbon economy.

Therefore, the specific objectives are the following:

- Finding the drivers of carbon leakage from increased carbon prices and testing their applicability for the industrial cluster of the PoR.
- Finding the drivers and barriers for the implementation of low-carbon technologies, suitable for the firms operating in the industrial cluster of the PoR.
- Finding the drivers of port competitiveness and selecting those that would be affected by the foreseen effects in the industrial cluster.
- Identifying and explaining relationships between the drivers mentioned above, identifying the ones that would lead to a reduction of the risk of carbon leakage while enhancing the implementation or development of low-carbon technology
- Assessing the effects on the competitiveness of the Port of Rotterdam.

1.5. Main research question and research sub-questions

According to the stated objective, the research questions are the following.

Preliminary research question:

How would a carbon tax on the industrial greenhouse gas emissions affect the competitiveness of the Port of Rotterdam?

Preliminary sub-questions:

A. What are the characteristics of the proposed carbon tax, and how would it complement the existing policy (EU ETS)?
B. What are the determinants of port competitiveness and what are the competitive advantages of the PoR over its competitors?
C. To what extent and under which conditions can a carbon tax enhance carbon leakage in the firms operating in the industrial cluster of the PoR?
D. To what extent and under which conditions can a carbon tax induce technological innovation aimed at the decarbonisation of the industrial cluster of the PoR?

Chapter 2: Literature review

2.1. Carbon pricing policies and carbon leakage

Markets are inherently unable to correct market failures and internalise unpriced externalities without intervention (Ashford, 2005). Carbon pricing policies are regulatory mechanisms that aim at internalising the environmental damage of CO2 emissions by pricing them under *the polluter pays* principle (Arlinghaus, 2015). There is increasing consensus in that carbon pricing is the single most effective mitigation instrument (Ramstein et al., 2019, Jenkins 2014, Bennear and Stavins 2007, Dolphin et al. 2020) as it can be applied to a variety of sources, with the potential to cover all the CO2 emissions of an economy under the same policy (Aldy, 2017). Compared to other instruments, carbon pricing mechanisms curb emissions at lower costs, across all activities related to energy production and consumption, and enhance the innovation needed to lower the costs of clean technology over time (Aldy, 2017), creating an opportunity for policies enhancing investment in low-carbon technology. There are currently two mechanisms of carbon pricing policies – and hybrid combinations- implemented; emission trading systems (ETS) and carbon taxes.

On the one hand, through ETS carbon emissions are curbed through a cap-and-trade system associated with *the right to pollute* (Arlinghaus, 2015). Permits are allocated by the Government to emitting sources through auction or direct assignment, with a cap restricting individual and aggregate CO2 emissions (Salant, 2016). The advantage of this mechanism is that the total emission level is fixed. However, this could also be a challenge for governments as both over and free allocation of permits can pushes down, making the policy ineffective (UN, 2020). Permits' prices act as any other commodity, resulting from the supply and demand for them. This gives volatile price signals to the market, making the cost of carbon emissions difficult to predict, which in turn creates uncertainty in firms' decision of investment in clean technology, as this decision is almost always positively correlated with the price of carbon (Arlinghaus, 2015).

On the other hand, taxes are mandatory, revenue-raising oriented fiscal policy (OECD, 2019b). As opposed to ETS, under a tax scheme, the price of carbon emissions is fixed, stable and predictable, thus making investment decisions easier for firms (Arlinghaus, 2015). At the same time, it offers less certainty than ETS on the extent of the emissions' reduction. Revenues from taxes are more uniform over time than from ETS, allowing governments to plan their allocation (Carattini et al., 2017). Carbon taxes can be charged upstream- at the point of fuel production-, downstream - at the point of fuel consumption-, or midstream at different points in between (Pomerleau and Asen, 2019).

In theory, the most effective implementation of carbon pricing policies is with a single economy-wide policy instrument, which is considered by economists as the *first best* solution to the market failure (Dolphin et al. 2020, Tirole 2012). However, the use of multiple policy instruments is justified in a *second-best* scenario, where the Pareto optimal condition cannot be realized due to the presence of more binding constraints in the general equilibrium system, addressed later in this chapter (Jenkins 2014, Bennear and Stavins 2007, Gawel et al. 2014, Dolphin et al. 2020). There are currently 57 carbon pricing schemes implemented or scheduled for implementation around the world, with 29 using explicit carbon tax at national levels and 28 ETS in national and sub-national levels. Together they cover 20% of global emissions, with about half of these priced at less than 10EUR/tCO2e (Ramstein et al., 2019). No country prices all emissions at the low-end benchmark of 30 EUR/tCO2e (OECD, 2018).

2.1.1. Carbon prices and carbon pricing gap (CPG)

There are several estimations for the price of carbon consistent with meeting the Paris Agreement's goals. They differ mainly on the assumption of whether complementary climate policies are also implemented. The IPCC estimates are of 125–5,600 EUR/tCO2e in 2030 and 225–13,200 EUR/tCO2e in 2050 to prevent peak temperatures to increase over 1.5°C in the 21st century with 0.5–0.66 probability (Rogelj et al., 2018).
The HLCCP (2017) estimates the lower end of carbon prices at 37–75 EUR/tCO2 by 2020 and 46–92 EUR/tCO2 by 2030 to comply with the Paris Agreement, if sufficiently ambitious complementary climate policies are in place.
The Carbon Pricing Corridors estimates the price of carbon per sector. For the chemical sector, it estimates prices of 28–46 EUR/tCO2e in 2020 and 46–92 EUR/tCO2e by 2030. For the power sector, prices between 22–33 EUR/tCO2e in 2020, rising to 35–92 EUR/tCO2e by 2035 are needed (Bartlett et al., 2018). The assumption is that carbon pricing is included in a policy mix that includes support for infrastructure development, market design, cheap access to capital for low-carbon projects, and R&D investments in low-carbon technology (Ramstein et al., 2019).

Carbon pricing policies have been implemented in an extremely limited and disconnected basis, at levels that are too low to drive behavioural change (UN, 2020). The *carbon pricing gap* (CPG) indicator is used to measure the stringency of the policies implemented. It is calculated as the difference between the benchmark values (BV), mentioned above, and the effective carbon rates (ECR), expressed as a percentage. ECR is calculated by combining information about the coverage and price of the mechanisms implemented in the legislation (Dolphin et al., 2020), and represents the price of CO2 emissions from energy use (OECD, 2018).

$$ECR = Explicit\ carbon\ taxes + Specific\ taxes\ on\ energy\ use + Emission\ permit\ price$$

$$CPG = \frac{BV - ECR}{BV}$$

The CPG can be interpreted as the extent to which polluters are not paying for the damage of their emissions (OECD, 2018). The largest and most comprehensive assessment of ECR to date is The Effective Carbon Rates 2018 by the OECD. The proportion of emissions priced at different levels in different sectors in OECD countries can be seen in Figure 1. Figure 2 shows a summary for all sectors and Figure 3 shows the CPG per sector.

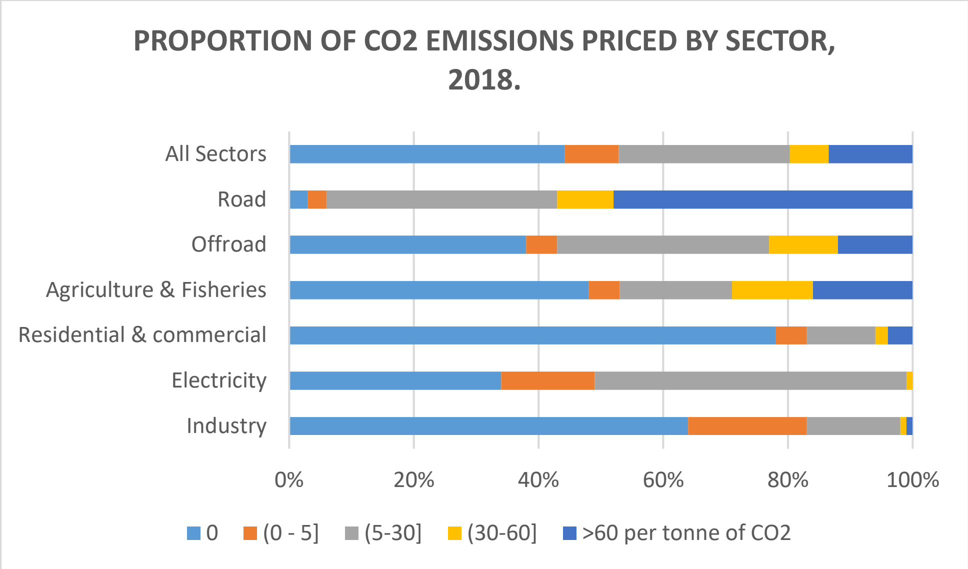

Figure 1: Effective carbon rates per sector and overall. Source: Author, 2020 based in OECD (2018)

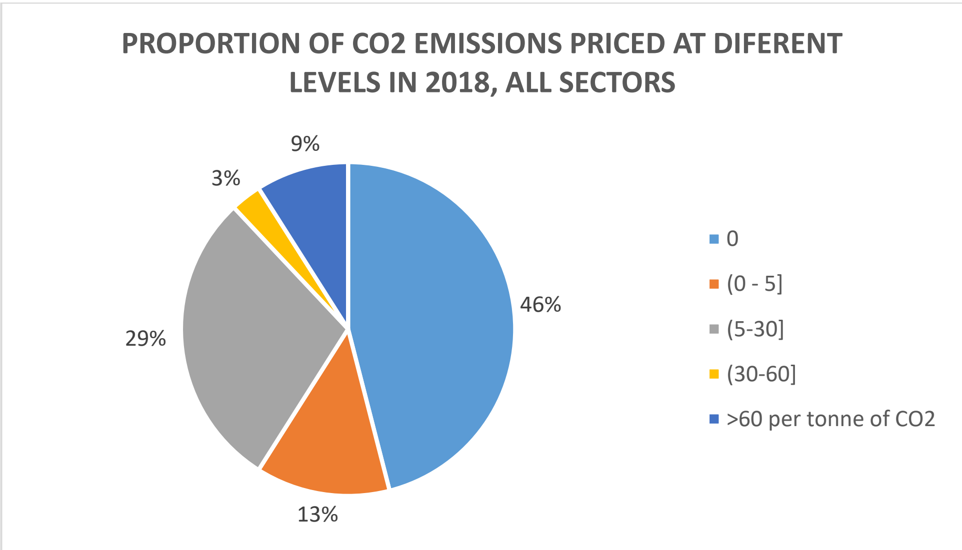

Figure 2: Proportion of CO2 emissions priced at different levels in 2018, All Sectors. Source: Author, 2020 based in OECD (2018)

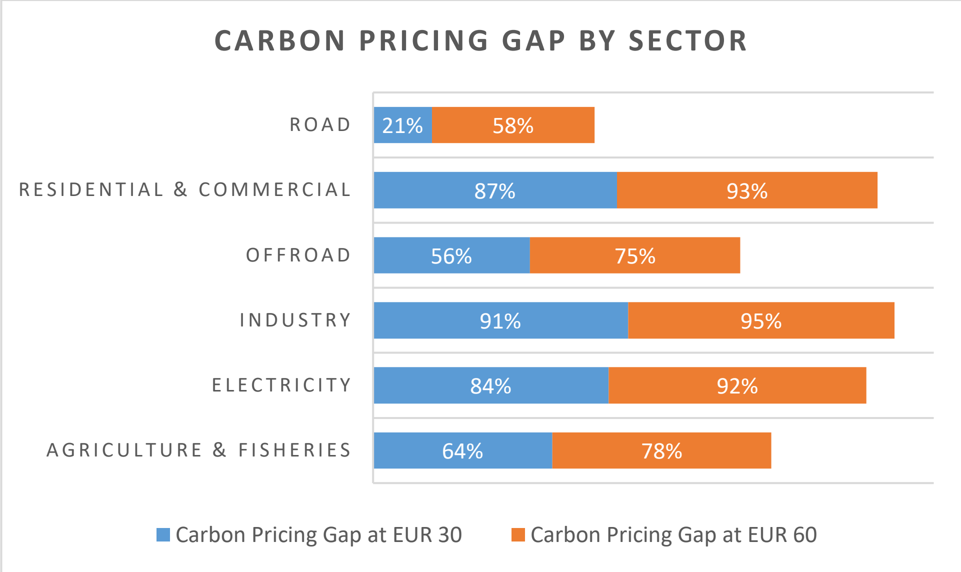

Figure 3: Carbon pricing gap per sector. Source: Author, 2020 based on OECD (2018)

Especially alarming is the fact that the CPG for industry exceeds 90%, while it accounts for over a third of the global CO2 emissions, and is responsible for nearly two-thirds of the increase of CO2 emissions in 2018 (OECD, 2019b). Energy-intensive industries (EIIs) are the most polluting sub-sectors, accounting for 64% of the total industry emissions (Gerres et al., 2019) and 30% of global GHG emissions (Fischedick et al., 2014). There is evidence that the gap is narrowing but at an extremely slow pace; if the gap's decrease was to continue by the current 1 percentage point a year, it would close by 2095 (OECD, 2018). This reflects the low stringency of carbon pricing policies and the urgent need to increase it.

2.1.2. Constraints to increase the stringency of carbon pricing policies

Two main forces are commonly pointed as influencing the design and preventing the full implementation of carbon pricing policies, explaining their low stringency; the fear of losing competitiveness in an ever more globalised economy, and political economy constraints. The former is developed in the next section. There is abundant literature on the political economy forces that constraint the stringency of carbon pricing policies and they can be classified into four groups. First, the existence of **large energy-intensive industrial sectors (EIIs),** whose large concentration of assets would lose a substantial share of their value (Jenkins, 2014), decreases the chances of implementation of carbon pricing policies and lower their stringency (Dolphin et al., 2020). Second, the ***public good* nature** of climate mitigation policies adds extra challenges. Namely, the large number of stakeholders involved, the diffuse nature of the climate externality that prevents for classic collective action to take place, and the fact that the collaboration of the main actors required to mitigate emissions is hindered because they bear a higher share of the mitigation costs than the benefits (Jenkins 2014, Tirole 2012). Third, the **low public acceptability** of the policies, especially in the form of a tax (Carattini et al., 2017)**,** that leads to low willingness to pay for, and high citizen resistance against, climate mitigation (Jenkins, 2014) regardless of whether the net cost is reduced to zero through tax refunds or other fiscal mechanisms (Dolphin et al., 2020). In this regard, UN (2020) analyses the negative socio-economic effects that carbon pricing policies could impose in the most vulnerable sections of the society. Fossil-fuel subsidies provide them with access to affordable energy, which would be lost if affordable and clean energy sources are not available. Thus, between the environmental goals of reducing CO2 emissions, and the humanitarian goals of providing universal access to energy would be at conflict (UN, 2020). Fourth, the **share of electricity**

coming from fossil fuels – and especially from coal- negatively impacts the stringency of carbon pricing policies (Dolphin et al., 2020). Although not intrinsically a political economy constraint, empirical research demonstrates a direct correlation between **GDP per capita** and both the decision to implement and the stringency of implemented policies. Carbon pricing induces additional costs, which wealthier legislations are better equipped to bear (Dolphin et al., 2020).

2.1.3. Competitiveness and carbon leakage

The effects of carbon pricing policies on the competitiveness of firms and sectors have been the focus of a large share of the literature on carbon pricing research. The different definitions and categorisation of the effects can be grouped into three main levels; firm, sectoral and national.

At the firm level, the effects will depend on the energy-intensity and energy-efficiency of the firm. *Ceteris paribus*, those firms with lower energy efficiency and higher energy intensity within a sector will face relatively higher production costs than more efficient firms (Aldy, 2017). This would decrease their competitiveness while providing an incentive to increase their energy efficiency and reduce their CO2 emissions (Aldy and Pizer, 2015). At the sectoral level, the effects on competitiveness arise from the difference in production costs induced by the regulation in sectors competing for the same international market. When legislations implement carbon pricing policies, the domestic production of the sector subjected the policy would be in a disadvantage against non-regulated countries with cheaper energy costs (Arlinghaus, 2015). This would be the cause of *carbon leakage*, in which energy-intensive industries would move to less-regulated countries, converting them in *pollution havens* (Wagner and Timmins, 2008). This would damage the local economy and potentially increase global emissions (Partnership for Market Readiness 2015, Carbon Market Watch 2015, Ellis et al. 2019, Wesseling et al. 2016). As a result, an increase in unemployment and a decrease in the level of investment is expected as firms struggle to keep up with the increased costs of production (Aldy and Pizer, 2015). At the national level, the effects of carbon pricing policies are less clear as the economy of a country consists of different sectors. The competitiveness of a whole economy is also determined by other factors like labour regulation, openness to trade and investment, labour skills and ability to innovate (Arlinghaus, 2015).

Most *ex-post* empirical studies find no statistically significant effects of carbon pricing policies in different dimensions of competitiveness (Ellis et al. 2019, Ferguson and Sanctuary 2019, Ecorys 2013, Arlinghaus 2015, OECD 2018), as well as no evidence on carbon leakage (CMW, 2015). Arlinghaus (2015) performs a thorough review of the literature analysing the empirical effects of carbon pricing on various indicators of competitiveness at the firm and sectoral level. The findings of all the reviewed articles arrive at the same broad conclusion: carbon pricing leads to substantial emissions abatement while not affecting the competitiveness of firms subjected to the policy. It is important to note that this does not mean that carbon pricing would never affect competitiveness. However, if carefully designed and implemented, carbon pricing can be introduced without eroding competitiveness. These findings are in line with the PMR (2015), which stated that carbon pricing policies have not induced carbon leakage on a significant scale but have rather enhanced innovation that offsets the costs of compliance with the policy. It is widely accepted that firms do not compete only on costs but also on the efficiency of turning different inputs into products and services with high value-added. However, for certain industries offering homogeneous products as commodities, cost competition is still highly relevant. While these findings provide strong evidence that carbon pricing does not necessarily affect the competitiveness of firms in the short term, the picture for the long term is auspicious. Subjected to carbon prices, firms are motivated to develop innovation such as more energy-efficient processes which in the long term will make increase their competitiveness (Arlinghaus, 2015). Industries or sectors with low carbon pricing gap are considered to have higher long-term competitiveness, as they are well prepared for a strong performance in an ever-closer low-carbon economy (OECD, 2018).

2.1.4. Drivers of carbon leakage

The hypothetical relocation of emissions resulting from the implementation of carbon pricing policies would take place through the substitution of domestic production by imports of inputs or final products, or through the complete relocation of industries. Droege (2013) identifies four categories of factors that would drive the relocation of emissions -and investment- resulting from carbon pricing. First, **the impact of the carbon price on sectors' cost structure** in the form of both direct costs, as the price paid for ETS or taxes on carbon, and indirect costs, that arise when upstream processes pass-through the carbon costs to downstream firms, particularly in electricity generation. Second, **the ability of a sector to pass-through increased costs**, which is determined by many factors that are unique to each sector. These factors are the level of competition and product price adjustment, the price elasticity of demand, the differentiation of products or services, demand trends, flexibility for substituting inputs, trade flows and transport costs. Third, **the abatement potential of a sector** which represents the alternative option for EIIs to paying a price for carbon, as long as new and appropriate technology is available, and implementing it is less expensive. Fourth, the **regulatory and policy environment** are important determinants for investment, as they represent the long-term expectations, contracts and the particular costs and pricing environment. Firms must rely on the available knowledge about options and risks, and the foreseen interactions between political support and future business opportunities.

As explained by Åhman et al. (2017), even when empirically unproven, the carbon leakage hypothesis and competitiveness concerns have been an important policy challenge and barrier for EIIs decarbonisation. Climate policy has been globally unable to provide long-term certainty and transformative responses required for EIIs decarbonisation. Instead, implemented policies have enhanced energy efficiency and focused on marginal emission abatement. At the same time, most EIIs have been protected from cost increases through the free allocation of permits, tax exemptions and compensation schemes at the expense of the policies' efficiency. The numerous exemptions and free allocation of permits have failed to make EU ETS an effective instrument, as emissions from the industrial sector have not decreased since 2012 and are not predicted to do so until 2030. Further, EIIs have received large amounts of free emission allowances, resulting in large profits from a system that is meant to make polluters pay (Carbon Market Watch, 2019). As a consequence, over 90% of industrial carbon emissions take place with no costs to the firms. The deep decarbonisation of EIIs requires globally coordinated action to allocate sufficient resources, enhance technology transfer, and avoid both unfair competition and carbon leakage (Åhman et al., 2017).

2.2. The theory of induced innovation

The concept of induced innovation has been long known. The first insights were given by Hicks (1932), who noted that *"a change in the relative prices of the factors of production is itself a spur to invention, and to invention of a particular kind - directed to economising the use of a factor which has become relatively expensive"* (p. 124). The mechanisms through which induced innovation works, as explained by Kennedy (2018), are seen in the panels of Figure 4. The X and Y-axis represent the quantity of inputs required to produce the good, the orange line represents the ratio of prices, and the dark-blue line represents the isoquant, resulting from all the existing technologies to produce a certain amount of the good.

Environmental damage is considered as an input represented by X, and all the other inputs are represented by Y. Panel 2 shows an increase in the cost of environmental damage, changing the relative prices of the inputs and incentivising the manufacturer to move to a new point in the isoquant, using a higher quantity of the now relatively cheaper input Y and less X. Panel 3 shows a new isoquant closer to the origin, induced by the effect of technological progress represented by the light-blue line. In this situation, it is possible to produce the same amount of good using fewer inputs. The development of new technology favouring particular inputs can be enhanced by policies. However, in the absence of policies, it would be expected to follow a neutral path as the light-blue line in Panel 3. Panel 4 shows how a carbon pricing policy induces technological change and its effects on the consumption of input X. A rise in the price of CO2 emissions would increase the cost of input X, spurring innovation aimed at using less of that input (represented by the steeper light-blue line) and moving the isoquant closer to the origin. It can be seen that the new technology enhances a reduction in input X. Panels 2 and 4 combined represent the effect of a higher carbon price in both using less carbon-intense inputs and developing or implementing new technology. This implies that climate policy can influence the rate and direction of technological innovation in the energy systems (Wang et al. 2019, Popp 2010).

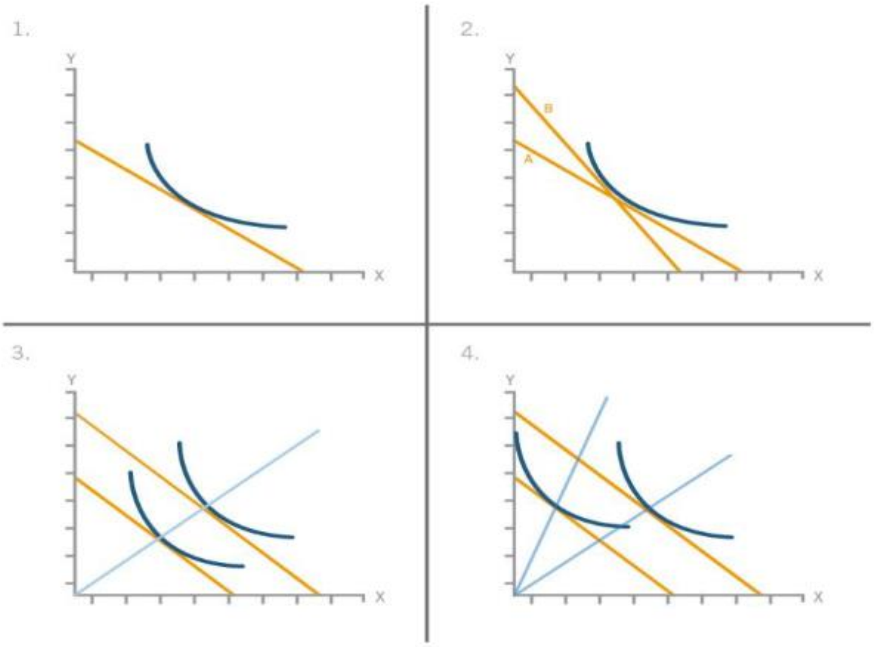

Figure 4: Mechanisms by which induced innovation works. Source: Kennedy 2018, p.10.

Innovation is a product of complex mechanisms, and it can be analysed from different perspectives and using different assumptions (Grubb, 2004). Empirical research on the subject is abundant and has found a large number of problems to test the induced innovation hypothesis. Different assumptions on how technology advances and various economic forces incentivising new developments are difficult to assess and control for (Kennedy, 2018). There is also an identification problem, as changes in the relative use of inputs can be due to substitution, technical change or a mix of the two, demanding a highly accurate specification of the production function (Jakeman et al., 2004). Gans (2012) estimates that a more stringent carbon policy would reduce the scale of carbon-intensive fuel usage, reducing incentives to improve fossil fuel efficiencies. As the results of studies estimating the potential CO2 emission reductions are highly dependent on both the models used- which inherently have limitations-and the data available, there is no agreement in the degree of innovation that carbon pricing could enhance. However, Kennedy (2018) reviews various studies and finds clear evidence that the increase in clean technology innovation is higher in the presence of a carbon tax than what it would be without it, lowering the costs of achieving a given level of emissions reduction. It is important to consider that the social benefits of cleaner technology are far larger than the private benefits of the firms implementing them, which represents a second market failure. To address both, regulation should include *direct emissions* policies that put a cap or price on emissions, and *technology-push* consisting on policies that enhance R&D investment by, for example, using the tax revenues as subsidises to R&D and capital equipment investment (Goulder, 2004). Further, estimations of the effect of induced innovation in the economy demonstrate a higher economic growth with this policy combination than what it would when the revenues are not dedicated to R&D (Kennedy, 2018) . When taking the social benefits into account, the incentives of carbon pricing policies to spur innovation are even bigger (Kennedy, 2018).

Wang et al. (2019) developed an original version of the Solow productivity model and analysed national-level historical data to investigate how energy-efficiency was affected by cost increases. They find that countries increased their energy efficiency or reduced their energy consumption by other means when the energy costs represented a larger fraction of the production costs. These findings are in line with Fried (2018) who finds that a price on carbon induces large changes in innovation, amplifying the price incentives induced by the carbon tax and reducing the relative price of clean to fossil energy.

2.3. Decarbonisation of energy-intensive industries (EIIs) and the role of Government

2.3.1. Description EIIs and challenges in their regulation

The EII is a subsector of industry compounded by oil refining, steel, petrochemicals, cement, ceramics, glass, paper and pulp production (Wesseling et al., 2016). EIIs provide the materials on which society relies, forming the base of the economy (Fischedick et al., 2014). There are three common characteristics of EIIs. First, the presence of economies of scale, which leads to both large-scale processing plants and the emergence of industrial clusters (Wesseling et al., 2017). Second, the high energy inputs required in processes that transform natural resources into basic materials, resulting in large GHG emissions (Wesseling et al., 2016). Third, high capital intensity as a consequence of large investments in infrastructure and technology with payback periods of 20 to 40 years, which provides few windows of opportunity to change technology (Wesseling et al. 2016, Droege 2013). These conditions create high barriers to market entry -and exit-, resulting in a small number of well-established multinationals owning factories around the world, and having a dominant position in the supply of basic materials (Wesseling et al., 2016). Partly because of these characteristics, EIIs face greater difficulties in the decarbonisation challenge than other sectors as the best available technologies (BATs), even when applied on a large scale, can curb emissions by 15–30% at best (Fischedick et al. 2014, Åhman et al. 2017). Åhman et al. (2017) explain that EIIs compete mainly on volume and price in international commodity markets. Therefore, differences in carbon prices resulting from dissimilar emission reduction goals of legislations affect them considerably, influencing the firms’ location and investment decisions. However, the authors note that these decisions are also influenced by a myriad of other factors such as the macro-economic conditions, political stability, transport infrastructure, labour legislation, access to markets and feedstock, and industrial policy among others.

Despite increasing pressure from local stakeholder groups on policymakers to regulate EIIs more stringently, the GHG emission control has been so far lenient, seeking to safeguard the sectors' economic competitiveness. Policies regulating EIIs have focused on incremental rather than radical innovation (Wesseling et al., 2016) even though it has been clear for decades that the latter is required to bring about a significant product, process and systems transformations, beyond those that dominant industries are capable to incrementally develop. Voluntary or negotiated agreements have been achieved, but they have been ineffective so far because the industry sector compromises only with what they can achieve with *business as usual* (Ashford, 2005).
EIIs are economically important sectors characterized by powerful, highly coordinated and well-connected lobbying groups, who oppose regulation. The industry associations usually align with the most conventional member and protect their competitiveness against any regulation perceived as threats (Wesseling and Van der Vooren, 2017), as the case of GHG emission regulations which induce new costs for the firms. They have also used the hypothesis of carbon leakage to avoid regulation, even though this theory applies only to some extent in sectors producing commodities, competing mainly on price in international markets, and not for specialised materials (Wesseling et al., 2016). EIIs are usually suppliers of other companies who will not pay a premium for low-carbon basic materials, as they assume that they will not be able to pass-through this extra cost to the end-consumer (Wesseling et al., 2016). The distance of EIIs from end users makes them less exposed to pressures from consumers demanding more sustainable practices, which combined with the small market for low-carbon materials creates an important barrier for the low-carbon transition. Regulating EIIs without surrendering to the pressure of firms that oppose it is essential to both stimulate radical innovations, unlikely to be created by incumbent firms, and bring economic profit to innovating firms (Ashford, 2005).

2.3.2. The role of Government in the industrial transition

As stated earlier, government intervention is crucial to solve environmental challenges that markets cannot -or at least have not been able to- solve on their own. A well-designed green industrial policy that at the same time prevents from carbon leakage and incentivises firms to implement low-carbon technologies is as important as it is challenging. The fact that our economies and systems are heavily based on fossil fuels makes any intervention altering their business cases - production and trading- an extremely sensitive and complex task, with broad and unforeseen consequences. The literature about the role of the government in the industrial transition and the appropriateness of regulatory interventions is varied, mostly differing on the extent to which government action is required and desirable to guide or induce transformations in the economy.

The most dominant approach during the last decades has been inspired by the neo-classical economic thinking based heavily in neoliberal ideals, which translates into the *market failure theory*. Guided by this approach, governments have followed economic principles that suggest market solutions to economic challenges, restricting government interventions to the provision of remedies for market failures (Busch et al., 2018). Advocates of the *market failure theory* argue that market failures are a necessary but not sufficient condition for government intervention (Mazzucato, 2015). According to Mazzucato (2015), the criteria for sufficiency results from a cost-benefit analysis of the benefits from the intervention against the associated governmental failures, of which three cases are identified. First, governmental decisions captured by private interests in cases involving nepotism, cronyism, corruption or rent seeking. Second, misallocation of resources by for example *picking winners and losers*, which is an implicit risk to most government interventions aimed at helping a certain group or sector, putting those sectors who do not receive the aid in a disadvantage. Third, undue competition with private initiatives and leading to the *crowding out* effect, which suggests that the rise in public spending leads to a reduction or private spending. This would happen when large states increase their borrowing, leading to substantial increases in the real interest rate, which in tun absorbs the economy's lending capacity and discourages businesses from making capital investments (Klenton, 2019). However, in modern economies operating well below capacity, government spending can even increase demand by creating employment and stimulating public spending, in an effect known as *crowding in* (Klenton, 2019). Mazzucato (2015) identifies four limitations of the market failure theory. The first is directionality, which relates to the assumption that after the intervention has been made and the market failure corrected, market forces on their own will know the direction of growth and development and direct the economy towards that path. Nevertheless, markets often provide a direction of change that is sub-optimal from a societal perspective as they are driven by private profits rather than by societal welfare. The second is evaluation and relates to the methods in which the market failure theory to evaluate whether the benefits of an intervention outweigh the costs of both implementing the policy and the governmental failures mentioned earlier. The author suggests that the micro-economic cost-benefit analysis tools are inappropriate to make such an evaluation as they are static, whereas economic development is a dynamic process. In this sense, current evaluation mechanisms do not measure the full impact of the implementation of a policy, as they do not consider the scenario in which the policies implemented transform existing or create new landscapes. The third limitation is organisation and it relates to the extent to which the state gets involved in the economy and the knowledge capabilities it obtains from its involvement. According to the market failure theory, the state should intervene as less as possible, which has led to massive outsourcing from governments to the private sector, preventing the government to acquire the required knowledge to drive and manage change. The fourth limitation consists on risks and rewards and relates to the distribution of risks and rewards when the government is the lead investor in capitalist economies through mission-oriented investments and policies. For instance, if the government invests in an innovation that fails, the taxpayers are the one that pay the costs, but the rewards are not distributed to taxpayers in the case of government investments in innovation that succeeds.

On the other hand, a more radical approach argues that the only way to achieve sustainable and prosperous development lies in a radical transformation of the economic systems as we know them and a more important role of the government in the economy (Busch et al., 2018). This approach follows Joseph Schumpeter's ideas that put innovation and *creative destruction* as the drivers of economic progress. These notions provide the foundation for the neo-Schumpeterian approach, giving an alternative role of the government, whose action and intervention would create and shape markets rather than being limited to respond to market failures (Busch et al. 2018, Mazzucato 2015). Furthermore, this stance suggests that government intervention in the economy is acceptable, desirable, and required to achieve a low carbon development (Busch et al., 2018). According to Busch et al. (2018), the neo-Schumpeterian approach involves two important insights about the benefits of a low-carbon transformation for economic and social development. First, the adoption of low carbon technology would act as a driver for further economic development, as technological and organisational innovation leading to the implementation of low-carbon technology would allow for the cost reduction of key production inputs. Second, it recognises innovation competition instead of price competition as the principal coordinating driver of the economy. According to the authors, this suggests that there are various possible trajectories for economic development, each of which might lead to radically different economic and social outcomes. Each possible economic development pathway is determined by the interactions and activities of networks of both private and public sector actors to create new technologies and business models, and the institutional frameworks that shape the markets in which these interactions take place. Under this perspective, restricting the government to only provide remedies for market failures, like internalising the cost of CO_2 emissions through carbon taxes, is not appropriate and even misguided, as it overlooks the wider institutional changes that are needed to support the mechanisms driving low carbon innovation (Busch et al., 2018). For example, the lack of finance for low-carbon technology to be scaled up, or the lock-in of industries heavily based on fossil fuels need of such a wider institutional change and support mechanisms that can only be achieved by a more active role of the government in the economy. This more active role can be exerted by creating and shaping markets and identifying key industrial sectors that can drive the industrial transition (Mazzucato, 2015).

2.4. Port competition and competitiveness

2.4.1. Contested definitions

The definition of port competition and competitiveness has historically been contested and there is no consensus in the literature on their definition (Scaramelli, 2010; van der Sluijs, 2007). The multifaceted characteristic of ports and the complex nature of the system that develops around them (Notteboom and Yap, 2012) leads to different approaches to competition and competitiveness, making it difficult to give an overarching definition.

Ports are seen as dynamic business networks, in which the success of the actors is highly correlated with the competitiveness of the whole system. Thus, the port's network value proposition depends to a great extent on the cooperation of the entire port community to develop and use resources efficiently, and to build competencies and capabilities (Parola et al., 2016).

2.4.2. Port competition

The definition of port competition and its drivers have evolved hand in hand with the development of the maritime industry, with each definition expanding the scope of the previous ones. They aim at defining the different areas in which competition is held, and the main actors competing in each.

Van de Voorde and Winkelmans (2002) identify three levels of competition. First, intra-port competition at the operator level, in which port operators compete with each other in each traffic category within a port. Second, inter-port competition at the operator level in a given traffic category, between operators from different ports located in the same range and serving an overlapping hinterland. Third, inter-port competition at the Port Authority level, who aims at increasing the competitiveness of the ports by providing infrastructure, enhancing public investment, optimal working conditions and fair competition within the port.

Haezendonck (2001) follows a similar approach to defining competition. However, she identifies an important fourth competition level; inter-port competition at a commodity level, in which actors compete for market share in a specific traffic category.

Both approaches stress that competition does not take place between entire ports, but rather between terminal operators or port undertakings on specific traffic segments. Also, the pre-condition for the competition are overlapping hinterlands (Scaramelli, 2010). This builds the notion of contestable hinterlands, as regions in which no single port has a clear cost advantage over competing ports, and several ports will have a share of the market (De Langen, 2007).

A different approach is taken by van der Sluijs (2007), who makes an important distinction between two seaport functions. Depending on the port function and the traffic segment being

analysed, there are either different determinants of port competition, or they overlap with different meanings.
The first function is as main port cargo throughput, in which competition occurs in different segments; containers, general cargo, dry and liquid bulk.
The second function is a place of business for industries and services. The author identifies 7 categories of determinants for port competition and suggests on their operationalisation as seen in Table 1.

Category	Determinant	Operationalisation
Fiscal	Fiscal climate	VAT, taxes
	Capital structure	Availability of risk capital
Labour	Availability of labour	Quality, quantity, costs, productivity, loyalty
	Labour organisation	Legislation and organisation, contracting and right of dismissal, flexibility of working hours, power of trade unions
	Skilled labour	Educational level
Space and infrastructure	Availability of space and real estate	Space for development, ground, industrial sites, headquarters
	Port Infrastructure	Available room and transhipment capacity
	Infrastructure of hinterland	Per mode, proximity of rail and inland shipping terminals
	ICT Infrastructure	
Accessibility	Maritime accessibility	Draught, nautical access
	Accessibility of hinterland	Flow, congestion, reliability of travelling time per mode
	Hinterland transport services	Price and quality of transport services per mode, quality of logistics service providers
Policy, legislation and regulations	Port policy	Quality of management and organisation
	Customs and inspection	Notification, fitting into the supply chain, service provision
	Legislation and regulations	Stability, permit procedures
	Enforcement level	
Natural and living environment	Environmental aspects	Relative to attracting labour
	Living climate	
Other	Stability of the business climate	Strikes, water levels, politics, earthquakes, crime rate
	Innovation	

Table 1: Determinants of port competitive position as a location for investment for industry and services according to van der Sluijs (2007, p.20). Source: van der Sluijs (2007, p.20)

On a different perspective, van Hassel et al. (2016) sees port competition taking place between *logistics chains*, which is also called the *transport nodes* perspective. Goods are moved by a logistic company from a hinterland region to a port where a shipping line moves the cargo to another port, from where the freight is transported to its destination by a hinterland operator. Under this perspective, ports are seen as mere links, and the chain with the lowest generalised cost will emerge as the most successful chain. The most important performance indicator here is the throughput volume.

The *cluster perspective* developed by De Langen and Haezendonck (2012) complements the later approach by applying cluster theories to ports. A key aspect is a recognition that interdependent firms cluster together in port regions, coordinating and sharing resources in various ways. This perspective provides four advantages. First, more determinants for port competitiveness like the intra-cluster competition. Second, additional measures of performance such as value-added. Third, a recognition of the inter-dependence of firms operating in the cluster, and collective action as a key element to enhance its competitiveness. Fourth, it addresses the importance of the Port Authority in attracting and facilitating industrial activity in the port region and improving the competitive position of the whole port complex. The key indicator under this perspective shifts from throughput volume to value-added in the port.

2.4.3. Port competitiveness

Building on the concept of port competition as a state of the market, port competitiveness is associated with how actors move within competitive scenarios. The concept is explained by Scaramelli (2010), who notes that it relates to the ability of producing and selling while facing competition, reacting to the strategy of competitors, competing within the market conditions and entering new markets. Furthermore, she explains that competitiveness relates to the ability of a given port to add value to the goods and services it provides by increasing the quality and securing customer loyalty. Lastly, she remarks that the concept includes both economic and non-economic aspects, quantifiable and not quantifiable, making competitiveness ever more related to quality more than quantity.

The study of the drivers of port competitiveness is as varied as its definitions. Parola et al. (2016) perform an exhaustive critical literature review on such drivers. They recognise the multifaceted nature of port competitiveness, finding many drivers that may be within or out of the Port Authority's control. The authors prioritise the main drivers of port competitiveness according to the number of citations of each one in academic papers selected from leading peer-reviewed international journals. A summary of their findings is shown in Table 2.

Rank	Driver	Definition
1	Port costs	Costs faced by customers. Direct as port fees or indirect as the costs incurred because of delays
2	Hinterland proximity	Geographical proximity to the main hinterland markets served by the port
3	Hinterland connectivity	Efficiency of inland transport networks
4	Geographical location	Position relative to shipping networks, inland market areas, logistic centres, etc.
5	Infrastructure	Number and quality of infrastructures and their appropriateness relative to customers' needs
6	Operational efficiency	Capacity to employ all its resources efficiently to deliver high performance
7	Port service quality	Quality of port facilities and capacity of differentiation against competitors
8	Maritime connectivity	Efficiency of shipping transport networks

9	Nautical accessibility	Capacity to accommodate large vessels at anytime
10	Port site	Extension of the entire port area, quality of terminal layouts and common spaces

Table 2: Drivers of port competitiveness according to Parola et al. (2016, p.7-8). Source: Parola et al (2016, p. 7-8).

Although the drivers in Table 2 are clearly stated and explained, they are not specific to a stakeholder, i.e. for an inland logistic operator the drivers of competitiveness will be different than for a shipping company, and for an investor willing to reinvest or looking for a port to locate his business.

Following that logic, Hales et al. (2016) develop *the balanced theory* as a model that simultaneously considers the effect of port strategy on customers, as *volume competitiveness*, and investors, as *investment competitiveness*. The drivers for each category according to the authors are shown in Table 3.

Rank	Volume competitiveness	Investment competitiveness
1	Port location	Port reputation
2	Service level	Financial resources
3	Port fees	Institutional structure
4	Port facility	Price
5	Cargo volume	Legal framework

Table 3: Drivers of port competitiveness for customers and investors according to Hales et al. 2016. Source: Author, 2020 based on Hales et al. (2016)

2.5. Conceptual framework

The first section of this chapter defined carbon pricing policies, explained how their adequate implementation allows for curbing CO2 emissions, and presented an overview of their current state and trends of their implementation. It stressed the importance and urgency of increasing their stringency as both carbon price levels and coverage, to adequately correct the market failure and internalise the environmental costs of CO2 emissions (see Figure 5). It summarised the main constraints preventing the full implementation of carbon pricing instruments with special focus on competitiveness issues and the hypothesis of carbon leakage through which emissions and investment would relocate to less-regulated legislations. This section finalised with the identification of the theoretical drivers of carbon leakage and the loss of competitiveness. The second section presented the theory of induced innovation, which proposes that firms would make a more efficient use of production inputs that increase their costs. This would be done by innovation aimed at increasing the efficiency of production processes or more radical innovation aimed at replacing the production input and not using it at all. The third section focuses on EIIs and the role of the government in their decarbonisation. It summarised the most important aspects and challenges faced in their decarbonisation and the difficulties to regulate them. Most importantly, different views in the literature about the role of the government and the appropriateness of its intervention in the economy were presented; from a spectator intervening only to fix market failures to an active institution creating and shaping markets. The third section focused on port competitiveness and presented different approaches to address port competition and competitiveness, stressing the importance of adequately identifying the specific segment and perspective for which competitiveness is assessed.

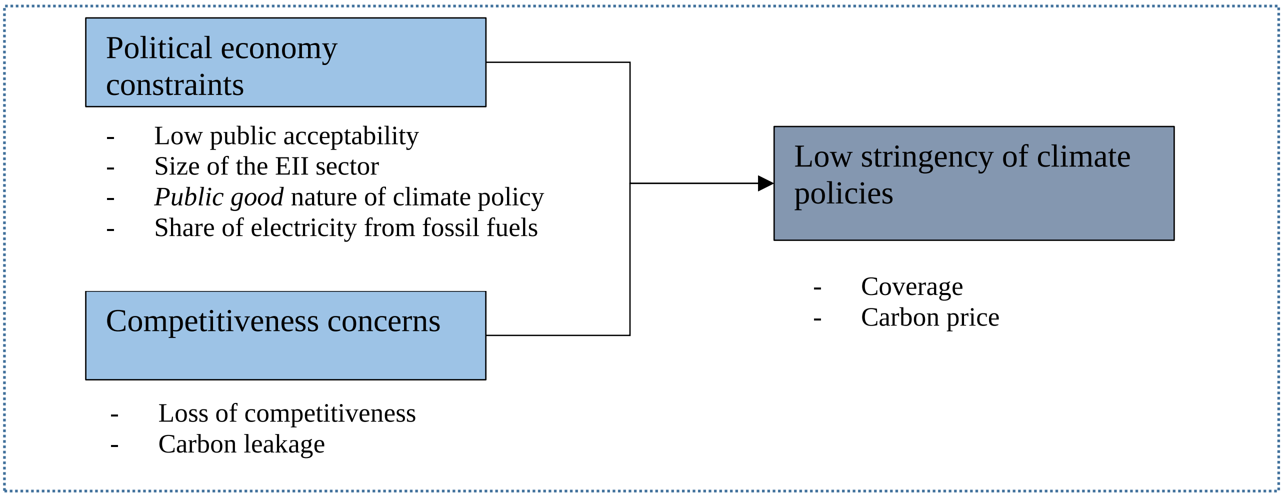

Figure 5: Context of the conceptual framework. Source: Author, 2020

The four sections developed in this chapter, as well as their expected causal relationships can be seen in the conceptual framework presented below.

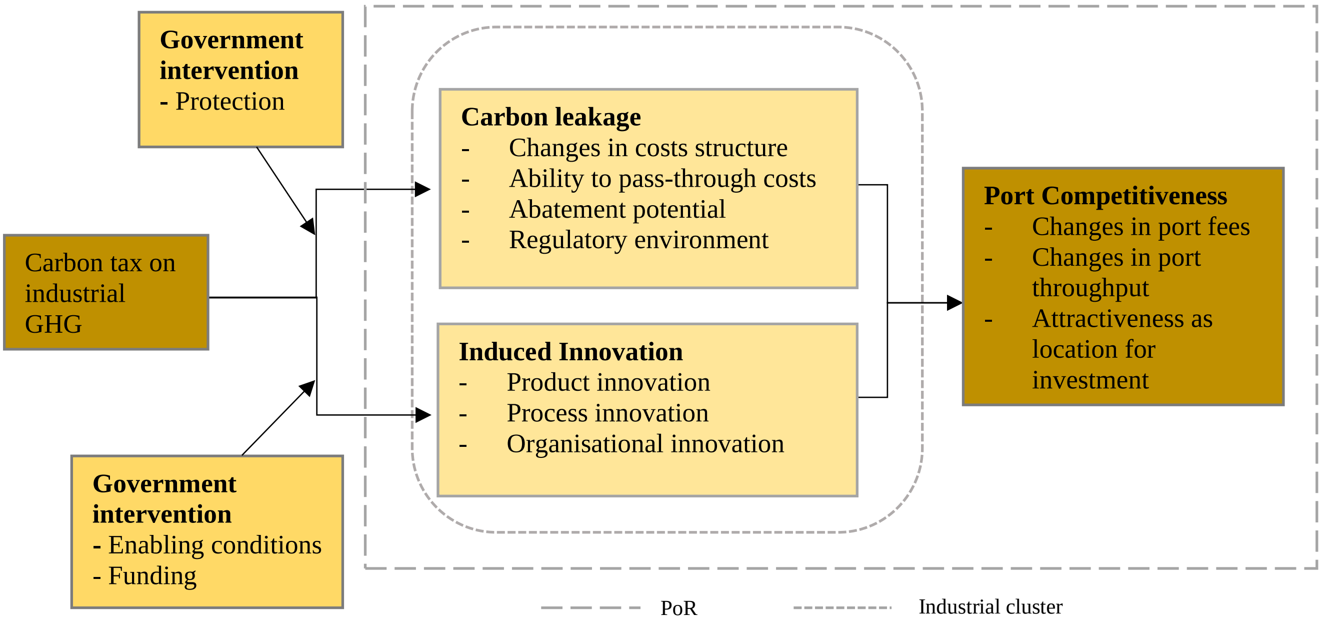

Figure 6: Extended conceptual framework. Source: Author, 2020

The conceptual framework consists of four parts. The first part will investigate the mechanisms by which the increased price of carbon will impact the competitiveness and induce carbon leakage in the firms operating in the IC of the PoR. A set of indicators will be developed for each driver of carbon leakage based on the theory presented in this chapter. The second part relates to the incentives that an increased price of carbon has on inducing technological innovation aimed at the decarbonisation of EIIs, potentially increasing their competitiveness in the low-carbon economy. The third part will investigate whether government intervention can mediate the effect of a carbon tax in the loss of competitiveness and prevent carbon leakage from taking place, while creating the conditions for firms to invest in low-carbon technology innovation. Furthermore, the aim is to identify the specific mechanisms – policies and regulations- that would prevent carbon leakage to occur on the one hand and incentivise the industrial transition on the other hand. The fourth part relates to how these combined effects will affect the competitiveness of the PoR by focusing on impacts in port fees, port throughput and its attractiveness as a location for (re)investment and production. This will be done by investigating if a higher price of CO2 emissions has the potential to reduce the production levels for firms operating in the IC or divert investment towards competing ports, thus affecting the competitiveness of the PoR. These effects will be measured with indicators created for selected drivers of the port competitiveness theories developed in this chapter.

Chapter 3: Research design, methods and limitations

This research is assessing the effects of a carbon tax in the attractiveness of the industrial cluster of the PoR as a location for investment, and consequently on the competitiveness of the PoR. According to the theory presented in the previous chapter, by increasing the cost of emissions, a carbon tax has the potential to induce both carbon leakage and technological innovation. Government intervention can play a key role buffering and enhancing these effects respectively, which is why identifying the critical points of intervention is of great importance. This chapter presents and describes the research design chosen to answer the research questions. It includes the research strategy, primary and secondary data collection methods, sampling method and sample, variables and indicators used, and data analysis technique. The validity, reliability, and limitations of the study are also discussed at the end of this chapter. The sample is included in this chapter before the operationalisation table, as many of the indicators refer to perceptions of experts of the sample.

3.1. Description of the research design and methods

This research will use the case study as a strategy. According to Van Thiel (2013), the case study can focus on almost anything that the researcher wants to research, from companies and organisations to processes, laws and decisions. The case study provides tools to investigate complex phenomena within their contexts (Baxter and Jack 2008, Blatter and Blume 2008). Under this strategy, the context in which the case is inserted is especially relevant, as it is assumed to strongly influence the phenomenon under study. Hence, the subject of the study is explored and explained in a real-life context, requiring in-depth rather than broad knowledge (Van Thiel, 2013). The case study usually focuses on a relatively small number of study units and a large set of variables, allowing the researcher to take a holistic approach to investigate the phenomenon. It requires large amounts of qualitative data to be collected and analysed, which provides high internal validity to the findings. The selection of the specific cases can be motivated by their unique characteristics, because they represent an example of the phenomenon being researched, or because it is the phenomenon's first occurrence. Research aiming at exploring, describing, diagnosing, designing and evaluating a phenomenon in its context usually use the case study as a strategy. There are several challenges inherent in this strategy. First, the tendency to widen the research's scope by trying to answer overly broad questions or focusing on an excessive number of objectives for one study. This can be overcome by strictly defining the case and placing boundaries to the study (Baxter and Jack, 2008). Second, as the investigated phenomenon is heavily influenced by is context, the findings often have low external validity, making them difficult to generalize. Triangulation with data obtained by different methods can strengthen the validity and reliability of the findings (Van Thiel, 2013).

The effects of environmental regulation in the competitiveness of energy-intensive firms and sectors are determined by a complex interaction of factors ranging from legislative, regulatory and political frameworks to the specific cost structure of the sectors, market conditions of competition, and technologies available. Given this complexity, the assessment of the effects of environmental regulation is unique to – and depends heavily on- the specific context and characteristics of both the legislation and the sectors analysed, requiring in-depth rather than broad knowledge. These characteristics make of the case study the most appropriate strategy to conduct this research, which investigates a single case ('*Carbon tax in industrial GHG emissions in The Netherlands*'), that was chosen because of the increasingly urgent need to understand the effects of more stringent climate policy in key sectors of the economy. The carbon tax has been formally proposed in the *Dutch National Climate Agreement (2019)* published by the parliament, and there are ongoing consultations with key stakeholders to adjust details for its implementation. The industrial cluster of the PoR represents an interesting case study as it is compounded by highly emitting energy-intensive industries that would be directly affected by the implementation of a carbon tax. On the other hand, the PoR is the base for the economy of the city and a strategic part of the economy of the country. While the Netherlands aims at drastically reducing CO2 emissions within this decade, and the European environmental policy is aiming at a net-zero economy in 2050, the assessment of the effects on the economy becomes of great importance.

3.2. Data collection methods and sampling

3.2.1. Data collection methods

The primary qualitative data used in this study was collected through semi-structured interviews. According to Van Thiel (2013), interviews are conversations in which the researcher obtains information by questioning one or more respondents. The objective of the interviews is to collect *non-factual* information, such as opinions and perceptions, covering information that cannot be obtained by other means. The selection of semi-structured interviews was motivated by both the previous knowledge of the researcher on the phenomenon being investigated, translated into a theoretical framework and the need to acquire new insights into the variables and sub-variables, investigating potential unknown relationships between them. Semi-structured interviews are a flexible method of data collection, as the researcher has the opportunity to ask supplementary questions to the respondents, allowing for a better and fuller understanding of the answers given. In a semi-structured interview, "*the questions are based on the operationalisation of the variables derived from the conceptual framework"* (Van Thiel, 2013 p. 94), which can guide the researcher in the formulation of appropriate interview questions. The questions are similar to all interviewees, which makes their responses comparable. However, the semi-structure interview allows for flexibility and improvisation, depending on the answers and insights given by the respondents. This provides an opportunity to collect and integrate unexpected insights from the responders, enriching the data.

Primary data was triangulated with secondary data to improve the reliability and validity of the study. Secondary data was collected from different sources covering the phenomenon under study, including official policy documents from the Government, studies commissioned by the Government to specialised consulting firms, facts and figures from the Port of Rotterdam Authority, and academic research that partly overlaps with the scope of this study. The search for academic research was done through Google Scholar, official policy documents were obtained from the website of the government's departments, and information of the PoR from their publicly available documents.

3.2.2. Sampling

Van Thiel (2013, p. 45) defines sample as "*a selection from the total population (N) of possible units of study*". She also explains that the need to select respondents arises from the impossibility to reach the entire population and every stakeholder. This study used the non-probabilistic method of purposive sampling to select the respondents. In purposive sampling, the researcher relies on his knowledge and judgement to make the selection of respondents (Dudovskiy, n.d.). The selection is often based on theoretical grounds, and the researcher often selects respondents who have significant knowledge about or represent an important perspective of the phenomenon under study (Van Thiel, 2013). The selection of the type and number of respondents for an interview does not follow fixed rules. The sample size should balance the representativity and depth of the findings. More respondents imply more representative findings at the expenses of depth, and fewer respondents allow for more in-depth knowledge at the expenses of generalization of the findings. Further, the case study strives for in-depth new insights rather than broad knowledge, and its goal is not generalization nor statistical representativeness.

As the operationalisation table presented in the next sub-section includes the data sources, the description of the sample is presented before the operationalisation. Given the complexity of the phenomenon under study in this research, the selection of the sample aimed at including experts from different sectors. This allows gathering the different perspectives about the impacts of a carbon tax in the variables and sub-variables shown in the operationalisation table and finding relationships between them. The sample composition is shown in Table 4.

Nr	Name	Organisation	Sector	Role
1	Bart Kuipers	Erasmus UPT	Academia	Senior researcher port economics
2	Wouter Jacobs	Erasmus UPT	Academia	Senior researcher port and regional economics
3	Arnold Mulder	ABN Amro	Banking	Sector banker energy
4	Juriaan Mieog	Royal Haskoning DHV	Consultancy	Associate director
5	Lennart van der Burg	TNO	Consultancy	Business development manager green hydrogen
6	Diederik Kuipers	Deltalinqs	Industrial	Project engineer climate program
7	Erik Klooster	VPNI – Oil industry	Industrial	Director
8	Martjin Broekhof	VNCI – Chemical industry	Industrial	Head of energy & climate
9	Cornelious Boot	BP Netherlands	Industrial	Head of government affairs
10	Lieuwe Brouwer	Municipality of Rotterdam	Public	Energy transition of the port industrial area
11	Alan Dirks	Port of Rotterdam Authority	Public	Program manager at the policy and planning department
12	Huibert van Rossum	Port of Rotterdam Authority	Public	Energy transition, external affairs & strategic environment management
13	Joris Hurenkamp	Port of Rotterdam Authority	Public	Business manager chemical industry

Table 4: List of interviewees. Source: Author, 2020

3.3. Operationalisation

The concepts presented in the conceptual framework shown in Figure 6 and developed in Chapter 2 are operationalised in this section. They are translated into specific variables and indicators that interviewees can understand and interpret.

The concepts and variables were defined within the context of this study. Sub-variables were created to address the different aspects that the variables intend to measure. Indicators were developed from the sub-variables and are used as a guideline during the interviews. Nevertheless, as this is qualitative research expected to gather new and rich information from the interviewees, the indicators represent the expected outcomes of the interviews. The structure of the interview is developed more openly, allowing for unexpected responses and insights.

Concept	Variables	Definition	Sub variables	Definition
Carbon leakage	Cost structure	Relates to the different types of expenses in which firms incur for the production and trading of their products. It is composed by fixed costs, which do not depend of the production levels, and variable costs which depend on production levels. The impact of carbon costs on an EII producer will depend on the amount of CO_2 emitted during the production process; in absolute and relative terms" (Droege, 2013 p.7)	Direct and indirect carbon costs	"Direct costs are associated with of complying with the rules of the carbon pricing policy (e.g. purchasing of emission certificates or paying the taxes charged). Indirect costs arise when downstream firms need to pay the carbon cost from upstream processes, in particular from electricity generation, as far as the costs are passed on to them" (Droege, 2013 p.7)
			Sunk costs	Sunk costs are those which have already been incurred and which are unrecoverable. The nature of the sunk costs prevents the firm from recouping them, and it may be forced to continue in business even if profits are well below what they would be in another industry or location
	Cost pass-through ability	"Cost pass-through is the degree to which a given absolute change in cost causes an absolute change in price. It arises when a business changes the prices of the products or services it supplies following a change in its costs" (Whelan et al. 2014, p.4).	Competition	"Rivalry in which every seller tries to get what other sellers are seeking at the same time: sales, profit, and market share by offering the best practicable combination of price, quality, and service." (WebFinance, 2019 n.p.)
			Price elasticity of demand	"A measure of how much the quantity demanded of a good respond to a change in the price of that good" (Mankiw, 2018 p.815)
			Differentiation of products	"Each firm produces a product that is at least slightly different from those of other firms. Thus, rather than being a price taker, each firm faces a downward-sloping demand curve" (Mankiw, 2018 p.321) "Differentiation is when a firm/brand outperforms rival brands in the provision of a feature(s) such that it faces reduced sensitivity for other features (or one feature)" (Sharp and Dawes, 2001 p.17)
			Demand trends	"Habits or behaviours currently prevalent among consumers of goods or services." (WebFinance, 2019 n.p.)
	Abatement potential	"Abating GHG emissions is the alternative option for EIIs to paying a price for carbon. Firms in EIIs engage in abatement efforts as long as this is less expensive than paying for emissions and that appropriate technologies and substitutes are readily available" (Droege, 2013 p.8)	Low-carbon technology development	"The sum of equipment, methods, knowledge and other modalities for low-carbon or carbon-free. It suits the need of adapting to a low carbon economy, reducing greenhouse gas emissions and preventing global warming." (Lv and Qin, 2016 p.108)
			Investment spending	"Money spent on capital goods, or goods used in the production of capital, goods, or services. Investment spending may include purchases such as machinery, land, production inputs, or infrastructure." (WebFinance, 2019)

			Revenue	"The income generated from sale of goods or services, or any other use of capital or assets, associated with the main operations of an organization before any costs or expenses are deducted" (WebFinance, 2019).
	Regulatory environment	The anticipated interactions between political support and future business opportunities. The regulatory framework concerning climate and energy policy in carbon-constrained and non-carbon- constrained regions is an important determinant for investment, as are long-term expectations, contracts and the particular cost and pricing environment (Droege, 2013, p.8)	Certainty of future price of carbon	Level of credibility of the price of carbon in the future, which affects the firms' decision of investment in low-carbon technology
			Environmental stringency	"The strength of the environmental policy signal – the explicit or implicit cost of environmentally harmful behaviour" (OECD, 2016 p.3)
Induced innovation for industries' decarbonisation	Product Innovation	"The introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses. This includes significant improvements in technical specifications, components and materials, incorporated software, user friendliness or other functional characteristics" (OECD, 2005 p.149)	Market drivers	"Market drivers are the underlying forces that compel consumers to purchase products and pay for services. These are trends that make markets develop and grow." (Reference, 2020 n.p.)
			Potential for product differentiation	Extent to which the products traded in the market can be differentiated from the competitors
			Sector propensity to innovate	"Innovative potential is a measure that characterizes the company's ability to implement the processes of innovation. It is a basic criterion for determining the effectiveness and efficiency of the process of creating and using innovations" (Valitov and Khakimov, 2015 p.1)
	Process Innovation	"The implementation of a new or significantly improved production or delivery method. This includes significant changes in techniques, equipment and/or software" (OECD 2005, p. 151). "Process innovations improve the transformation process, and they make the transformation process more efficient. This can have a direct effect on the profitability of a company" (Kemp et al., 2003 p.16).	Production method alteration	Changes in production methods such as techniques and/or machinery, or feedstock used as inputs the production process
			Barriers for the adoption of low-carbon technology	Forces or constraints keeping the sectors or firms from adopting low-carbon technology
	Organizational Innovation	"The implementation of a new organisational method in the firm's business practices, workplace organisation or external relations" (OECD 2005, p.153).	Permanent R&D investment	"R&D expense (short for research and development expense) is essentially the amount of money that a company spends to develop new products and services each year."
			Green business model	"A business model is a company's plan for making a profit. It identifies the products or services the business will sell, the target market it has identified, and the expenses it anticipates" (Kopp, 2019 n.p.) "A firm's business model is green when environmental issues make up an important part of the value proposition." (Andersen and Faria, 2015 p.4)
			Inter-firm partnership/cooperation	"A cooperation between business organizations that allow them to achieve their common goals more effectively." (WebFinance, 2019 n.p.)

Government intervention	Regulation	"The imposition of rules by government, backed by the use of penalties that are intended specifically to modify the economic behaviour of individuals and firms in the private sector" (OECD, 1993 p.73)	Creation and shaping of markets	Government interventions aimed at creating new markets for clean products or forms of energy, or shaping existing markets to ensure a cleaner production of existing products
			Protection of incumbent firms	Regulation aimed at protecting the competitiveness of incumbent firms presenting a highly exposed to carbon leakage or losses of competitiveness as a result of a higher carbon price
	Funding	Public funds in the form of grants or subsidies provided by the government to support the development or implementation of low-carbon technology	Scale up	Subsidies aimed making the existing technology available to mass markets, reducing its costs for firms
			Innovation	Funding aimed at research and the development of new low-carbon technologies
	Enabling conditions	Physical and legal conditions that are a pre-requisite for the implementation of low-carbon technology.	Legal framework	Removal of legal barriers to the deployment, production and transportation of novel forms of energy and feedstock such as hydrogen
			Renewable electricity	Setting the conditions for a large-scale deployment of renewable energy projects, that allow for low-carbon technologies to be net-zero emissions in the whole chain
			Infrastructure for low-carbon technologies	Development of the infrastructure required for firms to implement low-carbon technologies (i.e. Hydrogen backbone)
Port Competitiveness	Port fees	"Port charges are the fees that shipping operators and their customers pay to port authorities for the use of the port's facilities and services." (Chan, 2017 n.p.)	Cost increase	Increase in any of the fees (ship dues or goods dues) charged by the Port Authority to their customers for the use of port facilities
	Throughput	"Total volume of cargo discharged and loaded at the port. It includes breakbulk, liquid bulk, dry bulk, containerized cargo, transit cargo, and transhipment." (Philippines Port Authority, 2016 p.1)	Imports of inputs	Total amount of import of inputs for production arriving at the port
			Export of products	Total amount of exports of finished goods being exported from the port
	Attractiveness as location for investment	"A locality's ability to attract, create new business and investments, and maintain the existing ones (competitive local business on national and international level)" (Snieska et al., 2019 p.10)	Legal framework and regulations	Set of taxes (fiscal policy), rules, and laws or regulations that businesses must adhere to
			Business sustainability	"Business sustainability, also known as corporate sustainability, is the management and coordination of environmental, social and financial demands and concerns to ensure responsible, ethical and ongoing success." (Rouse, 2013 n.p.)
			Knowledge and innovation	The availability of technical knowledge to enhance innovation, existence of specialised labour force, and educational centres as universities or research institutes

Table 5: Operationalisation table: Concepts, variables, sub-variables and definitions. Source: Author, 2020

Concept	Variables	Sub variables	Indicators	Data collection method
Carbon leakage	Cost structure	Direct carbon costs	Likelihood of the induced costs to significantly change the cost structure of the firms and affect their profits	Primary qualitative data collection; semi- structured interviews with experts
		Sunk costs	Extent to which the existing installed and built capacity (infrastructure and machinery) will lose value	
			Perception of the sunk costs as barrier of exit	
	Cost pass-through ability	Competition	Level of international competition in the industry	
			Extent to which the competition in the market is based solely on price	
		Price elasticity of demand	Extent to which the demand will decrease as a consequence of a price increase of the goods	
		Differentiation of products	Current level of differentiation of products in the industry	
		Demand trends	Perception of the current status of the demand (Increasing, stagnant or declining)	
	Abatement potential	Low-carbon technology development	Availability of low-carbon technologies in production process and substitutes for carbon-intensive production inputs	- Secondary data - Primary qualitative data collection; semi-structured interviews with experts.
			Maturity and costs of new low-carbon technology (e.g. CO2 capture and sequestration)	
			Historical evidence of technological improvement	
			Market penetration of new low-carbon technologies	
		Investment spending	Investment in direct emission reduction from production processes (energy efficiency and low-carbon technology)	
			Investment in indirect emission reduction from energy use (more efficient use of electricity)	
		Revenue	Likelihood of increasing revenue from the implementation of the technology, net of the increased costs of introducing it	
	Regulatory environment	Certainty of future price of carbon	Considering a carbon tax as a credible long-term certainty for the price of carbon	Primary qualitative data collection; semi-structured interviews with experts.
			Perception of whether a credible carbon price signal could induce investments in cleaner technology	
		Environmental stringency	Perception of higher stringency of environmental regulation as a threat for future investment	
			Perception of higher stringency of environmental regulation as an opportunity to increase competitiveness	
Induced innovation for industries' decarbonisation	Product Innovation	Market drivers (i.e. price, quality)	Potential in the market to create new and less energy-intensive products	
		Potential for product differentiation in the market	Existence of specialised and cleaner products	
			Perception of the commodity-nature of the sector (chemicals and refineries)	
		Sector propensity to innovate	Perception of the level of innovation of the industry	
	Process Innovation	Production method alteration	Existence of proven cleaner technologies that could be implemented in the production process	

		Barriers for the adoption of low-carbon technology	Perception of the current costs of implementing new technology	
	Organizational Innovation	Permanent R&D investment	Perception of the level of collaboration between industries and research/academia	
			Perception of the level of investment of the industries in R&D	
		Green business model	Potential for the creation of new less energy-intense business niches	
		Inter-firm partnership/cooperation	Perception of the level of cooperation between firms in the cluster to reduce emissions	
Government intervention	Regulation	Creation and shaping of markets	Appropriateness or desirability of the government to regulate and intervene in the economy	
		Protection of incumbent firms	Perception of the need for the government to protect firms exposed to losses of competitiveness through regulation	
	Funding	Scale up	Perception of the availability and need for funding aimed at scaling up existing low-carbon technology	
		Innovation	Perception of the availability and need for funding aimed at research and innovation to develop new technologies	
	Enabling conditions	Legal framework	Existence of barrier in the current legal framework to the production or transportation of new forms of energy or feedstock	
		Renewable electricity	Perception of the current capacity of the country to produce renewable electricity to supply the low-carbon production of the industries	
		Infrastructure for low-carbon technologies	Perception of whether the government is responsible for developing the infrastructure required for the large-scale deployment of low-carbon technology	
Port Competitiveness	Port fees	Cost increase	Considering the impacts of the carbon tax on the industrial cluster to induce an increase in the port fees	
	Throughput	Imports of inputs	Considering the impacts of the carbon tax in the industrial cluster to reduce the import of inputs for production processes	
		Export of products	Considering the production levels of the industrial cluster to decrease as a consequence of increased production costs	
	Attractiveness as location for investment	Legal framework	Perception of the level of corporate taxes (high - low)	
			Considering a carbon tax to increase significantly the tax burden for existing businesses	
		Business sustainability	Green investment: Perception of the potential of a carbon tax to enhance investment in cleaner technology	
			Barriers for EIIs: Considering that the carbon tax represents a scenario in which it is increasingly difficult to perform energy-intensive production activities	
			Attract new businesses: Perception of the potential of a more stringent climate policy to attract new investment	

		Knowledge and innovation	Low-carbon technology development: Potential of stringent climate policy to induce research and development of new technology	
			Agglomeration potential: Potential of a more stringent climate policy to enhance the interaction between research/academia and companies	

Table 6: Operationalisation table: Concepts, variables, sub-variables, indicators and data collection methods. Source: Author, 2020

3.4. Validity and reliability

According to Van Thiel (2013), validity is a twofold concept involving internal and external validity. Internal validity represents the extent to which the research has measured what it intended to measure and there are two aspects to it; if the operationalisation adequately captures the theoretical construct, and the existence of the modelled interactions between variables. To tackle these challenges, the variables and indicators need to be exclusive and clearly defined. External validity refers to the generalisation of the findings; to what extent the findings can also apply for other cases. External validity is especially important in quantitative-statistical research that aims to adequately represent a population through a sample. In the case study and qualitative research, the findings are specific to ea.ch case and its context, resulting in limited external validity and generalisation. Developing a sound set of indicators and selecting the right sample enhances the validity of the findings (Van Thiel, 2013).

Reliability depends on the accuracy and consistency with which the variables are defined and measured (Van Thiel, 2013). High reliability means that the findings are not coincidental but a reflection of reality. In explanatory research, it means that the explanation provided by the findings is most likely the right one. Accuracy refers to the instruments used and to the accurate definition of the variables being measured, the values they can assume and their units, which can be seen in Table 5 and Table 6. Consistency refers to the idea of repeatability; if the same results were obtained, had the measurements been done in another time. As the circumstances and context in which the case is inserted change, this aspect of reliability is often hard to achieve (Van Thiel, 2013).

A relevant aspect of the discussion on validity and reliability is the idea of triangulation. According to Van Thiel (2013), triangulation enhances both validity and reliability as it allows double-checking of the data collection and findings. Similarly, Carter et al., 2014 define triangulation as a qualitative research strategy that allows testing validity through the convergence of information from different sources. This, in turn, allows developing a comprehensive understanding of phenomena being investigated. Carter et al. (2014) identify four types of data triangulation; method triangulation, investigator triangulation, theory triangulation, and data source triangulation. This research uses a few types of triangulation. First, data source triangulation was applied by selecting experts from different areas as primary sources, and by the use of various sources of secondary data to validate or support the data gathered. The secondary data used consists mainly of official governmental documents and policies, studies commissioned by governmental entities to specialised consulting firms, peer-reviewed academic literature, and facts and figures from the Port of Rotterdam. Second, investigator triangulation was employed to some extent, as besides the supervisor, two experts in port and regional economics were consulted in early stages of the research, to ensure a correct demarcation and focus of the research. Lastly, method triangulation was done through operationalisation, by which each variable and sub-variable is addressed with more than one measurement.

3.5. Data analysis techniques

The semi-structured interviews will be recorded, with authorisation of the respondents, allowing the researcher to stay focused on the conversation and interaction with the respondents. The recordings will be transcribed and read, highlighting the most important concepts and insights. The data will be structured through a coding process; demarcating the boundaries between, and adding labels to, different units of information (Van Thiel, 2013).

The analysis of the collected qualitative data will be performed with the software Atlas TI, which allows for the creation of codes, categories of codes and making connections between

them. In principle, the codes created will correspond with the sub-variables of the conceptual framework. Depending on the manner or order in which the concepts or codes are mentioned during the interviews, some codes could be merged (i.e. if come codes are always mentioned together), and more codes could be added.
Once the data is coded, different tools of the software allow for various types of analysis. The Co-occurrence table shows the combination of codes present in a quotation when the interviewee talks about at least two codes at the same time, and the Query tool investigates the relationships between codes. The reports created will be analysed and interpreted in the next chapter.

3.6. Limitations

Given the complexity of the phenomenon under study, the greatest limitation is the uncertainty to predict the behaviour of firms. The nature of the study is *ex-ante* as it aims to predict the effects of a carbon tax in different sectors and the relationship between them. Predictions inherently involve different degrees of uncertainty, which tends to increase with the complexity of the phenomenon being analysed. For example, it is difficult to predict to what extent the new regulatory conditions could spur innovation, and specifically what type of technology would be enhanced. As there are unforeseen effects of the carbon tax on different entities, probably unknown beforehand, the inclusion of all the different perspectives around the phenomenon is not possible. The selection of respondents aimed at addressing and including the main actors affected by the policy, but it does not include other potential actors that might be affected by it. Lastly, this research was performed amid the corona pandemic which has indirect implications in the data collection process. The interviews will be held virtually (online or telephone), creating a barrier between the researcher and the interviewees.

Chapter 4: Presentation of data and analysis

In this chapter, detailed information about the case study and an analysis of the collected data is presented. Each one of the variables and sub-variables of the conceptual framework are assessed by analysing the views of each stakeholder and finding relationships between them. The data is presented following a logic structure consistent with answering the research questions in the next chapter. The chapter starts by presenting the case study and the context in which is inserted in section 4.1. Section 4.2 presents the first quantitative view of the qualitative data gathered by presenting frequency tables of the sub-variables of each concept, based in the analysis performed with the software Atlas Ti. Additionally, this section describes the most important insights and inputs from the interviewees about the most frequently addressed variables and sub variables, which is required to elaborate on the relationships between them. Section 4.3 builds upon these insights and presents the analysis of the data gathered, making explicit the relationships found between the variables. Section 4.4 presents a summary of the relationships between variables and a discussion about practical implications of the findings.

An overview of the number of quotations per concept of the conceptual framework can be seen in Table 7.

Concept	**Quotes**
Carbon Leakage	194
Government Intervention	141
Case study and context	106
Induced Innovation	95
Port Competitiveness	46
Total	**582**

Table 7: Number of quotes per code group. Source: Author, 2020

These numbers give a first idea of the content of the data gathered in this research. It is important to mention that concepts with less quotes are not less relevant. For instance, the concepts of carbon leakage, government intervention and the context of the case study were mentioned and discussed in every interview as all the interviewees have the knowledge and expertise to comment and provide insights about these topics. On the other hand, port competitiveness is a relatively more specific topic, that was only discussed with some members of academia and the PA. Other respondents were not familiar with the competitiveness of ports, which explains the relatively fewer number of quotes. Nevertheless, the few interviews in which this concept was discussed provided rich and detailed information about the foreseen effects of a carbon tax in different aspects of the competitiveness of the PoR. More detailed information about the perceptions of interviewees about each concept, variable and sub-variable is presented in Annex 2.

4.1. The case study and context

The description of the case study was developed using both secondary and primary data. The first was collected from different sources covering environmental policies in Europe and the Netherlands. It includes official policy documents from the Government and the EU, studies commissioned by the Government to specialised consulting firms, and facts and figures from the Port of Rotterdam Authority. Primary data was collected from the sample through semi-structured interviews. The content of the data regarding the case study and context can be seen in Table 8 and consists mainly in three topics. The first relates to the PoR and it contains perceptions of its advantages, composition and competitors. The second relates to different aspects of environmental policies (EP) such as perceptions of the stakeholders about the mechanisms for pricing emissions, about the price level of emissions, and about characteristics of the proposed tax. The third includes insights and information given by the respondents about the process by which the National Climate Agreement has been developed, expectations of the upcoming European Green Deal and the general direction that environmental policies are taking in Europe.

CATEGORY	SUB VARIABLE	QUOTES
CASE STUDY AND CONTEXT	PoR: Advantages	28
	EP: Pricing mechanisms	24
	National Climate Agreement	12
	EP: Perception carbon price	11
	PoR: Cluster composition	9
	EP: Context	8
	EP: Characteristics of the tax	6
	European Green Deal	4
	PoR: Competitors	4
TOTAL		**106**

Table 8: Number of quotations of the case study and context. Source: Author, 2020.

4.1.1. The Port of Rotterdam and its industrial cluster

The PoR stretches approximately 40 kilometres from the City of Rotterdam towards the Maasvlakte 2 area, projecting from there into the North Sea (Port of Rotterdam Authority, 2016) as seen in Figure 7.

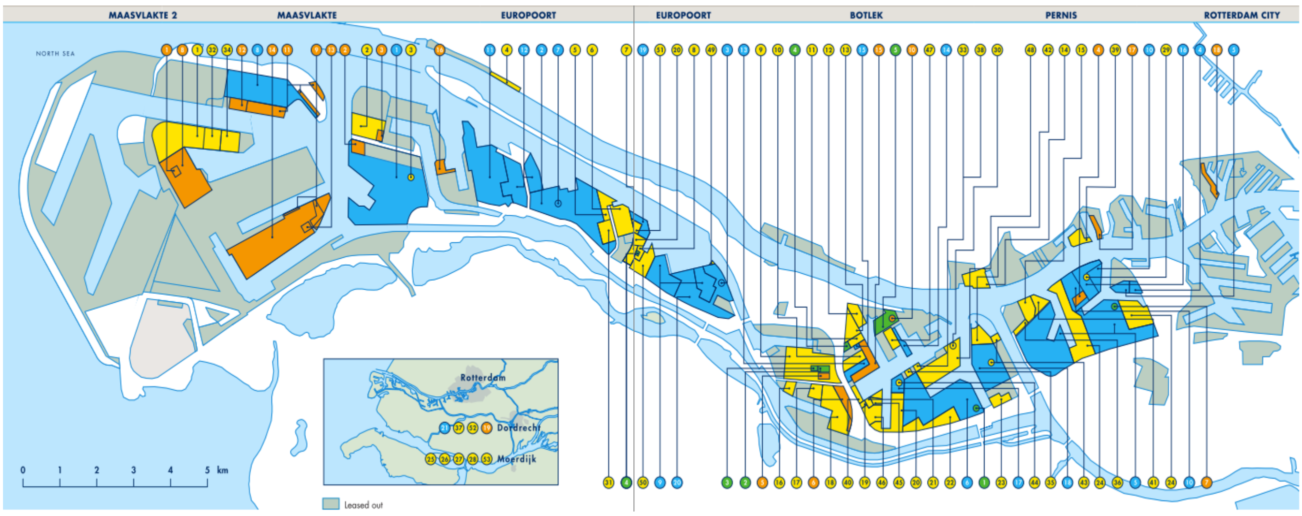

Figure 7: Location of the Port of Rotterdam. Source: Port of Rotterdam Authority's facts and figures, 2020.

The activities performed at the PoR are under direction of the Port of Rotterdam Authority (PA), whose mission is

> *"To enhance the port's competitive position as a logistics hub and world-class industrial complex. Not only in terms of size, but also with regard to quality. The core tasks of the Port*

Authority are to develop, manage and exploit the port in a sustainable way and to render speedy and safe services for shipping." (Port of Rotterdam 2018, p.1)

The PA is owned by the government (70%) and the Municipality of Rotterdam (30%), and its main sources of revenue are land rental and port fees. According to sources from the PA, although it is government owned, they have a separate business. Part of the profit that the PA makes is paid as dividend to the Municipality and the state.

The sites marked in Figure 7 are leased to firms from various sectors, mainly oil refineries and petrochemical production, as seen in Table 10. The PA also charges fees to ships for the use of port services. These revenues are mainly invested in public infrastructure and effective shipping handling. The former aims at improving the conditions of the port area by building roads, quay walls, jetties and the development of new port sites. The latter consists of traffic management systems, patrol vessels and energy control (Port of Rotterdam Authority, 2020).

The PoR is vital for the economy of the city and The Netherlands. According to figures from the Port of Rotterdam Authority (2020), the direct and indirect added value of the activities performed at the port was 45.6 billion euros in 2019, which represents a considerable 6.3% of the country's GDP. It also generates 385,000 jobs, considering direct and indirect employment, and has a turnover of approximately 710 million euros. When considering only the industrial cluster, these numbers are 75,000 jobs and 13 billion euros of added value to the Dutch economy.

The PoR is the largest and most important port in Europe and 10th in the world (Port of Rotterdam Authority, 2020). The port serves the hinterland of north-west Europe and competes with the ports located in the Le Havre-Hamburg range as seen in Figure 8.

Figure 8: Ports in the Le Havre - Hamburg range. Source: Author, 2020 using Google Maps.

The PoR greatly outperforms all its competitors when considering the dry bulk, liquid bulk, containers and breakbulk throughput categories. A comparison of the throughput of the ports in this range per category is presented in Figure 9 and Table 9.

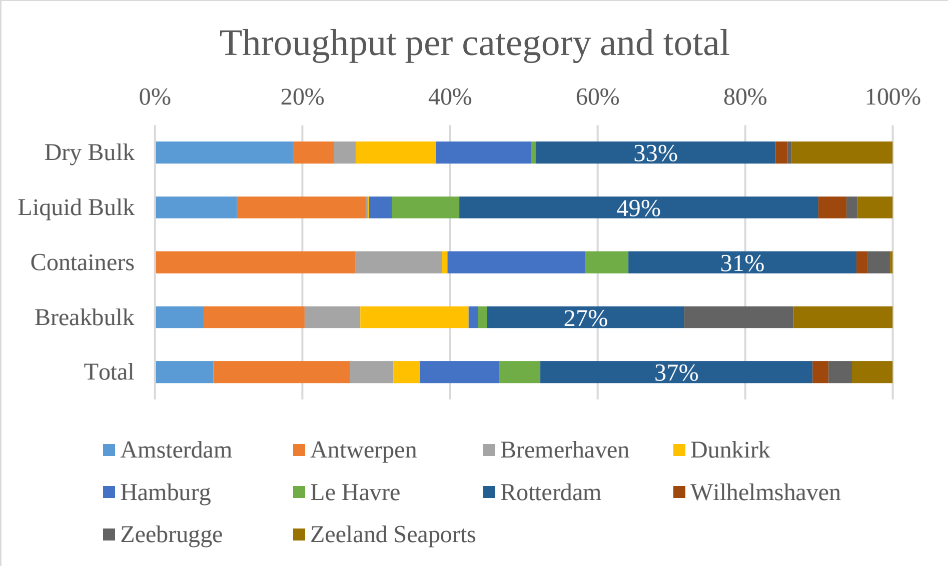

Figure 9: Throughput of each port in the Le Havre - Hamburg range per category. Source: Author, 2020 based in Port of Rotterdam Authority's fact and figures 2020.

Port (Country)	Dry Bulk	Liquid Bulk	Containers	Breakbulk	Total tp	Total M.S.
Rotterdam (NL)	**776**	**2,118**	**1,491**	**304**	**4,689**	**37%**
Antwerp (BE)	131	759	1.309	155	2,354	19%
Hamburg (GE)	307	134	899	15	1,355	11%
Amsterdam (NL)	446	485	0	76	1,007	8%
Bremerhaven (GE)	72	14	568	86	740	6%
Le Havre (FR)	14	398	283	14	709	6%
Zeeland Seaports (NL)	328	206	17	153	704	6%
Dunkirk (FR)	259	5	35	167	466	4%
Zeebrugge (BE)	12	67	152	169	400	3%
Wilhelmshaven (GE)	38	167	69	0	274	2%

Units: Gross weight in million metric tons.

Table 9: Throughput of the ports in the Le Havre-Hamburg range. Source: Author, 2020 based in Port of Rotterdam Authority's fact and figures 2020.

From the figures and tables above, it is obvious that, although not in every category, the closest competitors of the PoR is the Port of Antwerp. The total throughput of the PoR is almost twice that of Antwerp and over three times that of Hamburg. In the category of dry bulk, the closest competitors are the Port of Amsterdam and Zeeland, both located in the Netherlands. In the categories of liquid bulk and containers, the PoR competes mainly with Antwerp. In liquid bulk, the PoR has almost three times the throughput of Antwerp, and in containers, the throughput is almost equal.

These numbers and the dominant position of the PoR in the Le Havre-Hamburg range are explained by several factors that will be presented in detail in the next section, all them leading to the existence Europe's largest industrial cluster in Rotterdam. Particularly, the great dominance of the PoR in liquid bulk is explained by the composition of the industrial cluster and the activities performed in it. The cluster consists of over 120 industrial companies, mainly oil refineries, crude oil terminals, chemical and petrochemical industries and power generation plants. The composition of the industrial cluster can be seen in Table 10.

Products and services	Nr. of sites	Employees
Oil and oil products		
Oil refining	6	3,271
Refinery terminals	6	142
Tank terminals for oil products	9	535
Chemical, biofuels and edible oils		
Chemicals, biofuels and edible oils	42	6,167
Biofuels manufacturing and products	4	260
Edible oil refineries	5	477
Tank terminals for chemicals, biofuels and edible oils	16	843
Gas and power, coal and biomass		
Gas-fired power plants	9	107
Coal and biomass-fired power plants	5	594
Wind turbines	-	-
Natural gas terminals	2	-
Coal and biomass terminals	8	-
Pipelines and utilities		
Industrial gases and water plants	7	634
Pipelines	3	40
Total industrial cluster	**122**	**13,070**

Table 10: Composition of the industrial cluster of the PoR. Source: Author, 2020 based in Port of Rotterdam Authority's facts and figures, 2020.

The oil refining companies operating in the PoR are mainly multinationals with operations all over the world. Namely, BP Raffinaderij Rotterdam, Gunvor Petroleum Rotterdam, Koch HC Partnerships, ExxonMobil Lubricants, Shell Nederland Raffinaderij, Esso Nederland (ExxonMobil). Almost all of these companies also operate in the chemical industry, which focuses mainly on the production and commercialisation of base chemicals and represent 10% of the total European production capacity. According to sources from the PA and academia, this is the main difference with the chemical industry located in Antwerp, which specialises in higher value, fine chemicals. This phenomenon is explained to a large extent by the input-output relationship between oil refining and chemical production, in which the production of the second requires feedstock from the first. For this reason, the production of base chemicals clustered around the oil refineries in Rotterdam, leaving little space left for fine chemical production, which clustered around the bay nearby Antwerp. Both chemical clusters are strongly connected by pipelines, through which Rotterdam supplies cheap feedstock to Antwerp. According to a source from the academia, the proximity of both clusters and the efficient transportation networks between them allows for the entire area to operate as one large industrial complex, which big oil trading and petrochemical companies see as just one large market.

With this perspective, it is possible to see the chemical clusters of both ports not as competitors but as parts of a large industrial cluster, with an input-output relationship. Although both ports serve the same hinterland, they specialize in the production and trading of different products. Figure 10 shows the pipeline network that connects the ports of Rotterdam, Antwerp and the hinterland, facilitating the flow of products between both ports and strategically located places in the hinterland.

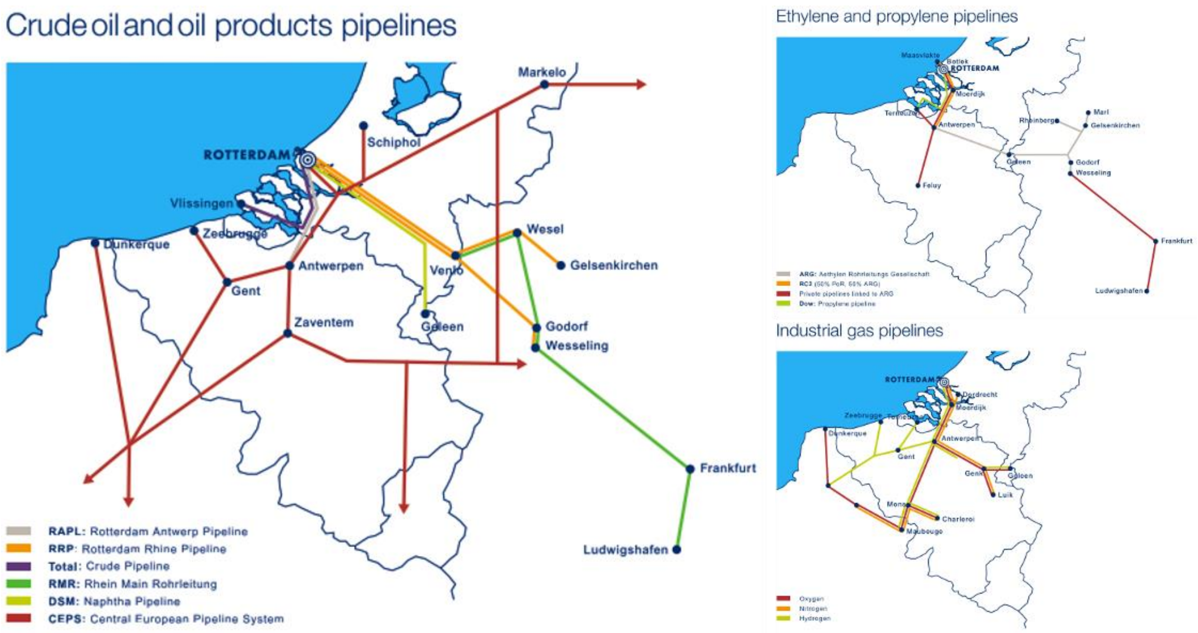

Figure 10: Pipeline network in the Port of Rotterdam. Source: Port of Rotterdam Authority's fact and figures, 2020.

4.1.1.1 Advantages of the PoR

There is a myriad of factors that create a favourable environment for industrial activity and explain the existence of Europe’s largest industrial cluster in Rotterdam. As seen in Table 8, the advantages of the PoR were greatly discussed and highlighted during the interviews. An overview of the factors that explain the strong position of the PoR according to the interviewees are presented in this sub section.

Geographical location, logistics and infrastructure

The benefit of the strategic geographical location of the PoR, is two-fold. Firstly, it is next to the coast, which gives direct access to the open sea, and secondly, it is located adjacent to wide rivers connecting it with the hinterland. This geographical advantage has favoured the creation of an extensive network of intermodal transport connections. There are over 400 international rail connections that start and end in the PoR, and direct links with European motorway networks which facilitate the rail and motorway transport. Inland shipping through the Maas and Rhine rivers allows direct access to important European economic centres in the Netherlands, Germany, Belgium, France, Switzerland and Austria as seen in Figure 11. Connections with the Danube and Main rivers make it possible to move cargo as far as the Black Sea. Inland shipping is especially suitable to move large volumes, and the availability of a wide variety of vessels make it possible to transport dry and liquid bulk, containers and project cargo (Port of Rotterdam Authority, 2020).

Figure 11: Inland Shipping from the PoR. Source: Port of Rotterdam website, 2020.

Over 1500km of pipeline network connecting companies within the PoR, to the Port of Antwerp and the German Ruhr region allows for a safe, efficient and sustainable transport of liquid bulk (Port of Rotterdam Authority, 2020). The PA has been constantly creating digital solutions, using data to develop real-time information services, automating processes and building partnerships and networks with firms and other ports. These efforts have resulted in the PoR being a state-of-the-art port in infrastructure, services and efficiency of logistic processes. The PoR has been positioned in the first place in Europe and second in the world on efficiency in seaport services, only behind Singapore, by the World Economic Forum's Global Competitiveness Report (2019). These conditions create a logistical hub in the PoR, facilitating industrial activity by bringing together suppliers, customers and a range of related companies, and making of the PoR the most cost-efficient location in connecting north-west Europe with the rest of the world.

Proximity to Rotterdam

According to a source from the academia, the PoR is benefited by its proximity to a major urban agglomeration as the city of Rotterdam, which provides a range of *urbanisation externalities*. Rotterdam has a highly educated population due to the presence of various universities and think tanks close to the port, such as Erasmus University and TU Delft, which have many specialisations in maritime engineering, mining, water management, chemistry and business management among others. Port and industrial operations require a wide range of specific skills that have been provided by local universities, which have been to some extent also sponsored by the industries, creating a win-win situation. There are various academic consultancy think tanks such as TNO and Deltares in the Netherlands, that have played an important role in the development of the industries and the port infrastructure.

The availability of highly educated and specialised labour force and a close relationship with academia creates favourable conditions for the operation of complex industrial processes, business management and the development of port infrastructure and services. The great variety of digital services and high-quality infrastructure offered by the PoR are one of its most important competitive edges. The development of these services, which apply technology and data analysis to provide users with real-time statistical information and performance, has been to a great extent possible thanks to the relationship between the PoR and academia, and the availability of highly specialised skills in Rotterdam. These conditions also facilitate the development and implementation of state-of-the-art technology in the industries, which has contributed greatly to their high production efficiency and puts them in a privileged position in the challenge posed by the energy transition and decarbonisation of EIIs. Think tanks and universities in the Netherlands are frontrunners in research and knowledge about the energy transition and low-carbon technologies, many of which are being tested and implemented in the industrial cluster of the Port of Rotterdam. One example of this is the testing of the Haliade-X 12MW, the world's most powerful offshore wind turbine of General Electrics in the Maasvlakte area of the PoR. According to sources from the banking sector and consultancy, the decision of testing it in Rotterdam is greatly motivated by the availability of technical knowledge and skills to perform all the tasks involved in a large and innovative project, such as preparation, installation and maintenance. Another example is the Porthos project organisation which will implement CCUS in the PoR and is currently in the phase of technical studies before its implementation.

Political and regulatory stability

The stable political and regulatory environment and low corruption indexes in the country create an attractive investment climate, by which investors have certainty that their investment is safe, regulations will not suddenly change and put their capital at risk. The World Economic Forum (2019) gives high marks to The Netherlands in macroeconomic stability. It ranks 4th in the world in the highly skilled workforce index and 2nd in the vibrant business dynamism index. The institutional framework, which is compounded by security, checks and balances, efficiency and commitment of the government to sustainability is ranked 4th in the world. There is a perception among companies of the Netherlands as being a strict country in environmental regulations such as sound and pollution. At the same time, companies consider the country as being highly reliable; once a firm obtains a permit, it has the certainty that it can keep doing business to model for a certain period under stable rules. The quality that industries get from good, clear and stable regulations help to create an attractive investment climate.

> *"Think about why is it that we in The Netherlands have so much industry, and heavy industry. It is because we have an attractive climate. Access to the sea, to the rest of Europe, rivers, a good infrastructure backbone, a lot of universities, knowledge centres are here. There's a decent and stable government. These are conditions that are very attractive for investment."*

- *Interviewee 8*

4.1.1.2. CO2 Emissions and energy transition

As seen in Table 10, the industries in the port are mainly EIIs whose operations rely heavily on fossil fuels. The activities performed in the industrial cluster of the PoR are responsible for 20% of the total CO2 emissions of The Netherlands, and the emissions of the cluster have grown by 49% between 1990 and 2016, reaching 30.6Mt of CO2 in 2015.

> *"If you look at the industrial area, those 30 Mt or so. Most of that is emitted by the top 20 large emitting companies. That's 80%. We are talking about coal coal-fired plants, refineries, and very large chemical plants. Those are the ones that need a lot of fuel to run."*

- *Interviewee 11.*

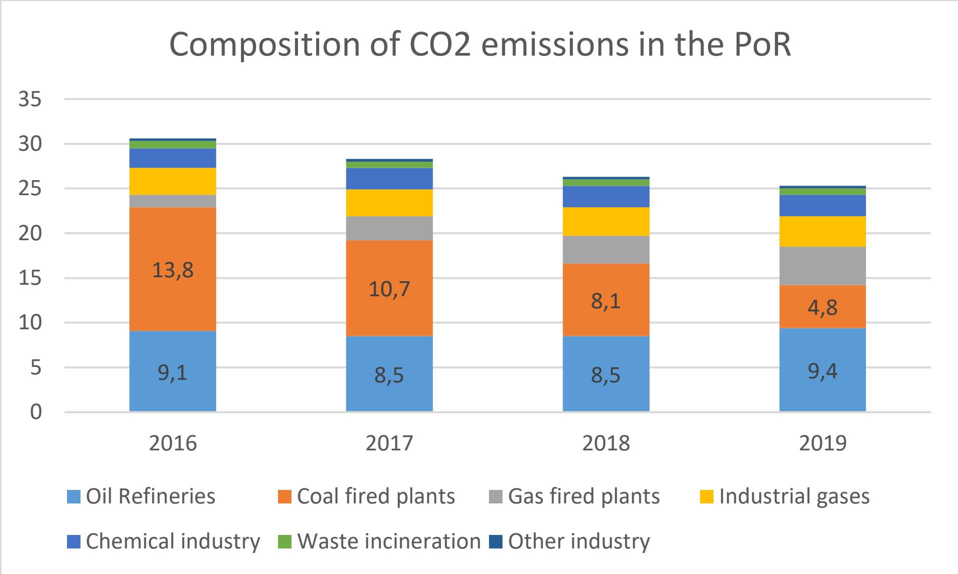

Figure 12: Composition of CO2 emissions in the industrial cluster of the PoR. Source: Author, 2020 based in The Port of Rotterdam website.

SOURCE	2016	2017	2018	2019
OIL REFINERIES	9,1	8,5	8,5	9,4
COAL-FIRED PLANTS	13,8	10,7	8,1	4,8
GAS-FIRED PLANTS	1,4	2,7	3,1	4,3
INDUSTRIAL GASES	3	3	3,2	3,4
CHEMICAL INDUSTRY	2,2	2,4	2,4	2,4
WASTE INCINERATION	0,8	0,7	0,7	0,7
OTHER INDUSTRY	0,3	0,3	0,3	0,3
TOTAL	30,6	28,3	26,3	25,3

Units: Megatons [Mt] of CO2

Table 11: Detail of composition of CO2 emissions of the industrial cluster od the PoR. Source: Author, 2020 based in the Port of Rotterdam website.

Figure 12 displays that total emissions have been declining since 2016, driven mainly by the closure of two coal-fired power plants and one gas-fired power plant. The emissions from the oil refineries and chemical industry have remained stable, while the gas-fired power plants have increased their emissions as seen in Table 11. The PA is currently making efforts to support companies in the energy transition as they are aware of the highly emitting nature of their activities, and the threat that a low carbon-based economy means for their business model. According to sources from the PA, 90% of the activities performed in the PoR are based in fossil fuels, which will have to change to deliver on the Paris Agreement and other decisions made at the national and European level. If actions are not taken, the PA fears to lose the 6 refineries, the fees charged to all the chemical companies, and ultimately losing 80% of their business. There is clarity from the PA in that the existing industry needs to be renewed by the production of green hydrogen, biofuels and synthetic base chemicals that are not based in fossil feedstock. The vision of the PA is that it cannot wait for industries to make these changes by themselves, but it needs to help them by investing together with them in innovation and the implementation of clean technology to avoid serious future damage to the business in Rotterdam.

To understand the challenge faced by the industrial cluster in the energy transition, it is necessary to analyse sector by sector, as not all the available low-carbon technologies can be implemented in every sector. Even within sectors, the analysis must be done factory by factory as they differ greatly in age and technologies implemented. There are complex interactions and energy flows between industries processes in the cluster and input-output relationships between the oil refining and chemical industries. Part of the production of the oil refineries is used as feedstock in chemical production, as seen in Figure 13.

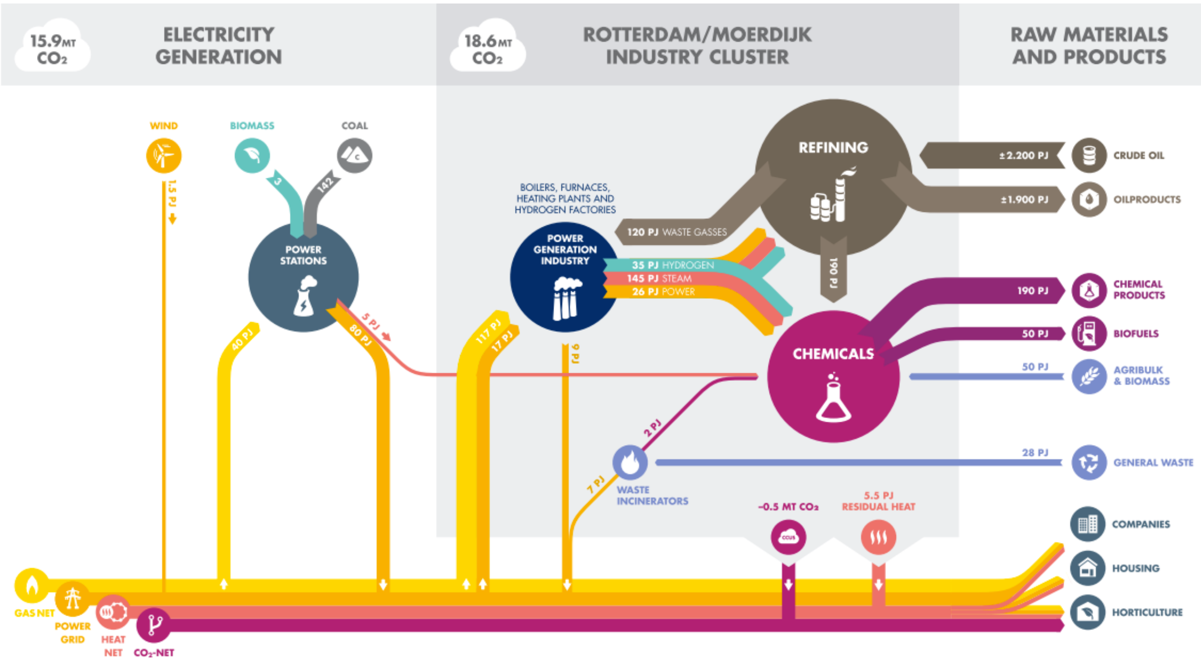

Figure 13: Flow of energy, input and outputs in the industrial cluster of the PoR. Source: Port of Rotterdam Authority, 2018

Some of the factories and plants in the PoR are state of the art installations and can be counted among the most efficient in the world. Shell and Exxon Mobile have large scale industrial complexes and have invested continuously to have state of the art oil and chemical complexes. Other installations are ageing, especially coal-fired power generation plants and old refineries, which have considerable room to improve their energy efficiency. For these facilities, the energy transition will be very difficult as switching their energy sources will require more structural and expensive developments.

> *"One of the worries we have in Rotterdam is that indeed the installations are ageing, that's one. That doesn't mean that they are not very much looking into energy efficiency as such, but there is some kind of a ceiling on that part, how much you can do"*
>
> - *Interviewee 13*

As it will be explained in further detail in later sections, the shift towards low-carbon technology is possible to the extent that there is a favourable business case for the firms. This means that firms will only invest in energy efficiency or the implementation of low-carbon technology in its production processes if they get a return over the investment within an investment cycle. Most of the low-carbon technologies are still too expensive to create a favourable business case and have not been tested in large scale industrial complexes and processes. The large investments required, and the short payback periods expected by the industry represent the main barriers to industrial energy transition in the PoR.

The PA plays a key role as a facilitator in the energy transition of the industrial cluster, connecting consultancy think tanks who have the state-of-the-art knowledge in low carbon technologies with the firms who will have to implement them. The PA also has the responsibility to enable the conditions for the energy transition to take place. According to sources from the Policy and Planning department of the PA, large steps can be made only if there is cooperation between the industry and the PA. For example, Shell and the PA are working on hydrogen production and the development of electrolysers, aiming to reach up to 2GW. Nevertheless, the production of hydrogen is a feasible option only if there is infrastructure to transport it. The PA is working with companies to build a hydrogen backbone, which costs rises to several hundred million euros. The backbone would consistofn a pipeline from Maasvlakte to the Rotterdam city area, where in the future it would connect to the national grid, and also connected to Antwerp. The PoR is taking up the project, looking at an investment in bio cells, and looking for funding. Negotiations are ongoing with the Regional Government, province of Zuid Holland, and with the National Government for investment or subsidies that allow the PA to make that long-term investment.

> *"And that's the role we choose as the Port of Rotterdam. We try to be an integrator between producer, user, transporter of hydrogen to be able to build the system that we need for 2030. How fast it goes; it could always be more."*
>
> - *Interviewee 11.*

4.1.2. Climate Policies: The Dutch National Climate Agreement and the European Green Deal

This section presents the latest developments in emissions-related climate policy in The Netherlands and Europe. Particularly, as seen in Table 8, the Dutch National Climate agreement, the European Green Deal and the European context regarding climate policies were mentioned in various interviews. This section presents the insights and inputs gathered during the interviews, and important information from secondary data.

4.1.2.1. The Dutch National Climate Agreement

To help tackle climate change, on the 23rd of February 2018 the Ministry of Economic Affairs and Climate issued a letter, which presented the Government's objectives for the National Climate Agreement. The central goal of the Government was to achieve a 49% reduction of CO2 emissions compared to 1990's levels. The process by which this agreement was reached reflects the *Dutch Polder Model*, a consensus-based policymaking approach by which agreements are reached through dialogue, with every stakeholder having an equal say and reaching solutions collaboratively. By involving the most relevant stakeholders throughout the entire process, the model aims at ensuring as much public support as possible. In the case of the *National Climate Agreement*, a wide range of stakeholders ranging from NGOs and government branch organisations to representatives of the industrial sector, agribusiness, banking and transport among others. Since 2018, over 100 parties have worked together in drafting the specific roadmap to achieve the proposed CO2 emissions reduction in 5 sectors; built environment, mobility, industry, agriculture and land use, and electricity. Sector platforms were organised in tables to facilitate the debate and draft the measures and instruments needed to deliver on each sector's target, which combined will amount to the 49% total reduction of CO2 emissions. Each table was asked to provide additional measures to reach an overall target of 55% CO2 emissions reduction, as the Dutch government was pushing for an increase in the European CO2 reduction target reaching 55% in 2030, in which case the national targets would follow suit. This consensus model is reflected in the data collected in this research. Although there are divergent views on the specific targets, incentives to curb emissions and penalizations for emitters, there is consensus in that action aimed at curbing CO2 emissions must be taken. As it will be explained in the next section about carbon leakage, all the interviewees are concerned by action taken by the Netherlands alone as it could distort *level playing field* and potentially damage the competitiveness of the industrial sectors.

> *"Looking at the government parties, some are very much in favour of the carbon tax and others are not. As an industry, we were not happy with it. We did agree to have at least other incentives in place that would allow us to make the transition, which in our opinion would be more constructive."*
>
> - *Interviewee 6*

The climate agreement's vision for the industrial sector by 2050 is:

> *"By 2050, we envisage the Netherlands to be a country with a thriving, circular and globally leading manufacturing industry, where greenhouse gas emissions are almost zero. We envisage a country where innovative businesses and initiators are willing to produce and innovate and where an innovative manufacturing industry, with ever-dwindling carbon dioxide emissions, is able to contribute to our prosperity, our well-being and the nation's employment."*(Dutch Ministry of Economic Affairs and Climate, 2019a, p.88)

To achieve this vision, the targets set to the industrial sector coincide with the ones at the national level; 49% reduction of CO2 emissions by 2030 compared to 1990's levels, aiming to achieve 55% reduction. These ambitious targets translate into a reduction of 14.3Mt on top of the 5.1Mt baseline reduction projected as a result of the existing policies. Taken together, the target for the industry is to reduce 19.1Mt by 2030, which represents a 59% reduction compared to 1990's levels. The target for the industry is significant and higher than for other sectors. The reasoning behind it is that the industrial emission reductions are cost-efficient, and the sector can achieve emissions reductions at lower costs than other sectors (Dutch Ministry of Economic Affairs and Climate, 2019a). This is partly due to the composition of the industrial sector in the Netherlands in which 12 companies, known as *the big twelve*, are responsible for 60% of the sector's emissions.

There is a range of low-carbon technologies and initiatives mentioned in the document that need to be scaled up to reach the targets. The technologies, which will be explained further in later sections, are related to process efficiency, energy savings, CCUS, electrification, production of blue and green hydrogen, acceleration of circularity by plastics recycling, and the use bio-based raw materials as inputs for chemical production. The rising abatement costs of implementing the different technologies are shown in Figure 14, where it can be seen that after a certain point the marginal abatement cost increases abruptly.

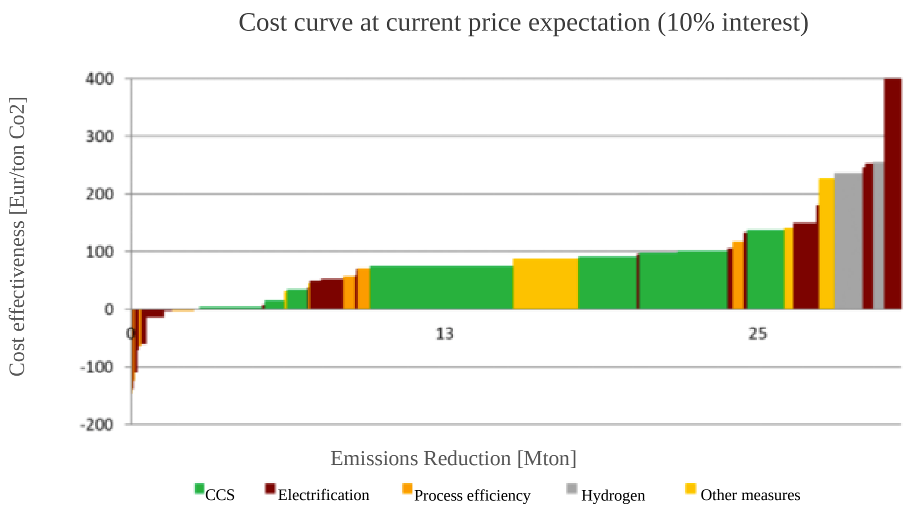

Figure 14: Cost curve for the abatement options. Source: Dutch Ministry of Economic Affairs and the Climate 2019, p. 92.

The Dutch National Climate Agreement proposes a carbon tax for the industry to take effect as of 2021, aimed at incentivising emission reduction and ensuring that the 14.3 Mt CO2 target by 2030 is reached a priori. The proposed carbon tax would be applied as a complement to the ETS price to ensure a minimum price of carbon. The proposed price starts in 30 Eur/ton of CO2 in 2021 and increases linearly to 125-150 Eur/ton of CO2 in 2030. These prices include the ETS price, which is expected to reach around 45EUR/ton in 2030. This means an expected carbon tax of 75-100 Eur/ton of CO2 in 2030 according to estimations from the PBL. The assumptions behind these prices are the following:

- 80% of the total carbon-reducing potential will be utilised until 2030
- 75% probability of reaching the carbon emission reduction target

An overview of the downsides of the current EU ETS system that motivated the need to reform it and introduce more ambitious carbon tax in the Netherlands can be seen in Annex 3.

4.1.2.2. The European Green Deal

On 11th December 2019, the European Commission presented the European Green Deal, a set of policies that aim at climate neutrality -zero net emissions of greenhouse gases- by 2050. Among other intentions, it aims at decarbonising the energy sector and supporting the industrial sector to innovate and become a world leader in the green economy (European Commission, 2019a). The Commission has stated that it will present an impact assessed plan by summer 2020. The aim is to set the GHG emission reduction target to a minimum of 50% and towards 55% by 2030 compared to 1990's levels (European Commission, 2019). The Commission recognises the key role that taxation can play in enhancing the transition towards a low-carbon economy, and the Green Deal mentions two actions in the field.

First, revise the Energy Taxation Directive (ETD), which will aim at reflecting the impact of different sources of energy more accurately and encourage businesses and individual to shift their behaviour. This, after a 2019 report of the Commission concluded that the ETD is no longer aligned with other climate EU climate policies (among which are the ETS), it does not incentivize investment in low carbon technology, and it does not promote emissions reductions and energy efficiency. Further, it was found that the ETD promotes the wide use of sectorial exemptions and reductions applied by the member states enhances and promotes the use of fossil fuels (European Commission, 2019b). The data collection process to perform an impact assessment of the reform of the ETD has started, as well as the economic analysis. The output of these processes will inform the Commission's decision about the reform of the ETD.

Second, the creation of the *Carbon Tax Border Adjustment* (CBTA) which would work as a tax on imports for selected industries. The aim is to ensure that the carbon content of the imports is more accurately reflected in their price, reducing the risk of carbon leakage from higher prices of carbon emissions in Europe. The specific design of the measure has not yet been defined, and an external study is being carried out during 2020 to assess the different options. By June 2021, the Commission will review and propose to revise all related climate-related policies, which will include a reform of the current EU ETS by widening the range of sectors covered. It will also consider using a bigger share of the revenues of the ETS system to support the finance of the energy transition.

There are several considerations in the data about the European policy context. Having two emission-related climate policies in course, at the national and European level, creates uncertainty and confusion in the industry. The current situation with the corona pandemic adds another layer of uncertainty as it is not clear if the policies will continue their stated development, and how they may be affected by it. Interviewees from the industry and the PA foresee that the priorities might have changed and that the climate policies will be delayed in their implementation. There are also concerns about the minimum price floor proposed in the Dutch National Climate Agreement being redundant, given that the European Green Deal will reform the EU ETS and make it compatible with the targets of 50-55% emissions reduction by 2030 and zero net emissions in 2050, both of which are higher than the targets in the Dutch National Climate Agreement.

4.2. Data preparation and analysis

This section presents an overview of the analysis of the data collected performed in the software Atlas TI. An overview of the number of quotes per variable and general comments are presented in this section. Information about each sub-variable, including the most important perspectives gathered through the interviews and the number of quotations per sub variable, will be presented in section 4.3. A detailed description of the perceptions of the interviewees on each sub variable is presented in Annex 2. The analysis of the relationships between variables found in the data and co-occurrence tables are presented in section 4.7.

Table 12 shows the number of quotations per variable, giving an overview of its content. The concepts of the table are sorted in the same order that they are analysed in section 4.3.

Concept	Variable	Quotes
Carbon Leakage (CL)	Cost structure (CS)	74
	Cost pass through ability (CPT)	70
	Abatement potential (AP)	28
	Regulatory Environment (RE)	22
	Total - CL	**194**
Induced Innovation (II)	Process innovation (Pr)	55
	Organisational innovation (O)	25
	Product innovation (Pd)	15
	Total - II	**105**
Government Intervention (GI)	Funding (F)	70
	Enabling conditions (EC)	38
	Regulation (R)	33
	Total - GI	**141**
Port Competitiveness (PC)	Attractiveness as location for investment (AB)	35
	Throughput (TP)	8
	Port fees (PF)	3
	Total - PC	**46**
Total		**476**

Table 12: Number of quotations per variable. Source: Author, 2020

The relatively low number of quotations for Port Competitiveness is due to the composition of the sample and their expertise. The only interviewees that have the knowledge or expertise to assess effects on the variables PF and TP are some members of the academia and interviewees from the PA. On the other hand, the variable AB was assessed by almost all the interviewees, who had different perspectives about the factors that are important for a location to attract investment, and how they would be affected with the introduction of a tax. Similarly, the concept carbon leakage was mentioned in all of the interviews, which explains its relatively large number of quotations. Government intervention was mentioned, either directly or implied, in every interview. The data was analysed while being collected, and the recurrent appearance of this concept made is apparent that plays an important role, and the conceptual framework would be incomplete without it.

4.2.1. The carbon and investment leakage hypothesis

This section presents the findings related to the risk of carbon and investment leakage for the industries operating in the PoR as a result of a higher price of carbon. Four variables were created to assess the risk of carbon leakage and measure the likelihood that firms decide to whether relocate their operations or divert investment to other locations both in Europe and the rest of the world. Following the operationalisation table, each variable is further divided into sub-variables and indicators. The number of quotations for each sub variable can be seen in Table 13. A description of the most relevant perspectives of the interviewees about each sub-variable can be seen in Annex A2.1.

CATEGORY	SUB VARIABLE	QUOTES	PERCENTAGE
CARBON LEAKAGE	RE: Level playing field	47	24%
	AP: Low-carbon technology development	39	20%
	AP: Investment spending	27	14%
	CS: Direct and indirect carbon costs	18	9%
	RE: Environmental stringency	18	9%
	CS: Sunk costs (SC)	10	5%
	CPT: Competition	9	5%
	RE: Certainty of future carbon price	9	5%
	CPT: Demand trends	7	4%
	AP: Revenue	4	2%
	CPT: Price elasticity of demand	4	2%
	CPT: Product differentiation	2	1%
	TOTAL	**194**	**100%**

Table 13: Number of quotes for the sub variables of the carbon leakage concept. Source: Author, 2020.

Table 13 shows that the level playing field is the sub-variable more frequently addressed in the concept of carbon leakage. This sub-variable was mentioned in every interview, and the data shows wide consensus among all the interviewees that this is perhaps the most important factor to consider when designing a policy instrument that prices CO2 emissions. A higher price of CO2 has the potential to substantially alter the level playing field and reduce the competitive edge of highly emitting sectors.

> *"What companies look at is level playing field. Is my business case, is my production here better off than anywhere else? Do we have a disadvantage in the Netherlands in regard of Belgium, or Germany, or wherever elsewhere in Europe? That's what they look at."*
>
> - *Interviewee 12*
>
> *"What does not work, is to say as a country or a region 'we are going to tax you and the rest of Europe doesn't'. That, in the end, doesn't work. Then those companies leave, you have 100,000 people unemployed, and no one wants that. So, it's not that easy."*
>
> - *Interviewee 2.*

The sub-variable low-carbon technology development was also addressed in most of the interviews. There is consensus in the data gathered in that the abatement technology is in itself mature, but the high costs are keeping firms from making favourable business cases for their implementation. The only abatement option that could substantially abate CO2 emissions for the industrial cluster is CCUS, currently under development. Electrification was also mentioned in most of the interviews, but its zero-carbon potential depends on whether the electricity is clean.

> *"I think that the technology is mature, but the question is who is going to pay for it. It's the business side, that's the big issue. What is also an important point is that this infrastructure is*

not only expensive, but it also demands energy. To transport the CO2 to the North Sea also involves CO2, it is difficult, but it is a solution"

- *Interviewee 1*

4.2.2. Induced innovation

This section applies the theory of induced innovation to the industrial cluster of the PoR and analyses the conditions by which firms could accelerate innovation by developing and implementing new low-carbon technology. In this research, the variables created to analyse the theory of induced innovation are product, process and organisational innovation. The number of quotes for each sub variable are shown in Table 14. A description of the most relevant perspectives of the interviewees about each sub-variable can be seen in Annex A2.2. A distinction must be made with regards to the low-carbon technologies assessed in this research. In this section, it refers to existing technology in early stages of maturity that needs further investment or development to be applied in the scale required. On the other hand, in the *Abatement Potential* sub-section of the *Carbon Leakage* section, the focus was on technology that is already implemented or planned for implementation.

CATEGORY	SUB VARIABLE	QUOTES	PERCENTAGE
INDUCED INNOVATION	Pr: Barriers for adoption of new technology (BAT)	43	45%
	Pr: Production method alteration	12	13%
	O: Green business model	11	12%
	O: Inter-firm partnership	9	9%
	Pd: Potential for product differentiation	6	6%
	Pd: Sector propensity to innovate	6	6%
	O: R&D support	5	5%
	Pd: Market drivers	3	3%
	TOTAL	**95**	**100%**

Table 14: Number of quotes for the sub variables of induced innovation. Source: Author, 2020

Table 14 shows that over 45% of the quotations form this concept addressed barriers for the implementation of low-carbon technologies. Variables such as the potential for product differentiation, sector propensity to innovate and market drivers became quickly apparent during the data collection. This allowed to focus on new insights about more complex sub-variables such as the barriers for the implementation of low-carbon technologies. Among the most promising technologies mentioned are green hydrogen, electrification and offshore wind for production of electricity. An important point to make is that, although the technology is in itself mature, it is only in the early stages of its maturity, and there are important barriers to overcome before it can be implemented. The share of renewable sources in the electricity grid, high costs of implementation and lack of demand for them are among the most important barriers.

"If you want to build a hydrogen backbone, that takes time. It's not a one-off project or a not even a cluster project. It's really reforming the whole industry as such and the whole economy. So, it's much more complex"

- *Interviewee 8*

4.2.3 Government intervention

The data presented for this sub-variable is divided into funding (F), regulations (R), and enabling conditions (EC). The number of quotes for each sub-variable are shown in Table 15. A description of the most relevant perspectives of the interviewees about each sub-variable can be seen in Annex A2.3.

CATEGORY	SUB VARIABLE	QUOTES	PERCENTAGE
GOVERNMENT INTERVENTION	F: Scale-up	43	31%
	F: Innovation	27	19%
	R: Protection	23	16%
	EC: Legal framework	16	11%
	EC: Renewable electricity	15	11%
	R: Creation of markets	10	7%
	EC: Infrastructure	7	5%
	TOTAL	**141**	**100%**

Table 15: Number of quotes for the sub variables of the concept government intervention. Source: Author, 2020

Table 15 shows that almost 50% of the quotes of this concept address funding. It is pointed out by all the interviewees that companies cannot bear the whole costs imposed by the implementation of low-carbon technologies without going bankrupt or diverting investment to other regions. The government certainly does not have the financial resources nor the know-how to implement and decide which carbon technologies should be developed and implemented. Currently, the role of the government in supporting the implementation of low-carbon technologies in the Netherlands is by making public funding available through subsidies or grants. An important distinction was made between the specific funding mechanisms required in to decarbonise the industrial cluster of the PoR. According to the data gathered, scale-up funding instead of R&D and innovation is required.

> *"The green hydrogen is being developed just as pioneering first installations that are being supported on innovation funds rather than from scale up funds"*
>
> - *Interviewee 8*
>
> *"In the Netherlands there is a lot of effort put in R&D and innovation, but there is no real support on scale-up funding. And of course, those industries need scale up financing. The big need is scale up and not R&D and innovation."*
>
> - *Interviewee 12*

By just having a high price of carbon that is too divergent from the European price, the incentive to invest in the Netherlands decreases and firms will start thinking of *sweating the assets* rather than investing in something new. As it was mentioned by all the interviewees, there must be a balance between the *carrot and the stick*, understood as penalisations and incentives for emitting and curbing CO2 emissions, respectively. The view of many respondents from the industry and the PA is that the current proposal of the National Climate Agreement and the European policy in general are focusing excessively in penalisations (stick) and not in support policies (carrots) for industrial transition and investment in low-carbon technology.

According to the interviewees, transitions at the scale required in the PoR are subsidy driven instead of markets driven. During the interview with the chemical industry (VNCI), the comparison was made with the case of Germany accelerating the ban of nuclear power and support of nuclear power. In this case, there was a heavy support from public funds to investment in renewable energy. As a result, Germany has decreased its share of nuclear energy and increased the share of renewables substantially. The public investment did work and created a momentum for renewables in the rest of the world. For instance, it has decreased the price of PVs and allowed the technology to be scaled up worldwide.

4.2.4 Competitiveness of the Port of Rotterdam

This section presents the data collected with regards to port competitiveness. The variables analysed are port fees, throughput, and attractiveness as location for investment (ALI). Table 16 shows the number of quotations per sub-variable. A description of the most relevant perspectives of the interviewees about each sub-variable can be seen in Annex A2.4.

CATEGORY	SUB VARIABLE	QUOTES	PERCENTAGE
PORT COMPETITIVENESS	ALI: Business sustainability (BS)	20	43%
	ALI: Legal Framework (LF)	8	17%
	ALI: Knowledge and Innovation (KI)	7	15%
	TP: Input imports	5	11%
	PF: Cost increase	3	7%
	TP: Product export	3	7%
	TOTAL	**46**	**100%**

Table 16: Number of quotations of the sub variables for the concept of port competitiveness. Source: Author, 2020

The relatively low number of quotations of this concept compared with the previous ones is explained by the sample's composition. Port competitiveness is a rather specific concept that was addressed by only a few interviewees. Nevertheless, there is wide consensus in that the variable that would be most affected by a carbon tax is the ALI. The specific mechanisms and set of relationships that would impact this variable are detailed in the next section.

A large share of the PoR's revenues come from land fees charged to the firms operating in the industrial cluster, and port fees charged for the use of services, entering the port and the cargo it brings. The throughput can be divided into containers and bulk, which consists mainly on inputs for the industrial activity. Consequently, changes in the production levels or the business model of the firms operating in the PoR could indirectly affect the business structure and business model of the PA.

4.3. Relationship between variables

This section presents the relationship between variables and sub-variables of the conceptual framework and operationalisation table. The relationships will be made explicit based on the analysis of the data presented in the previous sections of this chapter, complemented by an analysis performed in the software Atlas TI. Particularly, co-occurrence tables for selected codes with a relatively high number of co-occurrences is included in the analysis of each concept. This supports and strengthens the relationships found inductively by analysing the content interviews. The analysis will be divided into the carbon leakage hypothesis and theory of induced innovation, with government support and port competitiveness present in the analysis of both concepts. Each of these subsections includes a co-occurrence table of the selected sub-variables of each concept -in the columns- with the sub-variables of the other concepts -in rows. A section of overlapping relationships is included, explaining the relationships between the sub-variables of carbon leakage and induced innovation. Lastly, section 4.4. presents a summary of the relationships found and the implications for policymaking and the business model of the PA.

4.3.1. The carbon leakage hypothesis

There are various relationships between the sub-variables of carbon leakage and other sub-variables of the study, as seen in Table 17. The table was created based on the Co-occurrence tool of Atlas TI.

	CL: AP: Investment spending (IS)	CL: AP: Low-carbon technology development (LCTD)	CL: CS: carbon costs (DC)	CL: CS: Sunk costs (SC)	CL: RE: Certainty of the future carbon price	CL: RE: Environmental stringency (ES)	CL: RE: Level playing field (LPF)
API: Legal and regulatory framework (LF)	0	0	0	0	2	1	8
CL: AP: Investment spending (IS)	0	5	1	2	0	8	2
CL: AP: Low-carbon technology development	5	0	0	0	0	0	1
CL: RE: Environmental stringency (ES)	8	0	3	1	1	0	3
EP: Perception of the carbon price	1	0	0	0	1	0	4
EP: Pricing mechanisms (PM)	0	0	1	0	4	1	8
GI: F: Scale-up	1	7	0	0	1	2	6
GI: R: Protection	2	1	0	0	0	1	8
II: Pr: Barriers to the adoption of low-carbon technology	1	8	1	0	0	1	1
PoR: Advantages	1	3	7	7	0	1	2

Table 17: Co-occurrence table for selected sub-variables of carbon leakage with selected sub-variables of the study. Source: Author, 2020.

Particularly relevant for this research are the co-occurrences between the sub-variable *Level playing field* and the sub-variables *protection, scale-up, and pricing mechanisms* from the concept Government intervention, and with the sub-variable *legal framework* of the concept port competitiveness. The detail of how these variables are related is explained in the next paragraphs and shown in Figure 16.

The introduction of a carbon tax in the Netherlands would distort the level playing field for the firms operating in the PoR, as their production costs will be higher only for the facilities in this location. This distortion would affect the sub-variable of *regulatory and legal framework*, reducing the attractiveness of the PoR as a location for investment. As these companies are multinationals with facilities and operations in different regions of the world, there is a high risk of investment leakage. Firms will most likely divert investment to more profitable facilities were production costs are lower, allowing them to get a faster return on investment. The fear is that a high Dutch local tax may reduce the incentive for the firms to invest in the PoR, leading to a loss of competitive edges. If firms stop investing in facilities in the Netherlands, they will be technologically behind the rest, leading to a loss of business for the PoR in the future.

However, government support policies and regulations can buffer the effects of a carbon tax by mediating the distortion that it induces on the level playing field as seen in Figure 15. For instance, the free allocation of emission permits to companies with high risks of carbon leakage in case of the EU ETS, or the introduction of a CBTA in the case of a carbon tax, would reduce the distortion in the level playing field and consequently prevent the loss of competitiveness and investment leakage to take place. The composition of the policy mix in which the carbon tax is included is of great importance as besides penalising emitters, it can provide incentives for the industry to invest in CO2 abatement. Such incentives can be in the form of direct subsidies, tax rebates or exemptions for companies with undergoing investments in abatement technology.

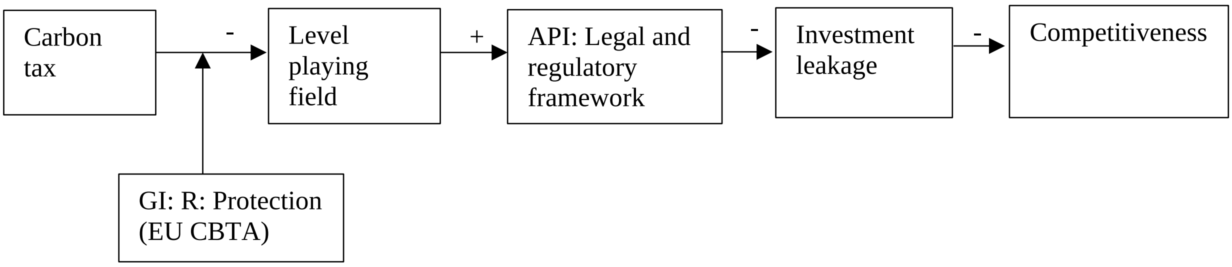

Figure 15: Carbon tax and effects in competitiveness through investment leakage. Source: Author, 2020

A recent example of the sensitivity of investment decisions to the level playing field is INEOS' investment case. INEOS is a UK owned multinational chemical firm who decided to make an investment of approximately 3 billion Euros in the industrial cluster of the Port of Antwerp instead of in the PoR. After a long bidding battle between both ports, the final decision started a discussion about whether the decision was influenced by the environmental stringency of the Netherlands and was used as an example of investment leakage. However, the CEO of the company stated publicly that the composition of the cluster in the port of Antwerp is more favourable for the needs of the company, which ultimately motivated the decision. Also, INEOS already had operations in Belgium and long-standing relations with the Port of Antwerp. The company employs 2500 people in their 9 manufacturing sites in Belgium, of with 6 are located in Antwerp (INEOS Group, 2019). This example illustrates that businesses analyse a myriad of variables for their investment decisions, with environmental stringency being just one of them. However, if regulations create an environment that is perceived as unfavourable for firms' production and business, the likelihood that they decide to invest in a rival port is high.

Table 17 also shows co-occurrences between the sub-variables *carbon costs* and *sunk costs* of the carbon leakage concept, and *PoR Advantages.* A carbon tax increases the production costs of firms, which is an incentive for them to relocate to regions with lower production costs. However, the enormous sunk costs of the firms in the PoR, the long-term commitments with suppliers and customers, and the benefits that firms obtain from being located at the PoR mediate this effect. Thus, the risk of carbon leakage in the form of ceasing production in Rotterdam and relocating operations to other regions is unlikely. The infrastructure and conditions that have developed around the port also act as strong barriers of exit, as they add value and efficiency to the industrial operations, unlikely to be found on a different location.
PoR discussed in the previous sections are the reasons why these companies have clustered in Rotterdam, conditions that will not change with a higher price of carbon; highly specialized labour force, strategic geographical location, proximity to an intricate and strong network of suppliers and customers, and efficient logistic services among others. The pipeline networks that have been built around the PoR is perhaps the most important feature preventing companies from relocating, as the alternative for them would be to build new pipelines to connect with suppliers and customers, or ship the enormous volumes of inputs-outputs, which would increase the costs significantly. This makes the real cost of doing business in Rotterdam difficult to assess as the firms benefit from a range of positive *agglomeration externalities*, and the cost disadvantage posed by a carbon tax would have to be extremely high as to outweigh all the benefits of being located in the PoR. This interconnectivity of the cluster can also be seen as a disadvantage. Just as a chain is as strong as its weakest link, changes on one firm will

inevitably have effects in the linked industries. These changes could vary from a reduction in the production levels to the decision to exit. These relationships are shown in Figure 16.

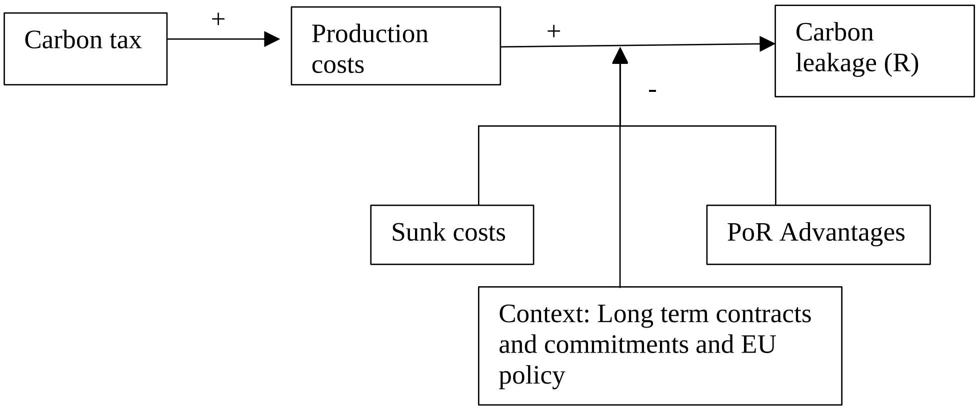

Figure 16: Carbon tax and carbon leakage mediated by sunk costs, advantages and long-term commitments. Source: Author, 2020

There are also arguments from a regional economic perspective against the relocation hypothesis. As it was pointed out, the investment and efforts to start operating in a different location are monumental, and firms would not take such a risk by relocating to other European countries. The trend in Europe is to make climate policy more stringent, and countries will most likely follow suit and increase the price of CO2 emissions shortly, which would leave the relocating firm with high CO2 price and without the benefits from the *agglomeration externalities* in the PoR. Thus, the decision to exit the European market, although unlikely as it sounds, makes more sense under this perspective than relocating within Europe. The demand for fossil-based products is decreasing in Europe, which would support the decision of exiting the European market, but there are at least two reasons against this argument. First, even in the most optimistic decarbonisation scenarios, European economies will remain relying on fossil fuels and fossil-based chemicals for at least another three decades, which ensures a market for that period. Second, the decarbonisation efforts are leading to the development of new sources of energy and feedstock that will overtake fossil fuels and fossil-based products as soon as the technologies can be scaled up. The firms in the industrial cluster of the PoR are in an extremely advantageous position to become frontrunners in the production of clean energy and products. With a long-term perspective, it would make more sense for the firms to invest in adapting their production processes to clean energy sources and implementing low-carbon technology instead of investing in traditional oil refineries or petrochemical facilities elsewhere.

Therefore, the scenario for the firms in the industrial cluster of the PoR is not auspicious in the future if they fail to adapt to the declining demand for fossil fuels and increasing demand for cleaner products in the long term. This acts against the carbon leakage hypothesis, as even if these firms relocate, the demand for their products will nonetheless decrease in the long term as the market is demanding cleaner, more sustainable products. This can be seen as an opportunity by these industries, who can become frontrunners in satisfying this increasing demand for cleaner products. The traditional oil and chemical industries are not growth industries, they are mature industries that are becoming less and less important to the regional economy. From a business perspective, it is much more interesting for the regional economy to strengthen the investments in renewables and low-carbon technologies, which are the technologies of the future. The extent to which firms can make these investments without disappearing in the attempt is a much harder question and depends on several factors assessed in this research.

However, even if the firms do not relocate, the competitiveness of the port could still be affected by a higher price of CO2 emissions. To appropriately assess the effect of this cost increase for the industrial cluster, the first step is to differentiate between the various companies and industries operating in the PoR, as some sectors have higher emissions and are more exposed to a CO2 price increase. For example, warehouses and storage companies will not be directly affected by the price increase, whereas coal-fired or gas-fired power plants and firms operating in the oil refining sector are more exposed as their emission levels are higher. The oil refining sector emits a much larger amount of CO2 than the chemical sector, which embeds the fossil-based feedstock in its products as seen in Figure 13. This means that the chemical industry does not emit all the carbon it uses as feedstock in its production process, but most of it is emitted when the products are burned by the customers. According to the data gathered, approximately one-third of the total emissions of the chemical industry are direct emissions, also called *energetic emissions*. The *non-energetic emissions,* which represent two-thirds of the total, are embedded in the products and are emitted when the products are used. This illustrates that the extent to which firms will be affected by a higher carbon price depends on the degree to which they are direct emitters (scope 1 emissions) or indirect emitters (scope 2 and 3 emissions). Oil refineries, coal-fired power plants and gas-fired power plants would be the most affected industries with the introduction of a carbon tax on CO2 emissions, and the chemical industry would be relatively less affected.

Nevertheless, in a highly integrated and interconnected cluster such as the PoR, the functioning of the whole industrial ecosystem depends on the interactions and trading taking place between the firms. This means that even if some firms are not directly affected by a higher price of CO2 emissions, their business might still be damaged indirectly by a reduction in the demand for their products or services. It is the case for all the suppliers and firms providing services to the oil refining industries, coal-fired power plants and gas-fired power plants, such as technical maintenance, warehouses and tank terminals among others. The chemical industry might also be affected indirectly, because a reduction in the production levels of the oil refineries as a consequence of an increase in the production costs would reduce the amount of feedstock available for chemical production, forcing them to import feedstock at a higher cost.

Regardless of the extent to which firms are affected, many of them already have low operational returns and profits. The most likely reaction of the companies to a cost increase in the short term would be to use the facilities in the PoR as *swing facilities*, operating them at a lower capacity. The throughput of the PoR is to a large extent dependent on the production level of the companies operating in the industrial cluster, as seen in Table 10. A reduced throughput translates into lower income for the PA, which in turn negatively affect its competitiveness. Hence, the total effect of a carbon tax in the competitiveness of the PoR from a cost structure perspective is negative. However, this effect can be mediated by regulation as a CBTA, which would buffer the effect of increased production costs in the production level. These relationships are shown in Figure 17.

By taxing imported goods according to their carbon content or the CO2 emitted in their production, the market price for both imported and locally produced goods with increased production costs is expected to be the same. In other words, the price of the goods will increase (both imported and locally produced), and any change in production levels will be a consequence of reduced demand for the goods in response to higher costs rather than a consequence of reduced demand for locally produced goods on behalf of imported ones. The CBTA regulation would need to be implemented at the European level to be effective and make the desired impact. As the PoR produces mainly to serve its hinterland, if the CBTA is implemented only in the Netherlands, then the imported goods will reach the market through any other port serving the same hinterland. This relationship is not shown in Table 17, as the sub-variable *throughput* of Port competitiveness was mentioned in only a few interviews, reducing the possibilities for co-occurrences with other variables. However, an analysis of the content of the interviews in which this sub-variable was mentioned makes this relationship clear.

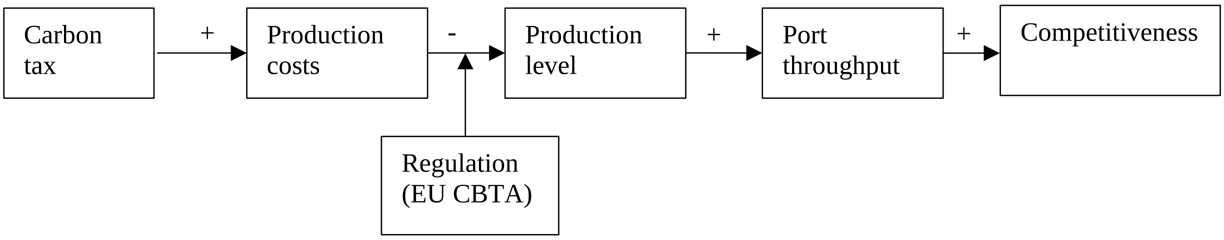

Figure 17: Carbon tax and effects in throughput and competitiveness. Source: Author, 2020

The variables of cost pass-through ability and abatement potential are related to variables and sub-variables of the theory of induced innovation and will be explained in detail in the section of overlapping relationships. Regarding the first, product differentiation is one of the mechanisms used for firms to pass-through increased production costs. In the case of the goods produced by the firms operating in the PoR, regulation can be a major market driver to create demand for new products and enhance product innovation. This, in turn, would increase the chances for product differentiation and pass-through the increased costs, preventing from carbon leakage as seen in Figure 18. This effect can be seen in detail in Figure 24. Regulations play a key role in the creation of markets that are not profitable from a business perspective. Examples like the EU regulation for biofuels and the ban of non-reusable plastic demonstrate that regulations can shape, create or eliminate markets. In the context of the industrial transition in the Netherlands and the PoR, such regulation needs to be implemented at least at the European level to create a market that allows for low-carbon technologies to reduce their costs and scale-up.

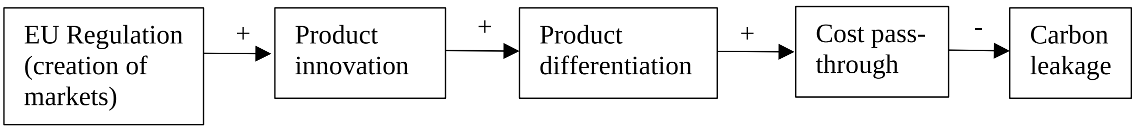

Figure 18: Cost pass-through and carbon leakage, in presence of EU regulation. Source: Author, 2020

Regarding the second, abatement potential is strongly linked to green investment and process innovation. In the presence of a carbon tax and government support in the form of subsidies or enabling conditions, firms would invest in implementing low-carbon technology, which will increase the options for CO2 abatement and decrease the risk for carbon leakage. This relationship can be seen in Figure 19.

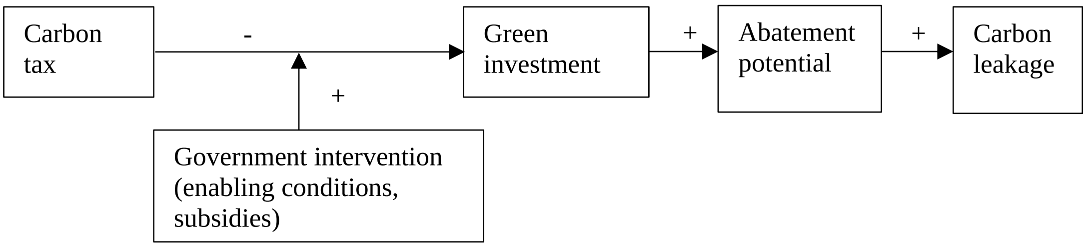

Figure 19: Carbon tax, abatement potential and carbon leakage. Source: Author, 2020

In the short term, CCUS is the only relatively realistic option to abate emissions for the oil refining and petrochemical industries. One of the reasons is the high temperatures needed in their processes, which are extremely hard to achieve with other sources of energy different than combustion of fossil fuels. Nevertheless, although CCUS technology has been proven and applied, it has never been implemented in an interconnected and large-scale industrial cluster like the one in the PoR, which makes it a pioneer and challenging work. The use of hydrogen for these industrial processes is a new development that, although is showing promising prospects in small scale applications, its costs are still extremely high for it to be scaled up. The electrification of industrial processes will undoubtedly improve energy efficiency, but it will only contribute to reducing CO2 emissions to the extent that electricity is generated from renewable sources. Additionally, as mentioned above, the high temperature needed in the processes of the oil refining and petrochemical industries is not achievable by electricity. While the outlined roadmap by the PoR is to some extent clear until 2030-2035, the scenario for the longer term is less certain. Considering the current amount of emissions saved in here are still approximately 15 Mt of CO2 that needs to be reduced until 2050.

Not every sector and factory are in the same position regarding the opportunities to abate CO2 emissions. The higher the amount of CO2 emissions of a sector or factory, the marginal cost of abatement becomes more exponentially more expensive. In sectors as the ones operating in the PoR, whose margins are already low, financing the abatement of CO2 emissions on their own is not a real option without going bankrupt, which makes government intervention necessary. In the short term, the only option of a substantial CO2 abatement for these industries is CCUS. In the long-term, the costs of blue or green hydrogen should decrease to a point in which the business case for their implementation is favourable. On the other hand, the business case for fossil fuels and fossil-based products is still favourable, especially enhanced by the current oil prices.

4.3.2. The theory of induced innovation

The main relationships found between the sub-variables of the theory of induced innovation and other variables of the study are shown in Table 18, which was made using the co-occurrence tool of Atlas TI. However, more relationships were found inductively by examining the interview transcripts.

	II: Pd: Market drivers	II: Pd: Potential for product differentiation	II: Pd: Sector propensity to innovate	II: Pr: Barriers for the adoption of new technology (BAT)	II: Pr: Production method alteration
CL: AP: Low-carbon technology development (LCTD)	0	1	0	8	3
CL: CPT: Demand trends	3	0	0	0	0
GI: EC: Legal framework	0	0	0	5	1
GI: EC: Renewable electricity	0	0	0	6	0
GI: F: Scale-up	0	0	0	7	1
GI: R: Creation of markets	3	3	4	1	0

Table 18: Co-occurrence table for selected sub-variables of induced innovation with selected sub-variables of the study. Source: Author, 2020.

Table 18 shows a strong relationship between the sub-variable *barriers for the implementation of low-carbon technology* of induced innovation, the sub-variable *low-carbon technology development* of carbon leakage, and the sub-variables *legal framework*, *enabling conditions and scale-up funding* of government intervention. Also, the table shows a relationship between the sub-variables *market drivers*, *potential for product differentiation* and *sector propensity to innovate* of induced innovation with *creation of markets* of government intervention and *demand trends* of carbon leakage. These relationships will be explained in detail in the following paragraphs.

The implementation of low carbon technology is heavily linked to government intervention, as different forms of government support are needed to overcome the existing barriers for its implementation. The introduction of a carbon tax with no support policies or regulations will not incentivise companies in the industrial cluster to invest in abatement technology or innovate in low-carbon products. The theory of induced innovation could only take place if both support policies and regulations are in place to provide incentives for firms to invest, and they act at different levels.

First, a carbon tax could induce green investment by reducing the profitability of investments in fossil-based technology, but this relationship is mediated by government support in the form of scale-up funding and enabling conditions for green investment, as seen in Figure 20. The industrial cluster of the PoR has the appropriate scale to become a frontrunner in the testing and implementation of low carbon technologies such as green hydrogen. It counts with an offshore wind power grid, large and highly emitting industries, pipeline networks and CCUS facilities. These are important factors to implement this new technology and create the market for it rather quickly. According to the data gathered, the scale is the most important feature when it comes to creating a favourable business case for hydrogen and bringing the costs down. That scale can be found in a place along the coast where there is transportation infrastructure, large industries, carbon emissions and know-how to implement, maintain and manage the new technology. However, as there is consensus among the interviewees in that the conditions are present in Rotterdam for the implementation of CCUS and hydrogen, there is also a consensus in that firms cannot make the investments by themselves without risking their permanency in business. Government support is crucial to both the financing of the transition and enabling conditions that create an attractive investment environment in the Netherlands, and Rotterdam in particular. Without support policies, a carbon tax will not induce green investment but could induce investment leakage instead, as explained earlier. The introduction of a carbon tax as part of a policy mix that also includes government support aimed at scaling up the existing technologies would incentivise firms to make the required investments.

Second, regulation can create new markets for cleaner products, which would incentivise product innovation in firms to satisfy the new demand as seen in Figure 21. As this relationship also has implications for the carbon leakage hypothesis, it will be described in detail in the next section about overlapping relationships.

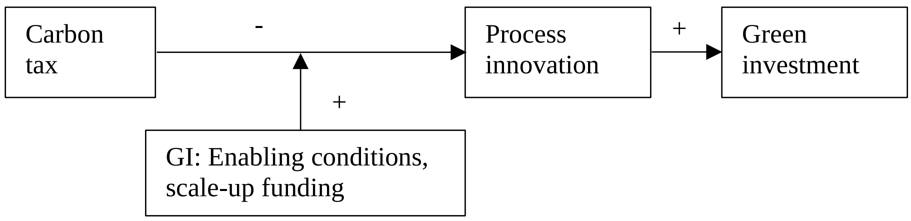

Figure 20: Carbon tax and green investment, mediated by government support. Source: Author, 2020

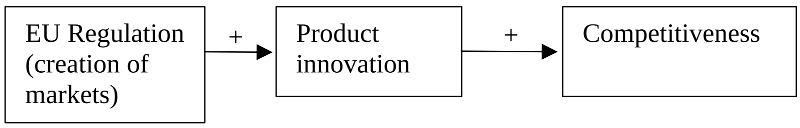

Figure 21: Regulations as enhancers of product innovation and competitiveness. Source: Author, 2020

The detailed mechanism by which green investment is enhanced is shown in Figure 22. As mentioned earlier, a carbon tax increases the costs of CO2 emissions, which is required to trigger investment in low carbon technology (green investment). In the case of the PoR, the options that could lead to substantial emissions abatement are too expensive for companies to make the investment on their own and make a favourable business case. This makes government support a vital element to create an attractive place for investment. Without it, a carbon tax could only be seen as a barrier for industrial activity and an incentive for investment leakage. The enhanced attractiveness as a location for investment will, in turn, incentivise the required green investment and enhance the competitiveness of the PoR as a frontrunner in industrial transition. According to the data gathered, although the most direct mechanism for government support is making public funding available through subsidies, it can also enable the conditions for green investment by, for example, making sure that the infrastructure required as a pre-condition for the implementation of low-carbon technology is in place. For instance, building a hydrogen backbone, infrastructure for CCUS, or large-scale deployment of offshore wind would give clear signals and certainty to companies in that the government is aligned and committed with the industrial transition.

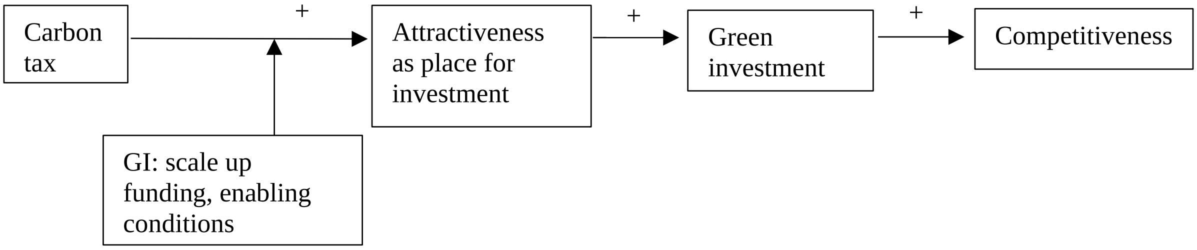

Figure 22: Carbon tax and impacts in competitiveness through green investment. Source: Author, 2020

During the last couple of years, developments and feasibility studies have been carried out by the *H-Vision* project for large scale production and utilisation of blue hydrogen in the PoR. The project has partners like Shell, BP and Uniper among others. The most recent results of the *H-Vision* research team were published by the Port of Rotterdam Authority (2019). They estimate CO2 savings of 2.2Mt to 2026 and 4.3Mt to 2031 from the implementation of the project, representing a 16% emissions reduction of the industrial cluster compared with 2018 levels. Estimations for the cost of CO2 abatement ranges from 86 to 146 EUR/ton of CO2 excluding ETS credits, and the industrial cluster would be able to produce 20% of its needs for heat and power by this technology. The feasibility study estimates an investment of 2 billion euros for the implementation of the project. The research team is now focusing on technical feasibility studies, and an investment decision could be made as early as 2021, with which the project could start operating by 2026.

On the other hand, declining demand for fossil-based products represents an incentive for firms to change their business model, which can lead to process and product innovations as seen in Figure 23. European environmental regulations will be ever more stringent in the short term, including a higher price of CO2 emissions, which has implications for the production of both existing products and innovation in new products. The facilities operating in the PoR supply mainly the European market, where the demand for traditional fossil-based products is expected to decrease and the demand for cleaner products is likely to increase. This represents an opportunity for companies to innovate in their production processes and produce the existing products with fewer emissions, or to innovate by creating new products. Both of these effects will translate into green investment and would lead to increases in competitiveness in the future carbon-neutral economy. Product innovation requires also of regulation that creates markets for these products, which is explained in detail in Figure 24.

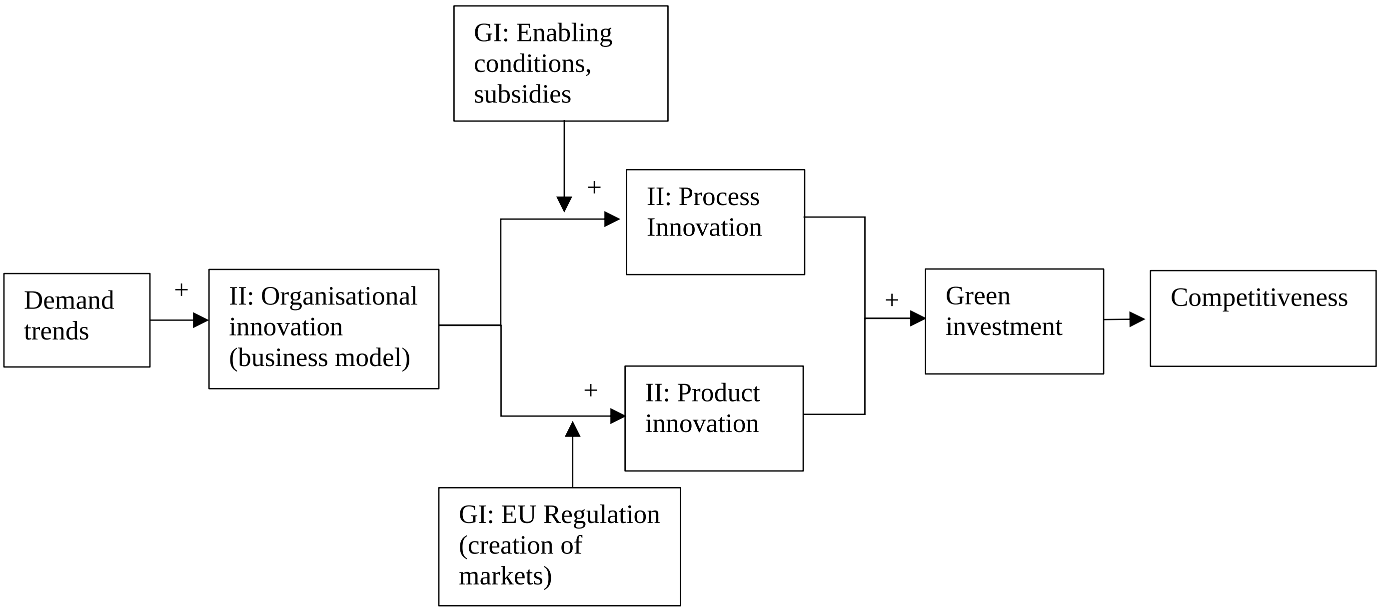

Figure 23: Demand trends and effects on innovation and competitiveness. Source: Author, 2020

4.3.3. Overlapping relationships

This sub-section presents relationships involving sub-variables from both carbon leakage and induced innovation, and their interactions with government intervention and port competitiveness.

Regulation can create markets for new products. When there is a market, firms will create business cases to satisfy the demand by innovating with new products or implementing new technology in their production processes. Product differentiation and the implementation of low-carbon technology in production processes increase the competitiveness of the industries operating in PoR in the future low-carbon economy. Given the relatively small scale of the Dutch industry, the regulation should be implemented at the European level at least. An example of this phenomenon can be found on the EU regulation for biofuels, which created a demand for a new product that would have not been created by the market on its own. As a result, there is a market for new products (biofuels) and companies have adapted part of their production processes to comply with the regulation and satisfy the demand. Similarly, regulation is required to create a market for both cleaner products and energy sources, such as green hydrogen. For example, there are 1.3Mt of grey hydrogen being produced currently in the Netherlands. If a regulation forced at least 10% of the hydrogen produced to be green, firms will follow and satisfy the demand. The production of new products or innovations in production processes of existing products would enhance the competitiveness of the PoR in the ever-closer low-carbon economy. The extent to which firms can implement new production methods is to a great extent mediated by whether the conditions for their implementation are in place. For example, production method alterations such as green hydrogen or electrification of production processes require either that the electricity grid is completely switched to renewables or dedicated offshore wind electricity production to ensure zero emissions in the whole chain. If these conditions are not in place, the implementation of the new technology as a consequence of newly created demand will not take place.

Also, product differentiation allows for firms to pass-through the increased production costs which would in turn act against carbon leakage.

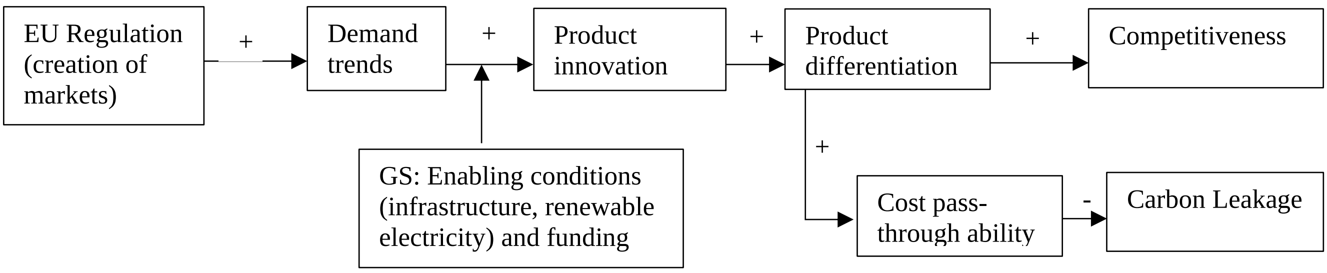

Figure 24: Regulation aimed at the creation of new markets and impacts on competitiveness and carbon leakage. Source: Author, 2020.

According to the data gathered, a carbon tax will provide the certainty of the future carbon price required by firms to plan their investment decisions. The extent to which this enhances the perception of the Netherlands -and consequently the PoR- as a place with stable and clear regulations are mediated by the regulations included in the policy mix. Without regulations protecting the industry from international competition, firms will not perceive the country as stable for investment. However, in the presence of clear penalisations and protection measures, the sub-variable stability of regulatory environment will be enhanced. The extent to which the enhanced perception of the Netherlands as a stable country translates into an increase in its attractiveness as a location for investment is mediated by the support policies implemented with the carbon tax. If support policies aimed at scaling up the existing low-carbon technologies are also implemented, their combination with a stable regulatory environment will trigger green investment, which in turn will increase the competitiveness of the PoR by becoming a frontrunner in low-carbon production.

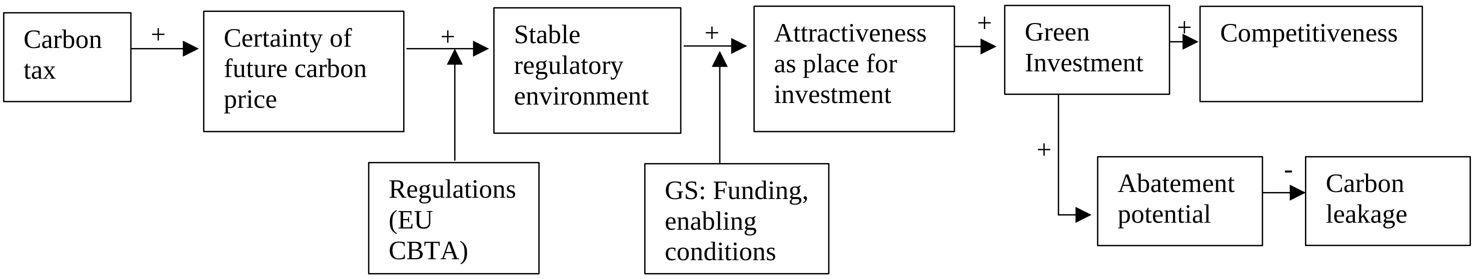

Figure 25: Certainty of future price of carbon and competitiveness. Source: Author, 2020.

As stated before, companies located at the PoR are multinationals with operations in various countries within and outside Europe. To analyse if the firms operating in the PoR would gain a competitive edge by implementing low-carbon technology, two cases are assessed. The first case is the introduction of a uniform European price for CO2 emissions and the CCUS system in place in the PoR, with a lower cost of transport and storage than the European CO2 price. In this case, the PoR would be an attractive place for investment as the CO2 cost terrace will be lower than in other European regions without CO2 abatement options. Firms located in the PoR would gain a competitive edge against the European competitors by having less CO2 costs. The second case considers a global perspective, and the CO2 cost comparison is made with the regions outside Europe in which firms operate; mainly the middle east, the USA and China. In this case, assuming that implementing a global price for CO2 is highly unlikely, there would be no competitive edge in the implementation and use of the CCUS technology in the PoR. The middle east, USA and China do not price CO2 emissions or price them at considerably lower levels than the projected cost of transporting and storing CO2. Thus, the production in these countries will be considerably cheaper than in the PoR. This is a simplified analysis, as other variables such as specific transportation and production costs for each region can amplify or reduce the differences in net costs. To protect the competitiveness of the European industry, mechanisms such as *Carbon Border Tax Adjustment (CBTA)* are required. By taxing the imports according to their carbon content, tackles directly the second scenario described.

From the analysis above is apparent that a higher price of CO2 emissions, if applied in the Netherlands alone, will not enhance the competitiveness of the firms in the industrial cluster of the PoR from a cost structure point of view. Even if with abatement options available, of which the most realistic in the short term is the CCUS, the production costs will increase in just one of their facilities. This is more likely to result in an investment leakage than in investment in low-carbon technology.

4.4. Summary and implications

A summary of the relationships detailed above can be seen in Figure 26 and Figure 27. The introduction of a carbon tax in a policy mix that includes protection for the industries operating in the industrial cluster of the PoR, added to the declining demand for fossil-based products would create the incentives for firms to innovate in their business models and aim for more sustainable operations and products. Organisational innovation is modelled as a precursor for product and process innovation, as they come as a consequence of a shift in firms' business models, vision or goals. Once firms can make favourable business cases for new products or the implementation of low-carbon technology, product or process innovation can take place. The extent to which this is realised in practice will depend on the support policies and regulations included with the carbon tax. For product innovation to take place, a regulation that creates new markets for cleaner products is required as firms will not make investments that are not profitable nor produce goods for which there is no demand. The lack of demand for cleaner products is keeping the technology from scaling up, which makes regulation needed as firms currently cannot make a business case for cleaner production. Similarly, government support in the form of subsidies or enabling conditions is required for firms to invest in low-carbon technology in their production processes. As explained earlier, the abatement options for firms in the industrial cluster of the PoR require investments that are too large to be done by firms on their own without seriously threatening their profitability and permanency in the market. Without subsidies, the most likely scenario is investment leakage instead of green investment. In this scenario, it is more likely that firms divert investment to increase the production in facilities located in regions with cheaper production costs than allocating resources for the decarbonisation of the facilities in the PoR. Enabling conditions also play an important role in creating an attractive investment climate, as they are a precondition for the implementation of many of the existing low-carbon technologies. For instance, for the electrification of processes and the production of green hydrogen, the electricity grid must be switched to renewables. Given the amount of electricity required in these processes, if the electricity is generated from fossil sources, the desired reduction of emissions will not take place and could even increase.

However, with the appropriate incentives in place, the implementation of a carbon tax has the potential to translate into green investment. This would increase the competitiveness of the firms operating in the PoR as frontrunners in low-carbon production and gaining a competitive advantage in the future net-zero carbon economy. In this scenario, the PoR would be positioned among the few -if not the only- places in the world where low-carbon production takes place in a large scale, creating a hub from which knowledge and technologies are spread.

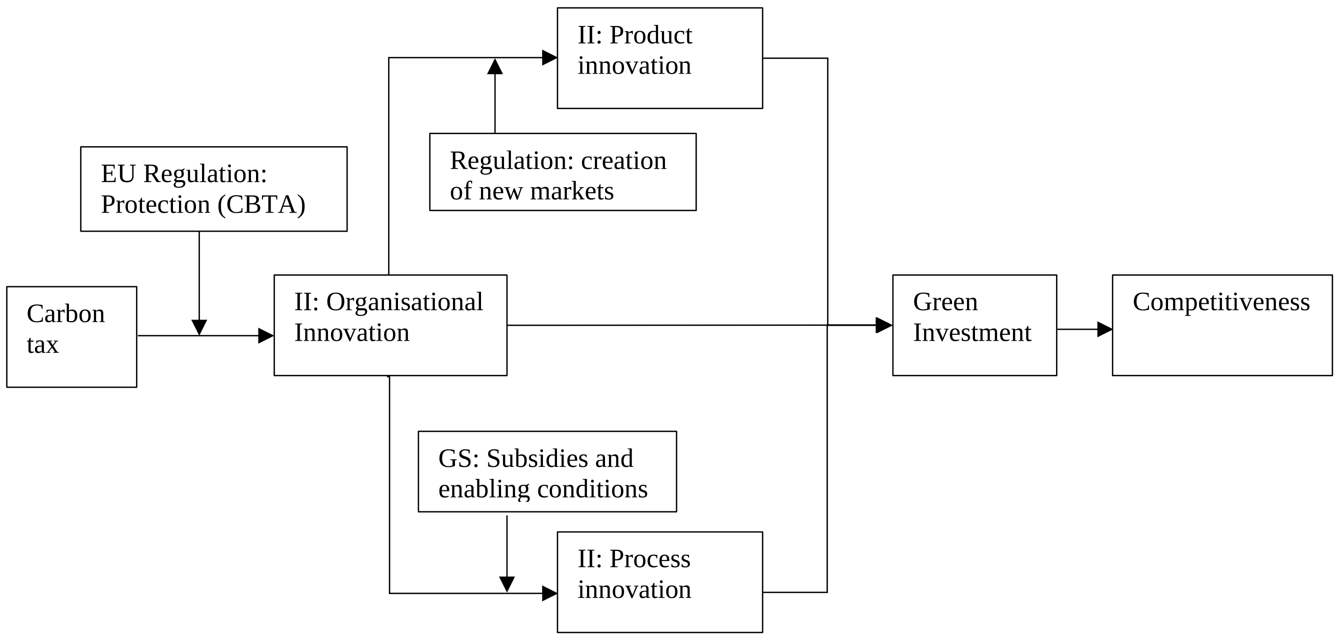

Figure 26: Summary of relationships for the theory of induced innovation applied to the case study. Source: Author, 2020

As it was mentioned in the paragraph above, regulations aimed at protecting firms from and avoiding carbon and investment leakage are needed for innovation to take place. Given the nature of the industrial cluster of the PoR and the international trade lanes in which firms operate, the relocation of operations is not as big of a threat as investment leakage. Regulations such as CBTA would buffer the effect of the carbon tax in the cost structure of firms, as it will allow for the market price of the goods to increase for both locally produced and imported goods. This would also reduce the distortions on the level playing field, which is part of the regulatory environment sub-variable, and reduce the risk of carbon leakage. Subsidies to scale up the technologies and enabling conditions are needed for firms to invest in low-carbon technology and mediate the effect of abatement potential and investment leakage. If companies can make favourable business cases by implementing the abatement options available, the risk of investment leakage is reduced. Regulation aimed at the creation of new markets will allow for product differentiation and the possibility of passing through the increased costs of production, reducing the risk of investment leakage.

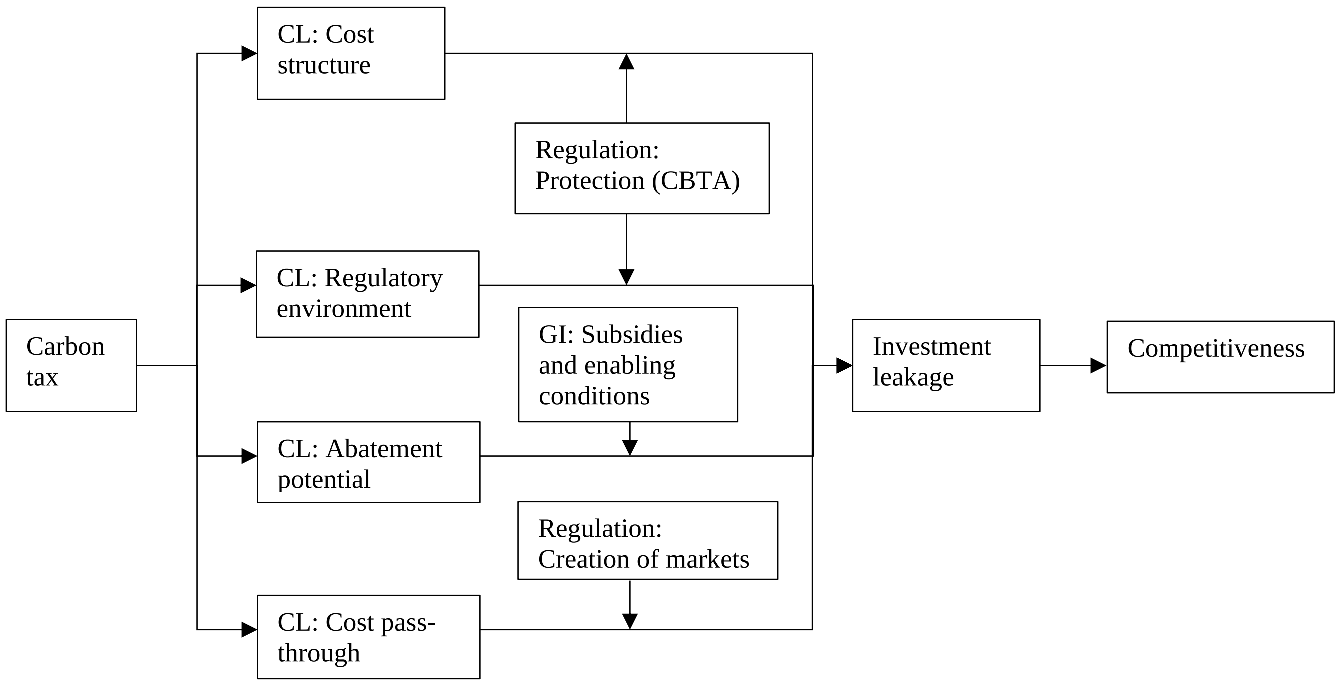

Figure 27: Summary of relationships between the carbon leakage hypothesis and competitiveness. Source: Author, 2020

These findings have implications on several levels and can be interpreted from different perspectives. From a theoretical point of view, there is a tendency to highlight carbon pricing as the main solution to abate CO2 emissions, arguing that by internalising their environmental costs firms will inevitably reduce their emission levels. The analysis performed shows that increasing the price of emissions is indeed an important and vital mechanism to abate CO2 emissions. However, in the case of the industrial cluster of the PoR, if a higher price of carbon is imposed in isolation the consequences could be detrimental for both the economy and the environment. The abatement options for these companies are in many cases substantially more expensive than their profits, which would make the adoption of cleaner technology not feasible. In this sense, the importance of the support mechanisms and regulations included in the policy mix in which the carbon tax is introduced cannot be stressed enough. It is important to mention that the industries in PoR require funding aimed at scaling up the existing technologies rather than funding aimed at innovation and creation of new technologies. One of the barriers for the adoption of hydrogen or CCUS is that they have not been implemented or tested in the scale required for large industrial complexes. This is an important implication for the design of subsidy schemes, which have been largely focused on R&D and innovation, but not in scaling-up the technologies. In this sense, the SDE++ scheme that has been broadened in 2020 to include not only renewable electricity production but also CO2 saving measures is in the right direction.

The findings are also relevant for policymaking and the governance of the decarbonisation of industry. According to the data gathered, there is a willingness from the firms to invest in cleaner technology and push the industrial transition in the PoR forward. The existence of relatively few highly emitting firms -the *big twelve*, responsible for 60% of the country's industrial emissions- organised in industrial clusters in the country represents an advantage in the decarbonisation challenge. The relatively few numbers of industries could make the assessment of the abatement options and coordination between stakeholders simpler, making it easier to reach agreements and enhance cooperation between the firms and policymakers. The fact that industries are organised in clusters makes it technically easier to implement low-carbon technologies on a large scale and facilitates the provision of the required infrastructure. These characteristics provide advantages for the decarbonisation of industry in the Netherlands, which could create momentum and push forward the decarbonisation of the industry in Europe. The great challenge from a policymaking and governance perspective is to reach agreements in several aspects. First, on which of the available technologies will be supported by subsidy schemes to be scaled up, and how will this decision be made. Second, to reach the balance between penalising emitters by increasing the cost of CO2 emissions while providing incentives that create an attractive investment environment in the country. Third, to ensure the supply of enough renewable electricity, a prerequisite for the implementation of low-carbon technologies such as electrification of processes and the production of green hydrogen.

As it can be seen throughout this analysis, government intervention and support play a key mediating role in almost every relationship between the variables of both carbon leakage and induced innovation. Government intervention can prevent investment leakage and create a favourable investment climate in the Netherlands. If the carbon tax is implemented in a policy mix that also includes support for industries in the implementation and scaling up of low carbon technology, they would act as a buffer for the distortions in the level playing field. The balance between the *carrot and the stick* is a key element to both prevent from investment leakage and incentivise the investment in low-carbon technologies. In this case, the carrots are the support policies, and the stick is the carbon tax. Both in combination would create an attractive investment climate and provide incentives for green investment. This would increase the PoR's competitiveness in the long term, by becoming a frontrunner in the implementation of low-carbon technology and clean production.

The findings are also relevant for the business model of the PA, whose development has been historically linked to highly emitting industries. The profits of the PA under its current business model are being threatened by two forces. The projected declining demand for fossil-based products in Europe and the increasing stringency of the climate policies in Europe - and the Netherlands in particular- have direct impacts on the activities performed by these industries and the investment allocated in their facilities. However, most of the advantages of the PoR that explain the clustering of the industries in this location will not change with a higher carbon price. This represents both a challenge and an opportunity for the PA to innovate in its business model. It has the potential to become the place for clean production and the knowledge hub for the implementation of low-carbon technologies at a large scale. The extent to which this happens is dependent on the balance between penalisations and incentives and in the pro-active ability of the PA to become a coordinator and facilitator of the industrial transition. To enhance its competitiveness in the future net-zero carbon economy, the PA needs to take a step forward and lead the transition of the industrial cluster. According to the data gathered, the PA has chosen to take that role and coordinate the efforts of decarbonisation of the industries.

However, the specific approach and the effectiveness of the measures adopted by the PA are not assessed by this study.

Chapter 5: Conclusions

5.1. Research purpose

In the next two to four decades, CO_2 emissions from the use of fossil fuels need to be eliminated and large amounts of CO_2 already in the atmosphere need to be removed to prevent the earth's temperature from rising above 2C. The consequences of climate change are manifold and will affect every aspect of human life; the way we operate our systems, the cities we live in, the amount and quality of food we produce, the products we consume, among many others. Governments, authorities, firms and citizens from all over the world are fully aware of this situation. Agreements have been signed by the world's most powerful nations and awareness campaigns have been deployed in almost every corner of the earth, trying to change people's habits and behaviours. Nevertheless, CO_2 emissions have not decreased, and in 2018 they reached an all-time peak. Policies aiming at curbing GHG emissions have been implemented in various regions with different degrees of success, and yet in the complete picture, emissions are still on the rise. One of the main barriers to reaching broader agreements in reducing CO_2 is that most of our economies and everyday life are heavily based of fossil fuels; the clothes we wear, roads we build, the fuels we use as transportation, the energy we use for heating and cooking and most of the products we use in daily life has been produced at least partly based on fossil fuels. Emissions from the industry sector represent one-third of the world's total emissions, and efforts aimed at curbing them can have broad positive and negative impacts. Among the most accepted policies to enhance the industrial transition is *carbon pricing*, a policy instrument aimed at internalising the costs of emitting CO_2 under the *polluter pays* principle. Economic literature suggests that if the externalities produced by emitting CO_2 are included in the cost structure of the firms, they will see them as a resource for production, creating an incentive to reduce their use. According to the theory of induced innovation, when one production factor increases its costs, firms have an incentive to innovate by finding innovative ways to make more efficient use of that resource or replacing it by a new production input. In the context of industrial transition and carbon pricing policies, CO_2 emissions represent the resource that increases its price, creating an incentive for firms to make less intensive use of this resource or innovate in technology that allows to no use it at all. However, the hypothesis of carbon leakage suggests that the opposite could happen, and firms would react to an increase in CO_2 price by relocating operations to less-regulated regions where production costs are lower and investments more profitable. As most countries' economies are highly sensitive to industrial activity, the threat of carbon leakage and its effects on the economy and the environment has kept many legislations hostage of the *business as usual*, and there have not been significant increases in the price of CO_2 nor reductions in emission levels.

This research assessed the applicability of both the carbon leakage hypothesis and the theory of induced innovation for the carbon tax on industrial GHG emissions proposed in the Dutch National Climate Agreement. The case study is the industrial cluster of the PoR, and the research aims at assessing the effects that such tax would have in its competitiveness by analysing both the risks of carbon leakage (C) and the opportunities for the implementation of low-carbon technology (D). Furthermore, this research unveiled and explained the relationships between these concepts in the context of the case study. It also identified policy mechanisms that could prevent carbon leakage to take place while providing incentives for the implementation of low carbon technology and accelerating the industrial transition of the PoR. Although the Dutch National Climate Agreement has not been implemented yet, this research gathers the perspectives and concerns of important stakeholders from various sectors about the consequences of the implementation of a carbon tax for the industries in the industrial cluster of the PoR.

5.2. Conclusions

5.2.1. Research question A: What are the characteristics of the proposed carbon tax, and how would it complement the existing policy (EU ETS)?

The last version of the Dutch National Climate Agreement drafted and published by the Dutch Ministry of Economic Affairs and Climate in June 2019, is a proposal that includes specific CO2 emission reduction targets for 5 sectors; built environment, mobility, industry, agriculture and land use, and electricity. The target proposed for the industrial sector is a 49% reduction of CO2 emissions by 2030 compared to 1990's levels, with measures aimed at achieving a 55% reduction. The Dutch government is pushing for an increase in the European CO2 reduction target for it to reach 55% in 2030 compared to 1990's levels, in which case the national targets would follow suit. These ambitious targets translate into a reduction of 14.3Mt on top of the 5.1Mt of CO2 emissions baseline reduction projected as a result of the existing policies such as the EU ETS. Taken together, the target for the industry is to reduce 19.1Mt by 2030, which represents a 59% reduction compared to 1990's levels. To reach this target, the proposal includes a tax that ensures a floor for the carbon price of 30 EUR/tonCO2 in 2021, increasing linearly to 125-150EUR/tonCO2 in 2030. The carbon tax would apply to the same industries currently covered by the EU ETS and is complementary to the EU ETS price. For instance, if the ETS price in 2021 is 20EUR/tonCO2 the amount of tax would be of 10EUR/tonCO2 to reach the price floor of 30EUR/tonCO2. Projections of the PBL on the EU ETS price estimate that it will reach around 45EUR/ton in 2030, with which the expected carbon tax to be paid by the industries will be of 75-100 Eur/ton of CO2 in 2030. These estimations consider that 80% of the abatement potential for the industry will be utilised by 2030 and that the targets are reached with 75% of probability.

However, the exact price levels of the carbon tax are still to be determined, and the Dutch National Climate Agreement is still under development. The government is currently performing consultations with stakeholders from various sectors to refine the exact price floor for CO2 emissions, its evolution until 2030, and additional policies to be included with the carbon tax.

5.2.2. Research question B: What are the determinants of port competitiveness and what are the competitive advantages of the PoR over its competitors?

The determinants of port competitiveness have been explained in Chapter 2 and include a wide range of factors that vary greatly depending on the perspective used to assess them. Factors commonly included in port competitiveness assessments are geographical location, accessibility to the hinterland, port fees, infrastructure, operational efficiency, maritime accessibility, fiscal climate, access to specialised labour force, among others (Parola et al. 2016, Scaramelli 2010, Hales et al. 2016, Meersman et al. 2016, Notteboom and Yap 2012). Given the characteristics of the PoR, this research includes the factor of attractiveness as a location for investment as one of the main drivers of port competitiveness. The PoR is the largest port in Europe and the tenth largest in the world. These positions can be explained to a great extent by the existence of a large industrial cluster in the PoR's area, whose inputs for production are mainly brought in through the PoR, generating large amounts of throughput.

There is a myriad of factors that create a favourable environment for industrial activity and explain the existence of Europe's largest industrial cluster in the PoR. The PoR is located next to the coast and adjacent to wide rivers, which gives direct access to the open sea and efficient connections with the hinterland. Inland shipping through the Maas and Rhine rivers provides direct access to important European economic centres, and connections with the Danube and Main rivers make it possible to move cargo as far as the Black Sea. This geographical advantage and the settling of large industrial facilities that need to transport their products to markets in the hinterland created the conditions for the development of a logistic hub, consisting in an extensive network of intermodal transport connections. There are over 400 international rail connections that start and end in the PoR, and direct links with European motorway networks which facilitate the rail and motorway transport of goods. The infrastructure that has developed in the PoR is one of its strongest advantages, which enhances the operational efficiency of the companies operating in the industrial cluster. There are over 1500km of pipeline networks connecting companies within the PoR, with the Port of Antwerp and with the German Ruhr region, which allows for a safe, efficient and sustainable transport of liquid bulk (Port of Rotterdam Authority, 2020). The proximity of the PoR to a major urban agglomeration such as the city of Rotterdam brings several urbanisation externalities. Rotterdam has a highly educated population due to the presence of various universities and think tanks in the proximity of the PoR. Port and industrial operations require a wide range of specific skills and highly specialised labour force that has been provided by local universities. The variety of digital services and high-quality infrastructure offered by the PoR is another of its competitive edges. The development of these services, which apply technology and data analysis to provide users with real-time statistical information and performance, has been to a great extent possible thanks to the relationship between the PoR and academia, and the availability of highly specialised skills in the labour force of Rotterdam and the Province of South Holland in general. Lastly, the stable political and regulatory environment and low corruption indexes in the Netherlands create an attractive investment climate.

The main finding of this research with regards to port competitiveness and the literature reviewed is the importance to assess activities performed at the ports when analysing changes in their competitiveness. The findings of this research link most directly with Hales et al. (2016) and their balanced theory of port competitiveness. This theory explicitly includes the vision of ports as locations for investment and assesses the main drivers of their competitiveness from this perspective. This research also incorporated the analysis performed by Snieska et al. (2019) about the drivers that make a location attractive for investment. Some of these drivers were incorporated to build the variable attractiveness as a location for investment of the concept of port competitiveness used in this research. The findings of this research are in line with the balanced theory of port competitiveness, and it is possible to conclude that, in this case study, the attractiveness as a location for investment is the most important variable of port competitiveness that would be affected by more stringent climate policy. This is not to deny the importance of other drivers as geographical location, access to the hinterland and efficiency among others, but these factors will not be affected by a carbon tax. These factors constitute the most important competitive edge to the PoR and represent an opportunity to increase its competitiveness. The major strength of the PoR is its strong position as a logistics hub, connecting efficiently the hinterland with the open sea. The challenge of the PA is to take the lead and incentivise the transition of the industry so that their production methods and products become cleaner, and the PoR keeps on being their location for production.

5.2.3. Research question C: To what extent can a carbon tax enhance carbon leakage in the firms operating in the IC of the PoR?

The composition of the industrial cluster consists mainly of EIIs; 6 oil refineries, 45 petrochemical companies, 9 gas-fired power plants and 2 coal-fired power plants. Oil refineries and petrochemical companies are owned by multinationals who also own facilities in other regions of the world, such as the Middle East, China, and the USA. The industries operating in the industrial cluster of the PoR are characterised by the production of low-value commodities with no product differentiation, and their trading is based in large volumes and low margins.

This means that the demand for these products is highly sensitive to changes in prices, which leaves little room for firms to pass-through increases in production costs. The carbon leakage hypothesis presented in Chapter 2 states that the introduction of a carbon tax would distort the level playing field, increasing the production costs for firms in the PoR and putting them in a disadvantage against competition operating in less regulated regions. This would translate into an incentive for firms operating in the PoR to relocate to less-regulated regions where production costs are lower. However, according to the data gathered and analysed in this research, it is unlikely that companies exit the PoR in the short-mid-term and relocate their operations as a consequence of the introduction of a carbon tax. An in-depth analysis of the trade lanes and the nature of the companies operating in the PoR shows that they produce base products mainly for the European market, and it is only their extra capacity that is exported. The potential relocation of these firms was analysed in two scenarios; relocation within Europe and to other regions. Regarding the first, the PoR remains on being the most cost-efficient location for production, and the introduction of a carbon tax in the Netherlands is in a context in which European climate policies are becoming ever more stringent. A clear example is the European Green Deal currently under development, which seeks to increase the stringency of environmental regulations, including a reform to the EU ETS aimed at increasing the price of CO2 emissions. Thus, it would not make sense for firms to embark in the challenge of relocating to or investing in another European country that most certainly with will also increase the price of CO2 emissions in the short term. Regarding the second scenario, the option is for firms to cease European production altogether and supply the European market with products from facilities located in other regions. This is not likely to happen in the short-mid-term, as the enormous sunk costs, long-term contracts that these companies have with providers and customers, and the benefits of being located at the PoR act as strong barriers of exit. Also, the support policies applied with carbon the tax, either at the national or European level, might include a CBTA which would increase the costs of importing goods that compete with European industry.

However, firms might use the facilities in the PoR as *swing facilities* in the short-mid-term, operating them at a lower capacity and reducing their production levels. The biggest threat, in this case, is investment leakage, as a higher price of carbon increases operational costs, which makes investments in the PoR less profitable than facilities in other regions. In this scenario, companies will *sweat their assets* and keep operating the facilities as they are, trying to make the most profit of their remaining operating life while they keep investing and increasing the production capacity of facilities in other regions. Facilities in the PoR will continue ageing with no significant new investment and keep losing their value until companies decide to cease operations or recoup their remaining value by, for example, selling them to investment funds.

The variables and indicators used in this research to assess the risk of carbon leakage are based mainly on the drivers identified by Droege (2013). This research validates these as important and appropriate drivers to assess the risk of carbon leakage of an industrial cluster. Perhaps the most important finding relating to carbon leakage and the theory presented in Chapter 2 is that the threat of investment leakage is a much serious than the relocation of operations. Even though there was no scientific proof of carbon leakage or losses of competitiveness in empirical ex-post studies (Arlinghaus, 2015), the findings of this research suggest that investment leakage is a real possibility in the case of a carbon tax implemented with no protection to incumbent industries. In the case of the industrial cluster of the PoR, the growth of firms in terms of production capacity will occur in facilities located in less regulated regions, where investments are more profitable. However, the current instruments used to protect incumbents from carbon leakage have received many critics, mainly because currently in Europe businesses are still not paying for the emissions, making the policies ineffective. Furthermore, firms receiving free allocation permits have passed-through their opportunity cost to the price of the products, which have resulted in windfall profits for firms (Droege, 2013). This highlights the importance of the design of the regulations aimed at protecting the industry and the need to increase the price of fossil-based products for the whole European market, with a mechanism such as the CBTA.

5.2.4. Research question D: To what extent can a carbon tax induce technological innovation aimed at the decarbonisation of the industrial cluster of the PoR?

According to the literature presented in Chapter 2, a higher carbon price is needed to induce the implementation of low-carbon technology. With a higher price of CO2 emissions, paying for CO2 abatement might become a more profitable option for companies than paying for the tax, depending on the availability and costs of CO2 abatement technology. The data gathered and analysed shows that the perception of all the stakeholders is in line with the theory. In the case of the industry operating in the PoR, there are no readily available technologies that could substantially abate CO2 emissions, besides the CCUS currently being developed by the Porthos project organization. Although there are technologies that could be applied to curb emissions in industrial processes and energy production, they have not yet been tested in large-scale industrial complexes. Furthermore, there are many operational challenges associated with their implementation that have not yet been solved. Among the most promising low-carbon technologies to curb emissions in industrial processes and energy production are green hydrogen and electrification. Both are real options to abate emissions only if the electricity grid is fully switched to renewables to ensure net-zero emissions in the whole production chain. Oil refineries need extremely high temperatures for some of their production processes, which are not achievable with electricity. Green hydrogen can be a solution, but the conditions have not yet been created to implement green hydrogen at a large scale. The enormous amount of renewable electricity needed for its production through electrolysis remains a challenge as there is no such production capacity in the Netherlands. Offshore wind is among the most developed renewable sources of electricity in the Netherlands, but technical aspects about how to land the electricity to the sites where industrial operations take place, and how to store it in a large scale, remain a challenge. Additionally, there is the need for a legal framework and infrastructure (i.e. hydrogen backbone) in place to ensure the safe production and transportation of hydrogen.

Most of the barriers mentioned above can be overcome if there is a market for green hydrogen and clean products that trigger investment in the development of solutions. The fact that the current costs of abatement options are too high, preventing the technologies to be scaled up and be made available for mass production, is largely due to a lack of market for technologies like green hydrogen and cleaner products. Regulation is perhaps the only mechanism that is able to create a market for low-carbon products and technologies, as firms will not make investments that are not profitable within their investment cycles and will not produce goods for which there is no demand. Analysis has shown that the lack of a market is keeping firms from making favourable business cases in order to implement low-carbon technology, which in turn is the main force stopping technologies to be scaled up.

Comparing these results with the theoretical review about the concept of induced innovation developed in Chapter 2, they are consistent with related work on the topic, but they expand the scope by including more insights. First, the literature reviewed tends to ignore or overlook the costs involved in technological development and innovation, which in this case study are enormous. In this case study, instead of innovating or paying for the tax, companies – or branches of multinationals- can go broke if their profits before tax are too slim. Indeed, many of the facilities in the PoR have abatement options that greatly exceed their profits when represented as EUR/ton CO2, leaving them without options to avoid paying for a higher price of carbon. Second, there is no consensus in the literature about whether a higher price of carbon could enhance or be detrimental for the industrial transition. The findings of this research suggest that a higher price of carbon is a necessary but not sufficient condition to initiate the decarbonisation of industry. Furthermore, this study concludes that a carbon tax on its own will not enhance the industrial transition of the companies operating in the PoR towards low carbon production and could instead induce investment leakage. However, the findings also suggest that in presence of support mechanisms, firms are willing to invest in low-carbon technology.

The findings of this research suggest that a carbon tax is required to provide the market signal, and government support is vital to create an attractive environment for investment in abatement technologies. This research also shows a willingness from firms to invest in low-carbon technology and accelerate the industrial transition, if they can make favourable business cases. The instruments to incentivise industry present in the data collected are direct subsidies, grants, and enabling conditions for the implementation of new technology. For instance, if firms see that the government has plans for a large-scale deployment of offshore wind, they will feel more confident about electrifying their processes. The policy mix implemented certainly needs to increase the price of CO2 emissions, but it must consider a balance between penalisations for emitting CO2 and incentives for firms to invest in low-carbon technology and initiate their decarbonisation.

5.2.5. Main research question: How would a carbon tax on the industrial greenhouse gas emissions affect the competitiveness of the Port of Rotterdam?

Depending on the design of the policy mix in which the carbon tax is implemented, its effects on the competitiveness of the PoR can be negative or positive. On the negative effects, the introduction of a carbon tax in industrial CO2 emissions has the potential to negatively impact the PA's profits and reduce the competitiveness of the PoR. The PoR's revenues come mainly from land fees charged to the firms operating in the industrial cluster, and port fees charged to ships entering the port and the cargo they bring in. A large share of the port's throughput consists of inputs for industrial operations. Consequently, changes in the production levels or the business model of the firms operating in the PoR, induced by a carbon tax, could indirectly affect the PoR's business structure and profits. On the other hand, the introduction of a carbon tax can distort the level playing field which reduces the attractiveness of the PoR as a location for investment, which is one of the drivers of port competitiveness. Firms will divert investment to other regions where they have operations and the facilities located at the PoR will lose their value with time. However, if the introduction of a carbon tax is coupled with supportive policies and regulations, it has the potential to enhance the PoR's competitiveness by incentivising green investment and becoming a frontrunner in the industrial transition. In both the European and international context, it is expected that climate policies become ever more stringent and the price of CO2 emissions increases substantially. In this scenario, highly emitting production processes are bound to disappear, which provides an opportunity for the industries located at the PoR to switch their business models and become frontrunners in the implementation of low-carbon technology and clean production.

The introduction of a carbon tax and more stringent climate policy unveils the weakness of the PA's business model and its dependence on highly emitting activities. The current business model of the PA is to a large extent based on profits from increased throughputs from industries heavily based on fossil fuels, for whom a higher carbon price is not beneficial. The economy in Europe is arriving at a point in which and highly emitting industrial activity will be increasingly restricted. Thus, the energy transition and more stringent climate policy aimed at increasing the price of CO2 emissions confronts the PA with a difficult situation. Its business model lies somewhere between its existing industrial legacy based in fossil fuels, and the environmental, societal, and political needs to move ahead with the energy transition. The conditions to successfully change their business model and innovate remain there. The advantages from its strategic geographical location, infrastructure, and logistics make it the most cost-efficient location to serve the hinterland. The availability highly educated and specialised labour, and close relationship with academia facilitates the development, testing and scale-up of low carbon technology.

5.3. Discussions and practical implications

This research aimed at developing and applying a framework to assess the implications of the implementation of a carbon tax on the competitiveness of the PoR. It analysed two potential effects on the EIIs operating in the industrial cluster of the PoR. On the one hand, this research tested the carbon leakage hypothesis by assessing the extent to which a higher price of carbon, represented by a carbon tax, can affect the competitiveness of the industries operating in the PoR and induce carbon and investment leakage. On the other hand, it assessed the extent to which a carbon tax can enhance technological innovation aimed at the implementation of low-carbon technology and the decarbonisation of these industries. Additionally, this research aimed at understanding the role of government in both preventing carbon and investment leakage and creating an attractive environment for green investment. As presented in the previous section, government support has found to have a direct impact in buffering the distortions induced by a carbon tax in the level playing field, with regulation that protects the industries' competitiveness. Government support is also required to create an attractive investment environment, preventing firms from diverting investment to other regions and incentivising them to invest in low-carbon technologies in their facilities in the PoR. The conceptual framework was built based on current scientific knowledge about the four core concepts of this research, and the findings confirm that the variables and sub-variables analysed for each of the concepts have an important role in explaining the effects induced by a carbon tax. Furthermore, the four main concepts and their variables are in practice interconnected and do not fit into closed boundaries. For instance, the attractiveness of the PoR as a location for investment can be influenced by regulations that also have implications for other variables. Regulations can increase the price of carbon which would distort the level playing field and provide an incentive for companies to divert investment. The distortions on the level playing field also depend on the regional context. Supranational policies, as in the case of Europe, can restore the level playing field, which makes this variable difficult to assess in isolation. Regulations aimed at protecting the competitiveness of EIIs, such as a CBTA, can buffer the detrimental effects on sub-variables of port competitiveness. On the other hand, regulations can also create new markets and induce demand for cleaner products, and government support would allow for companies to be frontrunners in the implementation of low-carbon technology. The extent to which low-carbon technology can be implemented depends to a great extent on whether the conditions are in place. Government support by subsidies or enabling conditions can increase the attractiveness of the PoR as a location for investment in green technology.

However, there is an important point of discussion regarding the use of public funds to subsidize private firms. Public funds come mainly from taxpayers' money, and their use should be largely influenced by public acceptance. This can be an obstacle in the industrial transition, as firms would be receiving vast amounts of funds from a public that is increasingly aware that these industries have not been returning much value to society. Furthermore, the current and future climate crisis is to a large extent due to the operations of these very industries, who have profited from emitting untaxed GHG for decades into a public good such as the atmosphere. On the other hand, these firms have generated a significant amount of employment and have contributed to a great extent in the development of the city of Rotterdam and the country's GDP. The heart of this discussion lies in whether there is willingness as a society to invest in the industrial transition and to give it priority over other issues such as healthcare, education, housing, pensions, among others.

Another point of discussion lies in the distribution of abatement costs among the industries. The abatement costs are not evenly distributed within the industries and facilities, and there are just a few firms with cheap abatement options in the Netherlands. Therefore, these companies are better equipped to bear higher carbon costs and might also get subsidies on the implementation of low-carbon technologies. For instance, in the case of oil refineries, the only facilities with relatively cheap abatement options are those who already have hydrogen production units, which gives them a comparative advantage over the rest of the refineries. Consequently, if the government introduces a subsidy on the implementation on green hydrogen, these companies will most likely receive the funds as they already have a hydrogen production unit and are closer to fully implement the technology. If the subsidy scheme is not carefully designed, it could lead to subsidies ending up benefitting just a few companies that have cheap abatement options and leaving for the rest to bear the costs of the carbon tax. Similarly, the decision on which technologies are to be subsidised is also controversial as several abatement technologies for the industrial cluster were identified in the collected data. Subsidies can also distort the market and benefit some technologies over others with the same abatement potential. This links to the critics to government intervention presented in Chapter 2, who suggests that by providing subsidies, the government would be *picking winners and losers.* This is not to deny the findings of this research, that consistently puts government intervention as having a key mediating role to both prevent from carbon (and investment) leakage and induce the implementation of low carbon technologies. The findings are also in line with and validate the SDE++ subsidy scheme implemented in the Netherlands. The production of renewable electricity lies at the core of most of the low-carbon technologies, and there is the need to accelerate the switch of the electricity grid to renewables as much as possible. If electrification or green hydrogen are produced with electricity from fossil sources, the effects could be an increase in the total emissions.

The fact that the abatement cost curve presents an exponential growth, with an increasing marginal cost of abatement has implications for the decarbonisation of the industry in the Netherlands. Given that the industry in the Netherlands is technologically advanced compared to the rest of Europe, the abatement cost curve for the Dutch industry probably makes it as or less attractive to invest in than in other countries. Under this perspective, it makes more sense from the cost-effectiveness of CO2 abatement to invest in other countries first before start investing in decarbonisation in the Netherlands. Then, for the industry in the Netherlands to be ahead of the curve and among the 10% best industry in Europe, it requires higher investments than in other European countries. This requires strong support schemes and invest in that as a society. In terms of where it makes more sense to make the first investment in curbing CO2 emissions from a European level, the Netherlands is not necessarily the priority. The lowest abatement costs are in banning out coal in countries as Germany and Poland, and the industrial transition is further down the line.

An interesting finding involves the certainty of future price of carbon required for firms to plan their investment decisions. Setting a floor to the price of carbon could provide a competitive advantage for firms in the Netherlands. The regulatory environment would be providing businesses with extra certainty, preventing them from investing at the wrong point in time and reducing the risk associated in their investment decision. By introducing price certainty, the investment decisions that businesses make will be at lower costs. This reduction in uncertainty leading to a reduction in the risk associated to the investment, also means that investors would be able to finance businesses at a lower rate. For instance, banks price the risk when financing businesses, who pay premiums according to the level of risk. If the risk is too high, banks might not even provide financing at all. To further reduce the risk, a price ceiling would also be necessary. Just as carbon prices falling below the price floor do not provide businesses with an incentive, prices skyrocketing can also have detrimental effects. It would cause firms to rush to make investment decisions that they regret when the price returns to normal levels. By introducing a minimum and maximum carbon price, firms are both incentivised to invest in low-carbon technology and protected from incorrect price signals that lead to wrong investment decision. As stated before, EIIs make investments with a long-term perspective. As such, long-term carbon prices are more relevant than current carbon prices and will drive the majority of the investment decisions. With this in mind, as long as the price of carbon increases by a given factor over time, firms will immediately have a different approach to investments. This certainty and predictability of the future price of carbon would make them invest in green technology.

There are also concerns about the development and use of CCUS, as it can slow down the development of other technologies. For instance, projects like Porthos need a business case to be implemented. This means that companies will sign a contract and commit to delivering CO2 to Porthos to store it under the North Sea. The danger lies in the fact that the companies will be legally committed to keeping using fossil fuels and paying to Porthos to store the emissions when they could be investing that money in scaling up clean technologies or the generation of renewable electricity. Although there is wide consensus in that CCUS is the only feasible option to abate emissions in the industrial cluster of the PoR in the short term, there is the need to find ways that ensure that it will not delay the scaling-up of low-carbon technology that do not use fossil fuels.

There are also potential negative impacts on the PoR's competitiveness and other sectors of the economy from the specific policies aimed at protecting the industry. According to the data gathered in this research, the policy mix should include a CBTA to prevent investment leakage, as mentioned in previous sections. This tax, while beneficial to protect the Dutch industry – or European industry, in the case of a European CBTA – has the potential to reduce the import of goods and negatively impact the container terminals, which according to sources from the PA is very sensitive to price. Thus, the specific design of the support mechanisms is of great importance, as while aiming to protect some industries it could have detrimental impacts on others.

Lastly, the future of the PoR as a key actor of the city and country's economy will depend on its ability to innovate in its business model and adapt it to the future European context, in which industrial activity based in fossil fuels will be ever more restricted. The role of the PA in this transition can be decisive as it has the potential to be the channel through which the government focuses the efforts of the decarbonisation of the industrial cluster. The PA should also take the lead and have a coordinating role in the development and building of infrastructure that enables the conditions for industry to implement low-carbon technology.

It is important to mention that the findings of this research are based on the case study of the PoR and its industrial cluster. Given the intricate relationships found between the environmental policy context, the nature of the industrial cluster of the PoR and other important variables, these results do not intend to be extrapolated to other industrial clusters, ports or EIIs.

5.4. Suggestions for future work

This research has focused on the impacts of a carbon tax on GHG emissions, proposed in the Dutch National Climate Agreement, in the competitiveness of the PoR. Although a large body of qualitative data was collected from stakeholders from various sectors, it does not include the views of every stakeholder either affected by a carbon tax or playing an important role in the industrial decarbonisation.

It would be interesting to widen the sample of stakeholders so that new perspectives about the implications of introducing a carbon tax can be included. This would allow identifying more points of intervention where regulations or government support are required to enhance the industrial transition while protecting the local economy. Further, a more in-depth analysis could be performed in the facilities of the industrial cluster of the PoR to identify the abatement potential of each one. This would allow to monetarise the investment required to implement the appropriate low-carbon technology and comply with the national or European reduction targets, or to bring the facilities in the PoR to the 10% best performing industries in Europe, pushing the industrial transition forward. Additionally, it would provide a close estimation of the costs that the technologies should have for companies to be able to make the investments and remain on business. These estimates can then be used by decision-makers as they provide information about the amount of subsidy that would be required to clean the entire production of the industrial cluster of the PoR.

As it was stated before, as long as there is no market for cleaner products, companies will not make the investments required to produce them. Further research aimed at disentangling the complexity behind the creation of new markets would shed light on the disruptions they would create on existing markets. From directly and indirectly impacted stakeholders such as suppliers, customers and related industries to the prices of goods for end consumers, national and international trade lanes, and effects on the regional economy, among others.

Further research is also required to identify and develop pathways to overcome the most pressing barriers for the scaling up of low-carbon technologies such as green hydrogen and electrification. For instance, by exploring the possibilities of both producing, transporting and landing the required capacity of renewable electricity to the PoR and importing it from regions with better natural conditions for its production, like sun exposure. There is the need to assess the absolute generation potential in the Netherlands and project the extra demand induced by fully switching the electricity grid and decarbonising industry. Comparing these results will give an estimation of the total amount of green electricity to be generated or imported. According to the findings of this research, the full potential of renewable electricity generation in the Netherlands is not enough to support a full industrial transition, which is one of the most important barriers in the decarbonisation of industry.

Another field of research opened by this research regards the drivers of cooperation between firms. Many of the aspects of scaling up low carbon technologies are based on the assumption that firms collaboratively finance projects aiming for a common goal. Nevertheless, the very nature of firms operating and trading in competitive scenarios is to develop technology and production techniques to be used by themselves, not to be shared with the competition. If there are efficiency gains or cost reductions from developing, scaling up and implementing technology, companies will want to have that as a competitive advantage against the competition. However, recent developments such as the Porthos project show that it is possible to develop joint projects involving competing firms. An assessment and analysis of the drivers of cooperation between firms would shed light on what are the factors behind this cooperation, which would, in turn, allow for policymakers to enhance them.

Lastly, it would be interesting to do *ex-post* quantitative research based on the framework built in this qualitative research. Quantitative indicators can be built based on this research. After the implementation of the carbon tax, quantitative data analysis could be used to test the hypothesis about the foreseen relationships found in this research. Depending on the data available, the indicators used on this research involving perceptions about future events can be adapted to measure real changes after the implementation of the tax.

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Annex 1: Research Instruments

ERASMUS UNIVERSITY, ROTTERDAM, THE NETHERLANDS
INSTITUTE FOR HOUSING AND DEVELOPMENT STUDIES (IHS)
MSc. URBAN MANAGEMENT AND DEVELOPMENT – UMD 16
May / June 2020

<u>INTERVIEW GUIDE FOR EXPERTS AND DECISION-MAKERS</u>

Research topic: Effects of a carbon tax in industrial GHG emissions on the competitiveness of the PoR

My name is Felipe Bravo. I am a Chilean student of the program Urban Management and Development at the Institute for Housing and Development Studies at Erasmus University, Rotterdam. This research aims to investigate the effects of a carbon tax in industrial GHG emissions, in the competitiveness of the Port of Rotterdam, by focusing on two potential effects in its industrial cluster. First, an increase in production costs would erode the competitiveness of the firms operating in the PoR. Second, pricing CO2 emissions would induce technological innovation, by which firms would gain competitiveness in an ever-closer low carbon economy. The combination of these effects would affect the attractiveness of the industrial cluster of the PoR as a location for investment, affecting the competitiveness of the PoR.

I am interviewing you because of your experience as a [researcher/expert in the chemical or oil industry/decision maker] and as an expert in this field. This interview is part of the data collection process for my thesis and the information shared will be confidential and used exclusively for academic purposes. The interview should take around half an hour, and I would like to record it to facilitate my analysis later if you permit me.

Part 1: Introduction

Q1: How long have you been working in this field?

Q2: Have you evaluated (quantitatively or qualitatively) the effects of environmental regulation in your sector?

Part 2: Carbon leakage

- <u>Cost structure</u>

Q3: Could a carbon tax substantially change the cost structure of the firms operating in the PoR?

Q4: Could higher electricity costs substantially affect the cost structure of the firms?

Q5: To what extent could the existing installed capacity lose value in a low carbon economy?

Q6: To what extent could the sunk costs (infrastructure-machinery) act as a barrier of exit if firms want to relocate?

Q: How likely is for firms to relocate as a consequence of higher costs of emissions?

- <u>Cost pass-through</u>

Q7: What are the main drivers of competition in the industries operating in the PoR? Do they compete mainly in international markets?]-> SECONDARY DATA

Q8: How sensitive is the demand to price increases in the product? -> SECONDARY DATA

Q9: Is the demand for the products currently increasing, stagnant or declining? -> SECONDARY DATA

Q10: Do the industry present opportunities to create product differentiation?

- <u>Abatement potential</u>

Q11: Are there low-carbon technologies available that have not been implemented in the production processes?

Q12: (If yes) What is the main reason why they have not been implemented?

Q13: How likely is that a carbon tax enhances firms' investment in clean technology?

Q14: How likely is that the investment on low carbon technology increases the firm's (sector's) revenue in the mid-long term?

- Regulatory environment

Q15: Do you consider the implementation of a carbon tax as a credible long-term certainty for a price of carbon?
Q16: (If yes) Could this certainty bring about an increase in investment in low-carbon technology?
Q17: To what extent could a carbon tax be perceived as a threat for the firms and future investment?
Q18: To what extent could a carbon tax increase the industries' competitiveness in the mid-long term?

Part 3: Induced innovation

- Product innovation

Q19: Is there potential in the market to create new low-carbon products?
Q20: To what extent are the products commercialized by these firms considered commodities?

- Process innovation

Q21: What would be the biggest barriers for the adoption of cleaner technology?
Q22: Are there public funds or Government support?

- Organizational innovation

Q23: What is the current level of collaboration to reduce emissions between firms in the cluster?
Q24: What is the current level of investment in R&D of firms in the cluster?
Q25: To what extent could a carbon tax induce more R&D investment in the industry?

Part 4: Attractiveness as place for business

- Regulatory environment – legal framework

Q26: How stringent do you consider corporate taxes in The Netherlands?
Q27: Could a carbon tax significantly increase the tax burden of firms?

- Business sustainability

Q28: How likely is that a carbon tax induce investment in low-carbon technology?
Q29: To what extent could a carbon tax be perceived as a barrier to perform energy-intensive activities?
Q30: How likely is that a carbon tax (more stringent climate policy) attracts new businesses (open new niches for the existing ones)?

- Knowledge and innovation

Q31: How likely is that a carbon tax (more stringent climate policy) enhances collaboration between academia/research and companies?

Part 5: Port competitiveness

- Port fees

Q32: Could the changes discussed in the industrial cluster induce an increase in Port fees?

- Throughput

Q33: Could the changes discussed in the industrial cluster reduce the import of inputs for production?
Q34: Could the changes discussed in the industrial cluster decrease the levels of production of the existing firms?

Would you like to add something else? Do you have any suggestions of other useful respondents? If I need further clarification on something we discussed, is it ok for you if I get in touch in a later stage?

Thank you for your time and attention.

Annex 2: Additional material – Perceptions of interviewees about concepts and sub-variables

A2.1. Carbon leakage

A2.1.1. Cost structure

This research assesses the likelihood that an increase on the price of carbon significantly increases the operational costs of the firms, forcing them to relocate or exit the market. It is logical to think that anything adding up costs to the operation of a company will directly affect its cost structure. However, the extent to which this increase would significantly affect the company's revenues and trigger a relocation decision is not clear and there are various elements to be considered. The two sub-variables analysed in this research are the significance of direct and indirect carbon costs in the cost structure of firms and the extent to which the sunk costs can act as a barrier of exit.

Direct and indirect carbon costs

The perspectives from the interviewees regarding the significance of a higher carbon price differ. There is consensus in that anything adding costs to the direct input of a company, whether that is energy, electricity, or the costs of supplies, would affect its cost structure. In this case, the CO2 emissions can be considered as an input for production as they are unavoidable in most of the production processes that use fossil fuels. Consequently, if there is a tax system in place that prices or increases the price of emissions, it would inevitably increase the operational costs of the firms.

Members of academia provide an interesting perspective regarding the increase in the price of CO2 emissions. According to their view, an increase in production costs due to a higher carbon price can also be seen as the increase in just one of many production items, or the addition of just one more tax among other taxes. From this perspective, the cost increase could not be as significant, as many production costs fluctuate constantly. An example of this is the oil price, which is now at extremely low levels of 20-30 USD per barrel, but it can be as high 120USD per barrel. Oil price has fluctuated greatly during the last decade and has a much stronger impact in the cost structure of the firms than a carbon tax. In this sense, the extra cost of a carbon tax can be counteracted by either unforeseen or planned reductions in other costs. Nevertheless, interviewees from the academia stress that even if the cost increase is not significant in isolation, it could add up to increases in other costs and create an environment in which is less attractive to invest in the Netherlands. There is a hypothetical threshold level that could be surpassed, and the addition of a carbon tax could be the tipping point. If that happens, there is consensus among interviewees in that companies will not close their operations in the PoR, but their growth will happen in other locations where production is cheaper. According to some sources from the PA and academia, this phenomenon is already happening in the PoR, where investment has been decreasing the last few years, leading to a less relevance of the industrial sector for the whole economy.

> *"What we already see is that there is not that much new production capacity coming into the Netherlands during the last couple of decades. And that is not happening only in the Netherlands but in Europe in general."*
>
> - *Interviewee 13*

Sunk costs as a barrier of exit

The industrial cluster of the PoR consists mainly of EIIs, as seen in Table 10. As stated in Chapter 2, one of the main characteristics of these industries is the large investments in facilities, technology, machinery and long payback periods, often in the range of 20-40 years. Although by definition sunk costs do not affect future investment decisions, they can act as a barrier of exit. In absence of sunk costs, a firm having less profit than what it could have elsewhere has an incentive to sell its assets and start operations in another industry or location. However, the nature of the sunk costs prevent the firm from recouping these costs, and it may be forced to continue in business even if profits are well below what they would be in another industry or location (OECD, 2019a). This is particularly true the industries heavily based on fossil fuels, which is the case for the industrial cluster of the PoR. Taking into account that the climate policy is becoming ever more stringent in the Netherlands and Europe and that the demand for fossil-based products is expected to decrease, these assets will only lose value in the coming decades, if they have not received major investments aimed at curbing emissions.

According to all the interviewees, the sunk costs of the companies in the industrial cluster of the PoR are enormous, as major oil refineries and chemical plants can cost up to 500 million to a billion USD. As explained before, while some facilities are state of the art, others are ageing, which means that their value has already decreased substantially. Additionally, if the installations have not had major investments in cleaner and more efficient ways of production, they are adding less value to potential investors, which makes it unlikely for companies to sell them to start operations in a different location.

> *"The companies that are already there have invested literally billions in their factories. And you don't close them down just like that. So, the ones that are here will probably stay for a while yet. But new investment in new companies, maybe new machinery to reduce that emissions, might not take place and will be invested where operations are cheaper"*
>
> - *Interviewee 11*

According to the interviewee from the banking sector, the billionaire investments and the long-term commitments that companies have to suppliers and customers are not the only reasons to consider the relocation unlikely. In the hypothetical case that these companies decide to exit the PoR, they would have to relocate all the production capacity elsewhere, which would require a monumental organisation task and investment case. Building new production lines, attracting new high-skilled workers capable in those areas, finding new suppliers, building pipelines to connect to the existing network, and to do everything quickly. Firms would need at least 10-20 years to earn back the investment. The analysis up to this point shows that the extra penalty that firms have to pay in a place where they already have all the ideal conditions does not weigh up against the alternative, which requires a big effort, investment and long payback for the investment.

There are also arguments from a regional economic perspective against the relocation hypothesis, as pointed out by respondents from academia. Under this perspective, if firms decide to cease their operations in Rotterdam, it would be to exit the European market altogether rather than closing out of a cost structure perspective to start operations in another European country. The EU environmental policy is expected to be more stringent in the short term and relocating to another European country would put them in the same situation.

In the short term, firms could use the facilities in the PoR as *swing facilities*, potentially operating them at a lower capacity and reducing their production levels. As stated before, many of the companies operating in the PoR are multinationals with operations in various countries around the world. According to sources from the PA, these firms operate in global markets and know exactly where the demand is and how much global demand there is, according to which they plan their production. Under ideal conditions, firms will produce at the highest rate possible for each facility, which results in the lowest costs per unit of production. If there is more demand than the combined capacity of the facilities, the firms might decide to build or buy new factories. On the contrary, if there is less demand than the combined production capacity, instead of running every facility at a lower rate, it is more cost-efficient to produce less only in the most expensive facility, i.e. the one with the highest cost per unit of production.

A2.1.2. Cost pass-through ability

One way for firms to avoid paying for the increase in production costs is to pass them through to the customers by adding the increase to the price of the products. The extent to which companies can use this mechanism depends on several variables. In this research, the cost pass-through ability is assessed by analysing the nature of the competition faced by the companies, the potential for product differentiation and demand trends.

Market and competition

As stated in section 4.1.1 the chemical industry in the PoR specializes in base chemicals and the oil refining industry on the production of a range of fossil fuels and feedstock for the chemical industry. Both of these industries manufacture products considered commodities and trade on international markets which are highly competitive on price. This means that if a legislation introduces a regulation that adds extra costs to an industrial sector competing for the same international market than firms in a less regulated legislation, the industrial sector of the former will be in disadvantage and more exposed to lose market share. Also, the industries in the PoR do not produce directly for end-users but for other industries, in what is called *B2B markets,* which are characterised by the trading of high volume and low margins. In this scenario, firms do not have much room to absorb the increase in production costs by cutting into the margin without depleting it. At the same time, by increasing in the price of their products they are prone to quickly lose market share against production from less regulated countries. *Ceteris paribus* -all other costs remaining the same-, the only option left for them is cutting into the already low profits. Hence, if the companies pass through the cost and the international competition does not follow suit, the risk of losing market share is high.

Demand trends

The demand for fossil-based products is dropping in Europe, pushed mainly by increasing awareness about the climate crisis and strict climate regulations, and it is expected to continue on this trend. Policies like the Dutch National Climate Agreement and the European Green Deal explained in the previous section, are a proof that this trend will continue and become stricter in the future, in line with the European net-zero emissions goals. Sources from the Policy and Planning department of the PoR recognise that refineries, as we know them, will disappear because there will be no more demand for them in the long term. On the other hand, demand for cleaner products and energy sources is increasing, creating an opportunity for firms to reinvent themselves and build upon the assets they already have, by for example changing the oil refineries to bio-based refineries or producing green hydrogen. Nevertheless, many of these technologies require high levels of funding to be scaled up, and still represent a promise of the future. Some industries might not be able to make the investments required to reinvent themselves in the long term and the PA fears that they will disappear and not be replaced by a new activity as the same. However, the lack of clean products at competitive prices ensures strong demand for oil and petrochemical products in the short term, as they are a foundational part of almost every activity we perform. These industries produce fuel for our cars and raw materials to manufacture products used in everyday life such as refrigerators, painting, clothing, roads, plastics, etc. As clean technology for the production of these industries becomes cheaper, the demand will certainly shift towards cleaner and fossil-free products.

> *"The added value of the chemical industry and the oil industry in the port of Rotterdam is decreasing. Other industries are becoming much more interesting for the regional economy. It is much more interesting to invest in renewables and new technologies and those are the growth industries of the future."*
>
> - *Interviewee 1*

Product differentiation potential

According to the theory, the opportunities for a firm to differentiate its products from those of the competition dependin on the type of goods produced and commercialised. If a firm can add specific value to their products and obtain some degree of differentiation, it can induce demand for these specific qualities that cannot be found in the products of the competition. This can act as a shield against unfavourable production conditions, i.e. higher production costs, as having a unique and special product leaves more margin for the firm to increase its price and keep the market share. As the production of the companies in the PoR consists mainly in base chemicals and fuels that are used as inputs for the production of intermediate or speciality products, there is no room for product differentiation without changing the inputs or adopting new production processes. The products manufactured and traded by the firms operating in the PoR are considered commodities and do not have significant differences from products of their competitors.

One opportunity for product differentiation that has been explored and developed strongly during the last years consists on using biomass as feedstock for the production of biofuels, which are used by the chemical industry to produce bio-based chemicals. The PoR has become the world hub for the bio-based fuels and materials in the last decade, and there is no other place in the world with the production capacity of biofuels as the PoR. Nevertheless, these biofuels are being developed and commercialised as an obligation from EU legislation to blend in bio-based fuels into fossil fuels. This obligation has created a market in which the price is not important anymore, because being the only producer ensures demand for the products as there is nowhere else to find them. The moment the EU retreats this obligation, the market will most likely disappear as these products are significantly more expensive than the traditional fossil-based alternative.

There are many concerns about the production of biofuels. Some of them are regarding the energy efficiency and indirect environmental consequences of using bio-based materials. Biomass is used as a feedstock because it is an organic material, and as such it contains cellulose which in turn contains carbon. Cellulose is more readily available *the first generation* of bio-based materials, which are divided into starch crops, sugar crops, vegetable oils and others (European Commission, 2015).

Starch	**Sugar**	**Vegetable oils**	**Others**
Maize	Sugar beat	Rapeseed oil	Maize Silage
Wheat	Sugar cane	Soybean oil	Cereal straw
Barley		Sunflower oil	Perennials
		Palm oil	Short rotation trees
			Forest residues

Table 19: First generation of biofuels by type and crop. Source: European Comission, 2015

When the chemical industry makes a business case for biofuels, a large supply of biomass is required, which consists of large areas of land with crops destined to be inputs for the industry. There are ongoing discussions about the priorities in the use of the land, regarding what other use could be given to that space, the most important one being food production. The great majority of the *first generation* of biomass comes from unsustainable land conversion in places like Brazil, Indonesia and Malaysia, where large areas of tropical forests and peatland are deforested to grow the required crops, which then have to be transported across large distances to reach Europe. The European Comission's report *The land use change impact of biofuels consumed in the EU (2015)* found that the total land use change due to the European policy amounted to 8.8Mha (millions of hectares), equivalent to the size of Austria, that translates into substantial emissions and foregone CO2 sequestration. The *second generation* of biomass is mainly residues from the agribusiness, from which is much harder to obtain the sugar needed and considerably more energy is required to create a product with similar characteristics than the traditional fossil-based alternative. This results in a much more expensive product, with the same characteristics of the alternative, and with potentially even more emissions if the energy source is not renewable.

As a conclusion, the markets for biofuels and biochemicals have been created as an obligation posed by EU regulation, not as a genuine product differentiation aimed at securing demand and market share. The supply of biomass for the production of biofuels and biochemicals is not carbon neutral and competes with other, more pressing global needs such as food production. Also, its use for the chemical industry is still considerably more expensive than traditional fossil-based inputs, driven mainly by the large amount of energy required to make the same product. If the power supply does not come from renewable sources, the production of bio-based chemicals could even induce a higher level of emissions. With this perspective, the use of bio-based materials in the chemical industry is not a real development solution.

A2.1.3. Abatement potential

The third variable analysed to assess the risk of carbon leakage of the industries in the PoR is the opportunities for CO2 abatement potential. The extent to which the industries can curb their CO2 emissions and avoid paying for the carbon tax would reduce the risk of carbon leakage if doing so is cheaper than relocating. This research analyses this variable by assessing the low carbon technology development, investment spending in low carbon technology and the likelihood that the implementation of available low-carbon technology could report revenues in the future.

Low carbon technology development

For companies to be able to abate their CO2 emissions, appropriate technologies and substitutes need to be readily available. In the case of the PoR, besides energy efficiency measures that need to be analysed factory per factory, the main efforts for CO2 abatement of the whole cluster are driven by the PA, who is committed to the energy transition and aims to bring the port in compliance with the targets of the Paris Agreement. Several projects have been launched or are being prepared for implementation in the coming years. The PA has commissioned a variety of studies and has worked closely with the industry to develop a roadmap towards the energy transition. The results have been published in the report *Three Steps Towards a Sustainable Industry Cluster (2018).* Of the options presented in the document, CCUS is the one that has the largest abatement potential. It is being developed by the Porthos project organisation, and aims at capturing, transporting and storing CO2 emissions under the North Sea as seen in Figure 28.

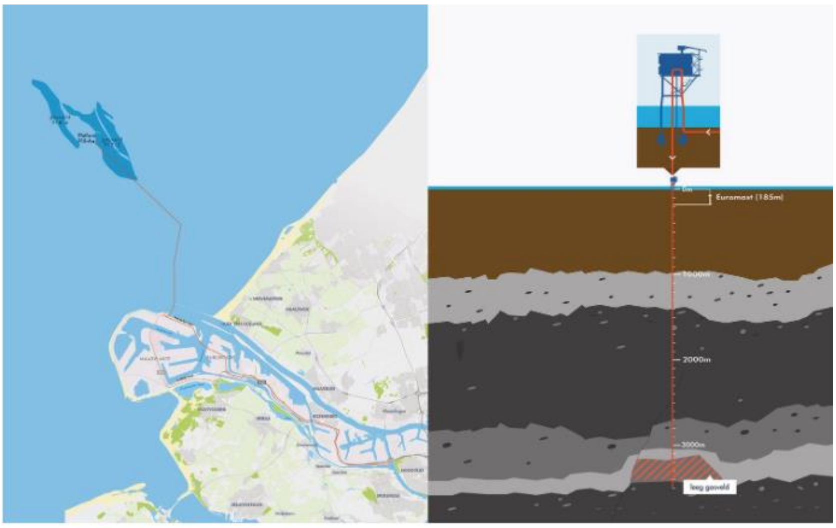

Figure 28: Porthos CCUS project layout. Source: Port of Rotterdam website.

STEP	ACTIONS	CO2 SAVINGS (MT)
1	Efficiency, developing infrastructure and CCUS	8
2	Towards a new energy system	4
3	Renewal of raw materials and fuel system (2030-2050)	1
	TOTAL	**13**

Table 20: Steps considered by the Port of Rotterdam for emissions abatement. Source: Port of Rotterdam Authority, 2018

The measures currently being taken by the PA in the decarbonisation of industry are divided into three steps. Step 1 runs from 2018 to 2025 and focuses on building infrastructure and enabling conditions for the supply and reuse of surplus energy and the implementation of CCS. The industrial cluster is closely connected by pipes and cables, which allows recycling heat and steam between factories. An expansion of the existing heat infrastructure will allow transporting the excess heat from the industries to the district heating network, by connecting to specific projects under development, such as South Holland Heat Alliance, EnergyWeb XL (residual heat in Moerdijk) and Botlek steam network (Port of Rotterdam Authority, 2018). There is a CO2 network connecting the PoR to the greenhouse horticulture sector in the Province of South Holland, where the CO2 is transported to and used to enhance plant growth, instead of burning gas for the same purpose. These projects contribute to the carbon-neutrality of the PoR by reducing the amount of gas burned to provide residential heating and CO2 for horticulture purposes. Although the industry also reuses some residual heat, this initiative does not represent a substantial CO2 abatement in industrial processes, but rather a recycling of an output of these processes that otherwise would go to waste.

Project organisation Porthos (Port of Rotterdam CO_2 Transport Hub and Offshore Storage), is a partnership between the PA, Gasunie and EBN. It has been developing the CCUS project for the PoR, which at this moment is in the technical development of the transport and storage infrastructure phase and is expected to operate by 2024. The project consists of capturing CO2 from the industrial processes in the PoR and transporting it via pipelines to empty gas reservoirs in the North Sea, as shown in Figure 28. The CCUS project is conceived as part of the energy transition of the industrial cluster in the PoR. It is expected to store 2.5Mt of CO2 per year for approximately 5 to 7 years in the explored empty gas wells in the North Sea. The project organisation Porthos will transport and store the CO2 captured from various companies who will supply the CO2 to a collective pipeline. The CO2 will be pressurised in a compressor station, and it will be transported to an offshore platform 20km off the coast, from where it will be pumped into empty gas wells over 3km below the North Seabeds.

The PA foresees that there will be more than sufficient interest by the companies to capture and store their CO2 emissions, as four of the biggest petrochemical companies -Shell, ExxonMobil, Air Liquide and Air Products- have already signed an agreement committing to use the CO2 infrastructure currently under development, and work on preparations for the project's implementation. The total reduction potential of step 1 is 4.9 Mt of CO2 up to 2030, with the possibility to increase by 2.6 – 3.5 Mt of CO2 by reusing CO2 in the built environment and horticulture (Port of Rotterdam Authority, 2018).

Step 2 consists of building capacity to switch the industry's energy source to renewables such as offshore wind, wind and solar. This requires an expansion of the energy infrastructure for electricity and hydrogen as well as the creation of markets for blue and green hydrogen. The estimated reduction potential of this phase is 3.5 to 4 Mt of CO2 by 2030. The hydrogen technology will be further explained in the next section.

Step 3 consists of the scaling-up of green hydrogen and electricity connected to the industrial cluster, with the estimated emission reduction of 1Mt by 2030.

These developments provide some opportunities to abate CO2 emissions in the industrial cluster, but even in the best-case scenario, there will still be 12 to 15Mt of CO2 emitted after these steps. According to the respondent from the Policy and Planning of the PA, there is some extent of certainty about what can be done from here to 2030-2035. After that period the roadmap becomes uncertain, with approximately half of the emissions to be cleaned up, and no clarity on how to abate them. This view is shared by respondents from TNO and consultancy firms and representatives of the industry (VNPI and VNCI) who are concerned about the costs of the abatement options and the lack a business case to scale them up. According to VNPI, some of the companies in the industries operating in the PoR have margins as low as 20-22EUR/ton CO2 emitted, which makes it unrealistic for them to implement any option of abatement that exceeds these prices. As seen in Figure 14, one of the most cost-efficient options to substantially reduce CO2 emissions is the CCUS which is expected to have a cost of 51EUR/ton of CO2 plus infrastructure and storage (Dutch Ministry of Economic Affairs and Climate, 2019a).

There are different perceptions among the interviewees regarding the level of maturity of the different technologies for CO2 abatement. Members of academia believe that the technology is in place and mature enough to be implemented, but it is the business side that prevents their scaling-up. On the other hand, representatives from industry and technical engineering firms are more cautious and stress that these technologies have never been proven at such a large scale in an interconnected industrial cluster. From the alternatives discussed, there is consensus in that CCUS is the most advanced technology, while perceptions regarding the extent to which hydrogen could be readily applied, even if the investment were not an issue, are divided.

Investment spending

Considering the unfavourable business case for the implementation of low-carbon technologies, the only option for firms to remain in business in a market with a higher carbon price is to make investments that will not be profitable in a direct sense but are necessary to survive into the future. To some extent, for internationally operating entities most investment decisions are made globally, with different regions where they have operations competing to attract investment. This makes the investment decision in low-carbon technology more difficult, as firms need to be on top of the list of who gets the investment on each investment cycle. Policymaking can play an important role in this regard by creating an environment that makes it attractive for firms to invest in new technology and creating a vested interest in investment in the Netherlands.

According to the data gathered from different departments of the PA, large multinationals are currently investing in low-carbon technology in the PoR. The previously mentioned Porthos project has the signed commitment of four of the biggest oil refineries to use the infrastructure currently under development and supply their CO2 emissions to the project. Although this commitment is not binding, it shows a shift in thinking by the industry, who is seeing in the development of low-carbon technology the opportunity to remain in business in the long term. Shell is actively working with the PA in green hydrogen production, aiming to build up to 2GW of electrolysers, and negotiations are ongoing for their investment in offshore wind. The fact that one of the largest oil companies in the world is changing its investment portfolio can create a momentum by which the competition follows suit, and the scaling up of low carbon technology is brought a step closer. Nevertheless, the share of green investment by the companies in the PoR is still very low, as stated by members of the PA. Approximately 12% of the investment in the PoR's petrochemical complex is related to bio and green investment and 85-88% is traditional fossil-related investment. The interviewees have the certainty that the share of green investment will increase in the future, enhanced by climate regulation, demand trends and current investment decisions of key stakeholders.

The perspective brought by members of the academia is auspicious regarding the investment in low-carbon technology in the PoR and the nearby ports. Although not in the scale required, the technology to produce hydrogen has been in place for some time and pilot projects and investments are taking place, especially in ports. Gasunie, the Dutch gas infrastructure provider and engine of all the gas pipelines, is working along with the industrial clusters of the North Sea ports to scale-up the hydrogen technology.

A2.1.4. Regulatory environment

The last variable analysed to assess the risk of carbon leakage for the industries in the PoR is the regulatory environment. In this research, it is defined as the anticipated interactions between political support and future business opportunities. Climate regulation and the particular cost and pricing environment faced by firms play an important role in investment decisions. To analyse how the regulatory environment affects the risk of carbon leakage, this research analyses the sub-variables certainty of future price of carbon, environmental stringency and level playing field.

Certainty of future price of carbon

Firms need as much certainty as possible about their future costs to plan their investment decisions. One of the reasons that have been appointed in the literature to explain the lack of action of the industrial sector in curbing CO2 emissions is that firms do not have a credible price of emissions to support their investment decisions. This research investigates whether a carbon tax can provide the required price certainty to enhance investment in low carbon technology.

The data collected from the Business Management of the PA supports the idea that the insecurity about future carbon prices stops firms from investing. As long as the exact level of the carbon tax continues to be uncertain, it will create a reluctance to invest in Rotterdam. In this sense, knowing the price of carbon, regardless of the level, will reduce the uncertainty that keeps firms from investing. Insecurity is considered a larger problem by firms than the price itself, within a certain price range. The current price of carbon is considered by the PA as too low to drive change in the production processes or products of the industry. According to previous conversations between the PA and firms, a price of 60 to 65 EUR per ton of CO2 including the ETS price would initiate innovation and investment.

More detailed information on this sub variable was collected from the banking sector, which also supports the idea that uncertainty is detrimental for investment decisions. An important aspect of the carbon price signal is the information it provides about the timing to make the investments. One of the main issues of the EU ETS is that firms do not know when to invest, as the price is volatile and affected by a myriad of external factors such as the number of permits in circulation, financial crisis, etc. As firms do not know when the price is at the optimal level to make the investments in low carbon technology, they do not take the risk of making the wrong decision and will not invest. For instance, if the price of carbon increases tomorrow and firms use that price as a signal to evaluate their investment, it might be profitable to decide to invest in low carbon technology. However, if the carbon price goes down in the future, firms that invested before will go bankrupt because they made the investment decision with the wrong price signal. According to the interviewee, if businesses had to choose, they will choose a CO2 price path starting at a certain level, and slowly increasing over a certain period to reach a given target. This does not mean that they would prefer a carbon tax instead of the EU ETS, as they see the ETS as a being more flexible and giving them more degrees of freedom, as opposed to paying a lump sum of money to the Government and not seeing anything in return. By setting a price floor that increases over time, the price of carbon does not have to be immediately high to trigger investments in low-carbon technology. As stated before, EIIs make investments with a long-term perspective. As such, long-term carbon prices are more relevant than current carbon prices and will drive the majority of the investment decisions. With this in mind, as long as the price of carbon increases by a given factor over time, firms will immediately have a different approach to investments. This certainty and predictability of the future price of carbon would make them invest in green technology.

Another interesting perspective given by the interviewee is that putting a price floor to the price of carbon could provide a competitive advantage for firms in the Netherlands. The regulatory environment would be providing businesses with extra certainty, preventing them from investing at the wrong point in time and reducing the risk associated in their investment decision. By introducing price certainty, the investment decisions that businesses make will be at lower costs. This reduction in uncertainty leading to a reduction in the risk associated to the investment, also means that the banking sector would be able to finance businesses at a lower rate. Banks price the risk when financing businesses, who pay premiums according to the risk. If the risk is too high, banks might not even provide financing at all. To further reduce the risk, a price ceiling would also be necessary. Just as carbon prices falling below the price floor do not provide businesses with an incentive, prices skyrocketing can also have detrimental effects. It would cause firms to rush to make investment decisions that they regret should the price return to more normal levels. By introducing a minimum and maximum carbon price, firms are both incentivised to invest in low-carbon technology and protected from incorrect price signals that lead to wrong investment decision.

Environmental stringency

This sub-variable assesses whether firms consider a more stringent climate policy, reflected in a higher price of carbon, as a threat for future investment or as an opportunity to enhance their competitiveness. The findings are that the effect will depend on the level of the CO2 price, the cost of abatement and whether the CO2 prices increases only in the Netherlands, Europe or globally.

Depending on the price level of CO2 emissions, firms could gain a competitive edge and make revenues by implementing technology such as the CCUS. This can happen if the price of a ton of CO2 emitted is higher than the cost of transporting and storing a ton of CO2 beneath the North Sea. In this case, companies connected to the CCUS infrastructure will have lower costs of production than those with no abatement options, who will pay the price of CO2 emissions. However, this scenario is only achievable if the same price of CO2 emissions is applied regionally, at least at the European level, and ideally at a global level. If this is not the case, regardless of the price of transporting and storing CO2 being lower than the carbon tax, companies could still increase their production in facilities located outside of the Netherlands, where the cost of emitting CO2 would be lower.

The level playing field

This sub-variable assesses the extent to which the introduction of a carbon tax in the Netherlands would induce distortions in the level playing field, and what its relationship with carbon or investment leakage is. The level playing field relates to the set of rules under which the production and trading of goods and services take place. Differences in environmental regulation across legislations can distort the level playing field and provide advantages or disadvantages to the competitive edge of sectors trading in international markets.

Interviewees from the PA stress that the climate issue is a global challenge that would be impossible to tackle by countries acting in isolation, especially by a small country like the Netherlands. Although they recognise that the Netherlands has a highly emitting economy, the contribution that it can make by curbing its emissions is marginal when considering the global context. Nevertheless, the PA is aware that the current CO2 price is not high enough to induce a reduction of emissions by the industry and is in favour of increasing the price as long as it increases for everyone. Different policy mechanisms affect the level playing field to different extents, and the view of the PA is that a carbon tax in the Netherlands alone will greatly affect the level playing field and the position of the industry in the PoR. The PA aims at a flat level playing field in the region, in which no port gains or loses competitive edges based on differences in regulations and is not in favour that the Netherlands alone increases the CO2 emissions through taxes. Nevertheless, they are supportive of other measures like reforming EU ETS by reducing the number of available emission permits, which will increase the prices, or introducing a tax in the most important countries in Europe. According to different sources in the PA, for a company looking for a place to start operations the costs do not differ greatly between the ports in North-West Europe. To make the investment decisions, firms assess all the variables that could potentially affect their production and business - regulations, labour rights, taxes, technology, logistic networks, etc. – and then decide for the most advantageous location. Thus, regulations implemented by the Netherlands alone that affect its attractiveness as a location for investment are likely to divert investments to nearby ports or other regions of the world.

Interviewees from academia have the same view regarding the level playing field and support the implementation of a carbon tax at the European level. In this case, the risk of carbon leakage for the companies in the PoR would not be high as the business of the refining and petrochemical industries is mainly focused on the European market and it is only its excess capacity that is exported. The importance of the specific design of the taxing mechanism is also highlighted, as the effects in the industry will vary greatly depending on the support mechanisms that the policy includes, like CBTA, exemptions or rebates. From a regional economic perspective, the introduction of a carbon tax only in the Netherlands would create a high risk of *investment leakage*, whereby companies would start investing in other locations as the PoR would become less attractive for investment.

Representatives from the industry share the concerns about the level playing field the importance of having a carbon pricing policy that makes an impact at the European level at least. From the chemical sector, the main concern is that the scale of the Dutch industry is too small to have a well-functioning and independent carbon price. The preference of the industrial sector is in strengthening the EU ETS, because it is already scaled to the rest of Europe, and the common view is that a national price of carbon would be detrimental for Dutch industry. If a higher carbon price is applied at the European level as part of a policy mix that also incentivizes investment, representatives from the Dutch industry state that companies would be able to make a business case for clean investments. However, there is consensus in that the mechanism will not work if the policy scheme is open to carbon or investment leakage.

A2.2. Induced Innovation

A2.2.1. Product innovation

Product innovation relates to the introduction of new goods and services, or changes in existing ones, that involve less CO2 emissions in their production processes, or have less carbon content embedded. This variable is assessed by analysing the sub-variables market drivers, the potential for product differentiation in the market and sectors propensity to innovate.

For the oil refining industry, the clearest opportunity for product differentiation is represented by biofuels, as they emit less CO2 than conventional fossil fuels when burned. Biofuels are produced from organic matter and are blended in conventional fuels like gasoline or petrol to reduce their CO2 emissions, and their main use is in transport. From the analysis presented in the *Abatement Potential* section about *product differentiation*, the market drivers for biofuels come from EU regulation that forces biofuels to be blended in fossil fuels. As long as the obligation remains in place there will be a market for biofuels, in which companies operating in the industrial cluster of the PoR have a favourable position. The Netherlands is the third-largest European producer of biofuels, with most of the production taking place in the PoR (Statista, 2020). According to the PA, the PoR has become one of the world's hubs for the production of bio-based fuels, and it is the place with the largest production capacity per unit of area. The shortcomings of future development based in biofuels are manifold and are explained in detail in the Annex A2.1. Perhaps the most important one for this research is that the production of biofuels is not carbon neutral when considering the whole production chain and the induced changes in land use. On the one hand, more energy is required to produce chemicals from biofuels with the same characteristics than the traditional petrochemicals. If the energy matrix is not entirely switched to renewables, the whole process might end up emitting more CO2. On the other hand, if the externalities from the induced changes in land use are considered, a substantial amount of emissions is added to the production of biomass. Furthermore, it competes for the space with food production and contributes to the deforestation of tropical forests in Brazil, Indonesia, and Malaysia.

> *"using bio-based raw materials for the chemical industry, you'll end up using way more energy than you are doing now with using fossils. So, if you don't have your energy economy completely turned into a sustainable one, then the use of biomass to making chemicals is not very wise."*
>
> - *Interviewee 13*

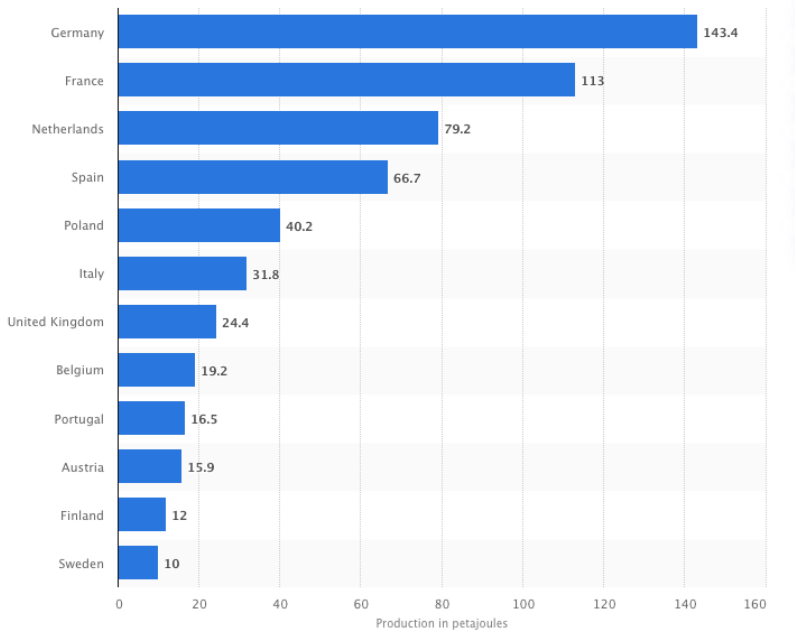

Figure 29: Production of biofuels in European countries. Source: Statista, 2020

The use of bio-based feedstock as an input for the chemical industry to produce *biochemicals* is also considered a product innovation for the sector, which carries the same shortcomings as biofuel production. According to data collected from academia, the whole industrial cluster of the PoR is related to the production of base chemicals, which makes it difficult for the industry to specialize in anything different. From a regional economic perspective, the industry in the PoR has specialized in the production of basic commodities, and the diversification into fine chemicals and specialties has taken place in the Port of Antwerp, representing its main competitive advantage.

According to data collected from the Business Management for Chemical industry in the PA, innovation for the industry is to a great extent focused in the products rather than in energy efficiency of their processes, as most of the carbon is embedded in their products. For instance, *polyurethanes* are polymers produced by the chemical industry and used to manufacture foams. Most of the product innovation in which the chemical industry focuses on consists, for instance, on how to use the foam to replace steel parts in cars and trains. This would lead to lighter cars and trains, consequently reducing the energy consumption in transportation. The chemical industry requires large amounts of energy to make these products, but in the life cycle of the products, the total amount of energy spent in the production is recovered by savings in less future fuel consumption. The chemical industry has historically developed new products that allow for energy savings in other sectors, like better housing insulation materials, and has a larger potential for product innovation than the oil refining sector.

For instance, there are ongoing investments by Air Liquide, Enerkem, Nouryon, the PA and Shell in the development of a *Waste to Chemicals* (W2C) plant. This will be the first plant of the kind in Europe and it will use large amounts of non-recyclable waste to produce *sustainable methanol*, an important input in chemical production, which will be purchased by Shell and Nouryon. The project is expected to transform the amount of waste equivalent to 700,000 households and reduce CO2 emissions by approximately 300,000 tonnes of CO2 (W2C, n.d.). The project has the support of the Dutch Ministry of Economic Affairs and Climate, the Municipality of Rotterdam, the province of South Holland and is financed partly by the European Union through the European Regional Development Fund.

A2.2.2 Process innovation

The second variable assessed is process innovation and relates to the implementation of new or improved production processes leading to significant emissions abatement, such as the adoption of new sources of energy and energy efficiency. The sub-variables analysed are production method alteration, barriers for the adoption of low-carbon technology and government support.

Production method alteration

In this research, production method alteration refers to the implementation of low-carbon technology that allows the new energy sources or cleaner feedstock for industrial processes. The indicator used is the awareness of the existence of proven cleaner technologies that could be implemented in production processes, leading to a substantial reduction of emissions. When asking interviewees about their awareness or knowledge about new and cleaner technology, the use hydrogen as an energy carrier was the most mentioned technology. Other measures as the use of alternative sources of renewable energy as offshore wind and geothermal, CCUS, biomass and electrification were also mentioned. This section covers focuses mainly on hydrogen production, as the resto of the mentioned technologies have been addressed in previous sections.

According to the data collected by consultancy firms TNO and Royal HaskoningDHV, the first aspect to clarify is that hydrogen is not a renewable source of energy on its own but acts as an energy carrier. The extent to which hydrogen is clean, depends on the energy source and production method used in its production, and there are mainly three categories. The first is known as *grey hydrogen*, and it is produced from natural gas, which is separated into hydrogen and CO2 by steam-methane reforming process (SMR). This process is currently in use by the industry in the PoR and according to sources from the PA it is a highly emitting process that is detrimental for the image of hydrogen as a clean technology. However, if the CO2 emitted in the SMR process is captured and stored through CCUS, the process becomes carbon neutral and the product obtained is known as *blue hydrogen.* Lastly, *green hydrogen* is produced by electrolysis, a process by which water (H2O) is split into hydrogen and oxygen, completely different than SMR. The process uses electricity as an input, that is fed into an electrolyser that separates hydrogen and oxygen from water molecules. If the electricity is produced from renewable sources of energy such as offshore wind farms or PV, the process generates zero CO2 emissions. As a rule of thumb, *blue hydrogen* is currently twice as expensive as *grey hydrogen,* and *green hydrogen* is four times more expensive than *grey hydrogen.* According to the interviewees from the consultancy firms and the PA, the main benefit of using hydrogen in industrial processes is, besides its potential carbon neutrality, that it allows to reach the high temperatures required in many chemical processes. Such high temperatures are impossible to reach with electricity and constitute one of the reasons for the dependence of fossil fuels in the industry. The use of hydrogen gives flexibility to the industry as it can be used as a feedstock or fuel in industrial processes and as an energy carrier for electricity generation.

Barriers for the implementation of new technology

The sub-variable of barriers for the implementation of low carbon technology, such as *blue and green hydrogen* is assessed by measuring the indicators of costs, supply concerns and business model. One insight from analysing Table 14, is the relatively high number of quotes of the barriers for the implementation of low-carbon technology compared with the potential for product differentiation or production process innovation. As it will be explained in the section assigned to this sub variable, the technologies and product innovations have been known for years, but their implementation has been kept from taking place mainly because of business case issues.

There is consensus among the interviewees in that the technologies presented in this research are in place and could be implemented if funding was available. However, sources from the consultancy firms and the chemical sector stress that technical and operational aspects of their implementation are not to be taken for granted. For instance, according to data collected from the chemical industry (VNCI) the use of hydrogen for chemical production is a very new application for which more testing is required before it can be scaled up. Interviewees from consultancy add that the technology has been proven in small scale research projects or laboratory experiments, but it has never been tested in the scale required as to be implemented in a large industrial complex as the PoR. As an example, the mentioned CCUS being developed by Porthos will be the first of its kind to be applied in a large scale.

> *"I think to really get to a good business case we need to realize that while the technology in itself is mature it's only at the very beginning of its maturity. The costs have not come down yet"*
>
> - *Interviewee 6*

Regarding the production of *green hydrogen* through electrolysis, interviewees from consultancy stress that the large-scale production is seen further away than many people think. There are currently electrolysers built on the scale of 5 to 10 MW, and plans to build electrolysers of 100MW in Germany, but not in the 1GW scale. Although it is technologically possible to build larger capacity electrolysers, there is consensus among all the interviewees in that the real challenge to scale up the technology lies in the business case. Companies like Siemens, Nouryon, NEL and ITM Power are currently working in the technology that allows for the automated production of larger electrolysers. However, their development and construction are strongly driven by current and projected demand for hydrogen to make a favourable business case. The existing projects producing *green hydrogen* by electrolysis are heavily subsidised as there is no market for hydrogen yet. According to a source from the PA, to create a business case around it the focus needs to be in the whole value chain; demand, production and supply. These three elements must be interconnected but quite often governments and companies focus on one of the elements, which is not enough to create a whole new business model. In the case of *green hydrogen*, the focus has been mainly put on overcoming the technical and technological challenges of the production and supply, when there is still no demand to create a market. Thus, as in any other market, as long as there is no demand for products it is not possible to scale them up, lower the costs and make them available for mass markets.

There is a tendency to point out the high costs of the new technologies - green hydrogen, CCUS, geothermal energy, among others – as the main barrier for their implementation. According to the data gathered from all the sources, the costs are still extremely high as a consequence of the lack of demand which prevents companies from creating profitable business cases. As stated before, firms operating in the energy sector and EIIs make investments with a long-term perspective. The investments in new facilities are large and facilities are expected to be in operation for several decades, allowing the firm to recoup the investments and make a profit. Perhaps the most important driver of the investment decision is the demand for the product, and if there is no demand or it has high degrees of uncertainty, firms will most likely not take the risk.

> *"there's not enough market for them (low-*carbon technology) so there should be public *support for that"*
>
> - *Interviewee 12*

According all the interviewees, public support and regulations can play a key role, and are perhaps the only mechanism that could create a market for *green hydrogen* and boost the implementation of low-carbon technologies. Cases such as the EU regulation for biofuels are pointed out by the majority of the interviewees as examples for regulations that act as major market drivers. Once the market was created, companies invested in installations, and in scaling up the technology. Government support and regulations will be further explained in the next sub-variable.

An interesting perspective is brought by the banking sector and relates to the funding of projects that implement low-carbon technology. According to the source, even if the business case is favourable, the project will need investors to contribute with covering the full amount of the large investment required. Projects will most likely need debt to be implemented as no company has these amounts of money as savings. Banks lend money for a period of 6 years, after which the project has to be refinanced, but the production facilities are projected to operate for 20-40 years. Firms can only refinance if they still have a healthy running project, otherwise the bank or any other investor will be hesitant to refinance. To finance projects of this scale, investors make sure that the electrolyser is well maintained, functioning and providing the desired volume of hydrogen during its entire lifespan. In innovative projects such as large scale *green hydrogen* production, it is difficult for investors to trust that the project has the operational knowledge to maintain a business according to model in the long-term, as there are various fields of expertise that play a key role in the operation of the project. Then, the financing of the project becomes a matter of having the right partners around it; engineering firms with in-depth knowledge about how the system works, trustworthy suppliers with the capacity to respond to increases in demand, maintenance firms with the know-how on the specific technology, among others. Investors also need certainty on other factors such as contracts for the supply of green electricity (produced by renewable sources) and its projected costs, legal permits to produce and store hydrogen and liability in case of accidents. Only when all these requirements and responsibilities are in place and the project partners have shared the risk can the bank or investor finance the project. The preparation and organisation of a project of this scale takes time; finding the right partners and ensuring that all the conditions demanded by the investors are in place is a difficult task. This can certainly act as a barrier for the implementation of large-scale innovative projects like low-carbon technologies. For instance, the 12MW turbine HaliadeX is installed in the PoR because it needs to be certified. The project consists on installing approximately 70-80 of these turbines in the North Sea, and banks will finance a large portion of the investment. The certification consists in independent technical engineering firms who confirm that the windmill has operated under the planned conditions and can certify that it works. For the case of the PoR, the PA has the coordinating role to ensure that the necessary conditions to get funding and implement the projects are in place. The high credibility of the PA, and the fact that it is a public entity partly owned by the government, is seen as an advantage by the banking sector.

> *"And for banks to finance that transition, I mean, companies can't do it all by themselves, the government is not going to pay all of it, so part will have to come from debt. And again. We need verification and consistency across a wide range of factors before we can finance"*
>
> - *Interviewee 3*

A source from the consultancy sector (Royal HaskoningDHV) also shares the concerns about the supply of green electricity for the production of *green hydrogen*. The first ideas when drafting the projects were to supply the electrolysers with excess of renewable electricity. However, the availability of excess electricity is not nearly enough as to keep a large-scale plant of *green hydrogen* production working and make a business case from it. It is estimated that windmills in the Netherlands produce excess electricity for approximately 300-500 hours a year, and to operate a large-scale *green hydrogen* plant it requires approximately 6,000-7,000 hours a year. Thus, the operation of these plants needs dedicated production of renewable electricity, if the country's electricity grid is not fully converted to renewable sources. According the PA this can be a big obstacle in the future large-scale production of *green hydrogen* in the PoR. There are not many sources of renewable electricity in the Netherlands at competitive costs. The electricity generated from offshore wind in the North Sea is unlikely to provide the amount of electricity needed in the future, as the demand is projected to be of 20Mt of hydrogen for the Netherlands and its hinterland, if regulations create a market for hydrogen, that could come through the PoR. The amount of electricity required to produce such large amount of *green hydrogen* will not be satisfied by windmills in the North Sea only, and options for the import of renewable energy will have to be developed. One option mentioned by the source is to produce energy with PV in places with favourable conditions such as Morocco and the Middle East. The electricity produced can be transferred into hydrogen via electrolysers, then with an ammonia facility it can be transformed it into ammonia, which could be transported to the PoR and crack it back into hydrogen. The costs of the energy in these areas are becoming low, and the total supply chain could outcompete the production of hydrogen in the Netherlands, given its high the electricity costs.

A2.2.3. Organisational innovation

In this research, organisational innovation is defined as changes in the firms' business practices, vision or goals aimed at developing a more sustainable business model. To assess the variable of organizational innovation this research analyses the sub-variables of permanent R&D investment, green business model and inter-firm partnership and cooperation.

According to sources from the PA, there is a high level of investment in R&D by the companies operating in the PoR. The PA has long standing connections with the Rotterdam Business School, the Rotterdam School of Management, TU Delft, and the Wuppertal institute among other think tanks and research centres. The PA has also founded PortXL, which is an innovation accelerator, and has a fund for innovation directed at CO2 reduction. The PA is also working together with industrial organisations such as Deltalinqs to find mechanisms to enhance the development of new technology. The PA also has developed *Plant One Rotterdam* which is a location where new sustainable technologies can be tested, with many of the technologies focusing on CO2 reduction. The PA is constantly scouting out for new technologies and trying to test them in the PoR. Members of the academia share the view that in the PoR the investment in R&D is relatively high, and it is one of the main advantages of being located in proximity of a large urban agglomeration as the city of Rotterdam.

However, there is a wide consensus among most of the interviewees in that scale-up funding rather than R&D funding is required to accelerate the industrial transition, and the efforts of the private and public sector have been mainly focused on R&D funding. As was stated in previous sections, the technological developments of the low-carbon technologies (CCUS, *green hydrogen*, offshore wind, etc) are in place and the technology is to a certain extent mature. What is needed for its implementation is to scale it up and test it on a large scale, which requires different kinds of funding mechanisms.

The sub-variable green business model measures whether there is potential for the firms operating in the industrial cluster to adopt more sustainable business models, and if the implementation of a carbon tax could be a driver of such a change. Interviewees from the PA stress that companies are fully aware of the declining demand for fossil fuels and that climate regulations in Europe will become increasingly more stringent. Big companies like Shell are already diversifying and investing in the production of cleaner forms of energy. The PA sees that oil companies in general are aware that they need to change their business models and switch from oil to energy companies by investing into renewable electricity from offshore wind, green hydrogen and all kinds of different clean technologies but fossil.

Sources from the academia have a similar view, which is enhanced by a regional economic perspective. They also point out at the example of Shell, who in the recent years has become a very important gas producer because of its relatively good environmental records, and is currently investing heavily in clean energy, specifically in green hydrogen and offshore wind.

The perspective from the industrial associations is similar but more cautious. They state that they are aware of the challenges imposed by climate change and more stringent climate regulations. According to the interviewee from the chemical industry, there is certainty that a whole different thinking is required to create a future carbon neutral industry. The business model of the private sector in general needs to take into account the whole value chain by also creating a circular economy with less waste and recycling more than just the CO2.

Nevertheless, any change in the firms' business model needs to be based on a profitable business case, that ensures that their business keeps going. Given the competitive markets in which they operate, this cannot be taken for granted and it needs support from public funding and regulations that create markets for cleaner products. According to all the interviewees, more stringent climate policy, as a higher price of carbon imposed by a carbon tax, has the potential to induce organisational innovation, but only if there are also appropriate incentives in place that could ensure the profitability of the firms.

The sub-variable interfirm partnership and cooperation is defined in this research as the level of cooperation in business organisations that allows them to achieve a common goal more effectively. The data collected suggests that the current level of cooperation in the industrial cluster is high, with many industrial associations such as Deltalinqs coordinating efforts for greening the industry and investing in CO2 reductions. In the case of the PoR, the PA acts as a facilitator and coordinator to enhance the cooperation of the firms in the industrial cluster. As it was explained in previous sections, the advanced infrastructure, pipeline networks, and implementation of projects for the reuse of heat have been coordinated by the PA to create conditions that benefit the effectiveness of operations for the industries in the PoR. Initiatives such as the Porthos project under development, is mentioned as a proof that firms can cooperate in the implementation of new technology when they see a benefit from doing it. According to sources from the PA, more stringent climate policy coupled with appropriate support measures and regulations, could enhance the cooperation between firms as it would create an incentive to invest in initiatives to reduce CO2 emissions, such as the building of a hydrogen backbone.

A2.3. Government intervention

A.2.3.1. Use of carbon tax revenues

A mechanism often discussed in the literature is using the revenues from the carbon tax to support the financing of the industrial transition. This was one of the most conflicting points in the interviews and there are opposed views among the interviewees. On the one hand, a source from the academia is strongly against this measure as it challenges the redistributive power of the government. One of the roles of the state is to redistribute wealth, and it would not correct to dictate the government how to use this faculty. Giving back the revenues of a tax to the source of the emissions and environmental problems is also seen as unfair, and against the *polluter pays principle* from which the carbon pricing mechanisms originate. Furthermore, it is argued that the polluting companies have been emitting untaxed CO2 for decades, and the negative externalities of the emissions have never been priced into any form of tax, allowing companies to made large profits for a long period.

"But if you purely look at it, if you demand as an emitter, that if you are taxed, the revenues from that tax are channeled directly into a subsidy, while the externalities have never been priced into your operations, then, to be frank, that's ridiculous."

- *Interviewee 2.*

On the other hand, representatives from the PA and industrial organisations are in favour of such a mechanism, as it would certainly facilitate and accelerate the industrial transition. Furthermore, many sources from these sectors see it as a precondition for firms to be able to make the investments in low-carbon technology. According all the sources from the PA, the fear for the PoR is that if the carbon price is too high and the revenues are not piped back into the same industry, firms will not be able to make the investments to implement low-carbon technology. Also, new investment opportunities could be created by investing the revenues to support the industrial transition, creating a competitive edge in the PoR. For instance, the PA is developing a project to build a hydrogen backbone that would attract companies that want to produce green hydrogen to the PoR. If the revenues of the tax were destined to build such infrastructure, it would create a competitive advantage for the PoR to attract new investment. The PA considers the mechanism of returning the revenues to the industry as the starting point to enhance the industrial transition and the base of the strategy to be followed. However, the challenge remains in creating a fair system as the increased production cost induced by a tax will be detrimental for the companies paying for the tax, and the revenues would benefit new industries from the hydrogen backbone.

"If you tax CO2, we think that should also support innovation by piping back all that money into the industry, to invest in CO2 measures, and not let it disappear into the giant tax pile of gold somewhere and no one knows what happens to it. It's not going to reach its CO2 emission reduction that we all want."

- *Interviewee 11*

Investing the tax revenues in supporting the industrial transition also has the support of other members of the academia and industry, who share the view that it would benefit the competitive position because it can be invested in measures that offset the disadvantages imposed by a carbon tax by giving, for instance, investment possibilities to those firms.

"I do think that in general, if you are paying something towards the ETS, those funds should actually go back to transitioning industry, our system. And not go to healthcare, it wouldn't make sense. They're paid to reduce carbon, so let's do that"

- *Martijn Broekhoff*

An example of subsidies that support the energy transition is the SDE++. This is a subsidy scheme in the Netherlands that benefits the production of renewable energy and the adoption of energy saving measures. This subsidy scheme was brought as an example of good government support policy by all of the interviewees, who stress the importance to strengthen it and create more mechanisms that support the financing of low-carbon technology. There is a common view in that policymakers are favouring businesses investing in low-carbon technology, which is considered as one of the strongest points of the Dutch approach to industrial transition. However, a source from the academia states that subsidies can disturb the market by distorting the market price of energy, which can lead to overcapacities or misallocation of resources.

A2.4. Port Competitiveness

A2.3.1. Changes in port fees and throughput

As stated before, the implementation of a carbon tax would not directly increase the costs of the PoR, as its emission levels are quite low (considering the activities of the PA, which exclude the industrial cluster). One of the biggest threats for the PA with the introduction of a carbon tax is the scenario in which companies decide to relocate or exit the market, which would undoubtedly influence the PA's income. Although according to most of the interviewees this scenario in highly unlikely, it would not be a wise strategic decision from the PA to increase the fees of port use or land rental to make up for the lost profit, as it would put the PoR in the wrong competitive direction. The PoR is already among the most expensive ports in Europe and increasing the costs will make other ports like Antwerp and Hamburg considerably cheaper, gaining a competitive edge against the PoR.

According to sources from the PA, a likely scenario for the implementation of a carbon tax is that companies decide to use the facilities in the PoR as *swing facilities*, operating them at a lower capacity and increase their production level in another region. This would translate into less throughput, which represents approximately half of the PA's income. Every ship that arrives pays fees for entering the port and per ton of cargo it brings in. Thus, the decrease in both the number of ships and the amount of cargo coming would reduce the income of the PA, which can be an important financial problem. One of the measures mentioned by once source of the PA, is to make temporary reductions in the land use fees for companies that run into financial shortcomings as a consequence of the increased production costs. The PA has taken measures like that in the past, as during the 2009 world financial crisis the PA reduced some of the prices in port use to attract ships to the PoR. The sources indicate that the PA would be willing to reduce their own income to allow the companies to survive and not leave a blank spot in the industrial cluster, which would translate into no income at all.

A2.3.2. Attractiveness as a location for investment

Perhaps the largest and most important impact that a higher price of carbon would have in the PoR is in its attractiveness as a location for business. As it was explained in the operationalization table in Chapter 2, this variable is included in the analysis of port competitiveness given the nature of the business model of the PoR, in which most of its revenues are generated by the industries that have located their operations in this location. The sub-variables created to analyse this variable are the legal and regulatory framework, green investment and knowledge and innovation.

The introduction of a carbon tax will increase the stringency of the regulatory and legal framework for companies operating in the Netherlands. This has the potential to distort the level playing field, as explained in section 4.3.4. There is consensus among all the interviewees in that the introduction of regulations that increase production costs will make firms' business cases less favourable for future investments in the Netherlands. The most likely reaction of multinational companies like the ones operating in the PoR to this cost increase is to divert investment to other locations where they have operations and production costs are lower. The investment leakage has negative implications for the competitiveness of the PoR, as facilities will continue ageing and firms will make the most profit out of their remaining operational life with no new significant new investments.

Annex 3: Existing carbon pricing policies - An overview of the EU ETS.

This annex presents an overview of the existing carbon pricing policy in Europe will be presented. Under the EU ETS, businesses are required to have permits to cover their greenhouse gas emissions. The number of emission permits for the EU decreases over time by a factor of 2.2% per year until 2030, driving a reduction in aggregate emissions. Governments allocate free allowances up to the level of the 10% most efficient European industries; the industries that are less efficient than the 10% best performing competitors have to buy permits to cover the emissions that exceed the benchmark. The benchmark is updated every 5 years, with the next cycles taking place in 2020 for the 2021-2025 period and in 2025 for the 2026-2030 period. This mechanism creates an industrial competition on the efficiency of carbon abatement, which consequently pushes the whole European industry. This is economically efficient, as the industries with the cheapest abatement options will be the first ones to reduce their emissions. The amount of free allocated permits in The Netherlands dropped significantly in 2012 and has been slowly but consistently decreasing since then, as shown in Figure 30. The total emissions from stationary sources have also been slowly decreasing since 2016, which can be mainly explained by the closure of coal-fired power plants. In November 2015, the Dutch parliament passed a motion to start phasing-out coal-fired power plants (EIA, 2016). Until 2016, 11 coal-fired power plants were still in operation in The Netherlands, of which the 8 oldest have been closed down. Three remain in operation, two of which are in the Maasvlakte area in Rotterdam. Further, The Netherlands adopted a law prohibiting the operation of coal-fired plants from 1 January 2030. The ETS system has not significantly contributed to curbing CO2 emissions, as from 2005 until 2016 they increased, and from 2016 to date, the reduction has been mainly driven by the closure of coal-fired plants.

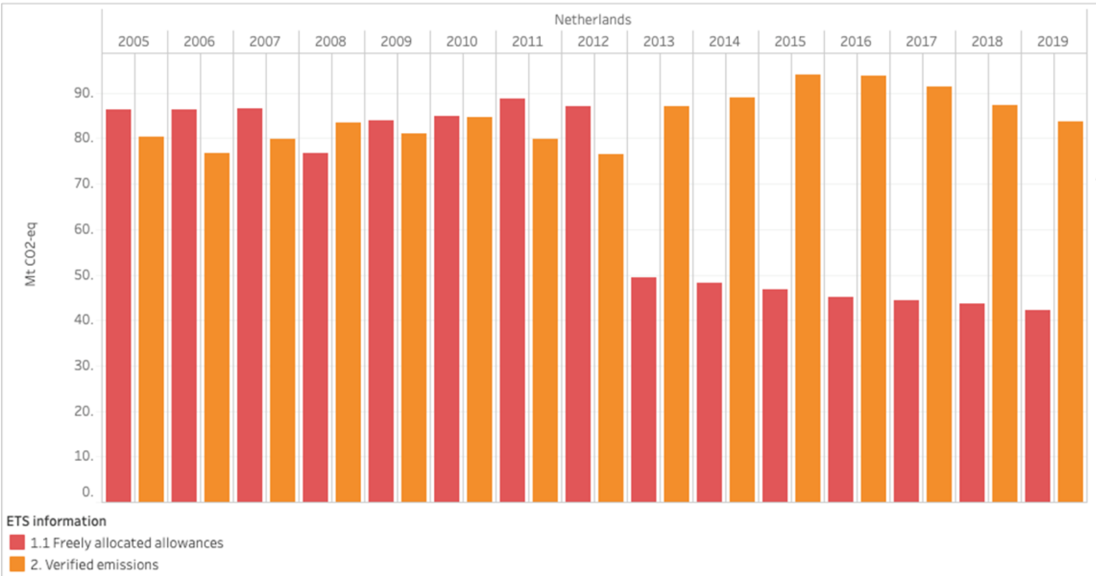

Figure 30: Free allocated allowances and emissions in The Netherlands. Source: EEA's website (European Environment Agency, 2020)

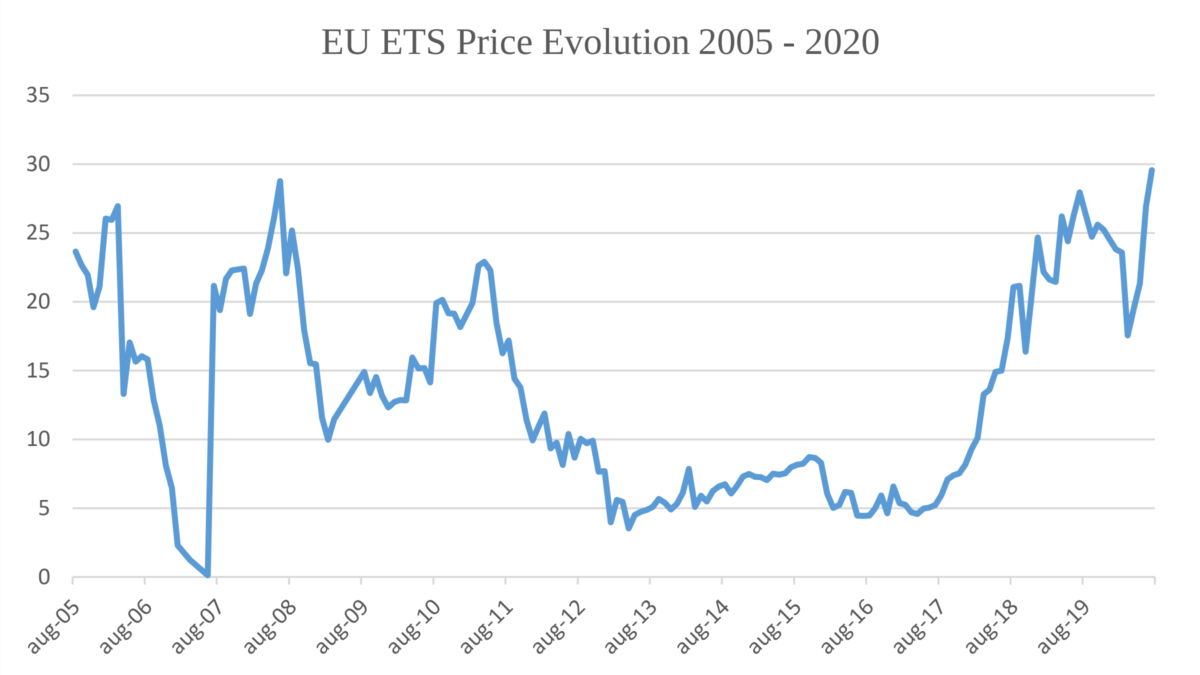

Figure 31: EU ETS price evolution, 2005-2020 period. Source: Author, 2020 based on Market Insider's data.

Since the 2008-2009 world financial crisis, there have been too many permits in circulation, which has pushed the ETS prices down, to levels that are too low to drive emission reductions. Further, the volatility of the permits' price, as shown in Figure 31, does not provide the certainty that the industry needs to make investment decisions. This phenomenon, added to the free allocation problem explained in Chapter 2, is appointed in the Dutch National Climate Agreement as one of the main reasons to include a price floor for the carbon price. This would ensure that the price is a strong and credible signal that enhances investments in energy efficiency and low-carbon technology by preventing the price from falling below a certain level.

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