# Blockers and enablers for decarbonising the Dutch chemistry, refinery and basic metals industries

## A study of relevant literature

Bram van de Glind & Evert Nieuwenhuis

GREEN EUROPEAN FOUNDATION

WETENSCHAPPELIJK BUREAU GROENLINKS
THINK TANK OF THE DUTCH GREEN PARTY

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## About this report

This report is an output of the transnational Climate Emergency Economy project, coordinated by the Green European Foundation. The project explores the challenge of decarbonising 'harder to abate' sectors, such as the chemistry, basic metals and refinery industries and international trade. WBGL, Green House Think Tank and Green Foundation Ireland each focus on a specific part of a climate emergency economy. This particular report was written by WBGL and focuses on Dutch energy-intensive industries.

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# Executive summary

## Scope and context

Industry accounts for 30 per cent of all Dutch greenhouse gas (GHG) emissions. The chemistry, refinery and basic metals industries are responsible for 79 per cent of these emissions. In the period 2010–2018, the absolute level of GHG emissions of Dutch energy-intensive industries (EIIs) was relatively stable. The downward trend that is required is not happening. Decarbonising these EIIs is essential for meeting climate objectives.

In 2019 the Dutch Government adopted a comprehensive policy package to reduce its emissions, including measures to reduce industrial emissions. An industrial CO2 tax and a subsidy instrument for CO2-reducing technologies represent some of the most relevant policies. Although this policy package is a step in the right direction, the overarching focus on cost efficiency and short-term reduction poses a risk for the development of more transformative technologies, such as electrolysis for hydrogen, and other electrification processes.

EIIs are characterised by highly competitive, internationally configured markets. The production assets are capital intensive and typically in use for decades. These dynamics mean that profit margins are low and that change happens at a slower pace. To overcome such blockers, governments must take an active role, be willing to invest and take risks, and set direction. This active role can be split out in two complementary strategies: (1) decarbonising production and (2) reducing demand.

## Decarbonising production

Producers can decarbonise their production by changing production processes, for example by replacing fossil-fuel-based processes for direct electrification, or indirect electrification by using hydrogen. Carbon Capture, Utilisation and Storage (CC(U)S) should be considered as a transitioning technology that has the potential to reduce emissions in the short term. Although the decarbonising potential of electrification, hydrogen and CC(U)S have been demonstrated, the wider adoption of electrification and hydrogen in particular represents a vast industrial transformation, which cannot be expected from industry on its own, given the low profit margins, long timescales and capital-intensive assets.

To incentivise industry to switch to producing low carbon materials, it is crucial to create a market for such materials. The Dutch government, as well as the European Commission, should help create this market through subsidies based on carbon contracts for difference (CCfD), green public and private procurement obligations, and a higher price on carbon. In addition, energy efficiency standards based on GHG-intensity can also enable decarbonisation and could provide certainty for industry at the same time.

For industry to be able to switch to low carbon production processes it is a requirement to have access to new types of infrastructure, for example pipelines and other transport options for CO2 and hydrogen. To ensure that the emissions from hydrogen and electricity production are low, it is essential to produce or import sufficient renewable energy. The industrial processes of the future will come with a sharp increase in electricity demand, which will require a different and expanded electricity grid. Regional, national and European policymakers must coordinate the development of such new infrastructure and must be willing to invest public money through green public investment funds.

The scale of renewable energy production that is required for the industrial transition and development of new infrastructure brings new environmental challenges and a potential dependency on other geographical areas. To soften such challenges, to make the transition easier and to reduce emissions faster, it is essential to focus on demand reduction as well.

## Reducing demand

A second and equally important strategy to decarbonise EIIs is the reduction of demand for the basic materials that EIIs produce. A narrow focus on technological solutions takes for granted that current demands for industrial basic materials will necessarily continue. Demand is not something that occurs out of thin air – various actors, including governments, together shape demand. First, demand can be reduced by using less industrial basic materials in final products, for example through design guidelines and building codes. Second, demand can be reduced by enhancing circularity. Various materials produced by EIIs are highly recyclable, such as plastics and steel. To enhance circularity, producers of final products should be regulated so that they design products in such a way that they can be better recycled. Third, overall demand for final products and activities involving high-carbon basic materials should be actively reduced, for example through consumption-based carbon taxing.

As Dutch EIIs produce mainly for export, potential Dutch policies that aim for demand reduction will at most have a marginal effect on EIIs within the Dutch border. To make demand-reducing policies more effective, they should be implemented at the European level. In addition to the necessary technology-based solutions, such an approach could help reduce emissions faster, soften other potential environmental issues and reduce potential dependency on other geographical areas. Although this report primarily focuses on Dutch EIIs, the need for the active roles of governments and for demand-reducing policies applies to other member states as well.

# Overview figure: Blockers, enablers and policy instruments for decarbonising production and demand (based on the literature)

| Category | Blocker | Enabler | Policy instruments | Implementation level |
|---|---|---|---|---|
| Contextual blockers | ▸ High level of competitiveness<br>▸ Strongly internationally oriented<br>▸ Capital-intensive properties<br>▸ Long timescales for investments<br>▸ Low profit margins | x | x | x |
| Decarbonising production | ▸ A lack of infrastructure for new technologies (CO2, hydrogen, electricity, heat) | ▸ Guidance and investments from the Government | ▸ A green public investment fund | ▸ National / Regional |
| Decarbonising production | ▸ Low or zero carbon production is possible, but more expensive. In the current market there is hardly a business case for industry | ▸ Create a market for low or zero carbon industrial materials. | ▸ A stronger national CO2 tax and ETS in combination with CBAM<br>▸ Green public procurement<br>▸ Green private purchase obligation<br>▸ CCfD based pilot projects for key technologies | ▸ National / EU |
| Decarbonising production | ▸ Electricity and non-feedstock fuels are cheap and represent only a small fraction of the costs of producers | ▸ Force producers to make energy efficiency and GHG-reducing investments | ▸ GHG-intensity standards | ▸ EU |
| Decarbonising demand | ▸ Basic industrial materials such as steel and plastics are too cheap; there is no strong incentive to minimise use | ▸ Force producers of final products and buildings to use less high-carbon basic materials | ▸ Building codes<br>▸ Design guidelines and directives | ▸ EU |
| Decarbonising demand | ▸ Current recycling options are highly limited | ▸ Force producers to design final products in such a way that allows for better recycling | ▸ Design guidelines and directives<br>▸ Extended producer responsibility | ▸ EU |
| Decarbonising demand | ▸ A strong focus on economic growth and a push for increasing production and consumption | ▸ Open a discussion about policies that aim to reduce demand for high-carbon goods and services | ▸ A consumption based carbon tax<br>▸ A tax on specific high-carbon goods and activities | ▸ National / EU |

# 1. Introduction

At the global level, the urgency to respond to climate change has starkly increased over the last couple of years. The Paris agreement in 2015 symbolised the commitment to react and is at this moment ratified by 189 parties. Energy-heavy industry is a problematic part of the global economy in terms of its contribution towards climate change. In Europe, energy-intensive industries (EIIs) accounted for around 15 per cent of all European emissions in 2015 (Wyns & Khandekar, 2019). In order to reach the objectives of the Paris agreement, the challenge of decarbonising the EIIs plays a crucial role.

Similar to trends at the global level, the urgency around climate change increased significantly in the Netherlands as well. The Government that was voted into power in 2017 emphasised the importance of a national Climate Agreement. This policy framework was agreed upon in 2019 after years of talks between various relevant actors. One of the five themes in the agreement is industry. Dutch industrial emissions account for 30,2 per cent of all national emissions (CBS, 2020). The agreement sets the target to reduce emissions from industry by 59 per cent in 2030, with 1990 as a base level. For 2050 the target is to be carbon neutral. The big question is *how* can these emission reductions in the Dutch energy-heavy industry be realised?

As the decarbonisation of heavy industry is such a crucial issue, there is a vast amount of literature available on various potential technical and policy solutions. These solutions can be divided roughly into two categories: solutions based on reducing emissions from production, and solutions based on reducing emissions from demand. Because 78,9 per cent of Dutch industrial greenhouse gas (GHG) emissions come from the chemistry, refinery and basic metals industries, this literature review is focusing on these three sectors (CBS, 2019). The purpose of this literature review is not so much to find *the* most effective policy, rather to focus on the required policy mix. Gerres and Linares (2020) emphasise rightly that individual measures will not be sufficient, and that a broader policy package has much more potential.

The transformation of Dutch EIIs will come with major changes in labour opportunities. Van Dril (2019) estimates that the overall Dutch Climate Agreement will create 39.000 to 72.000 jobs in industry and other sectors, but also that 6.000 to 11.000 jobs will be lost in the coal and oil sector. Although ensuring a just transition is essential, also in the context of Dutch EIIs, it doesn't fall within the scope of this study.

The overall aim of this literature review is to present an overview of the current knowledge about the blockers and enablers of decarbonising the Dutch refinery, chemistry and basic metals industries. This aim can be divided into two research questions:

**a.** How can the production of the Dutch chemistry, refinery and basic metals industries be decarbonised?

**b.** How can the demand of the Dutch chemistry, refinery and basic metals industries be decarbonised?

Before discussing potential technologies and policies, we first describe the Dutch basic metals, refinery and chemistry industries, followed by a brief outline of the current Dutch and European policy frameworks relevant to EIIs. Next, we outline the contextual blockers to decarbonisation, related to political economy dynamics. The continuing discussion is then structured along the two research questions: first, we focus on the options to decarbonise production and the policies that might enable these options; second, we examine the options to decarbonise demand as well as the related policy options. This report is written with the Dutch context in mind, but we briefly touch upon possible implications for other European countries as well.

# 2. Background

## 2.1 A brief description of the Dutch basic metals, refinery and chemical industries

### Basic metals industry

The basic metals industry uses iron ore and coal as the main feedstock materials for primary steel production, with coal also being used for heating processes. The by-product blast furnace gas is often used for electricity generation.

The only large-scale primary steel producer active in the Netherlands is Tata Steel IJmuiden (TSI). TSI almost covers the complete Dutch basic metals industry. In IJmuiden the first steel production facility was established in 1918. After various company transitions in recent decades, the facility in IJmuiden is currently owned by Tata, an Indian steel company and one of the biggest steel producers in the world.

In 2018, the Dutch basic metals industry emitted 7,0 Mton CO2eq, 14,3 per cent of all Dutch industrial GHG emissions (CBS, 2019). TSI tops the list of largest GHG emitters in the Netherlands with a total of 6.9 Mton CO-2eq. The Dutch EII is strongly export oriented, and the basic metals industry is no exception. Germany, Belgium, France, the UK and the US are the main importers of Dutch steel. Of all primary steel produced in the Netherlands, 85 per cent is exported.

### Refinery industry

The Dutch refinery industry is largely represented by the six refineries currently operating in the Netherlands. Some of those (Shell Pernis and BP Refinery Rotterdam) are some of the biggest refineries in the world. Refineries process crude oil to make products such as gasoline, kerosine, propane, butane and pentane. Extracting these fuels from crude oil is a highly energy-intensive process and causes a significant amount of GHGs.

The infrastructural possibilities at the port of Rotterdam made the region a perfect location for oil refineries. As such, five of the six refineries in the Netherlands are situated in the industrial region of Rotterdam. The economic benefits came at a cost of emitting 10,1 Mton in CO2eq, 20,7 per cent of Dutch industrial GHG emissions. The Dutch refinery sector exports 69 per cent of its final products (Sleen et al., 2019).

### Chemical industry

The Dutch chemical industry is diverse and produces a large variety of products, including chemical fertilisers, plastics, paint and semi-finished products. A large share of the emissions comes from producing the basic feedstock materials, such as ammonia, ethylene, methanol and propylene, mostly derived from fossil fuels. As such these industries are strongly connected to the refinery industry. The industrial facilities in Moerdijk, Terneuzen and Geleen represent some of the biggest chemical complexes in the world.

The availability of cheap natural gas from the northern part of the Netherlands facilitated the emergence of two large fertiliser production sites. Yara and OCI Nitrogen are two major fertiliser producers, and together cause 5,6 Mton of CO2eq emissions (CBS, 2019). A major challenge for the chemical industry is to replace oil and gas as both feedstock and energy sources.

In 2018 the overall chemistry sector caused 21,4 Mton of CO2eq emissions, covering 43,9 per cent of Dutch industrial emissions and 9,5 per cent of all Dutch emissions. Shell, Yara, Sabic, Dow, ExxonMobil, OCI Nitrogen, Air Products, Air Liquide and Nouryon are the major chemistry players in the Netherlands. The majority of these companies are foreign multinationals. Of the three sectors discussed in this paper, the chemistry sector is the most export oriented: 92,3 per cent of its products are for international markets.

## 2.2 Contextual blockers to decarbonisation

Since 2010, very little improvement has been realised by Dutch EIIs in terms of absolute reductions in GHG emissions. In 2010 the Dutch basic metal, refinery and chemical industries combined emitted 38,1 Mton of CO-2eq, in 2018 this was 38,5 Mton (CBS, 2019). Before looking ahead at future decarbonisation options, it is useful to examine why it is that the decarbonisation of Dutch EIIs does not seem to be happening. Various contextual blockers together form part of the explanation.

The EII is characterised as highly competitive and strongly internationally configured. The Dutch basic metals, refinery and chemical industries import most of their raw materials and export the majority of their output. The related production facilities represent only one part of a larger global value chain. Most of the products that are made by these industries are not final products, but processed raw materials. The chemistry industry produces basic chemical materials such as ethylene, propylene and methanol. The basic metals industry transforms coal and iron ore into steel, which later on in the value chain is turned into useful products, for example for the construction and automotive industries. The refinery sector produces not only gasoline and kerosine, but also other oil-based materials that serve as feedstock for the chemical industry. Because of the dependency on international trade, the basic metals, refinery and chemical industries are strongly dependent on global market prices. These dynamics mean that profit margins are generally low. This makes it challenging for industrial producers to make the required capital-intensive investments in low-carbon technologies.

As will be discussed later on in this paper, technically there are major opportunities for decarbonising EIIs. CC(U)S, hydrogen and electrification represent some of the most promising technological developments. Some of these technologies can already be applied, but lead to higher production costs. For example, low to zero carbon steel, produced by using hydrogen, would be about 20 per cent more expensive than conventionally produced steel (Hermwille, 2019). As long as carbon is insufficiently priced, and a market for decarbonised steel hardly exists, conventional steel production remains the only economically viable option for producers. A higher price will simply translate in being outcompeted by producers that can produce for a lower price. Putting a high enough price on carbon, combined with a carbon border adjustment mechanism (CBAM) to reduce the level of competition from foreign high-carbon producers, and the creation of a market for low-carbon industrial output, represent some of the major enablers for decarbonising EIIs.

The current overproduction of some sectors forms a complicating factor. Because countries rather avoid being dependent on others, industrial facilities are often regarded as a strategic asset (Bataille, 2020). This dynamic is one of the drivers of overcapacity in some sectors, forming an additional pressure on global market prices and ensuring low profit margins.

The capital-intensive nature of EIIs forms a last blocker to decarbonisation. Production plants operate for a period between 25 and 50 years, and require large investments. The use of new technologies generally requires replacement or retrofitting of existing facilities. The long timescales and high level of capital that is involved lead to high risks and generally result in conservative strategies. The current uncertainty in terms of technology, markets and policies makes industrial producers hesitant to invest.

The high level of competitiveness, the capital-intensive properties and the long timescales for existing facilities create strong lock-in effects for conventional production methods. These dynamics combined form a serious blocker to EIIs' decarbonisation.

## 2.3 A brief overview of the current policy framework in place

Dutch National policy

In 2019, after a long process of talks with experts, industry representatives and NGOs, the Dutch Government presented a comprehensive policy package aiming to reduce industrial emissions by 59 per cent in 2030, taking 1990 as a benchmark year. The policy document declares that a combination of process efficiency, CC(U)S, electrification, energy savings, hydrogen and enhanced circularity together can enable the desired emission reduction. To promote the required technological developments, several policies were announced, among which a national carbon tax for EIIs and a subsidy program for CO2 reducing technologies.

The Government declared that the carbon tax is strongly based on the EU's Emissions Trading System (ETS) and aims to give a stronger incentive to EIIs to decarbonise (Ministry of Economic Affairs and Climate, 2019). The tax will be functional in 2021 and gradually increase up to a level of 125–150 €/ton in 2030. The tax will not apply to all industrial emissions, but only those emissions that are to be reduced according to a set target. Just as with the ETS, producers receive exemptions when they produce with relatively little emissions, according to preset benchmarks. Because of the COVID-19 outbreak the Ministry of Economic Affairs and Climate Policy decided that tax will be weakened in the first few years. In practice this means that most producers don't have to pay until 2024–2025.

The SDE++ represents the most relevant subsidy program for CO2-reducing technologies. The subsidy was initially intended to stimulate renewable energy development, but the Government decided to broaden the scope and include CO2-reducing industrial technologies as well. In 2020, a total amount of 5 billion euros was made available to support projects for up to fifteen years. The allocation of the subsidies is based on the subsidy intensity of several technologies, expressed in €/avoided ton CO2. In this way the Government aims to achieve the most reduction at the lowest cost.

Besides taxes and subsidies, the Dutch Government also aims to reduce industrial emissions through agreements on energy-saving investments. Following the so called MJA3/MEE covenant, EIIs are obligated to make all energy-saving investments that are cost effective within five years. However, Siemons et al. (2020) point out that this covenant is not functioning well as there is a lot of unused potential in terms of energy-saving measures. If the agreements were to be fully kept to, an additional 3 Mton reduction could be within reach in only a few years.

All in all it is clear that efforts are being made to achieve significant emission reductions within the Dutch industrial sector. The Climate Agreement of 2019 can be seen as the kick of a new phase in Dutch climate policy. It is too early to draw strong conclusions about the policy package. However, the strong focus on cost efficiency, which is present throughout the whole package, seems to be a threat for reaching climate objectives.

EU policy

Dutch EIIs are not only affected by national policies, European industrial and climate policy strongly influences Dutch EIIs as well. The options for European policymakers are somewhat different when compared to national policymakers. The European Commission (EC) is not mandated to implement taxes, so a European carbon tax is currently not an option. Still, through norm setting, cap and trade systems and subsidy instruments, the EC plays an important role in decarbonising Dutch EIIs. In the following section we explore the ETS, the Industrial Emissions Directive 2010/75/EU and the most relevant subsidy programs.

The most influential European policy instrument relevant to Dutch EIIs is ETS. Under this system around 11.000 European producers – among which 450 are based in the Netherlands – must have emission allowances in order to emit GHG. Because each year fewer allowances are available, the combined emissions should reduce. In phase 3, between 2013 and 2020, each year 1,74 per cent fewer allowances were available. After 2021 (phase 4) the number of allowances will reduce by 2,2 per cent each year. Initially the cap should go to zero or at least to a very low level, to reach the EUs overall target of becoming climate neutral by 2050. A minimum of industrial emissions might still be possible when negative emissions become a viable option.

Allowances can be obtained in three ways: (1) through free allocation, (2) by auctioning, or (3) by purchasing from another company. For the free allocation of allowances the European Commission distinguishes between sectors that are sensitive to carbon leakage, and sectors that are not. EIIs such as the ones considered in this paper are regarded as sensitive to carbon leakage. This doesn't mean that each company that produces basic metals will get free allowances. Those basic metals producers that produce with relatively low emissions, receive more free allowances. To quantify the various producers in Europe the EC uses several sector specific benchmarks.

ETS is regarded as an effective instrument, but it has its downsides as well. The European Environmental Agency (2019) estimates that that ETS companies are on track to reach a 36 per cent emission reduction by 2030. Although is significantly lower than the target of 43 per cent, it is still substantial. Vollebergh and Brink (2020) state that allowance banking has taken the target out of reach. In earlier phases of the ETS, companies were rewarded too many allowances. Since the allowances remain valid indefinitely, they slow down emission reduction. Vollebergh and Brink also observe that emission are outsourced to other regions, leading to increased consumption-based footprints. Not all emission reduction is achieved by producing with lower emissions; some of the reduction simply reflects a shift of production and emissions to other regions. A carbon border adjustment mechanism (CBAM) could potentially halt this tendency, by putting a carbon price on imported goods.

Besides a cap and trade system for emissions, European EIIs are also affected by the Energy Efficiency Directive (Directive 2012/27/EU) that was adopted in 2012 and updated in 2018. The most recent objective prescribes a European energy efficiency target of 32,5 per cent. By increasing energy efficiency, the aim is to do the same or more, but with less energy. This doesn't put a pressure on economic growth and still reduces energy use and emissions. Following the directive, Dutch industrial companies must report on their energy use and energy-saving options to the Netherlands Enterprise Agency (RVO).

Through the ETS Innovation fund and the Horizon Europe program, the EC provides subsidies for green industrial technologies. The ETS Innovation fund is financed by the revenues of allowance auctioning, which represents an overall budget of around 10 billion euros between 2020 and 2030. The Horizon Europe program is the overall research and innovation fund and covers 80,9 billion euros for the period 2021–2027. EIIs can also apply to this fund. In the previous phase of the program Tata Steel IJmuiden received 7,4 million euros for developing HIsarna, a cleaner alternative steel production method.

Within its means, the EC provides a comprehensive policy mix aiming to reduce industrial emissions. The existing instruments already have a positive effect, but might also serve as a basis for stronger policies. Even though phase four comes with a sharper reduction path, ETS could be enforced even more by allocating fewer free allowances and implementing a CBAM. The Industrial Emissions Directive might be expanded for stronger norm setting for industrial emissions. The existing subsidy instruments could be expanded and targeted more specifically towards technologies such as green hydrogen (hydrogen produced with renewable energy) and electrification.

# 3. Discussion: Strategies for decarbonisation

A reduction in GHG emissions from the basic metals, refinery and chemical industries can be achieved in various ways. A distinction can be made between strategies that decarbonise production and strategies that decarbonise demand. The former achieves carbon reduction by emitting less carbon per given amount of output, the latter by reducing the amount of output itself. The following sections will be divided according to this distinction. First we will discuss the major options that are considered regarding decarbonising production. Second we examine options that rely on decarbonisation from demand. For each section we discuss related policy options as well.

## 3.1 Decarbonising production

By using different energy sources and feedstocks – or through alternative production processes – steel, refinery products and chemical products can be produced with lower GHG emissions. The development of such techniques heavily relies on innovation and technology. Electrification, CC(U)S and hydrogen represent some examples of promising technological pathways to decarbonise production. Engineers have demonstrated the functioning and carbon-reduction potential of these technologies, but often the higher production costs form a major blocker to scaling up. In addition, new production methods require new types of infrastructure, such as increased capacity of electricity grids, and pipelines for CO2 and hydrogen. Before looking at potential ways to overcome such blockers, we will first briefly outline the features, advantages and disadvantages of hydrogen, electrification and CC(U)S, as well as their relevance for the Dutch basic metals, refinery and chemical industries.

### Hydrogen

The energy-carrying capacity of hydrogen is regarded as a valuable property, which in certain contexts can replace other energy carriers such as coal, oil and gas (Parra et al., 2019). Hydrogen can be applied in many different ways and is highly relevant to the basic metals, refinery and chemical industries. For example, by using hydrogen and iron ore pellets, crude steel can be made without fossil fuels. In September 2020, the world's first fossil-free steel facility was opened in Sweden as part of the Hybrit project (Hybrit, 2020). However, for existing facilities such as TSI it is a major challenge to retrofit existing plants with hydrogen-based production options (Bataille, 2019).

A second appliance of hydrogen is in the fertiliser industry, which represents a significant part of the Dutch chemical industry. Yara and OCI Nitrogen produce various types of fertiliser, with natural gas as a core feedstock. Natural gas, together with nitrogen, is transformed into ammonia. This process causes a significant amount of CO2 emissions. The fertiliser production facilities of Yara and OCI Nitrogen cover around 7 per cent of all natural gas use in the Netherlands, about the same amount as all Dutch households combined (Kerkhoven, 2017). Hydrogen can replace natural gas; in this way the use of natural gas and the related CO2 emissions can be reduced significantly. As the Dutch chemical industry is highly diverse, there are many more ways in which hydrogen can contribute to decarbonisation.

A major share of the processes in refineries can be described in a simplistic way as heating crude oil to transform the raw material into usable fossil products. Hydrogen as an energy carrier can be used for this heating process, replacing current fossil-based fuels. However, be aware that using hydrogen can only decarbonise the production of refinery processes: the final products (gasoline, kerosine and other fossil based products) still contain carbon. Given that in the short term there is a limited amount of hydrogen available, certain applications might be favoured over others. Using hydrogen to produce gasoline and diesel might not be the most strategic use.

But clearly, hydrogen is a highly relevant technological option with strong decarbonisation potential. Changing production methods represents an important challenge, but the production of hydrogen itself might form the most significant challenge. Hydrogen can be produced through the electrolysis of water. By using electricity, water (H2O) can be split into hydrogen (H2) and oxygen (O2). For hydrogen to have the most severe decarbonisation impact, the energy source for the electrolysis process must be renewable. Hydrogen can also be made out of natural gas, as is happening in conventional fertiliser production. Shifting industrial production towards the use of renewable-energy-based hydrogen thus implies a significant increase in required renewable energy. In the case of the Netherlands, this will most likely be energy from offshore wind. The adoption of hydrogen by EIIs will result in a severe increase in energy demand. According to the current hydrogen plans of the Dutch Ministry of Economic Affairs and Climate Policy, the overall electricity capacity needs to increase by 30 per cent by 2030 (Wiebes, 2020). Acknowledging that the North Sea has a finite amount of space for offshore wind parks signals that the use of hydrogen has its challenges and limitations. It is likely that imported hydrogen will be required to meet future demand from Dutch EIIs. But there are also concerns in this area: the reshaping of the landscape of global energy trade, partly caused by the emergence of an international market for hydrogen, might come with serious geopolitical issues (Van de Graaf et al., 2020).

### Electrification

Electricity can be used directly for heating processes and for enabling chemical reactions (Stokking, 2020). Such direct electrification options can be applied in several industrial processes within the basic metals, refinery and chemical industries. For heating processes, electric boilers and heat pumps are some examples of applications (Den Ouden et al., 2017). A number of scholars regard indirect electrification through hydrogen as falling under the term electrification (see Lechtenböhmer et al., 2016 and Schiffer & Manthiram, 2017). Because of the importance of hydrogen, we regard it as a separate category in this review. When referring to electrification, we only consider direct electrification.

When direct electrification processes are widely adopted, especially in combination with the production and use of hydrogen, electricity capacity needs to be expanded significantly. Lechtenböhmer et al. (2016) examined the possible increase in electricity demand if all European EIIs completely electrify their production, including a share of their feedstock. The outcome is a projected increase in electricity demand of 1713TW, compared to a current total European electricity use of 2780TW, roughly a 60 per cent increase. Such numbers point out the scope of the transition that is required to facilitate such technological change. Such a stark increase in demand for electricity will put serious challenges on renewable energy production and the development of required infrastructure. Moreau et al. (2019) show that current proven reserves of various metals are insufficient to build the infrastructure that is expected to be required in 2050. What is more, the amount of raw materials that will be needed to set up such an infrastructure for renewable energy will come with social and environmental costs that need to be considered (Phadke, 2018; Sovacool, 2019).

### Carbon Capture, Utilisation and Storage (CC(U)S)

Various forms and terminologies exist around technologies that capture, sequester, utilise and/or use carbon (Herzog & Golomb, 2004). In this paper we adopt the term Carbon Capture, Utilisation and Storage (CC(U)S) because it is most relevant to EIIs, though some sources do not discuss utilisation extensively. The carbon emitted by EIIs can be captured, and afterwards either stored or utilised as feedstock. Herzog and Golomb define the capturing and storage of carbon as ‘the removal of CO2 directly from industrial or utility plants and subsequently storing it in secure reservoirs’ (p.1). However, some of the CO2 might not need to be stored, but can be utilised as feedstock for chemical processes such as the production of plastics and fertiliser (Al-Mamoori et al., 2017).

Technologies that enable the utilisation and storage of carbon are regarded as crucially important for reducing global carbon emissions (Leeson et al., 2017). In its scenarios for staying under 2 or 1,5 degrees, the IPCC sees an important role for CC(U)S (IPCC, 2018). However, CC(U)S is typically seen as a bridging technology (Selma et al., 2014). The options for storing carbon are limited, so at most CC(U)S is a temporary solution. But even though CC(U)S plays such a central role in future pathways to decarbonise EIIs, this technology is controversial for good reasons.

High levels of uncertainty exist around the economic competitiveness, environmental and safety impacts, and social acceptance of CC(U)S (Kuckshinrichs & Hake, 2015). First, the level of economic competitiveness relies on required technological developments, but is also strongly influenced by the market price of the EU ETS. When the price for emission permits goes up, CC(U)S becomes relatively more cost efficient. But the uncertainties around technological developments and carbon markets are unfavourable conditions for companies considering investment pledges. Second, various environmental and safety risks should be taken into account, most notably the risk of leakage from storage and the related governance and accountability issues (Leiss & Krewski, 2019). Third, the described uncertainties and environmental risks have led to scepticism in public debate and a hesitancy towards social acceptance (Selma et al., 2014). For CC(U)S to become a viable technology, it is crucial to gain sufficient social acceptance. Full transparency and public understanding of reliable risk assessments play a key role (Leiss & Larkin, 2019). The presence of multiple uncertainties forms important challenges for CC(U)S in becoming a truly viable part of the solution for decarbonising EIIs.

In the Dutch context, CC(U)S is also regarded as an essential technology for the transition of EIIs (Bracht & Braun, 2018). Dutch EIIs, NGO’s and the Ministry of Economic Affairs and Climate Policy completed a joint fact-finding investigation on CC(U)S as part of the process leading up to the national Climate Agreement of 2019. The stakeholders agreed to examine options for capturing carbon, and storing it under the sea, not under land. Empty gas fields in the North Sea are considered the most viable options. CC(U)S is a relevant option for all major three sectors considered in this paper: the basic metal, refinery, and chemical industries. The costs for CC(U)S applied to these sectors in the Netherlands are estimated at 20–85 €/tonne CO2 (Warmerhoven et al., 2018). Several major CC(U)S projects, which include Porthos, Aramis and Athos, are already in development. Various actors are involved, among them both publicly owned companies such as GasUnie and EBN, but also industrial players such as Tata Steel IJmuiden. The Dutch Government sees CC(U)S as an important technology and provides subsidies through the broader decarbonisation subsidy SDE++. To make sure that CC(U)S won’t become too dominant, the subsidy is designed in a such a way that no more than half of the reduction target will come from CC(U)S subsidies.

Despite the many risks and uncertainties, it seems that CC(U)S as a way to decarbonise Dutch EIIs is well on its way to become a part of the solution.

## 3.2 Policies to decarbonise production

In order to facilitate potential of technologies, such as hydrogen, electrification and CC(U)S, a range of policy directions are proposed in the scientific literature. The following section will give a brief overview of the most relevant options.

### Infrastructure development

The industrial shift towards new production methods with different energy and feedstock sources requires different sorts of infrastructure, most notably for CO2 and hydrogen. In addition, the capacity of the electricity grid needs to be vastly altered and expanded. The existing natural gas infrastructure in the Netherlands might be used and transformed into hydrogen infrastructure (Duvoort, 2019). Typically such major infrastructure is governed and managed by public–private partnerships. Accordingly, the literature points to national governments as having the responsibility to coordinate the development of the infrastructure needed for the decarbonisation of EIIs (Bataille, 2019; Bataille, 2020; Batool & Wetzels, 2019; Vogl et al., 2020). Currently, it seems that the lack of required infrastructure for hydrogen and CO2 forms a strong blocker to industry. A more active role by Dutch public authorities – for example by setting up a green public investment fund – could take away some of the uncertainties for producers and form an important enabler. Recently the Dutch Greens proposed such a fund as an alternative to the Dutch Groeifonds (growth fund) (GroenLinks, 2020).

### R&D expenditure

A second important policy area covers the promotion of R&D and the funding of key demonstration pilot projects. Typically R&D investments are lower in EIIs when compared to other sectors, and mainly targeted at marginal process improvements, instead of fundamental changes (Åhman et al., 2017). To alter the focus of R&D spending, it is important to base innovation systems on predetermined objectives, or ‘missions’ (Hekkert et al., 2020; Mazzucato, 2018). While R&D and mission-oriented innovation are considered key, scholars point out that the step towards commercialisation might be even more important (Bataille, 2019). Although Dutch EIIs can access a mission-oriented subsidy program (MOOI), the most substantial part of subsidies is allocated based on cost efficiency. The Dutch Government should take a more active role here and steer subsidies not only towards the solutions that are cost effective in the short term, but also to those solutions that have the potential to achieve more transformative emission reductions in the long term.

### Carbon pricing

Several low-carbon production technologies exist, but higher production costs block wider adoption. Policies that create a market for such low or zero carbon industrial production are crucial (Åhman et al., 2017). When policymakers increase the price of carbon emissions, low-carbon production methods automatically become relatively more favourable. Both at the national and European level, carbon pricing is already part of the policy mix. The EC puts a price on carbon by using a cap and trade system through the ETS. The national CO2 tax for industry must give an extra incentive to Dutch EIIs to decarbonise.

The higher the price on carbon, the stronger the incentive to decarbonise, but also the greater the risk that producers might decide to shift their production to another area. To avoid carbon leakage, both the ETS as well as the national industrial CO2 tax protect those industries that are sensitive to carbon leakage by freely allocating emission permits. On the one hand policymakers are afraid to harm industry too much, on the other hand environmental NGOs argue that free allowances take away much of the incentive to decarbonise.

The Dutch Environmental Assessment Agency points out that how the tax revenues are used is crucial (Vollebergh et al., 2019). When the revenues flow back to EIIs in the form of subsidies for CO2-reducing technologies, then the risks of carbon leakage are very small –and this is the case with the national CO2 tax. Nevertheless, a stronger ETS remains favourable over national measures, especially in combination with a CBAM.

### Project-based carbon contracts for difference (CCfD)

Policymakers can adopt project-based carbon contracts for difference (CCfD) to push low and zero carbon industrial products on the market (Gerres & Linares, 2020). CCfDs subsidise low and zero carbon production; based on a long-term contract, producers are paid for avoided carbon emissions. The amount paid for avoided emissions depends on the ETS price. For example, when a carbon price of €80 is agreed upon and when the ETS price is €25, then the producer receives €55 per tonne of avoided emissions. In this way a market with a stable and high carbon price is simulated, removing uncertainty for investors and producers. Sartor and Bataille (2020) argue that CCfDs are economically efficient, compatible with EU and WTO trade regulations and complementary to other relevant policy options.

The Dutch SDE++ can be seen as a type of CCfD instrument. What makes the SDE++ special is that CCfDs are allocated to those projects that can reduce emissions at the lowest cost. From an economic point of view this is desirable, but the cheapest reduction options in the short term might not be the most desired options for the climate in the long term. NGOs have rightfully criticised the SDE++ because it of its technology neutrality (Natuur & Milieu et al., 2020). By only focusing on short term costs, the subsidy does not take sufficiently into account other important factors. For example, CC(U)S is currently cheaper than electrification and green hydrogen options. NGOs are afraid that CC(U)S will become too dominant in the technology mix and will slow down the development of other more desired technologies.

With the current SDE++, the Dutch Government leaves technological choices up to the market. A more active role for the Government, in which CCfDs are allocated to specific projects, for example for the production of green steel or zero carbon fertilisers, would be an important addition to the current policy mix.

Energy efficiency standards

Energy standards for electric machines have been proven to be effective and efficient ways to reduce energy use and emissions (Molina et al., 2016). Although improvements have been made in the energy efficiency of Dutch EIIs, there is still plenty room for improvement. A recent study by Siemons et al. (2020) found that 3 Mton of GHG emission reductions can be achieved through energy-saving investments that have payback time of no more than five years, and are based on proven technologies, without the need for new infrastructure. The study points to stronger enforcement regulations being one of the potential solutions. An important reason for producers to not make these investments is that the cost of electricity and non-feedstock fuel is a relatively small part of the cost breakdown for sectors like the refinery and chemistry industries. Rissman et al. (2020) suggest that producers might prefer to reduce the largest costs, such as input materials and labour, and thus focus on maximising absolute cost reductions, instead of smaller but earlier payback investments.

Because businesses do not seem to make the required energy-saving investments voluntarily, even if they have a payback time of less than five years, GHG-intensity-based standards might be needed. Rissman et al. argue that the following applications might be good targets for standards: steam and hot-water systems, driers, water treatment systems, chilled water systems and cooling towers. Such standards should be implemented at the European level to maintain a level playing field as much as possible. For example, the European Industrial Emissions Directive could be expanded with such GHG-intensity-based standards.

Green procurement obligations

Procurement obligations can apply either to public or private entities. The idea of public procurement is widely mentioned in the literature (Cheng et al., 2018; Krupnick, 2020; Rainville, 2017). Governments procurements of industrial materials accounts for around 12 per cent in OECD countries (UNEP, 2017). Especially for larger countries, implementing a policy that obliges government authorities to purchase low-carbon materials such as steel for infrastructure projects, can be a way to create a market for low-carbon materials. However, as the Netherlands is fairly small, and a majority of the produce of EIIs is exported, it is questionable whether such an approach would be effective when applied to the national level. On the contrary, a European-wide public procurement policy for green industrial materials might be a strong enabler to decarbonise EIIs.

Sustainable procurement obligations are less known in the domain of the private sector. But if applied at the European level, private procurement obligations have a strong decarbonisation potential. For example, in the case of steel production, a procurement obligation for green steel applied to the European automotive industry might be a way to create a market for green steel. The percentage of required green steel can be set at a low level at first, but should increase over time. Because the cost of steel is a relatively small part of the total cost of car manufacturing, it would most likely only lead to a marginal increase in price for the consumer. According to Rootzén and Johnsson (2016) the increase in the retail price of a mid-sized passenger car produced with green steel would be smaller than 1 per cent. Similar procurement obligations for the private sector applying to other high-carbon materials such as ethylene, propylene and methanol might be strong enablers as well.

All in all, in order to optimise the decarbonisation potential of emerging technologies, a combination of infrastructure development, carbon pricing, mission-oriented innovation strategies, energy efficiency standards, green procurement obligations and other policies that create a market for low and zero carbon industrial products seem crucial in reducing emissions from production.

## 3.3 Decarbonising through demand reduction

The current and future demand of industrially produced materials such as steel and plastics depends on several dynamics, including price, availability, the design of products, recycling efforts and the very policies that shape these dynamics. But the demand for industrial materials is not just a natural phenomenon, it is the result of the actions and decisions of a range of actors. To use the words by Rinkinen et al. (2020) 'demand is made, not simply met' (p.8). Policymakers play an important role here. In this next section we will distinguish between three main ways to reduce demand: (1) increased material efficiency in use, (2) optimised recycling and circularity, and (3) reduced usage and consumption levels. Afterwards we briefly discuss the most relevant policy options to enable demand reduction.

Material efficiency

Ultimately, the production of industrial materials is often only the first step in a long production chain. Therefore, reducing the amount of these materials in final products leads to a lower demand for such basic materials. As a significant share of steel is used for buildings, this application provides good examples. One way to reduce the use of steel in construction is by replacing it with wood. Gustavsson et al. (2006) show that increased use of wood can reduce the amount of concrete and steel that is required in the construction of buildings. Another way to decrease the use of steel in construction is by using multiple sizes of steel beams. For high buildings, often just one beam size is used for the whole building. While in practice, the beams higher up in the building need to carry much less weight and can thus be smaller. By using multiple beam sizes the total amount of required steel can be drastically reduced (Allwood et al., 2012; Bataille, 2019). The current low steel price related to the global overcapacity of steel production is part of the problem here.

As plastics are relatively cheap, similar dynamics are at play. For refinery products, material efficiency seems a less relevant strategy, mostly because much of the produce is final products.

Recycling and circularity

Steel and plastics are two product categories that are highly recyclable. Currently around 85 per cent of all end-of-life steel is recycled (Broadbent, 2016). Typically, when using the basic oxygen furnace (BOF) method, as used at Tata's steel production facilities in IJmuiden, 10 to 30 per cent scrap iron is used as input. Still, at the global level, 15 per cent of end-of-life steel is wasted. Although plastics are also recyclable, the recycling rate is much lower. In Europe around 70 per cent of plastics end up in landfills or are burnt for energy production (Plastics Europe, 2017). In terms of plastics recycling there seems to be a lot of potential.

A key challenge for recycling is the process of sorting, which requires a lot of time and energy (Garcia & Robertson, 2017). The wide variety of plastic types that are used is a problematic factor. The bulk of plastics needs to be sorted by type before it can be recycled. In addition, many products are designed in such a way that makes it nearly impossible to take apart the different materials when the product is disposed of. In the case of steel, copper contamination forms a problem. When scrap iron contains too much copper, recycling is not possible anymore, or the steel will be of lower quality (Daehn et al., 2017). Policymakers have a task here to enhance recycling options, through norm setting, requirements for product design and by implementing producer end-of-life responsibility.

Reduce use and consumption levels

Some scholars argue that efficiency gains will nearly always be outcompeted by increased consumption levels, also referred to as the rebound effect (Magee & Devezas, 2016; Schneider, 2008). To decarbonise consumption, Lorek and Fuchs (2013) argue, more focus should be on the levels and patterns of consumption, instead of focusing on improving efficiency. For example, car sharing platforms could potentially reduce car ownership (Zhou et al., 2020). Such a shift from ownership to usage might reduce the demand for steel and plastics, as fewer vehicles are required.

The increasing size of floor space per person forms another relevant example. Most OECD countries have seen the average floor space increase over the last decades (Serrano et al., 2017). Larger living spaces require more materials, including steel, and in addition require more energy for heating. Policies that aim to reduce the average floor space can have a significant impact on material and energy use. But the current 'more-is-better' paradigm and the continued focus on economic growth leave little room for policies that aim to reduce usage and consumption levels (Lorek & Spangenberg, 2014).

## 3.4 Policies to reduce demand

Material efficient design standards, guidelines and building codes

More efficient use of industrial materials can be achieved through policy instruments such as standards, design guidelines, and building and infrastructure codes (Allwood et al., 2012; Wyns et al., 2019). Building codes could ensure that the amount of steel used in construction is reduced. Another example of an effective standard is the European norm for car manufacturers. By setting a standard for the maximum amount of gCO2/km of the average car sold by a manufacturer, car makers are forced to sell more fuel-efficient cars. Which in the end leads to a reduction in the demand for diesel and gasoline, two major output products from the refinery industry. Similar policies that regulate the use of industrial materials in final products could be applied in other domains, and contribute to demand reduction through increased material efficiency. For example, restrictions on the use of plastics in final products could help reduce demand for basic chemical materials such as propylene.

### Standards, guidelines and building codes that optimise recycling options

To enhance recycling, standards play an important role as well. Currently many products are designed in ways that make recycling nearly impossible. Often because materials are too much interwoven. Design standards that force producers to design products in such a way that materials can be sorted and recycled at the end-of-life stage can reduce the demand for new raw materials as feedstock (Enkvist et al., 2018). The existing EU Ecodesign Directive is a good example. Extended producer responsibility is another way to increase recycling rates (Filho et al., 2019). Currently producers are hardly responsible for their products once they are disposed of by the consumer. Extending producers' responsibility to include recycling and waste treatment might incentivise producers to design products differently. This could be stimulated by introducing a materials passport, which contains information about the quantitative and qualitative properties of the materials used in a product or building (Honic et al., 2019). Policies that enhance recycling and foster circularity, such as design standards and extended producer responsibility, can reduce the demand for new industrial materials. Moreover, if such standards are applied not only to European producers, but also to imported goods, the climate gains could go even beyond the European border. As the EU is the world's largest single market, it is a highly important market also for non-European producers.

### Policies that aim for a reduced demand of final products

So far the demand-reduction policy options mentioned are all based on efficiency improvements in one way or another, either through more efficient use of materials in new products, or through better making use of used materials instead of wasting them. All the above options take for granted the demand for final products, based on our current lifestyles that assume certain levels of comfort and convenience. Reducing final demand is, unfortunately, hardly considered as an option in the literature in decarbonising EIIs. Allwood et al. (2012) state this as follows: 'The fall-back option that no policymaker would ever condone, except in times of war, is to reduce final demand' (p.5). Allwood et al. add that we actually could be living with less stuff. Policies that aim to reduce the average floor space, that aim for a reduction in vehicle ownership or discourage the consumption of certain high-carbon consumption goods are hardly considered in the policy arena. Several issues play a role here. A possible reason for this could be that policies that restrict peoples' lifestyles might not be very popular among voters. Nevertheless, greens should keep pushing for such policies as they embody a serious enabler to reduce demand for energy-intensive basic materials.

In general, policies that aim to reduce demand for carbon-intensive industrial materials face two major challenges. At first, the international characteristics of the industrial sectors discussed in this paper require demand-reducing policies at the international level. The majority of the output is for foreign markets, so reducing domestic demand in the Netherlands will at most have a marginal impact on Dutch industrial emissions. Second, design standards and extended producer responsibility require an international approach. When only Dutch producers are required to meet certain standards, they might simply be outcompeted by foreign producers that are free from such standards. At last, policies aiming to reduce demand are likely to face challenges because they are in direct conflict with the objective of economic growth (Lorek & Spangenberg, 2014). For demand-reducing policies to become a more viable option, it might be needed to question and rethink the unlimited push for economic growth.

# 4. Conclusion

This literature review has examined the blockers and enablers for decarbonising the Dutch chemistry, refinery and basic metals industries. Strategies to decarbonise production as well as those aiming to decarbonise demand both have considerable potential to contribute towards achieving a Dutch zero carbon EII.

Hydrogen, electrification and CC(U)S form three major technological opportunities which potentially allow for significant emission reductions. The major reason why these technologies are not yet adopted more widely is that they are more expensive compared to conventional production methods. Currently, green industrial production is not able to compete with brown industrial production. To alter the market in favour of green production and to reach climate objectives, a range of effective policy options exist for the Dutch government. Some of the relevant policy options to decarbonise production are a stronger CO2 tax; the development of infrastructure for CO2, hydrogen, heat and electricity; mission-oriented innovation policies; and subsidies for pilot projects through CCfDs.

It is questionable whether decarbonising production only will reduce emissions fast enough. What is more, low-carbon technology based-solutions come with new challenges, such as an unprecedented increase in electricity demand, with consequences for metal extraction, related social impacts and local spatial issues. Moreover, such an energy transition might also reshape geopolitical relations, especially if, for example, hydrogen becomes the new dominant energy carrier (Van de Graaf et al., 2020). The current policy focus seems to be primarily on technological options. To reduce emissions faster, to soften other potential environmental issues and to reduce potential dependency on other geographical areas it is crucial to give more priority to demand-reducing policies. Demand for steel, plastics, refinery products and other basic materials can be reduced through standards, taxation, design guidelines, building codes and extended producer responsibility. Such policies will be much more effective when applied at the European level.

The findings of this study apply primarily to Dutch EIIs, but as EIIs in other European countries face similar challenges, the relevance of this report goes beyond the Dutch border. Any European government that aims to decarbonise its EII must take an active role, must be willing to take risks and must steer its industry in the right direction. However, the specific outcomes of this report cannot be applied simplistically to other contexts. Geographical and contextual circumstances mean that each country, sector and industrial cluster requires a specific policy approach.

All in all, realising the severity of the challenge of decarbonising EIIs, it is clear that a comprehensive policy package is required, one which focuses on both decarbonising production and reducing demand, and is guided by strong international cooperation.

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