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Towards a Flemish Industrial Low-carbon Transition Framework

Exploratory Report to prepare a Flemish Industrial Transition Framework for a Low-Carbon Economy

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Authors:

Tomas Wyns
Gauri Khandekar
Matilda Axelson
Isobel Robson

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Members of the Advisory Committee

The advisory committee to this study consisted of the following members:

Non-governmental members:
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Ellen Vanassche (Voka)
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Dries Maes (Departement EWI)
Joris Recko (Vlaams Energie-agentschap)
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1 EXECUTIVE SUMMARY / MANAGEMENTSAMENVATTING

1.1 ENGLISH VERSION

Goal of this study

In 2011 the European Commission published a roadmap for moving towards a competitive low-carbon economy in 2050. This EU roadmap sets out a cost-effective trajectory towards an 80% greenhouse gas (GHG) reduction by 2050. The European Commission is currently preparing an update of this roadmap to match the increased ambition level of the Paris agreement, under which parties have committed to limit the global increase in average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5° C above pre-industrial levels. Europe is therefore, facing an unknown transition to a low-carbon and sustainable economy in a relative short time frame.

The Flemish government supports the European long-term objective to reduce GHG emissions by at least 80% to 95% by 2050 (compared to 1990 levels) with interim objectives set for 2020 and 2030, and has approved on May 19th 2017 the "Vlaamse energievisie" which documents the vision of Flanders on a carbon-neutral and sustainable energy system.

It is obvious that industry will be a part of and play an important role during this transition. New technologies, products, raw materials and production processes will be needed. One of the actions in the "Vlaamse energievisie" was to investigate the possibility of developing sectoral roadmaps. Therefore, this study investigates low-carbon roadmaps developed across Europe as well as the added value of additional roadmaps. These sectoral roadmaps can be a useful instrument and guidance towards a low-carbon production and products pathway.

This report profiles Flemish energy intensive industries, in the context of the transition to a low-carbon economy, through the analysis of relevant data, studies and technology roadmaps. The goal of this report was to utilise information and input from relevant stakeholders in order to investigate the added value of developing future industrial low-carbon visions for Flanders. It also sought, with an optimal contribution by industry, to put forth a proposal on the possible scope and blueprint of a future facilitative framework towards a Flemish low-carbon economy taking into account the interactions and possible synergies between energy intensive industries and the rest of the economy.

Scope and Methodology

The scope of the study covers the energy intensive industries in Flanders. In Flanders the energy intensive sectors are refining, chemicals (including rubber and plastics), iron and steel, food and beverages, non-ferrous metals, ceramics, pulp and paper, textiles and wood products. In practice, the selection of the sectors coincides with the scope of industrial installations covered by the EU Emissions Trading System (ETS). The data presented in this report seeks to follow this sector scope as closely as possible (e.g. through the use of emissions data reported under the EU ETS or by aggregating data at NACE 2 level).

The project was executed between February and November 2018 and consisted of three phases:

Phase 1:

First, a detailed profiling of the Flemish energy intensive industries, including a comparison with four key neighbouring European countries - Germany, France, the Netherlands and the UK - was carried out through a literature study. This included sector specific data and time series on GHG emissions and energy use but also socio-economic data such as gross value added (GVA), employment and investments. For a selection of important energy intensive industry products, a brief analysis of trade flows was conducted. Using this information and additional literature, a brief SWOT analysis was carried out for the Flemish energy intensive industries in the context of moving towards a low-carbon economy. Furthermore, recent Flemish studies or research projects, relevant in the context of moving to a low-carbon industry, are presented. Finally, a short overview of Flemish strategies and policies that link to industrial decarbonisation and the circular economy was developed.

The second part of the analytical work compared the Flemish (energy intensives) industrial profile with those of the above-mentioned neighbouring countries and explored connections between Flemish industry and neighbouring industrial clusters.

This was followed by an analysis of low-carbon (European, global, regional and cluster) roadmaps focussing on energy intensive industries and published since 2010. In addition, an inventory of technological mitigation options for major energy intensive industrial sectors was created.

During this phase, a first consultation was held with the advisory committee with regard to the scope and design of a possible future Flemish industrial low-carbon framework.

Phase 2:

The next step of the process investigated the possible added value of a Flemish industrial low-carbon framework and the role of the Flemish government and industrial sectors in the development of the scope and design of such a future Flemish industrial framework. An electronic survey was carried out to consult all members of the advisory group with the goal to gain insights into preferences regarding the scope and implementation options of such an industrial transition framework. The results of this survey were afterwards discussed with the advisory group was. This survey was constructed using feedback and information gathered in Phase 1. The results of the survey were used as a discussion tool to facilitate the design of a possible forthcoming Flemish low-carbon industrial transition framework.

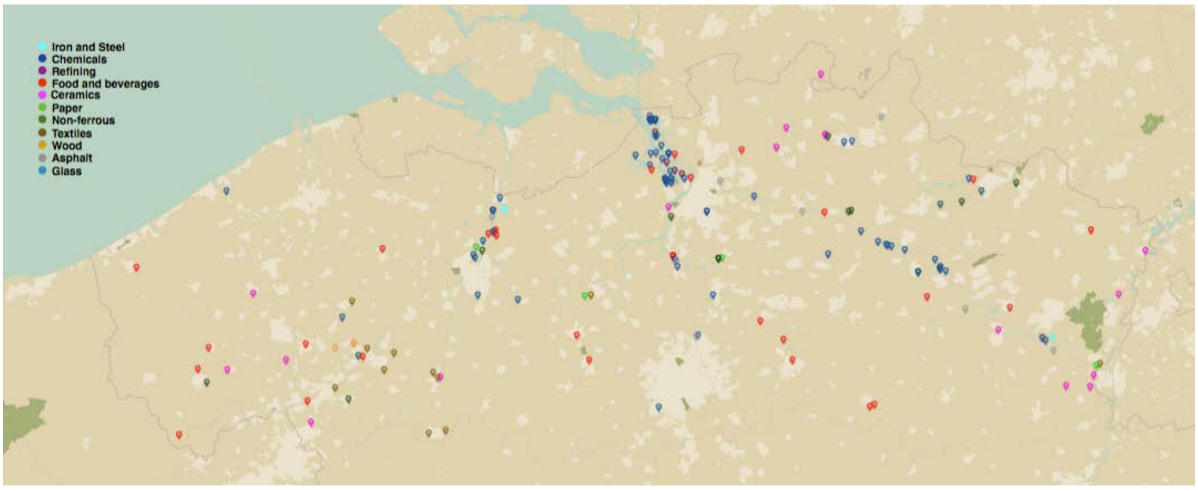
Phase 3:

The final phase of the project aimed at the further elaboration of the development of a future Flemish industrial transition framework towards a low-carbon economy. This was done through intensive consultations with stakeholders, including the use of an ad hoc working group (a selection of representatives from the advisory committee of this study). The result is an action plan for the development of an industrial low-carbon transition plan for Flanders together with the next steps that will be taken to start this process.

Profiling the Energy Intensive Industry in Flanders

General findings

Flemish economy wide GHG emissions in 2016 stood at 77.7 million tonnes carbon dioxide equivalent (Mt CO_2-eq), 36% of which were industrial sectors emissions (27.9 Mt CO_2-eq). The energy intensive industries in Flanders, which fall under the scope of the EU ETS, represented 80% (22.4 out of 27.9 Mt CO_2-eq.) of industrial GHG emissions in the same year. There exists a strong concentration of industrial GHG emissions in Flanders with the 10 largest emitting companies contributing the vast majority of Flemish industrial GHG emissions.



Mapping of industrial EU ETS sites in Flanders

On a sectoral basis, in 2016, the refining, chemicals and iron and steel sectors in Flanders combined represented almost 90% of Flemish industrial emissions covered by the EU ETS. The top 40 Flemish industrial emitters constituted approximately 90% of all industrial EU ETS emissions in 2016 (the top 10 alone accounted for 72%) and included all (large) refineries and steel producers. Most of the remaining large emitters in the list of 40 are chemicals producers. There are also 6 food and beverages companies, 3 paper producers, 2 non-ferrous companies and one company each of ceramics, textiles and glass production who figure in the top 40 list. The emissions of Flemish industrial EU ETS sectors fell 16% between 2005 and 2016 (from 26.7 to 22.4 Mt CO_2-eq.), taking into account the changes to the EU ETS scope in that period. The most significant emission reductions happened in the chemicals sector (-26% or from 11.4 to 8.4 Mt CO_2-eq.) and the combination of ceramics, non-ferrous, food and textiles industries (-18% or from 3.9 to 3.2 Mt CO_2-eq.) over the same period. Part of the emission reductions in the latter sectors can be explained by industrial closures which ensued during that period. In particular, smaller industries such as ceramics and textiles, but also the automotive industry, were affected more significantly by industrial closures during that period.

In 2016, the final[1] Flemish energy use was 1,232 petajoules (PJ). Energy use by industry (both as feedstock and for energetic use) was 673 PJ or 55% of final Flemish energy use. Non-energetic (feedstock) use was 279 PJ or 22.6% of the Flemish total energy use. The main fuel sources (non-energetic and energetic use) were Naphtha (165 PJ), Natural gas (133 PJ), electricity (94 PJ), other fuels (76 PJ) and coal/cokes (84 PJ). Compared to 1990, the total final energy use in Flanders went up 44% (from 852 to 1,232 PJ) with industrial energy use (incl. use as feedstock) rising 70% (from 395 to 673 PJ) - the major contributor of this increase. The total final energy use of excluding feedstock in Flanders went up 17% (from 769 to 903 PJ) over the same period, with industrial energy use (excl. use as feedstock) rising 13% (from 312 to 385 PJ).

In the period 2003-2014 the total GVA (current prices) in Flanders increased 44% (from EUR 145 Bn to EUR 209 Bn). The value added of the industrial sectors, considered in this study, as aggregated, increased 10% in same period (from EUR 18.5 billion to EUR 20.4 billion) but with significant

[1] Excluding energy use in transformation of energy and bunkers.

difference in growth rates between sectors. As a result, the contribution of these sectors to the overall Flemish GVA decreased from 12.75% in 2003 to 9.74% in 2014. In the period 2003-2014, the total employment (number of persons) in Flanders increased by 11% from 2.4 million to almost 2.7 million while the industrial sectors (as aggregate of listed NACE codes) saw a 17% decline in direct employment - from 232,822 to 192,432. The indirect employment generated by these sectors wasn't taken into account. Again, there are significant differences between sectors, but the downward trend is present among all industries covered here. The share of the number of people employed in these industries as part of total Flemish employment went from 9.7% to 7.3 % between 2003 and 2014.

The (basic and intermediate) products produced by the industrial sectors covered in this study account for the majority (57%) of exports[2] of goods produced in Flanders. The combined value of exports of chemicals, pharmaceuticals, plastics and rubber stood at almost EUR 100 Bn in 2015. The trade balance, on a sector by sector basis, shows a surplus in most industries with the exception of the minerals industry (which is dominated by mineral fuels, crude oil and distilled refining products) given Flanders is a significant net-importer, and the construction materials industry which had a small trade deficit in 2015.

The rest of the EU (and neighbouring countries in particular) are important trading partners of Flemish industry, pointing to firmly embedded value chains not only in Flanders but also in Europe. Almost a quarter of the export and its associated welfare is created through extra-EU exports. Due to the high growth in major emerging economies, the export share to economic region's outside EU should have increased more significantly. However, this has not been the case, which resulted in a declining market share in international (ex-EU) trade. The latter share has clearly not been following the world growth pace.

Within the context of future decarbonisation, it must be noted that the past years emissions from EU ETS companies have remained relatively flat, with a slight increase most recently. Some smaller sectors registered a reduction of emissions, but these are most likely due to closures happening since 2008. At the same time, the value added (in absolute terms) of most of the industrial sectors to the economy increased (and hence improved their CO_2 efficiency) and industry kept investments at a high level. Under the 'energiebeleidsovereenkomsten' (voluntary agreements on energy efficiency by industry), important energy savings are still happening in Flemish EU ETS companies. Bringing down emissions from energy intensive industries further as a contribution to the European target of -80 to -95% by 2050 will hence be a major challenge. The incremental evolutions as seen in the emissions and energy consumption profiles will not suffice to reach a deep level of decarbonisation. This points to the need for a major industrial transformation over the next decades.

This context, together with the result of profiling Flemish energy intensive industries (especially their important contribution to the Flemish GDP), shows that an intelligent approach on transformation must be designed. The transition cannot erode competitiveness of the industry since closures will negatively impact welfare in Flanders and simply shift emissions to more competitive regions.

To better understand the challenges and opportunities for energy intensive sectors in the context of the transition to a low-carbon economy a brief SWOT analysis was developed, the summary of which is shown in the table below. This helped identify priorities with regard to the scope of a future industrial low-carbon transition framework for Flanders.

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[2] Bron: Flanders Investment and Trade (FIT), 2016, gedetailleerde Vlaamse in- en uitvoercijfers 2015. consulted via https://www.flandersinvestmentandtrade.com/export/marktstudie/vlaamse-buitenlandse-handel-2015

Strengths	Weaknesses
• Central geographical location • Excellent connectivity (logistics) • At the core of European value (& supply) chains • Clustering of production plants/processes and process optimisation (esp. Chemicals & Refining) • Strong presence of large multinationals creates positive spill-overs for smaller (local) companies in industrial clusters • Refining has due to Integration of world-class stream cracking installations and availability of surplus coking a 'Must Run' status • Highly skilled labour force • Strong reputation for research and business expenditure on R&D (BERD)	• High energy cost related to EU policy (exposure to prices) • Most (large) investment decisions are taken by multinational companies with decision making centres outside of Flanders. • Relatively high labour costs • Regulatory complexity especially for multinationals • Open economy and location → vulnerable to international trade disruptions • Need for more and updated infrastructure given status as a major logistics hub
Threats	**Opportunities**
• Global sectoral developments (US shale gas & shale oil, new investments in Middle East, overproduction in emerging economies like China) • EU & global trade disruptive events (e.g. Brexit, US mercantilism) • Disruptions during transport and power sector low-carbon transition • Industrial low-carbon technologies deployment → (significantly) higher electricity demand → demand for investments in low-carbon power production • Circularity → lowered demand of basic products/materials • EU ETS → (future) higher CO_2 prices → more carbon exposure → uneven global playing field	• Energy/power-sector transition → industrial demand response/storage opportunities • Well placed industrial clusters offer opportunities for industrial symbiosis and better economic resilience in a low-carbon economy • Circularity → new business models and higher value-added products and services

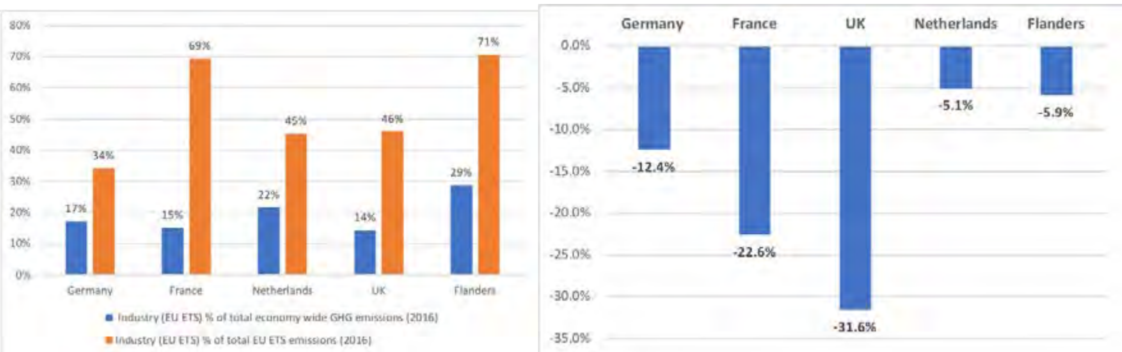
SWOT analysis of Flemish energy intensive industries in the context of a low-carbon and energy transition

Comparison of Flemish energy intensive industries with those in neighbouring countries (UK, DE, NL, FR)

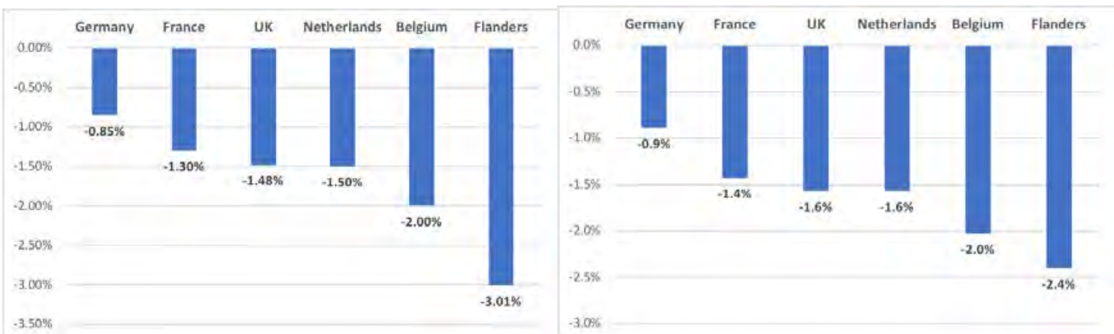
The energy intensive industry in Flanders has a higher share (%) of GHG emissions to the over-all economy and as share of the emissions under the EU ETS compared to all neighbouring countries due to the concentration of large industrial sectors in a small region and the low CO_2 intensity of electricity production in Flanders (and Belgium).

Flanders and The Netherlands saw the smallest reduction in GHG emissions from the energy intensive industries between 2008 and 2016 (-5.1% and -5.9% respectively) as compared to the dramatic reduction in industrial emissions in the UK (-33%), France (-23%) and Germany (-12.4%). However, the reductions in the UK and France ensued as a result of major closures of large industrial plants (e.g. steel and refining) over that period. Closures also happened amongst Flemish industry in that period but were mostly in the textiles, ceramics and automotive industries which have a much lower CO_2 intensity. No large steel, refining and chemicals plants closed in Flanders during that period. The larger emission reductions in Germany can be partially explained by N_2O emissions mitigation in the chemicals industry which occurred shortly after similar measures were taken in Flanders (partially before 2008).

The contribution of the energy intensive industries in Flanders to the Flemish GVA is high: 10% in Flanders compared to 4% in the UK and 7% in Germany. While Flanders did register the most significant decline in the energy intensive industries' contribution to the Flemish GVA between 2003-2014 (-3%) as compared to Germany (-0.85%) and The Netherlands (-1.5%) over the same period, Flanders had started from a much higher baseline. The relative decline (as a % of economy-wide value added) does not necessarily imply an economic contraction of these industries. Indeed, the industrial absolute GVA is still increasing, but at a smaller rate compared to other sectors in the economy. However, a relative decline does indicate a loss of market share especially in relation to other countries/regions.



[Left] share of industrial (EU ETS) emissions as part of total economy and the EU ETS in Flanders and neighbouring countries in 2016 (sources: European Environment Agency, Sandbag, Vlaamse Overheid). [Right] Relative change in GHG emissions from industrial sectors between 2008 and 2016 (Sources: Eurostat and Vlaamse Overheid)



[Left] Change in share of industrial GVA to economy wide GVA between 2003 and 2014, [Right] change of employment in (selection of) industrial sectors as share of total employment between 2003 and 2014 (Sources: Eurostat and NBB)

There is a high level of similarity between Flanders and the Netherlands as concerns the relative shares of GHG emissions between the different sectors (e.g. large shares of emissions of refining and chemicals industries). The Netherlands and Flanders also possess two large harbour areas with major industrial presence (e.g. Antwerp and Rotterdam).

Flemish industrial sectors do not operate in isolation from the rest of Europe. There exist major infrastructure links (i.e. pipelines) between the industrial clusters in the Netherlands and the Nordrhein Westfalen region in Germany. Coordination between these regions will important during the transition to a low-carbon economy. Flanders can make use of the recent 'Trilateral Strategy for The Chemical Industry' established by the respective governments and companies of these regions to discuss supra-national energy policy, infrastructure and enabling measures for innovation for the chemicals industry in particular.

Finally, practical interregional cooperation already exists between industry in the Ghent harbour region and the Dutch Terneuzen area in the shape of the new Northsea Port venture. A group of companies in this area (united under SmartDelta Resources) recently presented what is likely the first interregional low-carbon roadmap. It clearly shows the benefits (but also challenges) of cooperation among neighbouring industrial clusters. These international processes deserve specific attention in the development of a Flemish industrial low-carbon transition framework.

Analysis of Industrial low-carbon Roadmaps

General Inference

The study of key European (and regional) roadmaps revealed that across a range of sectors (steel, chemicals, ceramics and paper) but also across multiple industrial sectors in a country (Netherlands) or region (Port of Rotterdam), in theory, deep emission reductions (beyond 80%) are possible but challenging. Many breakthrough technologies still need to be proven commercially (e.g. carbon capture and utilisation or storage (CC(U)S) and Hydrogen-based feedstock/synthetic fuels) are presented as essential technologies for deep emission reductions.

However, a mix of different technologies will need to be applied within and across industrial sectors depending on local circumstances e.g. the availability of pure CO_2 streams and storage locations, affordable and reliable biomass and/or Hydrogen (H_2) (e.g. via renewable electricity), potential for industrial symbiosis, and so on. High levels of capital expenditure (CAPEX) will be required for deeper mitigation in all cases and operational expenditure (OPEX) of the new technologies will also be higher as compared to the those used currently.

It is also highly likely, when looking at the technology roadmaps that electricity demand will rise significantly in most decarbonisation scenario's, adding extra challenges for the energy system. Also, according to the impact assessment of the European Commission's energy roadmap 2050 (2011), non-energetic energy use will not significantly go down up to 2050.

There exists a high level of consistency between the policy recommendation across most of the roadmaps considered in this report. First, they show there is a clear need for a 'mission oriented' R&D framework with specific attention to supporting of large industrial demonstration projects. This includes facilitating finance or access to capital for these technological challenges. The roadmaps also stress the urgency of implementation due to the long investment cycles in energy intensive industries. These investment cycles cover a period of 20-30 years and hence leave only one investment cycle between now and 2050. Furthermore, most roadmaps argue in favour of a coherent and stable regulatory framework to safeguard the competitiveness of energy intensive industries. Finally, the roadmaps make a link with the ongoing energy transition in Europe and the transition of the energy intensive industries.

Relevance for Flanders

For Flanders the information in the considered roadmaps can be useful at a general level but a direct application of technologies and pathways of European roadmaps to Flanders is not straightforward.

The specific regional context (e.g. availability of affordable biomass, H_2 and electricity or access to CCS infrastructure) will be important to assess the applicability of (technological) mitigation options in Flanders. It is clear however, that regardless of the specific options chosen in Flanders, a significant amount of CAPEX will be required over the next decades to finance investments in low-carbon production processes and related infrastructure. McKinsey & Co (2017) estimated the CAPEX required for a Dutch industrial low-carbon transition to be EUR 55-71 billion by 2050 (for respectively -80% and -95% emissions reductions). The possible similarity between Dutch and Flemish industry invites a closer look of the industrial low-carbon transition and implementation in The Netherlands and an analysis of the different solution pathways and the relevance for Flanders thereof.

Assessment of low-carbon breakthrough technologies

This study looked at recent developments in low-carbon breakthrough technologies in the steel, chemicals, paper and ceramics industries. In particular, technologies that could lead to deep emission reductions in industrial processes were assessed.

In the steel industry a promising carbon capture and utilisation (CCU) technology is being piloted at the Arcelormittal site in Ghent. This technology (Steelanol) and CCU in general can play a significant role in Flemish industrial decarbonisation given its high potential to reduce emissions in petrochemicals production (e.g. from ammonia, ethylene and propylene production). Therefore, a future industrial transition framework for Flanders should explore the potential of integration of industrial value chains. H_2-based steelmaking shows promise for major emission reductions, but its commercial viability will largely depend on low-cost (and renewable energy based) H_2 production. It might therefore not be compatible with existing production of steel in Flanders because the process is a change from the current integrated steel production route.

For the Flemish chemicals industry new low-carbon processes that replace processes using naphtha as a feedstock (for ethylene, propylene, butadiene and BTX production). With regard to ammonia production, which currently uses methane as a feedstock, technologies are being developed that use H_2 or carbon capture and storage (CCS). However, many of the breakthroughs depend for commercial success to a large extent on the availability of low-cost and low-carbon produced H_2. The overall electricity demand and the necessary installed capacity (and costs) are likely to rise significantly. This will especially be the case when CO_2 is used as a feedstock. Investing in bio-based chemicals, in particular if bio-based inputs can be used to produce high value chemicals, can be relevant for Flanders. However, sufficiently large and stable supply chains of biomass must be ensured together with an economically viable price for the bio-based inputs. For these breakthrough technologies (esp. H_2 and biomass-based chemicals) to compete with existing fossil fuel based technologies, more R&D, optimisation and the availability of cheap abundant and reliable low-carbon electricity and biomass will be required.

Research in advanced circular economy technologies and techniques which allow the recovery of basic chemicals and plastics or to allow waste to be converted will be crucial to enable the transition to low-carbon chemicals in Flanders. A circular economy will likely reduce the above-mentioned additional high demand for low-carbon electricity and biomass in Flanders.

In the paper sector, most of the technologies assessed will have a significant impact on electricity consumption but can reduce the energy consumption and GHG emissions on the whole. The application of these technologies will likely depend on the specific type of paper production plants. For ceramics, options exist to optimise heat use (e.g. through the use of combined heat and power generation (CHP)). Applying breakthrough technologies can be a challenge for smaller ceramics producers in Flanders due to the high CAPEX of the investments in relation to the turnover of the plants.

Long-term and patient R&D support seems an essential requirement for bringing breakthrough technologies from the laboratory through pilot and demonstrations to the market, in particular through support for pilot and demonstration plants. Several of the technologies mapped have received significant EU funding, including some of the more advanced breakthroughs such as the HIsarna low-CO_2 steel project. But also, national financial support such as that from the German Federal Ministry of Education and Research or the Dutch Economics Ministry has played a vital role in the technology development essential for a low-carbon transition.

Scope and Design of a facilitative Flemish Industrial Transition Framework towards a low-carbon economy

Based on the feedback received through an indicative survey and discussions with the advisory group, it can be concluded that there is no need for a Flemish industrial low-carbon roadmap (or multiple sectoral roadmaps) that only focus on scenarios, technologies and costs of transition to a low-carbon economy.

There is however interest in an approach that considers the facilitation of a broader industrial transition in Flanders. This could be defined as a facilitating Flemish industrial transition framework towards a low-carbon economy, related to innovation, infrastructure and financing. Based on the feedback received during the stakeholder process in the advisory group, the following elements will have to be taken into account when considering such an approach:

- It is important to avoid duplication and fragmentation of industrial policy and hence the EU sectoral roadmaps (and forthcoming initiatives) and international influences need to be taken into account when developing a Flemish industrial transition framework.
- The energy transition in Belgium and Flanders can have important impacts on industrial competitiveness and the industrial low-carbon transition and vice versa. Both processes therefore need to be(come) well aligned.
- The transition framework is meant to *facilitate* (in particular innovation, financing and infrastructure) and should not be seen as an instrument to place additional GHG mitigation targets or trajectories on industrial sectors.
- The transition framework can look at industrial clusters, value chains and the possible synergies between companies, industrial and non-industrial sectors.
- The term ‘low-carbon’ while commonly used in this context can be confusing. The transition is not meant to reduce the presence of the chemical element ‘carbon’ in products or processes and shall not prevent the utilisation of CO_2 in industrial processes.

In general, the transition framework should focus on constructing an enabling or facilitating environment through innovation, financing and infrastructure. It must allow synergies and symbiosis between companies, sectors, regions and policies. This could include enabling (or removal of hurdles for) higher levels of circularity along the value chains of basic industries and the alignment of industrial transition with the ongoing energy transition and vice-versa.

Finally, developing such transition framework will require the support of multiple stakeholders (e.g. industrial companies, sectors, specialised scientific institutions, innovation actors in Flanders, unions, NGO's, the financial sector, technology providers, industrial suppliers, customers, energy suppliers and network operators, and governmental administrations with responsibilities in these areas). Ideally, the overall governance of such process happens through a constructive dialogue between the public sector and the industrial sectors.

Towards a Flemish industrial transition framework for a low-carbon economy

It is important that Flemish industry prepares for the transition to a low-carbon economy and focuses on innovation in order to remain competitive during this transition with perspective 2050. **The Flemish government must respond optimally to this by developing a specific framework to ensure competitiveness of Flemish companies.**

The purpose of a transition framework is to create a facilitating framework for industry to enable the low-carbon transition of the industry. The framework will therefore have to capture information that can be useful to remove barriers and to facilitate synergies. On the other hand, it is important that know-how and experiences with innovative technologies can be used efficiently in order to drive forward the innovation landscape. Finally, a competitive framework is needed to attract investments in Flanders to achieve a win-win between climate ambitions and prosperity. This was also endorsed in action 5.2.2. 'Transition framework for the transition to a low-carbon economy' from the preliminary draft Flemish Climate Policy Plan 2020-2030. Countries and regions that proactively develop a vision and strategic innovation excellence and provide the necessary co-financing will also have a greater chance of receiving European funding.

Given the scale of the transition, the societal importance and the large number of stakeholders involved, it is important that the preparation to **this transition is done in a coherent manner, supported by the government, the business community and other relevant stakeholders**. After all, this is a long-term transition that involves many (technological and economic) uncertainties and risks. The transition framework must make clear to the parties involved what their role and commitment can be in this process. The whole process must therefore be transparent and, in addition, adjustments to it must be possible.

The starting point for the development of an industrial transition framework is the use of knowledge already present in Flanders (and outside Flanders) and the existing economic landscape in Flanders.

In addition, a number of **research questions** were drawn up. The transition framework will have to address these in consultation with the relevant stakeholders. Insights from **a techno-economic analysis of the different high-level technologies and their opportunities** can be used to address these research questions.

No agreement on how the transition framework will be developed, or how the transition framework must deal with these research questions, was reached between the parties involved during this study. The **following steps** can contribute to furthering this:

- Interdepartmental coordination between the Department of Economy, Science and Innovation (EWI) and the Department of the Environment (Omgeving) about a future approach. The aim is to finalize this alignment through a proposed action plan before the end of 2018.
- Identification of involved actors.
- Finalisation of the plan on how to develop a Flemish industrial transition framework in consultation with the actors involved.

In carrying out the above steps, it will be ensured that:

- Continuation of existing cooperation between various actors involved remains crucial.
- Generic aspects are discussed at the Flemish level to the extent possible to avoid fragmentation and duplication of consultation. Typical local aspects (such as infrastructure and logistics and local bottlenecks / barriers) can be discussed at local level.
- The workload for the companies and the actors involved in dealing with the research questions is kept to a minimum.

1.2 NEDERLANDSTALIGE VERSIE

Het doel van deze studie

In 2011 publiceerde de Europese Commissie een routekaart voor de overgang naar een competitieve koolstofarme economie in 2050. Deze EU-routekaart stelt een kosteneffectief traject voor tot een reductie van het broeikasgasemissies (BKG-emissies) met 80% tegen 2050. De Europese Commissie bereidt momenteel een actualisering van deze routekaart voor om deze in overeenstemming te brengen met het verhoogde ambitieniveau van de overeenkomst van Parijs, waarbij partijen zich ertoe hebben verbonden de wereldwijde stijging van de gemiddelde temperatuur tot ruim onder 2 ° C ten opzichte van het pre-industriële niveau te beperken en zich in te spannen om de temperatuurstijging tot 1,5 ° C te beperken. Europa staat daarom voor een nog niet gekende overgang naar een koolstofarme en duurzame economie in een relatief kort tijdsbestek.

De Vlaamse regering steunt de Europese langetermijndoelstelling om de uitstoot van broeikasgassen tegen 2050 met ten minste 80% tot 95% te verminderen (ten opzichte van 1990) met tussentijdse doelstellingen voor 2020 en 2030, en heeft op 19 mei 2017 de "Vlaamse energievisie" goedgekeurd, die de visie van Vlaanderen op een koolstofneutraal en duurzaam energiesysteem in kaart bracht.

Het is duidelijk dat de industrie deel zal uitmaken van en een belangrijke rol zal spelen tijdens deze transitie. Nieuwe technologieën, producten, grondstoffen en productieprocessen zullen hiervoor nodig zijn. Een van de acties in de Vlaamse energievisie was om de mogelijkheid te onderzoeken om sectorale routekaarten te ontwikkelen. Daarom zijn in deze studie bestaande low-carbon routekaarten (roadmaps) die in heel Europa zijn ontwikkeld en de toegevoegde waarde van aanvullende routekaarten onderzocht. Deze sectorale routekaarten kunnen een nuttig instrument en een leidraad zijn voor koolstofarme productie- en productroutes.

Dit rapport brengt een doorlichting van Vlaamse energie-intensieve industrieën in het kader van de transitie naar een koolstofarme economie, door analyse van relevante gegevens, studies en technologische roadmaps. Het doel van dit rapport was om informatie en input van relevante stakeholders te gebruiken om de meerwaarde te onderzoeken van het ontwikkelen van toekomstige industriële koolstofarme visies voor Vlaanderen. Het rapport streefde er ook naar om, met een optimale bijdrage van de industrie, een voorstel in te dienen over de mogelijke scope en architectuur van een toekomstig faciliterend kader voor een Vlaamse koolstofarme economie, rekening houdend met de interacties en mogelijke synergiën tussen energie-intensieve industrieën en de rest van de economie.

Scope en methodologie

De scope van het onderzoek betreft de energie-intensieve industrieën in Vlaanderen. Voor Vlaanderen betreft het de sectoren: raffinage, chemicaliën (inclusief rubber en kunststoffen), ijzer en staal, voedingsmiddelen en dranken, non-ferrometalen, keramiek, pulp en papier, textiel en houtproducten. In de praktijk valt de selectie van de sectoren samen met het EU-emissiehandelssysteem (ETS). De in dit rapport gepresenteerde gegevens zijn erop gericht deze sectorale afbakening zo nauw mogelijk te volgen (bijvoorbeeld door het gebruik van emissiegegevens die zijn gerapporteerd in het kader van de EU-ETS of door gegevens op NACE 2-niveau samen te voegen).

Het project werd uitgevoerd tussen februari en november 2018 en bestond uit drie fases.

Fase 1:
Eerst gebeurde een gedetailleerde doorlichting van de Vlaamse energie-intensieve industrieën, inclusief een vergelijking met vier belangrijke Europese buurlanden - Duitsland, Frankrijk, Nederland en het VK - uitgevoerd door middel van een literatuurstudie.

Dit omvatte sectorspecifieke tijdreeksen van broeikasgasemissies en energieverbruik, maar ook sociaaleconomische gegevens zoals bruto toegevoegde waarde (GVA), werkgelegenheid en investeringen. Voor een selectie van belangrijke energie-intensieve industrieproducten werd een korte analyse van handelsstromen uitgevoerd. Aan de hand van deze informatie samen met aanvullende literatuur werd een korte SWOT-analyse uitgevoerd voor de Vlaamse energie-intensieve industrieën in de context van de transitie naar een koolstofarme economie. Verder werden recente Vlaamse studies of onderzoeksprojecten gepresenteerd die relevant zijn in het kader van de overgang naar een koolstofarme industrie. Ten slotte werd een kort overzicht van Vlaamse strategieën en beleidslijnen, die verband houden met industriële decarbonisatie en de circulaire economie, gepresenteerd.

Het tweede deel van het analytisch onderzoek vergeleek het industriële profiel van de Vlaamse (energie-intensieve industrie) met dat van de bovengenoemde buurlanden en onderzocht de connecties tussen de Vlaamse industrie en aangrenzende industriële clusters.

Dit werd gevolgd door een analyse van low-carbon roadmaps (Europese, wereldwijde, regionale en cluster) met focus op energie-intensieve industrieën die sinds 2010 zijn gepubliceerd. Daarnaast is een inventaris gemaakt van technologische mitigatiemogelijkheden voor grote energie-intensieve industriële sectoren.

Tijdens deze fase werd de begeleidingsgroep bij deze studie ook geraadpleegd met betrekking tot de scope en de krijtlijnen van een mogelijk toekomstig Vlaams industrieel low-carbon transitiekader.

Fase 2:
Tijdens volgende fase van het proces werden de mogelijke toegevoegde waarde van een Vlaamse industrieel low-carbon transitiekader en de rol van de Vlaamse overheid en industriële sectoren bij de uitwerking van de scope en het ontwerp van een dergelijk verder kader onderzocht.

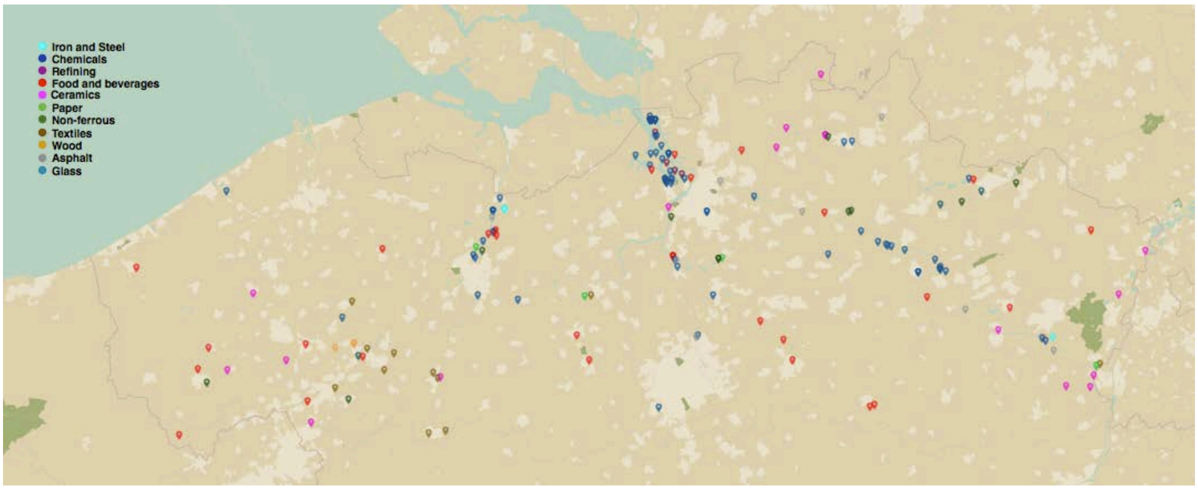
Door middel van een (online) bevraging werden alle leden van de begeleidingsgroep bij deze studie geconsulteerd, met als doel verder inzicht te verkrijgen met betrekking tot de voorkeuren van de stakeholders aangaande de scope en design van een industrieel transitiekader. De resultaten van de bevraging werden nadien besproken met de adviesgroep. De enquête werd opgesteld aan de hand van informatie verzameld en feedback van de stakeholders tijdens fase 1 van dit project. De resultaten van de enquête werden gebruikt als een discussietool met als doel het ontwerpen van een mogelijk Vlaams koolstofarm industrieel transitiekader te faciliteren.

Fase 3:
De laatste fase van het project was gericht op de verdere uitwerking van de opbouw van een toekomstig Vlaams industrieel transitiekader naar een koolstofarme economie. Dit gebeurde door middel van intensieve raadplegingen van de stakeholders in de begeleidingsgroep, waaronder het gebruik van een ad hoc werkgroep (een selectie van vertegenwoordigers van de begeleidingsgroep

van deze studie). Het resultaat is een plan van aanpak voor de ontwikkeling van een industrieel low-carbon transitieplan voor Vlaanderen samen met de volgende stappen die genomen gaan worden om dit proces op te starten.

Doorlichting van de Vlaamse energie-intensieve industrie

In 2016 bedroegen de totale BKG-emissies in Vlaanderen 77,7 miljoen ton CO_2-equivalent (Mt CO_2-eq), waarvan 36% BKG-emissies afkomstig van industriële sectoren (27,9 Mt CO_2-eq). De energie-intensieve industrieën in Vlaanderen, die onder het EU emissierechtenhandelssysteem (ETS) vallen, vertegenwoordigden in hetzelfde jaar 80% (22,4 van de 27,9 Mt CO_2-eq.) van deze industriële broeikasgasemissies. Er bestaat een sterke concentratie van industriële broeikasgasemissies in Vlaanderen, waarbij de 10 bedrijven met hoogste BKG-emissies verantwoordelijk zijn voor de overgrote meerderheid van de Vlaamse industriële BKG-emissies.



Industriële EU ETS bedrijven in Vlaanderen

Op sectorniveau vertegenwoordigden de raffinage-, chemie- en ijzer- en staalsector in Vlaanderen samen in 2016 bijna 90% van de Vlaamse industriële emissies die onder het EU ETS vallen. De top 40 van Vlaamse industriële sites met hoogste BKG-emissies vertegenwoordigden samen in 2016 ongeveer 90% van alle industriële EU ETS-emissies (de top 10 alleen vertegenwoordigde 72%) en omvatte alle (grote) raffinaderijen en staalproducenten. De meeste van de resterende grote vervuilers in de lijst zijn producenten van chemicaliën. Er zijn ook 6 voedsel- en drankenbedrijven, 3 papierproducenten, 2 non-ferro bedrijven en telkens één bedrijf uit de keramische, textiel- en glasproductie die in deze top 40 staan. De uitstoot van Vlaamse industriële EU ETS-sectoren daalde tussen 2005 en 2016 met 16% (van 26,7 naar 22,4 Mt CO_2-eq.), rekening houdend met de wijzigingen in de EU-ETS-scope in die periode. De belangrijkste emissiereducties vonden plaats in de chemische sector (-26% of van 11,4 tot 8,4 Mt CO_2-eq. tussen 2005 en 2016). De reducties in de keramische, non-ferro, voedingsmiddelen- en textielindustrie samen bedroegen -18% (van 3,9 tot 3,2 Mt CO_2-eq.) over dezelfde periode. Een deel van de emissiereducties in de laatste sectoren kan worden verklaard door industriële sluitingen die in die periode hebben plaatsgevonden. Met name kleinere industrieën zoals keramiek en textiel, maar ook de automotive industrie, werden in deze periode meer getroffen door industriële sluitingen.

In 2016 bedroeg het finale[3] Vlaams energieverbruik 1232 petajoule (PJ). Het energiegebruik door de industrie (zowel als grondstof als voor energetisch gebruik) was 673 PJ of 55% van het finale

[3] Exclusief energiegebruik in de transformatie-sector en bunkerfuels.

Vlaamse energieverbruik. Het niet-energetisch gebruik, dat is het gebruik van brandstoffen als feedstock, door industrie betrof 279 PJ of 22,6% van het Vlaamse totale energieverbruik in 2016. De belangrijkste brandstofbronnen (niet-energetisch en energetisch gebruik samen) voor industrie waren nafta (165 PJ), aardgas (133 PJ), elektriciteit (94 PJ), andere brandstoffen (76 PJ) en kolen/cokes (84 PJ).

Ten opzichte van 1990 steeg het totale finale energieverbruik in Vlaanderen met 44% (van 852 naar 1.232 PJ). Het industrieel energiegebruik (inclusief gebruik van brandstoffen als feedstock) steeg met 70% (van 395 naar 673 PJ) en vormt de belangrijkste reden voor de totale toename in Vlaanderen. Als het gebruik van brandstoffen als feedstock *niet* in rekening wordt gebracht dan steeg het totale finale energiegebruik in Vlaanderen in dezelfde periode slechts met 17% (van 769 naar 903 PJ), waarbij het industriële energiegebruik exclusief gebruik van brandstoffen als feedstock met 13% steeg (van 312 naar 385 PJ).

In de periode 2003-2014 steeg de totale bruto toegevoegde waarde gegenereerd in Vlaanderen met 44% (van EUR 145 miljard naar EUR 209 miljard). De toegevoegde waarde van de energie intensieve industrie in Vlaanderen steeg met 10% in dezelfde periode (van EUR 18,5 miljard naar EUR 20,4 miljard), maar met een aanzienlijk verschil in groeipercentages tussen de sub-sectoren in de energie-intensieve industrie. Terwijl de absolute toegevoegde waarde van de energieintensieve industrie steeg daalde de bijdrage van deze industrie tot de algemene Vlaamse bruto toegevoegde waarde van 12,75% in 2003 naar 9,74% in 2014.

In de periode 2003-2014 steeg de totale werkgelegenheid (aantal personen) in Vlaanderen met 11% van 2,4 miljoen tot bijna 2,7 miljoen, terwijl de energieintensieve industrie (gebaseerd op de samenvoeging van de relevante NACE-codes) een daling van 17% in de directe werkgelegenheid noteerde - van 232.822 naar 192.432. De indirecte werkgelegenheid die door deze sectoren wordt gegenereerd, is hier niet in aanmerking genomen. Nogmaals, er bestaan aanzienlijke verschillen tussen de deelsectoren, maar de neerwaartse trend is aanwezig in alle sectoren die in deze studie worden behandeld. Het aandeel van het aantal werknemers in deze industrieën ten opzichte van de totale Vlaamse werkgelegenheid daalde tussen 2003 en 2014 van 9,7% tot 7,3%.

De (basis- en tussenproducten) geproduceerd door de industriële sectoren die in dit onderzoek worden behandeld, vertegenwoordigen de meerderheid (57%) van de uitvoer[4] van de in Vlaanderen geproduceerde goederen. De gecombineerde waarde van de uitvoer van chemicaliën, farmaceutica, kunststoffen en rubber bedroeg in 2015 bijna EUR 100 miljard. De handelsbalans, sector per sector, vertoont een overschot in de meeste industrieën, met uitzondering van de mineralenindustrie (die wordt gedomineerd door minerale brandstoffen, ruwe olie en gedistilleerde raffinageproducten) waarvan Vlaanderen een belangrijke netto-importeur is, en de bouwmaterialenindustrie die in 2015 een klein handelstekort had.

De rest van de EU en in het bijzonder de buurlanden vormen belangrijke handelspartners van de Vlaamse industrie en wijzen op stevig ingebedde waardeketens, niet alleen in Vlaanderen, maar ook in Europa. Bijna een kwart van de export en de bijbehorende welvaart wordt gecreëerd door extra-EU-exporten. Omwille van de sterke groei in de belangrijkste opkomende economieën, had dit exportaandeel naar de buiten de EU gelegen regio's meer moeten stijgen. Dit was echter niet het

[4] Bron: Flanders Investment and Trade (FIT), 2016, gedetailleerde Vlaamse in- en uitvoercijfers 2015. consulted via https://www.flandersinvestmentandtrade.com/export/marktstudie/vlaamse-buitenlandse-handel-2015

geval, wat resulteerde in een dalend marktaandeel in de internationale (extra-EU) handel. De evolutie van deze laatste volgt duidelijk niet het groeitempo van de rest van de wereld.

Met het oog op de transitie naar een toekomstige lagekoolstofeconomie moet echter worden opgemerkt dat de emissies van EU ETS-bedrijven de laatste jaren relatief stabiel gebleven zijn, met zelfs een lichte stijging in de afgelopen jaren. Sommige kleinere sectoren registreerden wel een emissiereductie sinds 2008, maar deze is waarschijnlijk toe te schrijven aan sluitingen die zich sinds 2008 hebben voorgedaan. Tegelijkertijd is de toegevoegde waarde (in absolute termen) van de meeste industriële sectoren wel toegenomen (en dus de CO_2-efficiëntie verbeterd) en bleven investeringen op een hoog niveau. Onder de 'energiebeleidsovereenkomsten' zijn er nog steeds belangrijke energiebesparingen aan het gebeuren in Vlaamse EU ETS-bedrijven. Het terugdringen van de uitstoot van energie-intensieve industrieën als een bijdrage aan de Europese doelstelling van -80 tot -95% tegen 2050 zal daarom een grote uitdaging vormen. De incrementele evoluties zoals te zien in emissies en energieverbruik zullen niet voldoende zijn om een transitie naar een koolstofarme industrie te bereiken. Dit wijst op de noodzaak voor een grote industriële transformatie in de komende decennia.

De context van deze uitdaging, samen met het resultaat van de doorlichting van Vlaamse energie-intensieve industrieën (i.h.b. hun belangrijke bijdrage aan het Vlaamse BBP), tonen aan dat een intelligente benadering voor een Vlaamse industriële low-carbon transitie nodig is. De transitie mag het concurrentievermogen van de industrie niet aantasten, omdat sluitingen de welvaart in Vlaanderen negatief zullen beïnvloeden en de emissies eenvoudig naar meer competitieve regio's zullen verschuiven.

Om de uitdagingen en kansen voor energie-intensieve sectoren beter te begrijpen in het kader van de transitie naar een koolstofarme economie, werd een korte SWOT-analyse ontwikkeld, waarvan de samenvatting in de onderstaande tabel wordt getoond. Dit hielp bij het identificeren van prioriteiten met betrekking tot de reikwijdte van een toekomstig industrieel koolstofarm transitiekader voor Vlaanderen.

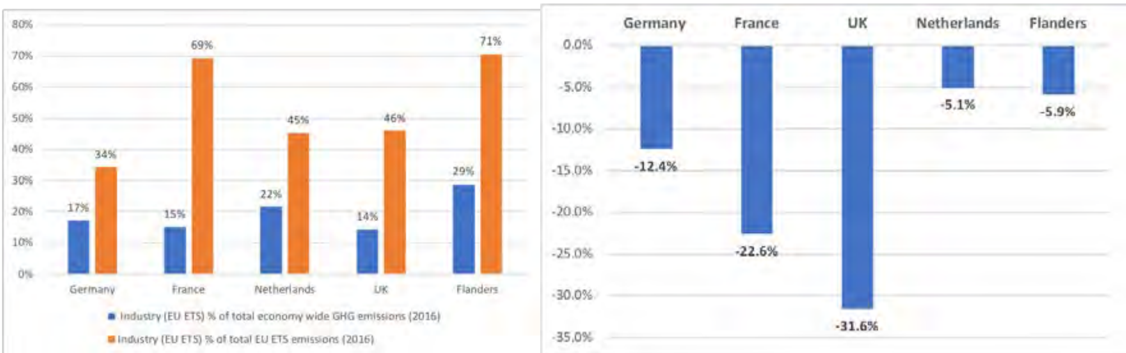
Sterktes	Zwaktes
• Centrale geografische locatie • Uitstekende (logistieke) verbindingen • Bevindt zich in het hart van Europese waarde- & aanvoerketens • Clustering van productieprocessen en procesoptimalisatie (met name in chemie en raffinage) • De sterke aanwezigheid van grote multinationals zorgt voor positieve spillovers voor kleinere (lokale) bedrijven in industriële clusters • Raffinagecapaciteit heeft omwille van integratie van stroomkrakers van wereldklasse en vanwege de beschikbaarheid van surplus coking de status 'Must Run' • Hooggeschoolde arbeidskrachten • Sterke reputatie voor onderzoek en bedrijfsuitgaven voor O & O (BERD)	• Hoge energiekostenbeleid van Europa (blootstelling aan prijzen) • De meeste (grote) investeringsbeslissingen worden genomen door multinationale ondernemingen met beslissingscentra buiten Vlaanderen. • Relatief hoge arbeidskosten • Regelgevende complexiteit, vooral voor multinationals • Open economie en locatie die kwetsbaar zijn voor verstoringen van de internationale handel • Behoefte aan meer en ge-update infrastructuur omwille van de status van belangrijk logistiek knooppunt
Bedreigingen	**Opportuniteiten**
• Wereldwijde sectorale ontwikkelingen (Amerikaanse schaliegas en schalieolie, nieuwe investeringen in het Midden-Oosten, overproductie in opkomende economieën zoals China) • EU en wereldwijde handels-verstorende gebeurtenissen (bijvoorbeeld Brexit en Amerikaans mercantilisme) • Disrupties tijdens de transitie naar koolstofarme transport- en energiesector • Industriële koolstofarme technologieën met (aanzienlijk) hogere elektriciteitsvraag → vraag naar investeringen in koolstofarme energieproductie • Circulariteit → lagere vraag naar (basis)producten • EU ETS → (toekomstige) hogere CO_2-prijzen → meer blootstelling aan deze prijzen → ongelijk mondiaal speelveld	• Energie/energiesector transitie → opportuniteiten voor industriële vraagrespons en opslag van energie door industrie • Goed geplaatste industriële clusters bieden mogelijkheden voor industriële symbiose en hogere economische resilientie in een koolstofarme economie • Circulariteit → nieuwe bedrijfsmodellen, producten en diensten met een hogere toegevoegde waarde

SWOT-analyse van Vlaamse energie-intensieve industrie (in de context van de low-carbon transitie)

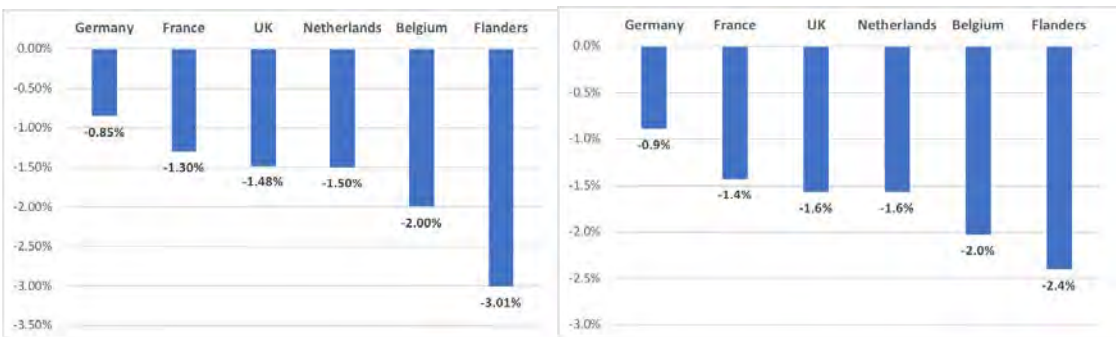
Vergelijking van de Vlaamse energieintensieve industrie met deze in de buurlanden

Ten opzichte van alle buurlanden heeft de Vlaamse energie-intensieve industrie de grootste relatieve bijdrage (%) aan de totale broeikasgasemissies in de economie. Ook voor wat betreft de emissies onder het EU ETS zijn deze in Vlaanderen proportioneel het hoogst voor de industriële sectoren ten opzichte van de situatie in de buurlanden. Dit heeft te maken met de concentratie van grote industriële sectoren in een kleine regio samen met de lage CO_2 intensiteit van de elektriciteitsproductie in Vlaanderen (en België).

Vlaanderen en Nederland zagen de kleinste reductie in broeikasgasemissies van de energie-intensieve industrieën tussen 2008 en 2016 (respectievelijk -5,1% en -5,9%). Dit staat in contrast met de dramatische daling van de industriële emissies in het VK (-33%), Frankrijk (-23%) en, in mindere mate, Duitsland (-12,4%) over dezelfde periode. De emissiereducties in de industrie in het VK en Frankrijk waren echter in grote mate het gevolg van grote sluitingen van grote industriële installaties (zoals staal en raffinage) in die periode. Er waren in die periode ook binnen de Vlaamse industrie sluitingen van productiecapaciteit, maar deze waren vooral aanwezig in de textiel-, keramiek- en automobielindustrie, dewelke een veel lagere CO_2-intensiteit hebben. In die periode zijn in Vlaanderen geen grote staal-, raffinage- en chemiefabrieken gesloten. De grotere emissiereducties in Duitsland kunnen gedeeltelijk worden verklaard door N_2O-emissiebeperking in de chemische industrie die na 2008 plaatsvond, kort nadat soortgelijke maatregelen werden genomen in Vlaanderen (gedeeltelijk vóór 2008).



[Links]: percentage van industriële (EU ETS) BKG-emissies in totale BKG-emissies (blauw) en totale EU ETS emissies (oranje) van Vlaanderen en de buurlanden in 2016 (Bronnen: European Environment Agency, Sandbag en Vlaamse Overheid). [Rechts]: Relatieve verandering in BKG-emissies van energie-intensieve sectoren in Vlaanderen en buurlanden tussen 2008 en 2016 (Bronnen: Eurostat en Vlaamse Overheid)



[Links]: Verandering in het aandeel (%) van de toegevoegde waarde van de energie-intensieve industrie in de totale toegevoegde waarde van de economie tussen 2003 en 2014. [Rechts]: Verandering in aandeel van werkgelegenheid in energie-intensieve industrie in totale nationale werkgelegenheid tussen 2003 en 2014 (Bronnen: Eurostat en NBB)

De bijdrage van de energie-intensieve industrieën in Vlaanderen aan de Vlaamse bruto toegevoegde waarde is hoog: 10% in Vlaanderen vergeleken met 4% in het VK en 7% in Duitsland. Vlaanderen zag wel een grotere relatieve daling van de bijdrage van de energie-intensieve industrie aan de totale Vlaamse bruto toegevoegde waarde (uitgedrukt als de evolutie van het % van de toegevoegde waarde van energie-intensieve industrie als onderdeel van de gehele economie) tussen 2003-2014 (-3%) in vergelijking met Duitsland (-0,85%) en Nederland (-1,5%) over dezelfde periode. Hier moet aan toegevoegd worden dat Vlaanderen van een hogere baseline vertrok. De relatieve daling betekent niet noodzakelijkerwijs een economische inkrimping van deze industrieën. Inderdaad, de industriële absolute toegevoegde waarde neemt nog steeds toe, maar in een kleiner tempo vergeleken met andere sectoren in de economie.

Er bestaat een grote gelijkenis tussen Vlaanderen en Nederland wat betreft de relatieve grootte van broeikasgasemissies uit de verschillende industriële sectoren (bijvoorbeeld grote emissies van de raffinage- en de chemische industrie zowel in Nederland als Vlaanderen). Nederland en Vlaanderen hebben ook twee grote havengebieden met een grote industriële aanwezigheid (e.g. Antwerpen en Rotterdam).

Vlaamse industriële sectoren opereren niet geïsoleerd van de rest van Europa. Zo zijn er grote infrastructuurverbindingen (b.v. pijpleidingen) tussen de industriële clusters in Nederland, Vlaanderen en de regio Noordrein Westfalen in Duitsland. In het kader van de transitie naar een lage koolstofeconomie zal coördinatie tussen deze regio's belangrijk zijn. Daarom kan Vlaanderen bijvoorbeeld gebruik maken van initiatieven onder de recente 'Trilaterale Strategie voor de Chemische Industrie', opgericht door de respectieve overheden en bedrijven van deze regio's om supranationaal energiebeleid, infrastructuur en ondersteunende maatregelen voor innovatie voor de chemische industrie in het bijzonder te bespreken.

Ten slotte bestaat er al praktische interregionale samenwerking tussen de industrie in de Gentse havenregio en het Nederlandse Terneuzen-gebied in de vorm van het nieuwe Northsea Port. Een groep bedrijven binnen dit gebied, verenigd onder SmartDelta Resources, presenteerde onlangs wat waarschijnlijk de eerste interregionale koolstofarme routekaart is. Het toont duidelijk de voordelen (maar ook uitdagingen) van samenwerking tussen aangrenzende industriële clusters. Deze samenwerkingsverbanden verdienen specifieke aandacht bij de ontwikkeling van een Vlaams industrieel low-carbon transititiekader.

Analyse van industriele low-carbon roadmaps

Algemene bevindingen

De analyse van de belangrijke Europese (en regionale) roadmaps geeft aan dat in een groot aantal sectoren (staal, chemicaliën, keramiek en papier) op Europees maar ook op nationaal (Nederland) of regionaal niveau (Haven van Rotterdam), in theorie, diepe emissiereducties (meer dan 80 %) mogelijk zijn maar nog steeds grote inspanningen vergen. Veel baanbrekende technologieën die evenwel nog commercieel bewezen moeten worden (zoals opvang, transport, opslag en/of gebruik van CO_2 (CC(U)S) en op waterstof gebaseerde grondstoffen en synthetische brandstoffen) worden voorgesteld als essentiële technologieën voor diepe emissiereducties.

Er zal echter een mix van verschillende technologieën moeten worden toegepast binnen en tussen industriële sectoren. De toepassing is echter afhankelijk van lokale omstandigheden, b.v. de beschikbaarheid van zuivere CO_2-stromen en opslaglocaties voor CO_2, betaalbare en betrouwbare biomassa en/of waterstofproductie (H_2) (bijvoorbeeld via hernieuwbare elektriciteit), potentieel voor industriële symbiose, enzovoort. Het toepassen van deze nieuwe technologieën zal gepaard gaan met hoge kapitaalintensiteit (CAPEX), maar ook de operationele uitgaven (OPEX) van de nieuwe technologieën zijn vaak nog steeds ook hoger zijn in vergelijking met de momenteel gebruikte procestechnologieën.

Volgend uit de analyse van technologische roadmaps is het ook zeer waarschijnlijk dat de vraag naar elektriciteit vanuit de industrie aanzienlijk zal stijgen in de meeste decarbonisatiescenario's en daardoor extra uitdagingen toevoegt voor het energiesysteem. Daarenboven stelt de Europese energieroadmap 2050 van de Europese Commissie (2011) dat in het algemeen, het niet-energetisch energiegebruik in de industrie ook niet aanzienlijk zal dalen tot 2050.

De meeste roadmaps die bekeken werden in deze studie zijn consistent voor wat betreft hun beleidsaanbevelingen. Ten eerste laten ze zien dat er een duidelijke behoefte is aan een 'missiegericht' O&O beleidskader met specifieke aandacht voor de ondersteuning van grote industriële demonstratieprojecten. Dit omvat het faciliteren van de financiering voor deze technologische uitdagingen. De roadmaps geven ook aan dat er urgent werk moet gemaakt worden van implementatie omwille van de lange investeringscycli in de energie-intensieve industrie. Omdat deze cycli periodes van 20 tot 30 bestrijken blijft er eigenlijk maar een grote investeringsronde over tot en met 2050. Voorts pleiten de meeste roadmaps voor een coherent en stabiel regelgevend kader om de concurrentiepositie van de energie-intensieve industrie te vrijwaren. Tenslotte leggen de roadmaps ook vaak de link met de low-carbon transitie in de energiesector en vragen ze een sterkere band met de transitie van de energie-intensieve industrie.

Relevantie voor Vlaanderen

Voor Vlaanderen kan de informatie in de bestudeerde roadmaps nuttig zijn op een algemeen niveau, maar een directe vertaling van technologieën en trajecten van Europese roadmaps naar Vlaanderen is niet triviaal.

De specifieke regionale context (bijvoorbeeld de beschikbaarheid van betaalbare biomassa, H_2 en elektriciteit of toegang tot CCS-infrastructuur) zal belangrijk zijn om de toepasbaarheid van (technologische) mitigatiemogelijkheden in Vlaanderen te beoordelen. Het is echter duidelijk dat, ongeacht de specifieke opties die in Vlaanderen zullen worden gekozen er een aanzienlijk investeringsbedrag (CAPEX) nodig zal zijn in de komende decennia om investeringen in koolstofarme productieprocessen en gerelateerde infrastructuur te financieren. Zo schatte McKinsey & Co (2017) de CAPEX die vereist is voor een Nederlandse industriële koolstofarme overgang op 55-71 miljard euro tegen 2050 (voor respectievelijk -80% en -95% emissiereducties). De mogelijke gelijkenis tussen de Nederlandse en de Vlaamse energie-intensieve industrie nodigt uit tot een diepere analyse van de industriële low-carbon transitie en implementatie in Nederland en hoe/of de verschillende voorgestelde trajecten relevant kunnen zijn voor Vlaanderen.

Analyse van innovatieve low-carbon technologieen voor de industrie

Deze studie keek naar de recente ontwikkelingen in low-carbon doorbraaktechnologieën in de staal-, chemie, papier- en keramische industrie. In het bijzonder werden technologieën beoordeeld die tot grote emissiereducties in industriële processen konden leiden.

In de staalindustrie wordt een veelbelovende carbon capture and utilisation (CCU) technologie getest op de Arcelormittal-site in Gent. Deze technologie (Steelanol) in het bijzonder en CCU in het algemeen kunnen een belangrijke rol spelen in de Vlaamse industriële low-carbon transitie, gezien het grote potentieel om emissies in de petrochemische productie (bijvoorbeeld afkomstig van ammoniak-, ethyleen- en propyleenproductie) te verminderen. Daarom moet een toekomstig industrieel transitiekader voor Vlaanderen het potentieel voor integratie van industriële processen en waardeketens verder verkennen. Staalproductie op basis van H_2 belooft grote emissiereducties, maar de commerciële levensvatbaarheid zal grotendeels afhangen van goedkope (en op hernieuwbare energie gebaseerde) H_2-productie. Dit nieuw proces is ook hoogstwaarschijnlijk niet verenigbaar met de bestaande staalproductie in Vlaanderen omdat het nieuwe proces een heel grote verandering is ten opzichte van de huidige geïntegreerde staalproductielijn.

Voor de Vlaamse chemische industrie zijn nieuwe low-carbon processen die processen gebaseerd op nafta (feedstock) kunnen vervangen voor ethyleen-, propyleen-, butadieen- en BTX-productie. Voor ammoniakproductie, nu gebruik makend van methaan als feedstock zijn er technologieën in ontwikkeling die gebruik maken van waterstof of koolstof-opslag (CCS). Veel van deze doorbraaktechnologieën hangen echter voor commercieel succes in grote mate af van de beschikbaarheid van goedkope low-carbon H_2 productie. Ook de hogere totale elektriciteitsvraag en de benodigde geïnstalleerde productiecapaciteit en daaraan gerelateerde kosten zullen dus waarschijnlijk aanzienlijk stijgen. Wanneer CO_2 als grondstof wordt gebruikt, zal de extra elektriciteitsvraag nog hoger zijn. Investeren in bio-based chemicaliën, in het bijzonder als bio-based inputs kunnen worden gebruikt om hoogwaardige chemicaliën te produceren, kan relevant zijn voor Vlaanderen. Er moet echter worden gezorgd voor voldoende grote en stabiele toeleveringsketens voor biomassa en ook voor een economisch haalbare prijs van de bio-based inputs. Als deze doorbraaktechnologieën (in het bijzonder H_2 en op biomassa gebaseerde chemicaliën) willen concurreren met bestaande op fossiele brandstoffen gebaseerde technologieën zal er meer doorgedreven O & O nodig zijn samen met de optimalisatie van processen op grote schaal. Voorts zal er ook nood zijn aan beschikbaarheid van voldoende goedkope, betrouwbare low-carbon elektriciteit en biomassa.

Onderzoek naar geavanceerde circulaire economie technologieën en technieken die het terugwinnen van basischemicaliën en kunststoffen mogelijk maken of ervoor zorgen dat afvalstromen kunnen worden omgezet in feedstock of energie voor de industrie, zal cruciaal zijn om de overgang naar koolstofarme chemicaliën in Vlaanderen mogelijk te maken. Daarenboven zal een circulaire economie de druk verlichten op de bovenvermelde grote bijkomende vraag naar low-carbon elektriciteit en biomassa in Vlaanderen.

In de papiersector zullen de meeste van de geëvalueerde doorbraaktechnologieën ook een aanzienlijk effect hebben op het elektriciteitsverbruik, maar het energieverbruik en de uitstoot van broeikasgassen zullen wel verminderen. De toepassing van deze technologieën zal waarschijnlijk afhangen van het specifieke type van papierproductie-installaties. Voor de keramische industrie bestaan er opties om het warmtegebruik (bijvoorbeeld door middel van warmtekrachkoppeling (WKK)) te optimaliseren. Het toepassen van innovatieve technologieën kan een uitdaging zijn voor kleinere keramische producenten in Vlaanderen vanwege de hoge CAPEX die gepaard gaat met sommige van deze investeringen in verhouding tot de omzet van de fabrieken.

Langdurige en geduldige O&O ondersteuning lijkt een essentiële vereiste om doorbraaktechnologieën van het laboratorium naar de markt te brengen in het bijzonder door middel van het ondersteunen piloot- en demonstratieprojecten. Verschillende van de in kaart gebrachte technologieën hebben reeds aanzienlijke EU-financiering ontvangen, waaronder enkele van de meer vergevorderde innovaties zoals het HIsarna-project low-CO_2 staal project. Nationale financiering voor low-carbon technologieën zoals die van het Duitse federale ministerie van

Onderwijs en Onderzoek of het Nederlandse Ministerie van Economische Zaken heeft ook een vitale rol gespeeld in de technologische ontwikkeling die essentieel is voor een koolstofarme overgang.

Scope van een Vlaams industrieel transitiekader naar een lagekoolstofeconomie

Op basis van de feedback die is verkregen via een indicatieve enquête en de besprekingen met de begeleidingsgroep bij deze studie, kan worden geconcludeerd dat er geen behoefte is aan een Vlaamse industriële low-carbon roadmap (of meerdere sectoriële roadmaps) die zich louter richt op scenario's, technologieën en kosten van overgang naar een koolstofarme economie.

Er is wel interesse voor een aanpak die het faciliteren van een bredere industriële transitie in Vlaanderen in overweging neemt. Dit zou kunnen worden gedefinieerd als een faciliterend Vlaams industrieel transitiekader voor een koolstofarme economie, gerelateerd aan innovatie, infrastructuur en financiering. Op basis van de feedback die is ontvangen tijdens de consultaties met stakeholders in de begeleidingsgroep, zullen de volgende elementen in aanmerking dienen genomen worden bij het ontwikkelen van een dergelijke aanpak:

- Het is belangrijk om dubbel werk en versnippering van het industriebeleid te vermijden en daarom moeten de EU-sectorale roadmaps (en toekomstige initiatieven) en de internationale context in aanmerking worden genomen bij de ontwikkeling van een Vlaams industrieel transitiekader.
- De energietransitie in België en Vlaanderen kan belangrijke gevolgen hebben voor het industriële concurrentievermogen en de industriële low-carbon transitie en omgekeerd. Beide processen moeten daarom (komen) goed op elkaar worden afgestemd.
- Het transitiekader is bedoeld om innovatie, financiering en infrastructuur te vergemakkelijken en mag niet worden gezien als een instrument om aanvullende broeikasgasemissiedoelstellingen of reductietrajecten voor industriële sectoren in te voeren.
- Het transitiekader kan kijken naar industriële clusters, waardeketens en de mogelijke synergiën tussen bedrijven, industriële en niet-industriële sectoren.
- De term 'koolstofarm', hoewel vaak gebruikt in deze context, kan verwarrend zijn. De transitie is niet bedoeld om de aanwezigheid van het chemische element 'koolstof' in producten of processen te verminderen en mag het gebruik van CO_2 in industriële processen niet voorkomen.

In het algemeen moet het transitiekader gericht zijn op het realiseren van een faciliterende omgeving door middel van innovatie, financiering en infrastructuur. Het moet voorts synergiën en symbiose tussen bedrijven, sectoren, regio's en beleid mogelijk maken. Dit kan onder meer door het mogelijk maken van (of het wegnemen van hindernissen voor) doorgedreven circulariteit langs de waardeketens van de basisindustrieën in Vlaanderen en de afstemming van industriële transitie op de energietransitie en vice-versa.

Ten slotte zal de ontwikkeling van een dergelijk transitiekader de steun van meerdere stakeholders vereisen (bijv. bedrijven, sectoren, gespecialiseerde wetenschappelijke instellingen, innovatie-actoren in Vlaanderen, vakbonden, NGO's, de financiële sector, technologieleveranciers, industriële leveranciers, klanten, energieleveranciers, netbeheerders en overheidsdiensten met bevoegdheden in deze gebieden). Idealiter vindt de governance van een dergelijk proces plaats door middel van een constructieve dialoog tussen de publieke sector en de industriële sectoren.

Naar een Vlaams industrieel transitiekader voor een lagekoolstofeconomie

Het is van belang dat de Vlaamse industrie zich voorbereidt op de transitie naar een lage koolstof economie en inzet op innovatie om competitief te blijven tijdens deze transitie met perspectief 2050. **De Vlaamse overheid moet hier optimaal op inspelen door een concreet kader uit te werken om de competitiviteit van de Vlaamse bedrijven te garanderen.**

Het doel van een transitiekader is een faciliterend kader voor de industrie te scheppen om de low carbon transitie van de industrie mogelijk te maken. Het kader zal dus enerzijds informatie dienen te capteren die nuttig kan zijn om barrières te verwijderen en om synergiën te faciliteren. Anderzijds is het belangrijk dat de knowhow en de ervaringen met innovatieve technologieën op een efficiënte manier aangewend kunnen worden om een stuwende kracht te krijgen in het innovatielandschap. Tot slot is een competitief kader nodig om de investeringen te kunnen aantrekken in Vlaanderen om tot een win-win te komen tussen klimaatambities en welvaart. Dit belang werd ook onderschreven in actie 5.2.2. 'Transitiekader inzake de omschakeling naar een koolstofarme economie' uit het voorontwerp van Vlaams Klimaatbeleidsplan 2020-2030. Landen en regio's die proactief een visie en strategische innovatie-excellentie ontwikkelen en de nodige cofinanciering voorzien, zullen daarenboven ook een grotere kans hebben om Europese financiering te krijgen.

Gezien de omvang van de transitie, het maatschappelijk belang en het grote aantal betrokken partijen is het belangrijk dat de voorbereiding op deze **transitie op een coherente wijze gebeurt, gedragen wordt door overheid, bedrijfsleven en andere relevante stakeholders**. Het gaat hier immers over een lange termijn transitie waaraan veel (technologische en economische) onzekerheden en risico's verbonden zijn. Het transitiekader moet voor de betrokken partijen duidelijk maken wat hun rol en engagement hierin kan zijn. Het hele proces moet dan ook transparant zijn en bovendien moet bijsturing mogelijk zijn.

Het startpunt van de opmaak van een industrieel transitiekader is de kennis die reeds aanwezig is in Vlaanderen (en buiten Vlaanderen) en het bestaande economisch landschap in Vlaanderen.

Daarnaast werden een aantal **onderzoeksvragen** opgesteld, waarbij in samenspraak met de relevante stakeholders het transitiekader een manier moet vinden om deze te behandelen.
Ook kunnen er inzichten verkregen uit **een techno-economische analyse van de verschillende high level technologieën en hun opportuniteiten**, ter ondersteuning van de onderzoeksvragen, gebruikt worden.

Over hoe het transitiekader zal worden opgebouwd, of hoe het transitiekader deze onderzoeksvragen moet behandelen, kan nog gee door alle betrokken partijen gedragen werkwijze worden voorgesteld. Volgende stappen kunnen hiertoe bijdragen:

- Interdepartementale afstemming tussen het Departement Economie, Wetenschap en Innovatie (EWI) en het Departement Omgeving over de verdere aanpak. Er wordt gestreefd deze afstemming met een voorstel van plan van aanpak voor eind 2018 te finaliseren.
- Identificatie van betrokken actoren.
- Finaliseren van het plan van aanpak in samenspraak met de betrokken actoren.

Bij de uitvoering van bovenstaande stappen zal er over gewaakt worden dat:

- Verderzetting van de bestaande samenwerking tussen verschillende betrokken actoren cruciaal blijft.
- Generieke aspecten in de mate van het mogelijke op Vlaams niveau besproken worden om versnippering en ontdubbeling van het overleg te vermijden. Typisch lokale aspecten (zoals infrastructuur en logistiek en lokale knelpunten/barrières) kunnen op lokaal niveau besproken worden.
- De werklast voor de bedrijven en betrokken actoren bij het behandelen van de onderzoeksvragen tot een minimum beperkt wordt.

PREFACE

In 2011 the European Commission published a roadmap for moving to a competitive low-carbon economy in 2050. It sets out a cost effective trajectory towards an 80% *greenhouse gas* (GHG) *reduction by 2050. The European Commission is currently preparing an update of this roadmap* to match the increased ambition level of *the Paris agreement, under which parties have committed to limit the global increase in average temperature to well below 2°C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5° C above pre-industrial levels. Europe is therefore, facing an unknown transition to a low-carbon and sustainable economy in a relatively short time period.*

The Flemish government supports the European long-term objective to reduce GHG emissions by at least 80% to 95% by 2050 (compared to 1990 levels) with interim objectives set for 2020 and 2030, and approved on May 19th 2017 the "Vlaamse energievisie", documenting the vision of Flanders on a carbon-neutral and sustainable energy system.

It is obvious that the industry will be a part of and play an important role during this transition. New technologies, products, raw materials and production processes will be necessary. One of the actions in the "Vlaamse energievisie" was to investigate the possibility of developing sectoral roadmaps.. Therefore, in this study, existing low-carbon roadmaps developed across Europe and the added value of additional roadmaps are investigated. These sectoral roadmaps can be a useful instrument and guidance towards a low-carbon production and products pathway.

When discussing the added value of additional industrial sectoral low-carbon roadmaps, the correlation with European regulation should be taken in account. It should be noted, that there is a clear distinction between the ETS and non-ETS sectors. ETS-sectors are regulated by harmonized European rules and are operating on an international scale. The transition to a low-carbon economy however, will result in an important transformation even for the ETS companies. On the other hand , the ETS sectors will produce products that reduce emissions in the non-ETS sector. Therefore, this link and the ratio between process emissions and avoided emissions is also very relevant. Different scenarios predict a CO_2 *value that will be much higher than the current value. However, this value is uncertain. Also, the specific sectoral exposure to this change is still uncertain and depends on the development of carbon pricing systems and the resulting burden on industry outside of the EU. This study therefore aims to identify the steps needed to keep Flemish companies competitive and innovative in a low-carbon environment and develop a useful framework while avoiding overlaps with EU-instruments.*

The Department of Environment and Spatial Development has ordered an exploratory study to investigate the added value of the development of an industrial low-carbon roadmap for Flanders. The goal of this study is to identify the possibilities for Flanders to undertake the transition to a low-carbon European economy, including the contribution of industrial sectors to lowering GHG emissions in other sectors. This can take the form of transition pathways, roadmaps or even innovation scenarios or an enabling framework.

2 INTRODUCTION

2.1 GENERAL APPROACH AND STRUCTURE OF THIS PROJECT

This report profiles Flemish energy intensive industries, in the context of the transition to a low-carbon economy, through the analysis of relevant data, studies and technology roadmaps. The goal of this report was to utilise information and input from relevant stakeholders in order to investigate the added value of developing future industrial low-carbon visions for Flanders. It also sought, with an optimal contribution by industry, to put forth a proposal on the possible scope and blueprint of a future facilitative framework towards a Flemish low-carbon economy taking into account the interactions and possible synergies between energy intensive industries and the rest of the economy.

This report contributes to establishing the role of the Flemish government in facilitating this low-carbon industrial transition.

The scope of this study is the energy intensive industry sector in Flanders. In practice this scope will coincide with the sectors covered by the European Union (EU) Emissions Trading System (ETS). For Flanders, these sectors are refining, chemicals (including rubber and plastics), iron and steel, food and beverages, non-ferrous metals, ceramics, pulp and paper, textiles and wood products. The main focus of this study will be on the sectors with highest share of greenhouse gas (GHG) emissions within industry (i.e. steel, chemicals and refining).

The research consisted of three phases:

Phase 1:

First, a detailed profiling of the Flemish energy intensive industries, including a comparison with four key neighbouring European countries - Germany, France, the Netherlands and the UK - was carried out through a literature study. This included sector specific data and time series on GHG emissions and energy use but also socio-economic data such as gross value added (GVA), employment and investments. For a selection of important products from energy intensive industries a brief analysis of trade flows was conducted. Using this information and additional literature, a brief SWOT analysis was done for the Flemish energy intensive industries in the context of moving towards a low-carbon economy. Furthermore, recent Flemish studies or research projects, relevant in the context of moving to a low-carbon industry, are presented. Finally, a short overview of Flemish strategies and policies that link to industrial decarbonisation and the circular economy has been developed.

The second part of the analytical work compared the Flemish (energy intensives) industrial profile with those of the above-mentioned neighbouring countries and explored connections between Flemish industry and neighbouring industrial clusters.

This was followed by the analysis of low-carbon (European, global, regional and cluster) roadmaps focussing on energy intensive industries published since 2010. In addition, an overview of technological mitigation options for major energy intensive industrial sectors was created.

During this phase, a first consultation round was held with the advisory committee with regard to the scope and design of a possible future Flemish industrial low-carbon framework.

Phase 2:

The next step of the process investigated the possible added value of a Flemish industrial low-carbon framework and the role of the Flemish government and industrial sectors in the development of the scope and design of such a future Flemish industrial framework. An electronic survey was carried out to consult all members of the advisory group with the goal to gain insights into preferences regarding the scope and implementation options of such an industrial transition framework. The results of this survey were afterwards discussed with the advisory group was. This survey was constructed using feedback and information gathered in Phase 1. The results of the survey were used as a discussion tool to facilitate the design of a possible forthcoming Flemish low-carbon industrial transition framework.

Phase 3:

The final phase of the project aimed at the further elaboration of the development of a future Flemish industrial transition framework towards a low-carbon economy. This was done through intensive consultations with stakeholders, including the use of an ad hoc working group (a selection of representatives from the advisory committee of this study). The result is an action plan for the development of an industrial low-carbon transition plan for Flanders together with the next steps that will be taken to start this process.

2.2 GUIDANCE TO THE STRUCTURE OF THIS REPORT

This report starts by profiling the Flemish industries in Chapter 3. This includes sector-specific data and time series on GHG emissions and energy use, and socio-economic data such as GVA, employment and investments. For important products from energy intensive industries, a brief analysis of global trade is presented. This is followed by a brief discussion of the policy landscape in Flanders (and where relevant, the EU) in relation to the transition to a low-carbon industry and economy. This includes an analysis of present Flemish Research & Innovation (R&I) initiatives and other Flemish (policy) research that can be relevant (e.g. Key Enabling Technologies mapping, Carbon Capture and Usage (CCU) inventory). It is followed by a fly-over with regard to the broader policy and regulatory landscape in Flanders, again, with objective of facilitating a transition to a low-carbon economy. Chapter 3 concludes by presenting a brief ‘SWOT’ analysis of Flemish (energy intensive) industries, in particular with regard to the transition to a low-carbon economy.

Chapter 4 profiles comparable industries in neighbouring countries (UK, France, Netherlands and Germany). Across the same sectors analysed in Chapter three, for each country, emissions, GVA and employment data is considered. This is followed by a brief assessment of industrial regions similar to the Flemish industrial cluster.

Chapter 5 presents a synopsis of a selection of the most pertinent European low-carbon roadmaps that were analysed extensively during this project and how these roadmaps can be relevant for Flanders.

Chapter 6 presents a literature review of the latest developments with regard to low-carbon breakthrough technologies in iron and steel, chemicals, paper and ceramics production. An assessment of the possible relevance of these technologies to these same industrial sectors in Flanders is then presented.

Chapter 7 investigates the possible scope of a Flemish industrial transition framework and the role of the Flemish government and industrial sectors to develop such a framework. The main tools for assessing the specific preferences and concerns of the stakeholders (represented in the advisory committee to this study) were an electronic survey together with further discussions within the advisory committee.

Finally, chapter 8 presents a practical way forward by demonstrating the need for a Flemish industrial transition framework. It also identifies the main research questions that can assist with the development of such framework and shows how the development of the framework can be organised. The chapter ends with outlining the next steps that will be undertaken to start with the development of a Flemish industrial transition framework.

3 PROFILING FLEMISH INDUSTRY

3.1 INTRODUCTION

The scope of this study are the energy intensive industries in Flanders. In practice this scope will coincide with the sectors covered by the EU ETS. For Flanders these sectors are refining, chemicals incl. rubber and plastics, iron and steel, food and beverages, non-ferrous metals, ceramics, pulp and paper, textiles and wood products.

First, the GHG emissions of these industries and these emissions as a share of the total economy will be looked at, including their evolution over time. Next, the energy use of these industries is presented, including the different energy sources and evolution since 1990[5]. The analysis on avoided emissions in the use of the products is important from both an economic as environmental perspective, and was advised by the advisory committee. However, due to time constrains this was not taken into account.

The emissions data used in this section comes from the 'Vooruitgangsrapport (*Progress Report*) 2016-2017, Vlaams Klimaatbeleidsplan (*Flemish Climate Plan*) 2013-2020, luik mitigatie (*part mitigation*),' published by the Vlaamse Overheid (*Flemish Government*) in February 2018[6] and from the data sheet 'ETS Vaste Installaties - emissies en toewijzingen_individueel, per gemeente en per sector' published by the Departement Omgeving (Afdeling EKG) (*ETS stationary installations – emissions and allocations*) at the Vlaamse Overheid in 2017[7]. The energy data is in this report is based on the 'Energiebalans Vlaanderen (*Flemish Energy* Balance) 1990-2014'[8] and the "Balansen EMIS cijfers' spreadsheets published by The Flemish Institute for Technology Research (VITO).

For each of the industrial sectors (at NACE2 level) important socio-economic parameters and their evolution over time is presented. This includes the evolution of GAV, employment and investments of these industries in Flanders. For some of the main industries, trade data of important products will be presented. The data for these parameters comes from the annual statistics published by the 'Nationale Bank van België (NBB)' and 'Statbel'. Major trade flows are also identified.

For sectoral outline the NUTS 2 (Nomenclature of territorial units for statistics) classification was used and NACE 2 levels for identification of sectors. The latter does not fully match with the industrial sectors covered by the EU ETS in Flanders, but is deemed sufficiently representative with regards to the use of major socio-economic parameters in this report. Under this classification, refining and cokes production fall under the same category, as do the non-ferrous and ferrous metals production. For the chemicals industry, the categories 'chemicals production' (NACE 20) and plastics and rubber production' (NACE 22) were merged. The pharmaceutical sector has not been considered due to its much lower energy and GHG intensity.

The following NACE2 level sectors were considered and have been aggregated as being most representative of the energy intensive industries (covered by the EU ETS).

[5] The analysis on avoided emissions by the use of the products is important from both economic as environmental perspective, and was advised by the advisory committee. However, due to time constraints this was not taken into account.
[6] https://www.lne.be/sites/default/files/atoms/files/VORA2016-2017_Mitigatie.pdf
[7] https://www.lne.be/eu-ets-vaste-installaties-cijferoverzicht-vlaanderen-toewijzingen-en-emissies
[8] A new edition 'Energiebalans 1990-2016' is available now.

- Manufacture of food products, beverages and tobacco products (10-12)
- Manufacture of textiles, wearing apparel and leather products (13-15)
- Manufacture of wood and of products of wood and cork (except furniture); manufacture of articles of straw and plaiting materials (16)
- Manufacture of paper and paper products (17)
- Manufacture of coke and refined petroleum products (19)
- Manufacture of chemicals and chemical products (20) and manufacture of rubber and plastics products (22)
- Manufacture of other non-metallic mineral products (23)
- Manufacture of basic metals (24)

For the analysis of investments in Flanders, the more detailed NACE 3 level was used where needed. The data for these parameters analysed in this section comes from the annual statistics published by the 'Nationale Bank van België (NBB)' (for GVA and employment) and from Statbel for investments[9].

This chapter starts with an aggregate profile of Flemish industry. This includes GHG emissions, energy use, GVA, employment, investments and sectoral concentration. Subsequently, a similar analysis is presented for the main energy intensive sectors separately. This is followed by an assessment of trade and trade flows for products of energy intensive industries. Next, a brief overview is provided of relevant research projects and initiatives in relation with the decarbonisation of energy intensive industries. This includes investigating present Flemish R&I initiatives and other Flemish (policy) research that can be pertinent (e.g. Key Enabling Technologies mapping, CCU inventory). The chapter ends with a SWOT analysis of these industries in Flanders in the context of a transition to a low-carbon economy.

3.2 AGGREGATE PROFILING OF FLEMISH INDUSTRY

3.2.1 Greenhouse gas emissions

In 2016 the economy-wide GHG emissions of Flanders were 77.7 million tonnes carbon dioxide equivalent (Mt CO_2-eq). Emissions from industrial sectors[10] stood at 27.9 Mt CO_2-eq or around 36% of total emissions. Since 1990, economy-wide emissions in Flanders decreased 10% (from 86.4 Mt CO_2-eq to 77.7 Mt CO_2-eq), while emissions from industry fell 13% (from 32 Mt CO_2-eq to 27.9 Mt CO_2-eq).

[9] All data used was extracted from NBB http://stat.nbb.be/?lang=en (Regional accounts by A38 - NUTS 2) for GVA per sector and employment per sector en Statbel https://bestat.statbel.fgov.be/bestat/crosstable.xhtml?datasource=095cb5e3-a398-4372-8f30-3f9d96b3abd7 (Omzet en investeringen per jaar, trimester, provincie en economische activiteit (NACE 2008) volgens de BTW-aangiften) for investments per sector.
[10] This includes both the emissions from industry covered and not covered by the EU Emissions Trading System.

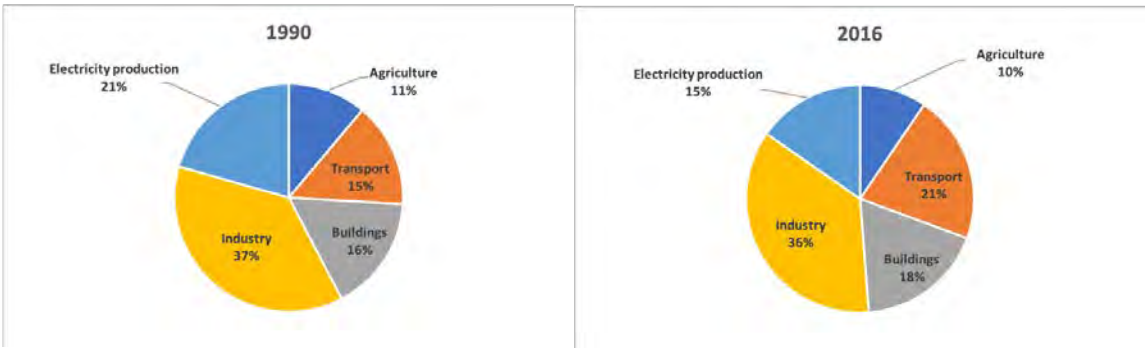


Figure 1: Shares of sectoral emissions 1990 [Left] and 2016 [Right] (as a percentage) (Source: Vlaamse overheid, 2018)

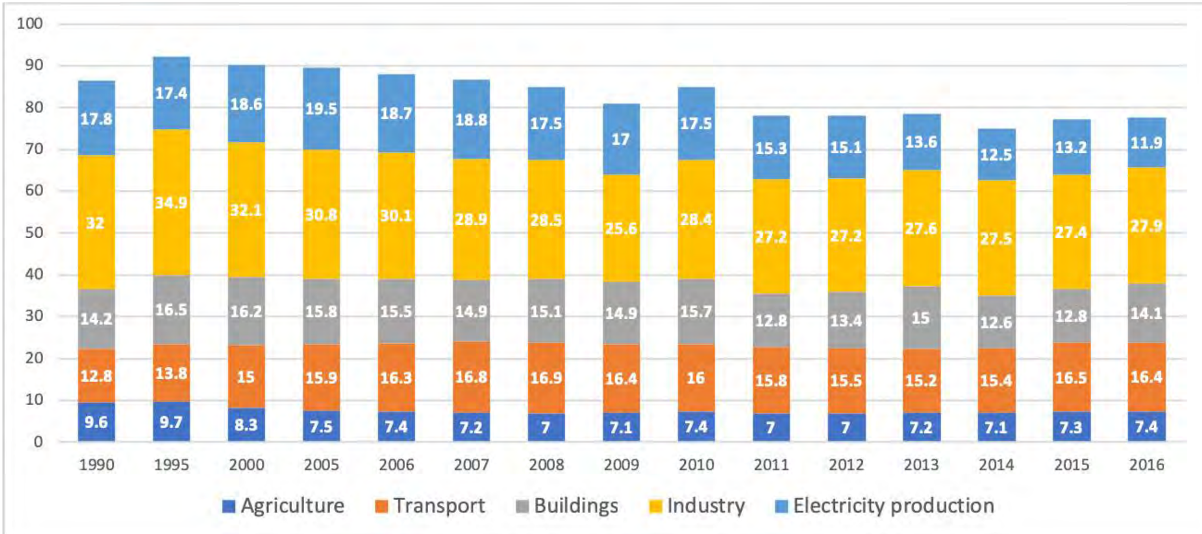


Figure 2: Flemish economy-wide GHG emissions between 1990 and 2016 (Mt CO_2-eq) (Source: Vlaamse overheid, 2018)

The energy intensive industries in Flanders, which fall under the scope of the EU ETS, represented 80% (22.4 out of 27.9 Mt CO_2-eq.) of Flemish industrial GHG emissions in 2016. The share of Flemish industrial EU ETS sectors as part of overall Flemish industry fell from 87% to 80% between 2005 and 2016, taking into account the changes to the EU ETS scope in that period[11].

[11] The changes to EU ETS scope are discussed in the Vooruitgangsrapport – luik mitigatie 2017 bij Vlaams Klimaatbeleidsplan 2013-2020 p. 24

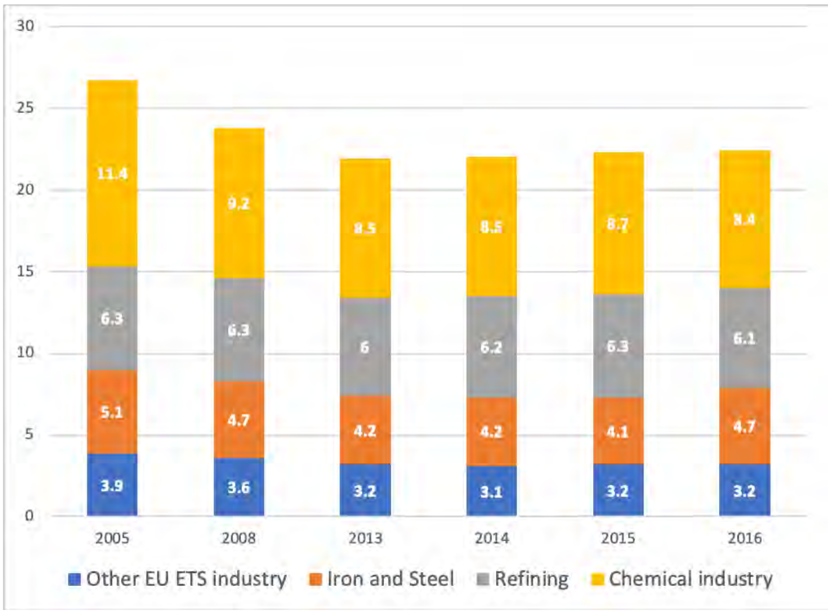


Figure 3: Evolution of GHG emissions under EU ETS (Mt CO_2-eq.). (Source: Vlaamse Overheid, 2018)

The emissions of Flemish industrial EU ETS sectors fell 16% between 2005 and 2016 (from 26.7 to 22.4 Mt CO_2-eq.), taking into account the changes to the EU ETS scope in that period. The most significant emission reductions ensued in the chemicals sector (from 11.4 to 8.4 Mt CO_2-eq -.a fall of 26%) and in the ceramics, non-ferrous, food and textiles industries (as a combination) (from 3.9 to 3.2 Mt CO_2-eq. - a fall of 18%) over the same period. Part of the emission reductions in the latter sectors can be explained by industrial closures during the period. In particular, smaller industries such as ceramics and textiles, but also the automotive industry, were affected more significantly by those industrial closures. The sensitivity to closures indicates that an intelligent approach on industrial transformation for Flanders must be designed to avoid risking the erosion of competitiveness of the industry since closures will negatively impact welfare in Flanders and simply shift emissions to more competitive regions.

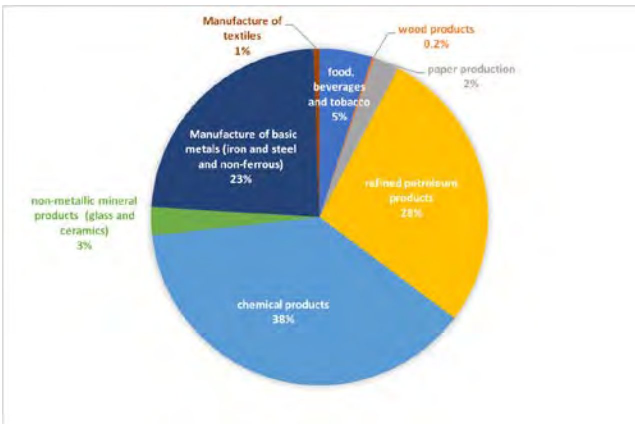


Figure 4: Sectoral shares of industrial GHG emissions covered by the EU ETS in Flanders in 2016 (Vlaamse Overheid, Departement Omgeving , afdeling EKG, 2017)

There exists a strong concentration of large industrial GHG emitters (under the EU ETS) in Flanders both on a sectoral and site basis. On a sectoral basis the combined refining, chemicals and iron and steel sectors in Flanders represented almost 90% of Flemish industrial emissions covered by the EU ETS in 2016. The top 40 of the largest industrial emitters accounted for 90% of those emissions. Only the top 10 largest industrial emitters accounted for 72% of Flemish industrial EU ETS emissions in 2016. The top 40 list consists of all (large) refineries and steel producers. Most of the remaining large emitters in the list are chemicals producers. The rest include 6 food and beverages companies, 3 paper producers, 2 non-ferrous companies and one company each of ceramics, textile and glass production.

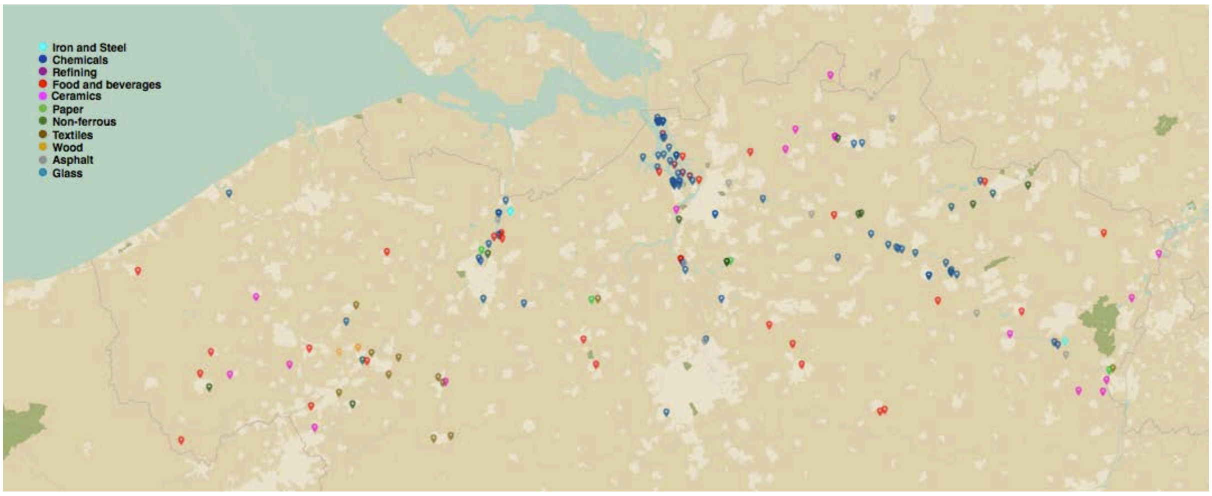


Figure 5: Mapping of industrial EU ETS sites in Flanders. (Sources: IES-VUB, Vlaamse Overheid, Departement Omgeving , afdeling EKG, 2017)

3.2.2 Energy use

In 2016, the final[12] Flemish energy use was 1,232 PJ. Energy use by industry (both as feedstock and for energetic use) was 673 PJ or 55% of final Flemish energy use. Non-energetic use was 279 PJ or 22.6% of the Flemish total energy use. The main fuel sources (non-energetic and energetic use) were naphtha (165 PJ), natural gas (133 PJ), electricity (94 PJ), coal/cokes (84 PJ) and other fuels (76 PJ).

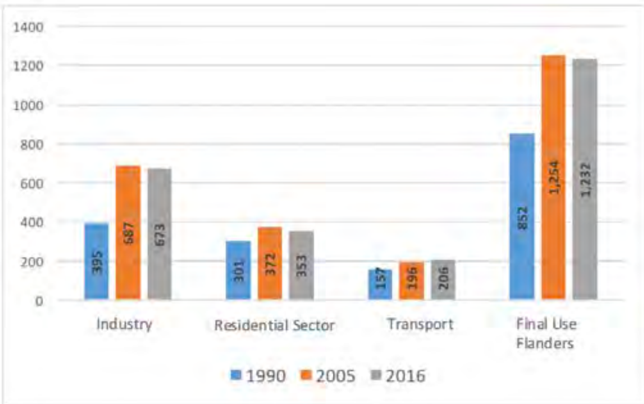


Figure 6: Final energy use of Flanders and major sectors in 1990, 2005 and 2016 (PJ) (Source: VITO, 2017)

Compared to 1990, the total final energy use in Flanders went up 44% (from 852 to 1,232 PJ), with industrial energy use (incl. use as feedstock) rising 70% (from 395 to 673 PJ) - the major contributor to this increase. The total final energy use excluding feedstock in Flanders increased 17% (from 769 to 903 PJ) over the same period, with industrial energy use (excl. use as feedstock) rising 13% (from 312 to 385 PJ).

[12] Excluding energy use in transformation of energy and bunkers.

Figure 7: Share of final energy use per sector in Flanders in 1990 [Left] and 2016 [Right] (Source: VITO, 2017)

3.2.3 Gross value added

In the period 2003-2014 the total GVA (current prices) increased 44% - from EUR 145 Billion (Bn) to EUR 209 Bn. The value added of the aggregated industrial sectors (as listed above) increased 10% in same period (from EUR 18.5 Bn to EUR 20.4 Bn) but with a significant difference in growth rates between sectors. As a result, the contribution of these sectors to the overall Flemish GVA fell from 12.75% in 2003 to 9.74% in 2014.

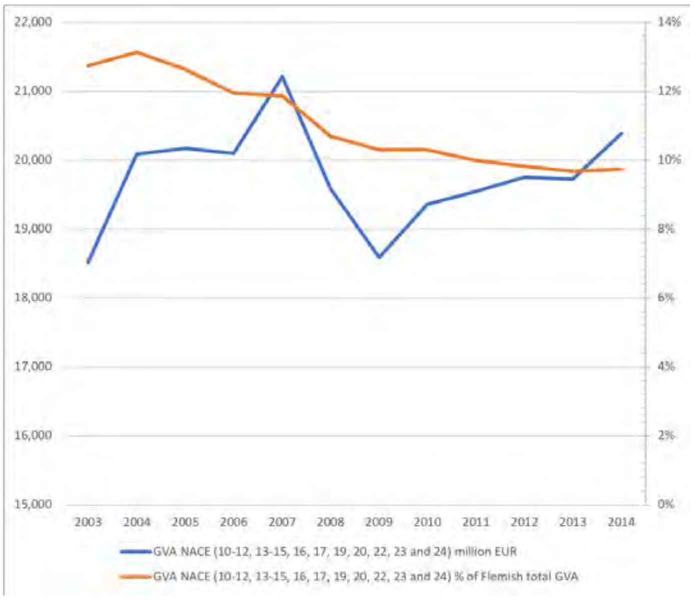


Figure 8: GVA of the industrial sectors together (absolute figure in EUR millions) and as percentage of Flemish total GVA between 2003-2014 (Source: NBB)

3.2.4 Direct Employment

Between 2003-2014, the total employment (number of persons) in Flanders grew 11% - from 2.4 Million (Mn) persons to almost 2.7 Mn persons. Indirect employment was not considered. The industrial sectors (as aggregate of listed NACE codes) registered a 17% decline in employment - from 232,822 to 192,432 persons between 2003 and 2014. Again, there are significant differences between sectors but the downward trend in direct employment was present in all industries covered here[13]. The share of number of people employed by these industries compared to total Flemish employment fell from 9.7% to 7.3 % between 2003 and 2014.

[13] The sectors covered here do also have an important part of subcontracted employment but specific data was not directly available for an assessment in the context of this study.

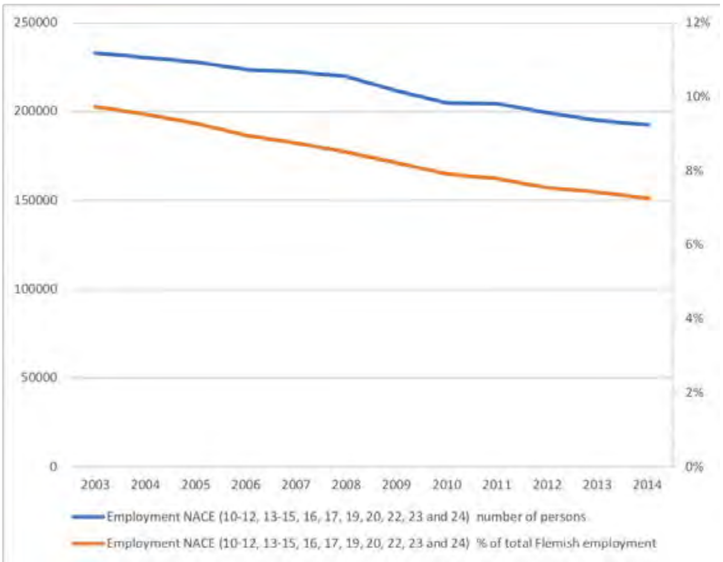


Figure 9: Employment in the industrial sectors combined (absolute, number of persons) and as percentage of Flemish total employment between 2003-2014 (Source: NBB)

3.2.5 Investments

Between 2005 and 2017, total investments in the industrial sectors covered here[14] have grown steadily from EUR 2.08 Bn to EUR 3.66 Bn. 2017 seemed to be an exceptional year as concerns investments which were EUR 800 Mn higher than the 2016 figures (EUR 2.8 Bn). Between 2005-2016 the share of industrial investments as a percentage of total investments in Flanders hovered between 12-15%. In 2017 this figure was 16%.

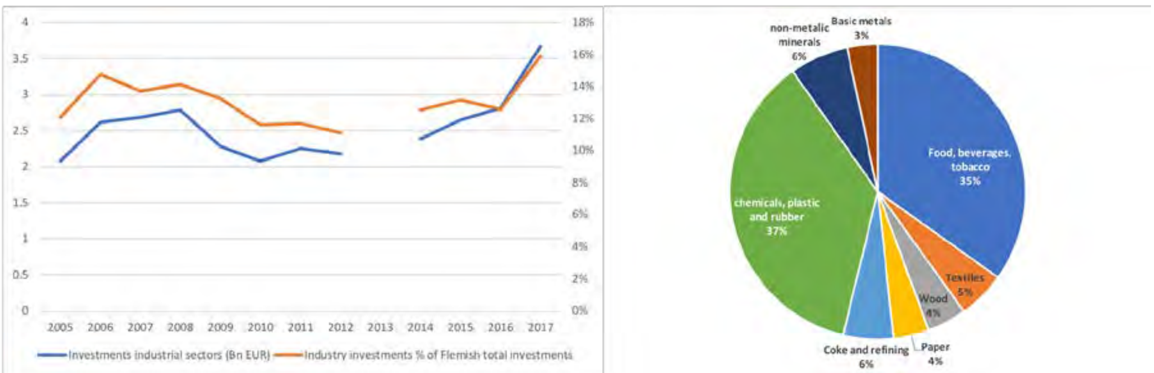


Figure 10: [Left] Energy intensive industry investments in Flanders (in EUR billions and as a percentage between 2005 and 2017 – *2013 data missing*), and [Right] Share of investments in Flanders amongst energy intensive industries. (Source: NBB)

3.2.6 Flemish industrial structure and concentration

Section 3.2.1. demonstrated that most of the Flemish industrial GHG emissions are concentrated amongst the top 10 emitting companies. Industry contribution to employment and value added is highly concentrated in Flanders: just a small group of companies is responsible for most of the value added and employment. De Ruytter et. al (2012) show that in the chemicals and food and beverages industries, just 20% of the companies generate 80% of industrial employment and value added.

[14] Aggregate of NACE 10-12, 13-15, 16, 17, 19, 20, 22, 23 and 24

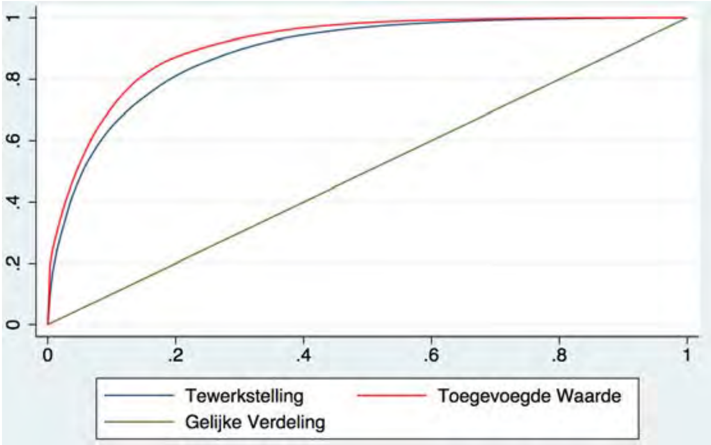


Figure 11: Distribution of GVA and employment in the Flemish chemicals industry (x-axis: share of companies, y-axis: share in employment (blue), value added (red), hypothetical equal distribution (green)) (Source: De Ruytter et al., 2012)

Most of these companies are multinational corporations with global operations. These companies also exhibit a higher productivity (+4%) in comparison to smaller/local corporations. But there also exists an important positive spill-over from these larger firms towards smaller companies that form part of the same cluster. Further improvement in the performance of (local and smaller) companies, according to the De Ruytter et al. (2012), will depend on the enhancement of human capital (e.g. skills that enhance a firm's capabilities), more profound anchoring of multinational corporations in Flanders, and the strengthening of regional industrial clusters. While these suggestions apply to the general performance of industrial sectors, they are also relevant for the development of an industrial low-carbon framework for Flanders

3.3 CRUDE OIL REFINING

3.3.1 Greenhouse gas emissions

Flanders has three large crude oil refineries (operated by Exxonmobil, Total and Gunvor). The GHG emissions from crude oil refining in Flanders remained relatively flat between 2005-2016 with emissions in 2005 standing at 6.3 Mt CO_2-eq and at 6.1 Mt CO_2-eq in 2016. In the same period, the share of crude oil refining emissions as part of the Flemish industrial EU ETS emissions varied between 24% and 28%.

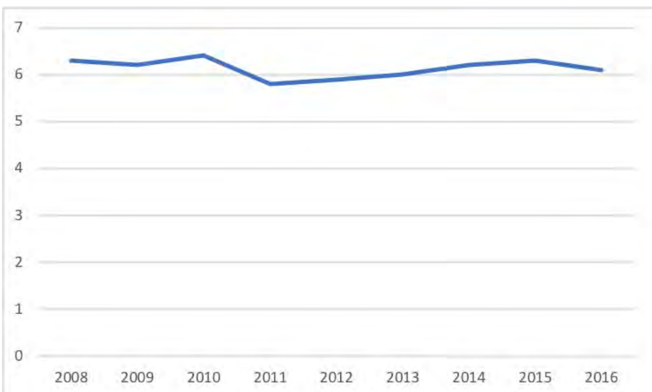


Figure 10 Evolution of GHG emissions of the refining industry covered by EU ETS in Flanders (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017)

3.3.2 Energy use

The main energy input for refining is crude oil. In 1990, the input of crude oil in Flemish refineries stood at 1,250 PJ, growing to almost 1,940 PJ in 2002, and declining afterwards. In 2016, the energy input stood at 1,426 PJ.

The main refining outputs (measured in PJ) in 2016 are gas- and diesel-oil (37%), heavy fuel oil (15%), gasoline (15%), other petroleum products (14%), naphtha (8%) and kerosene (5%). Between 1990-2016 there was a slight increase in the shares of gas- and diesel-oil (from 35% to 37%) and naphtha (from 5% to 8%) while the share of gasoline decreased (from 19% to 15%).

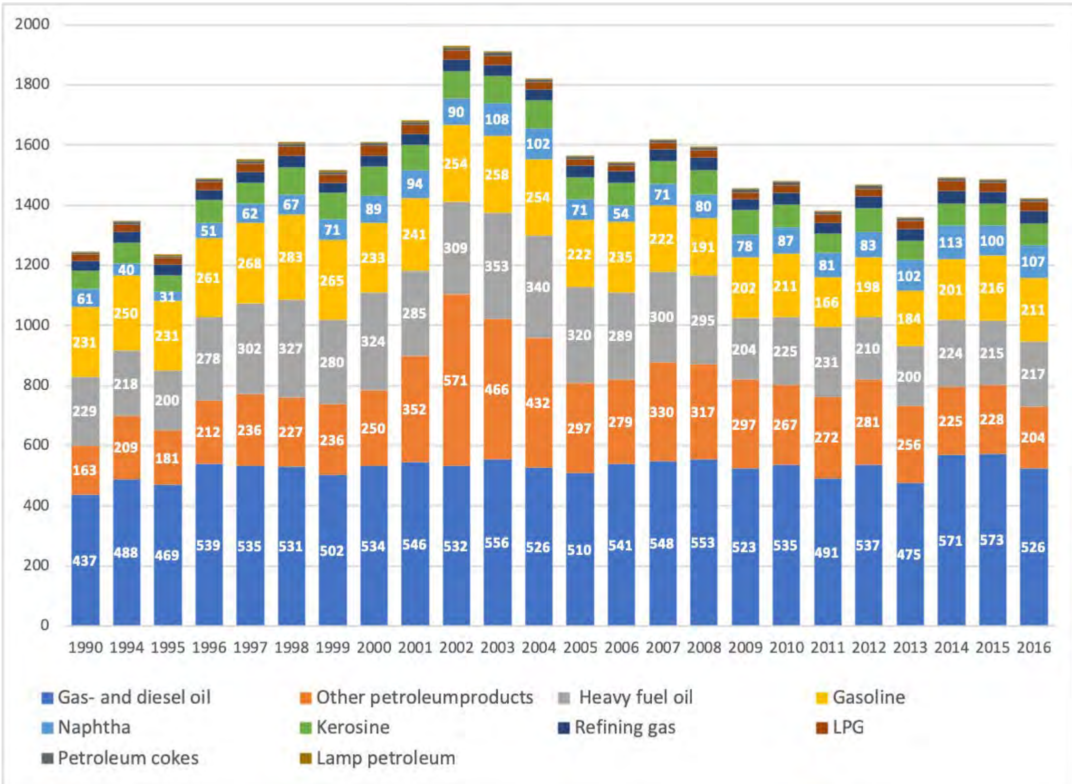


Figure 11: Outputs of crude oil refining in Flanders 1990 to 2016 (PJ) (Source: VITO, 2017)

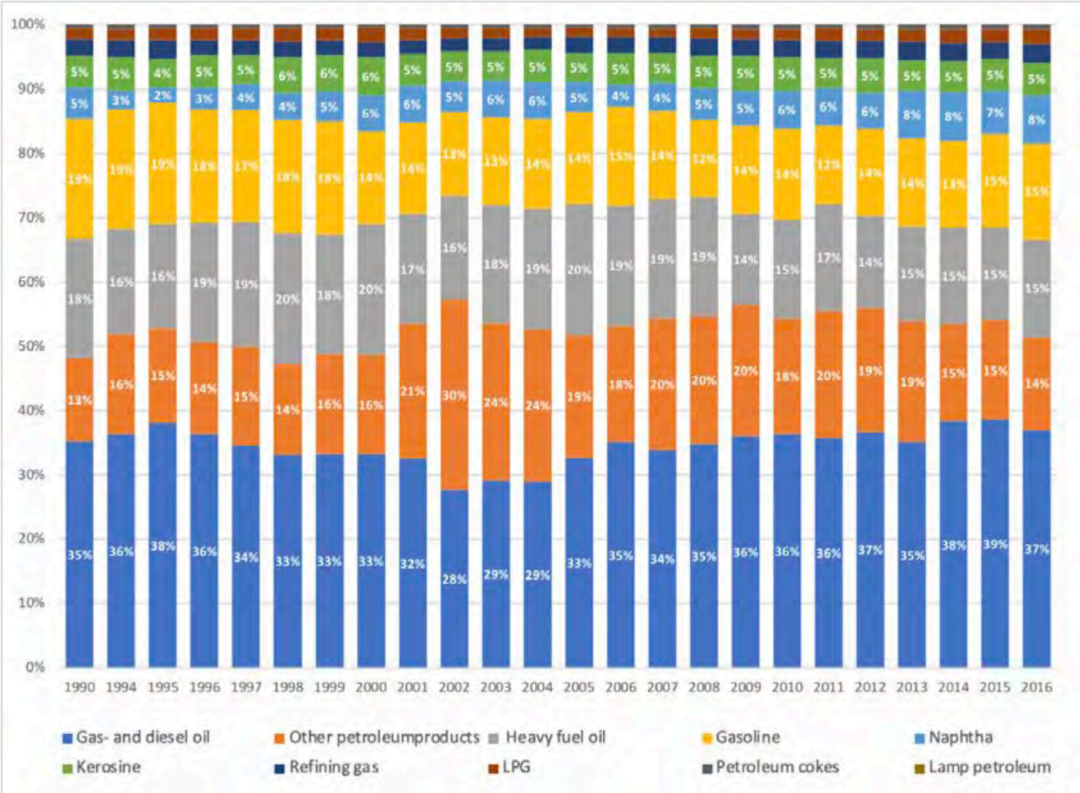


Figure 12: Relative outputs of crude oil refining in Flanders 1990 to 2016 (Source: VITO, 2017)

3.3.3 Gross Value Added

Between 2003 and 2014, the GVA of refining of petroleum products and cokes production in Flanders increased by 4% (from EUR 950 Mn to EUR 986 Mn). On the other hand, the share of this sector's contribution to the Flemish GVA decreased from 0.65% to 0.47% over same period.

3.3.4 Employment

Employment increased by 5% between 2003 and 2014 (from 3,591 persons to 3,788 persons): the only one out of all industrial sectors listed here to see an increase. Employment share of petroleum products and cokes production to total employment in the Flemish economy dropped slightly from 0.15 to 0.14% in the same period.

3.3.5 Investments

During 2005-2017[15], the refining (and cokes) industry invested EUR 1.7 Bn, or 0.7% of the total investments in Flanders during that period.

3.4 CHEMICALS PRODUCTION

3.4.1 Greenhouse gas emissions

The petrochemical cluster in Antwerp is among the largest in the world. This is reflected in the presence of three world class steam-cracking facilities as well as other large basic chemicals

[15] Minus the year 2013 for which no data was available.

production plants (e.g. ammonia). The Flemish chemicals industry along with steel production is the largest GHG emitting sector under the industrial sectors covered by the EU ETS and industrial emissions at large in Flanders. The chemicals industry represents 38% of the industrial GHG emissions under the EU ETS in Flanders. In 2005 this share stood at 43%.

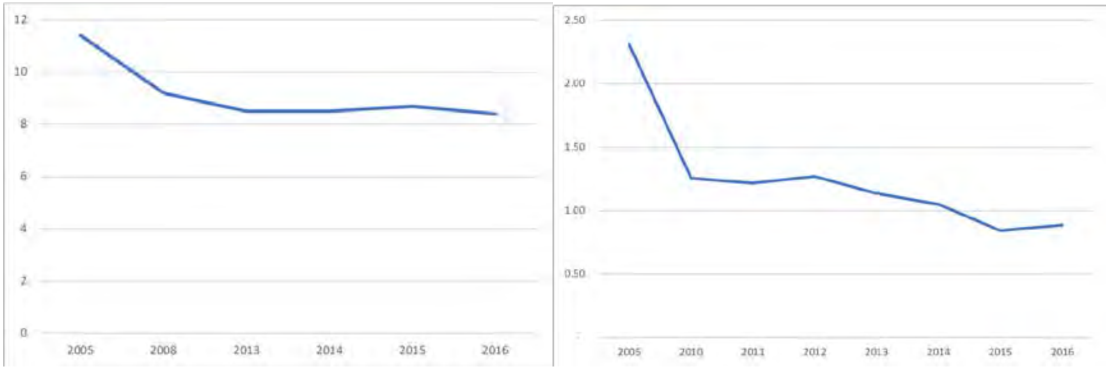


Figure 13: [Left] Evolution of GHG emissions chemical industry covered by EU ETS in Flanders (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017) [Right] N_2O emissions from chemicals industry in Flanders between 2005 and 2016 (Mt CO_2-eq.) (Source: VMM, 2016)

Between 2005 and 2016, emissions from the chemicals industry dropped 26% (from 11.4 Mt CO_2-eq to 8.4 Mt CO_2-eq). A significant part of this reduction came about from the mitigation of N_2O emissions from chemical production processes[16]. However, process efficiency improvements have played an important role too especially when taking into account the fact that the production of goods strongly increased since 2005 which shows a decoupling between emissions and production.

3.4.2 Energy use

Energy consumption (use of fuels as feedstock and energetic use) of the Flemish chemicals industry increased between 1990 and 2016 (from 164 PJ to 410 PJ), with a major leap between 1990 and 1994. Currently, the chemicals industry is responsible for 33% of final energy use in Flanders and 61% of Flemish industrial final energy use for both feedstock and energetic use.

[16] In particular the N_2O emissions from nitric acid production dropped from 2 Mt CO_2-eq. in 2005 to 0.4 Mt CO_2-eq. in 2013. Source: Vlaamse Overheid, 2018, Voortgangsrapport 2016-2017, Vlaams klimaabeleidsplan 2013-2020, luik mitigatie. p. 26

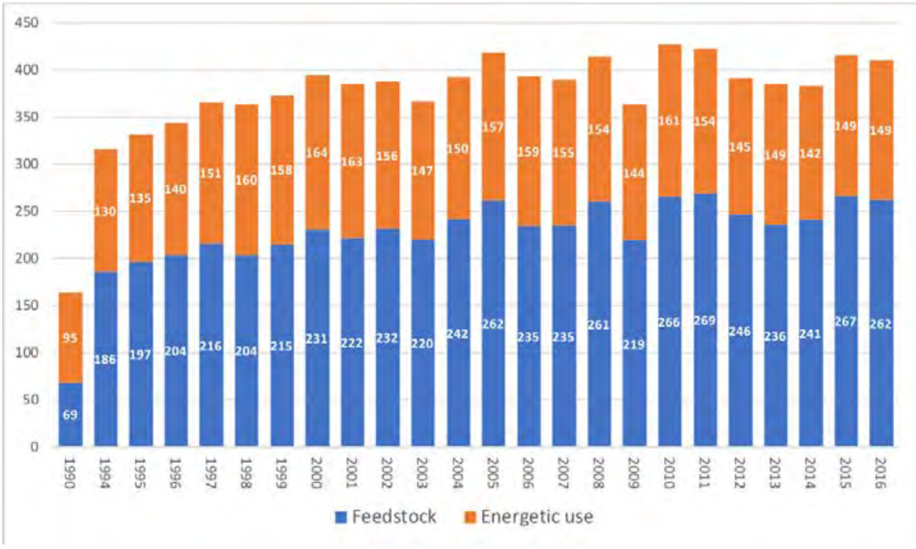


Figure 14: Evolution of feedstock and energetic use of fuels in Flemish chemicals industry between 1990 and 2016 (PJ) (Source: VITO, 2017)

Naphtha (together with Liquefied Petroleum Gas (LPG)), is the main feedstock for steam-cracking installations in the Flemish petrochemicals industry (e.g. for ethylene and propylene production). New installations and expansions in the 1990s led to an increase in demand. Since naphtha is an important distillate in crude oil refining, there exists close integration between some of the basic chemicals production in Flanders with the refining industry. This link has strengthened over time. In 1995, the refining output covered only 20% of the chemicals sector's naphtha demand. In 2016, this share increased to almost 70%.

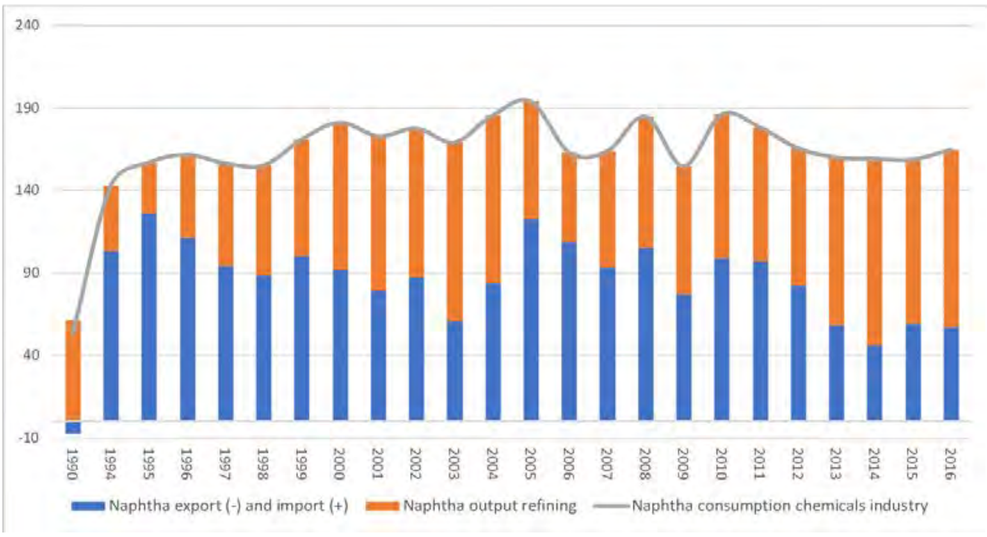


Figure 15: Evolution of Naphtha imports, production in Flanders and consumption by the chemicals industry between 1990 and 2016 (PJ) (Source: VITO, 2017)

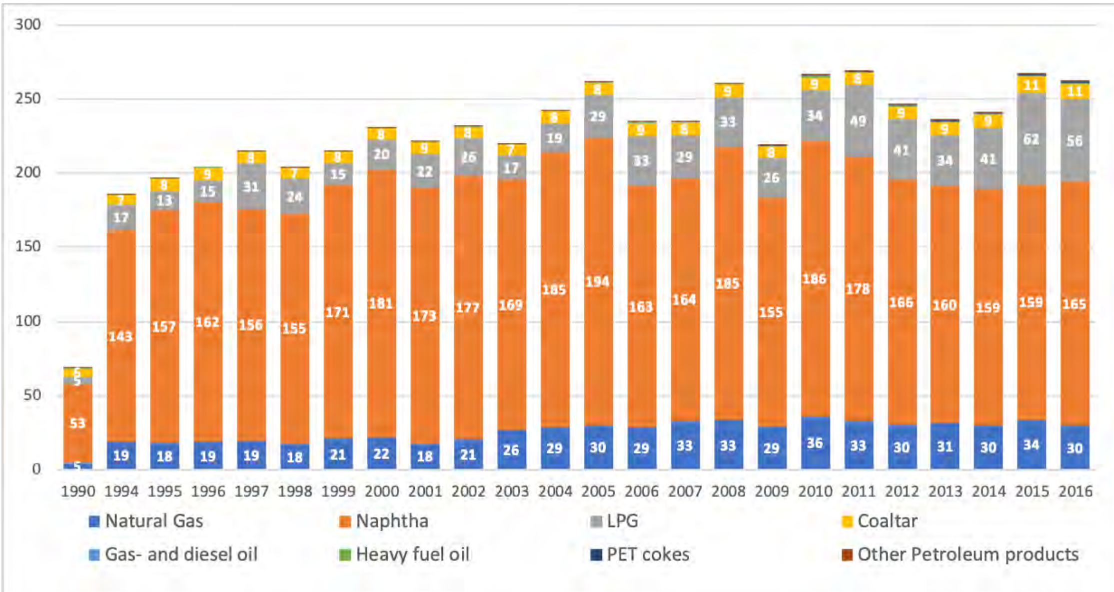


Figure 16: Evolution of feedstock use of fuels by Flemish chemicals industry between 1990 and 2016 (PJ) (Source: VITO, 2017)

With regard to the energetic use, the most important sources for the chemicals industry include fuel derived from naphtha cracking processes, followed by natural gas and electricity. After the significant rise in energy use in the 1990s, there has been a stable trend until 2016, although production continued to increase.

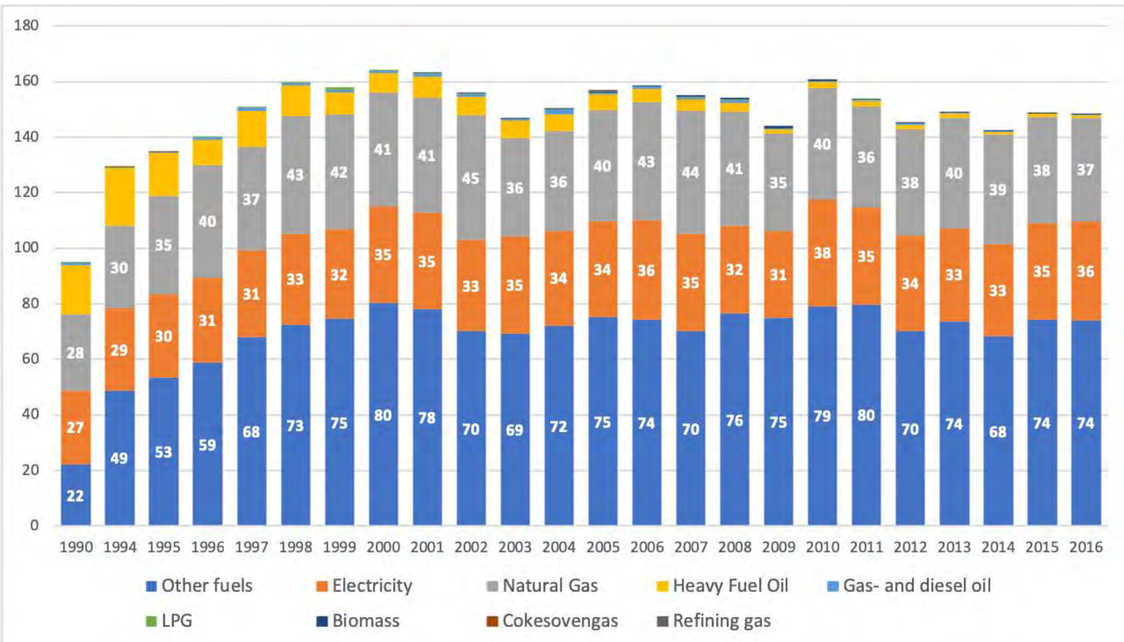


Figure 17: Evolution of energetic use of fuels by Flemish chemicals industry between 1990 and 2016 (PJ) (Source: VITO, 2017)

3.4.3 Gross Value Added

In the period 2003 to 2014, the GVA of the combined sectors of chemicals, plastics and rubber production in Flanders increased 17% (from EUR 6.9 Bn to EUR 8 Bn). On the other hand, the share of these sectors' contribution to the Flemish GVA decreased from 4.8% to 3.9% over same period.

3.4.4 Employment

Employment fell 12% between 2003 and 2014 (from 58,590 persons to 51,767 persons). The share of employment to the total Flemish economy dropped from 2.45% to 1.95% in the same period.

3.4.5 Investments

The chemicals (including plastics and rubber) industry is the largest industrial investor in Flanders. During 2005-2017,[17] the sector invested EUR 11.1 Bn, which represented 4.8% of the total investments in Flanders over that period.

3.5 IRON & STEEL AND NON-FERROUS METALS PRODUCTION

3.5.1 Greenhouse gas emissions

There are two important steel producers in Flanders. In Ghent, there is an integrated steel-plant owned and operated by ArcelorMittal. In Genk, a smaller amount of steel is produced by Aperam via electric arc furnaces (EAF) using scrap steel. Between 2005 and 2016, the GHG emissions of the Flemish steel industry accounted for between 19-21% of the industrial GHG emissions covered by the EU ETS in Flanders. The emissions of the steel sector dropped slightly between 2005 and 2016 (5.1 Mt CO_2-eq in 2005 and 4.7 Mt in 2016).

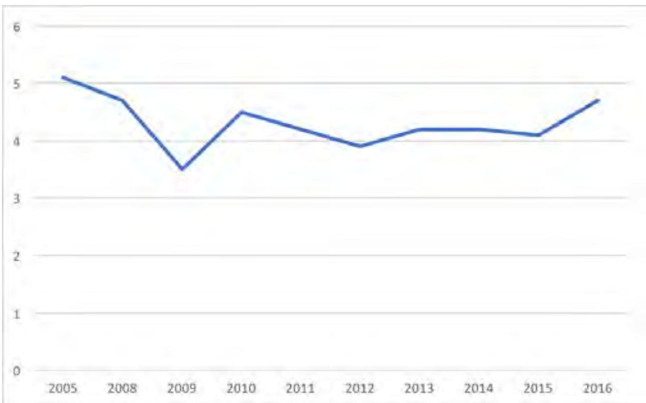


Figure 20: Evolution of GHG emissions by Flemish steel production under EU ETS (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017)

The non-ferrous metals industry is responsible for a small share of industrial GHG emissions in Flanders, with emissions standing at 0.49 Mt CO_2-eq in 2016 or 2.2% of industrial emissions covered by the EU ETS in Flanders. GHG emissions in the non-ferrous metals industry increased 40% between 2005-2016 (from 0.35 Mt to 0.49 Mt CO_2-eq), with a major jump between 2007 and 2008.

[17] Minus the year 2013 for which no data was available.

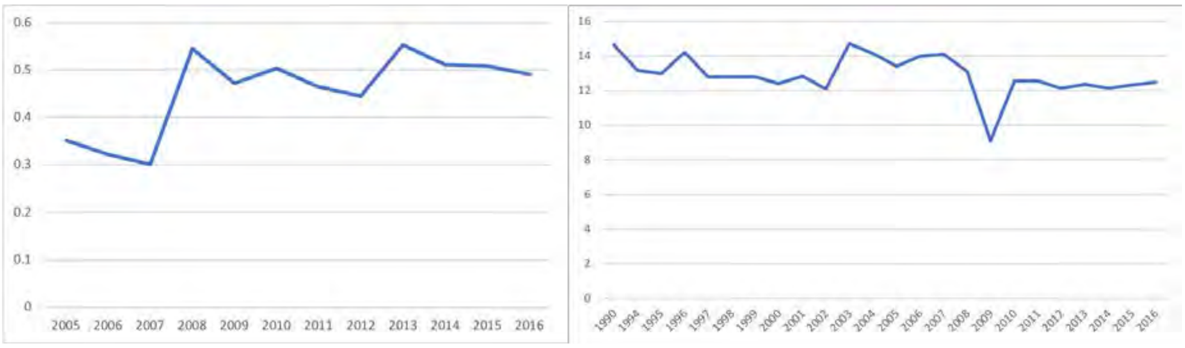


Figure 18: [Left] Evolution of GHG emissions of non-ferrous metals industry under EU ETS (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017) [Right] Evolution of energy use in non-ferrous metal production in period 1990-2016 (PJ) (Source: VITO, 2017)

3.5.2 Energy use

In 2016, the final energy use of the steel industry was 84 PJ or 7% of total final energy use in Flanders and 12% of Flemish industrial final energy use. The final energy use in steel production in Flanders remained relatively stable between 1990-2016. Most of the energy inputs for steel production in Flanders come from cokes and coal. In the period 1990-2016, the share of coal for hot iron production increased at the expense of cokes, in particular due to lower cokes imports. The amount of blast furnace gas produced steadily increased, most of which was used for electricity production[18]. The final energy use of the non-ferrous metals industry declined almost 15% in same the period (from 14.6PJ in 1990 to 12.5 PJ in 2016). Energy use remained largely stable between 2010 and 2016.

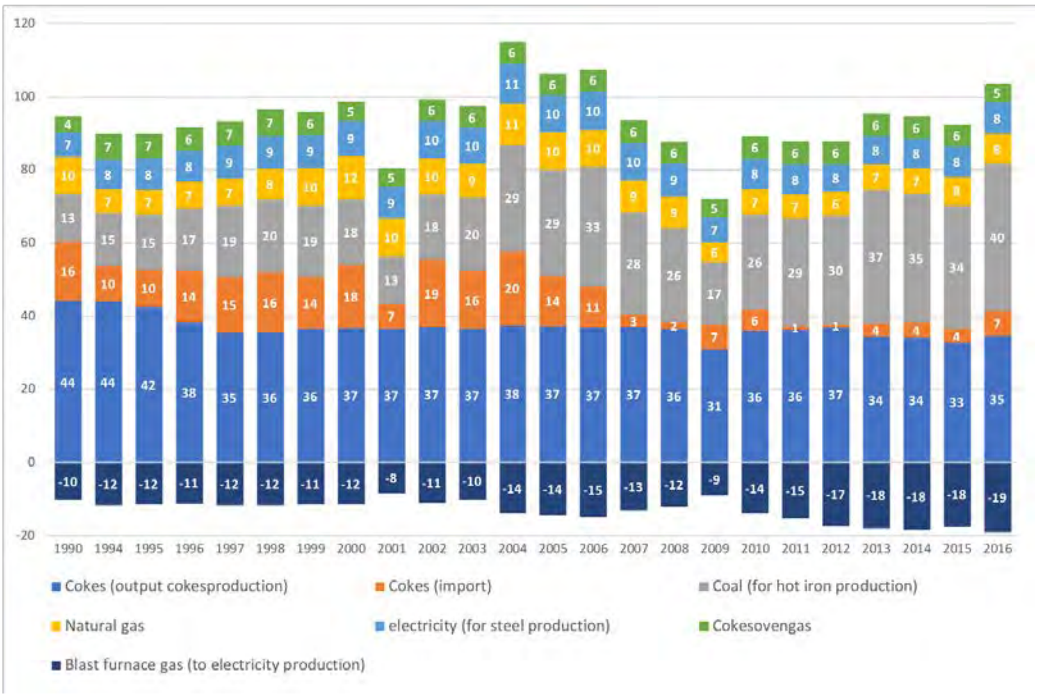


Figure 19: Evolution of energy use in steel production (excl. transformation of coal to cokes) in period 1990-2016 (PJ) (Source: VITO, 2017)

[18] In 2016, the emissions for steel waste gases in power production stood at 5 Mt CO_2-eq. a rise of 1.4 Mt compared to 2005 (3.6 Mt CO_2) or 39%.

3.5.3 Gross Value Added

In the period 2003-2014, the GVA of the manufacturing of basic metals in Flanders decreased 6% (from EUR 2 Bn to 1.9 EUR Bn). The share of this sectors' contribution to the Flemish GVA decreased from 1.37% to 0.9% over same period.

3.5.4 Employment

Employment in manufacturing of basic metals in Flanders fell 20% between 2003 and 2014 (from 22,099 persons to 17,764 persons). Employment as a share of the total employment in the Flemish economy dropped from 0.92% to 0.67% in the same period.

3.5.5 Investments

The basic metals industry invested EUR 1 Bn between 2005 and 2017[19], or 0.4% of the total investments in Flanders during the same period.

3.6 OTHER INDUSTRIAL SECTORS

3.6.1 Manufacture of paper and paper products

Greenhouse gas emissions

Pulp and paper production are responsible for a small share of industrial GHG emissions in Flanders, with emissions standing at 0.54 Mt CO_2-eq in 2016 or 2.4% of industrial emissions covered by the EU ETS in Flanders. Between 2005 and 2016, the emissions of paper production increased 17%.

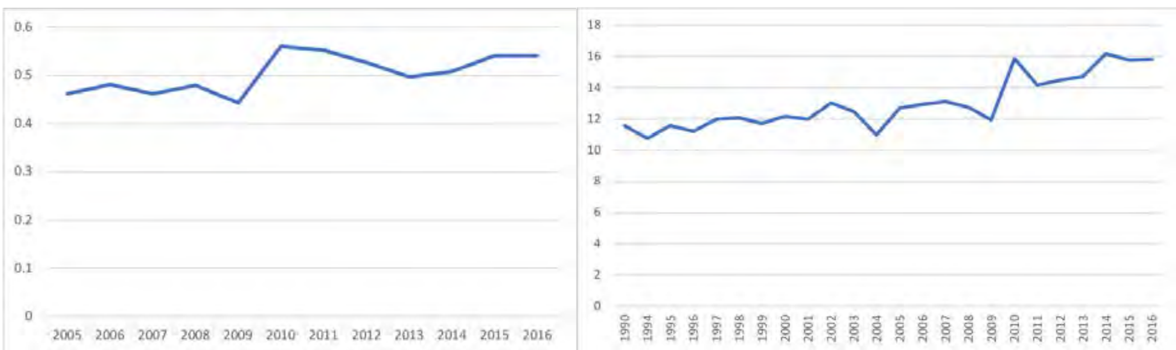


Figure 20: [Left] Evolution of GHG emissions of paper industry under EU ETS (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017) [Right] Evolution of energy use in paper production in period 1990-2016 (PJ) (Source: VITO, 2017)

The final energy use of the paper industry (including publishing) increased 36.5% between 1990 and 2016 (from 12PJ to 16PJ), with a significant jump in consumption between 2009-2010. This increase in emissions and energy consumption is mainly explained by the establishment of a new on-site Combined Heat and Power production (CHP) plant replacing an installation in the electricity sector resulting in lower overall net emissions.

[19] Minus the year 2013 for which no data was available.

Gross Value Added
Between 2003-2014, the GVA of the manufacture of paper and paper products in Flanders rose 9% (from EUR 729 Mn to 791 EUR Mn). During the same period, the share of this sector's contribution to the Flemish GVA decreased from 0.50% to 0.38%.

Employment
Employment decreased 20% between 2003 and 2014 (from 10,100 persons to 8,117 persons). Employment as a share of the total Flemish economy dropped from 0.42% to 0.31% in the same period.

Investments
The paper and paper products industry, while being a relatively small sector, invested EUR 1.2 Bn between 2005 and 2017[20], or 0.5% of total investments in Flanders over that period.

3.6.2 Food and beverages production

Greenhouse gas emissions
In 2016, the food and beverages industry was responsible for 5% (1.1 Mt CO_2-eq) of industrial GHG emissions in Flanders covered by the EU ETS. The GHG emissions in the food and beverages industry increased 8% in the period 2005-2016 (from 1.04 Mt CO_2-eq to 1.12 Mt CO_2-eq).

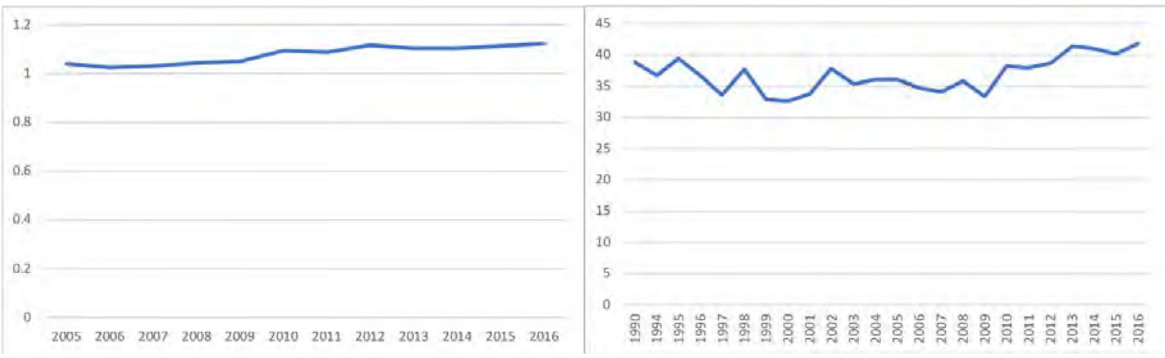


Figure 21: [Left] Evolution of GHG emissions of food industry under EU ETS (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017) [Right] Evolution of energy use in food, beverages and tobacco production in period 1990-2016 (PJ) (Source: VITO, 2017)

Energy Use
The final energy use of food and beverages production in Flanders rose 8% between 1990 and 2016 (from 39PJ to 42PJ).

Gross Value Added
During the 2003-2014 period, the GVA of food, beverages and tobacco production in Flanders grew 30% (from EUR 4.3 Bn to EUR 5.6 Bn), the largest relative increase of any considered sector. However, the share of these sectors' contribution to the Flemish GVA decreased from 2.96% to 2.67% in same period.

[20] Minus the year 2013 for which no data was available.

Employment

Employment dropped 5% between 2003 and 2014 (from 69,896 persons to 66,481 persons). The share of employment to the total employment in the Flemish economy dropped from 2.92% to 2.51% in the same period.

Investments

The food, beverages and tobacco industry is the second largest industrial investor in Flanders having invested EUR 10.6 Bn or 4.6% of total Flemish investments between 2005 and 2017[21].

3.6.3 Textiles production

Greenhouse gas emissions

The textiles industry is responsible for a very small share of industrial GHG emissions in Flanders, with emissions standing at 0.13 Mt CO_2-eq in 2016 or 0.6% of industrial emissions covered by the EU ETS in Flanders. Between 2005 and 2016, emissions related to textiles production did decrease significantly (-26%), largely due to plant closures between 2007-2010.

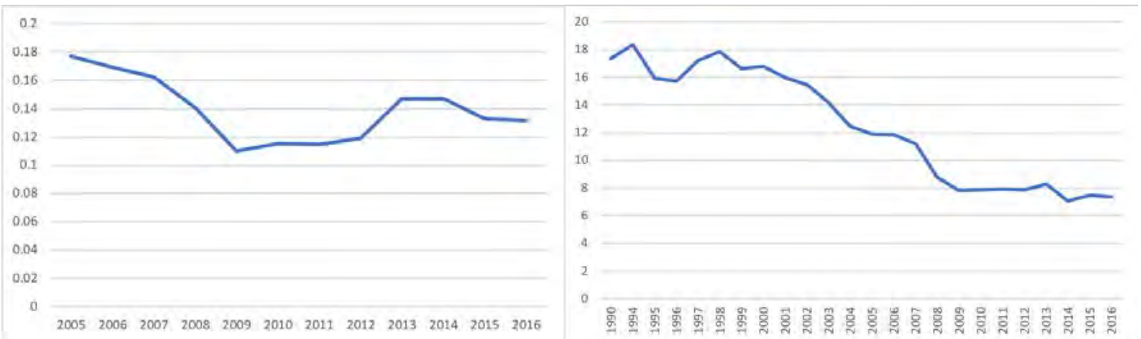


Figure 22: [Left] Evolution of GHG emissions of textiles industry under EU ETS (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017) [Right] Evolution of energy use in textiles industry in period 1990-2016 (PJ) (Source: VITO, 2017)

Energy Use

The final energy use of textiles production in Flanders followed a declining trend during the period 1990-2016, dropping from 17 PJ to 7.3 PJ or a decrease of 58%.

Gross Value Added

Between 2003 and 2014 the GVA of the manufacture of textiles in Flanders decreased 33% (from EUR 1.9 Bn to EUR 1.3 Bn), the largest relative decline amongst all the considered sectors. The share of this sector's contribution to Flemish GVA also decreased from 1.29% to 0.60% over same period.

Employment

Textiles saw the largest relative and absolute fall in employment out of all industrial sectors listed, with a decrease of 51% between 2003 and 2014 (from 41,004 persons to 20,214 persons). Employment as a share of the total employment in the Flemish economy dropped from 1.72% to 0.76% in the same period.

Investments

Even with a significant decline in GVA and employment over the past decade, the textiles industry still invested EUR 1.6 Bn or 0.7% of the total investments in Flanders between 2005 and 2017.

[21] Minus the year 2013 for which no data was available.

3.6.4 Glass and ceramics (part of non-metallic minerals industry)

Greenhouse Gas Emissions

The ceramics industry is responsible for a small share of industrial GHG emissions in Flanders, with emissions standing at 0.42 Mt CO_2-eq in 2016 or 1.9% of industrial emissions covered by the EU ETS in Flanders. Between 2005-2016, the emissions related to ceramics production did decrease significantly (-22%) a key reason being plant closures which ensued between 2008 and 2010.

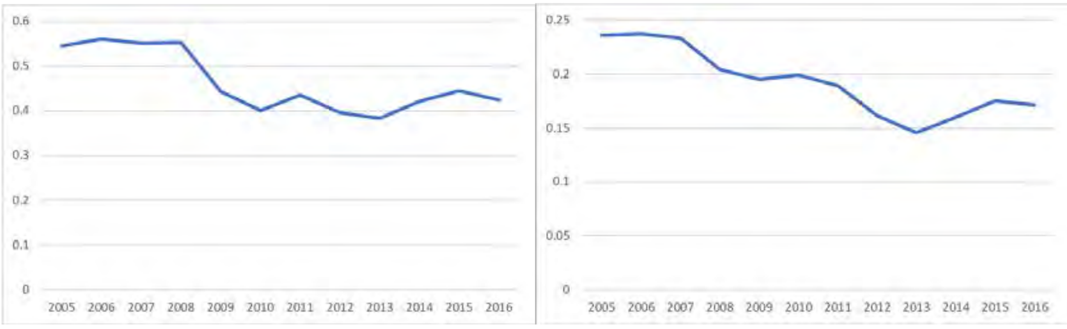


Figure 23: Evolution of GHG emissions of the Flemish ceramics industry [Left] and glass industry [Right] under EU ETS (Mt CO_2-eq.) (Source: Vlaamse Overheid, Departement Omgeving , Afdeling EKG, 2017)

The glass industry accounts for a very small share of industrial GHG emissions in Flanders, with emissions standing at 0.17 Mt CO_2-eq in 2016 or 0.8% of industrial emissions covered by the EU ETS in Flanders. Between 2005 and 2016, emissions related to glass production decreased 27% (from 0.24Mt CO_2-eq to 0.16 Mt CO_2-eq), a key reason being plant closures between 2007 and 2010.

Energy Use

Ceramics and glass production are part of the non-metallic minerals industry, represented in 'De Vlaamse Energiebalans'. The non-metallic minerals industry registered an 11% increase in final energy use between 1990 and 2016 (from 14.5 PJ to 16.1 PJ). However, between 2005 and 2016, final energy use fell 5%.

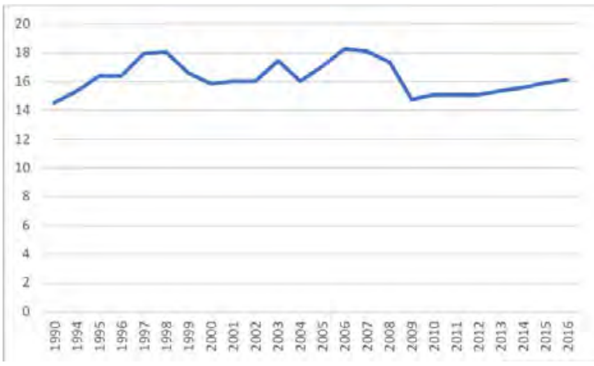


Figure 24: Evolution of energy use in Flemish non-metallic minerals industry in period 1990-2016 (PJ) (Source: VITO, 2017)

Gross Value Added

Between 2003-2014, the GVA of the manufacture of non-metallic mineral products in Flanders increased 15% (from EUR 1.1 Bn to EUR 1.3 Bn). The share of these sectors' contribution to the Flemish GVA however decreased from 0.79% in 2003 to 0.63% in 2014.

Employment
Employment in the sector fell 7% between 2003 and 2014 (from 17,720 persons to 16,418 persons) while the share of employment to the total employment in the Flemish economy dropped from 0.74% to 0.62% in the same period.

Investments
The non-metallic minerals sector invested almost EUR 2 Bn or 0.8% of total investments in Flanders between 2005-2017[22].

3.7 TRADE OF (BASIC) INDUSTRIAL PRODUCTS

The basic materials produced by the industrial sectors covered in this study account for around 46% of Flemish exports in 2015[23]. The largest contribution comes from the combined value of exports of chemicals (excl. pharmaceutical products), plastics and rubber, which stood at almost EUR 59 Bn in 2015. The trade balance, on a sector by sector basis, shows a surplus in most industries with the exception of the minerals industry (which is dominated by mineral fuels, crude oil and distilled refining products) given Flanders is a significant net-importer and the construction materials industry which had a small trade deficit in 2015 .

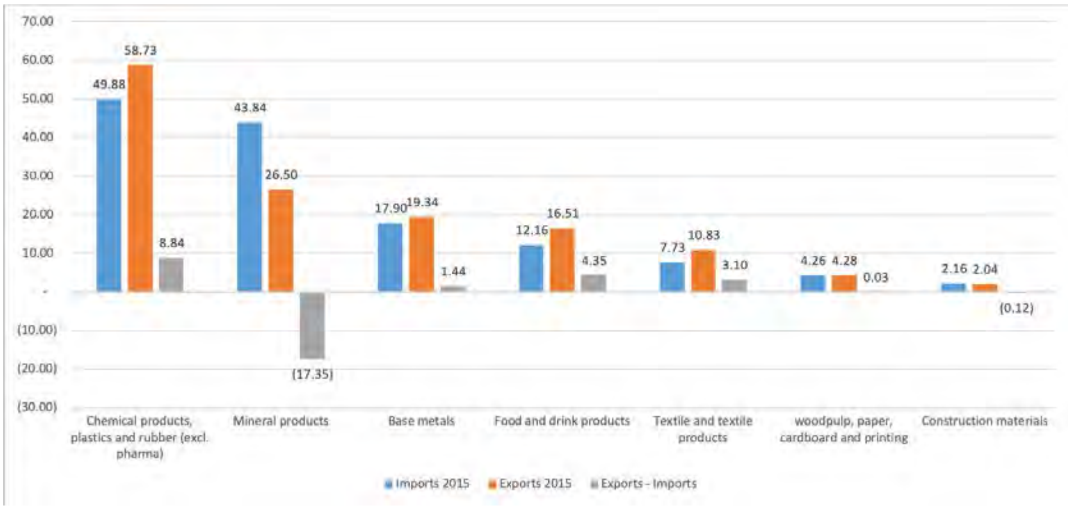


Figure 25: Import and Export values of select industrial sectors in 2015 (Bn EUR) (Sources: FIT and NBB)

[22] Minus the year 2013 for which no data was available.
[23] Bron: Flanders Investment and Trade (FIT), 2016, gedetailleerde Vlaamse in- en uitvoercijfers 2015. consulted via https://www.flandersinvestmentandtrade.com/export/marktstudie/vlaamse-buitenlandse-handel-2015

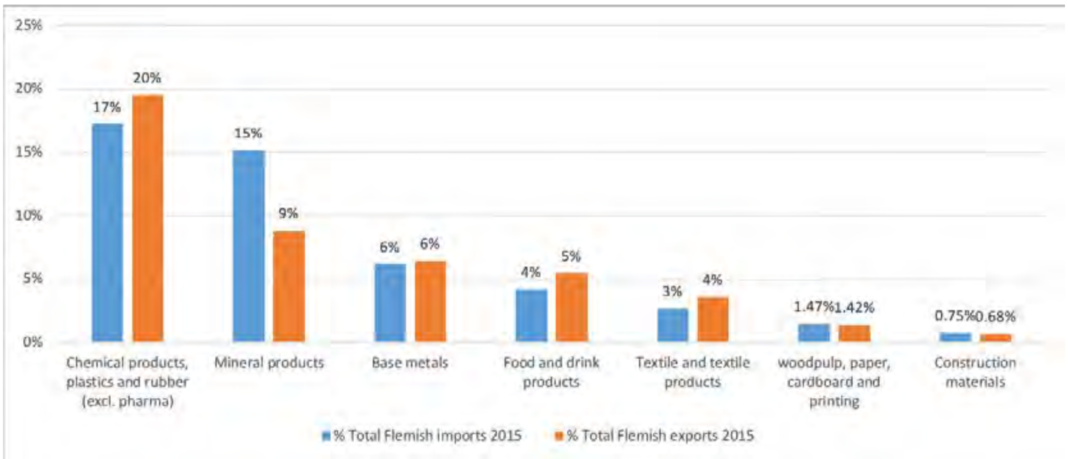


Figure 26: Import and Export values as (%) share of total Flemish import and export of goods in 2015 (Sources: FIT and NBB)

On a more detailed product by product basis, a similar picture emerges. Organic chemicals formed the third largest share of Flemish exports (after motor-vehicles and pharmaceutical products) at 8.9% of total Flemish goods exports in 2015. It is also the largest product group imported by Flanders at 9.63% of total Flemish imports in 2015. Plastics and rubber products are the 6th biggest export group for Flanders. In 2015, plastics and rubber represented 6.95% of total Flemish exports of goods, while accounting for only 4.41% of Flemish goods imports in the same year. Iron and steel constituted 2.78% of Flemish goods exports and 2.04% of the imports in 2015. Mineral oils and distillation products are by far the largest group of products imported into Flanders (14.04% of Flemish imports in 2015) and also form a major part of exports (8.26% in 2015).

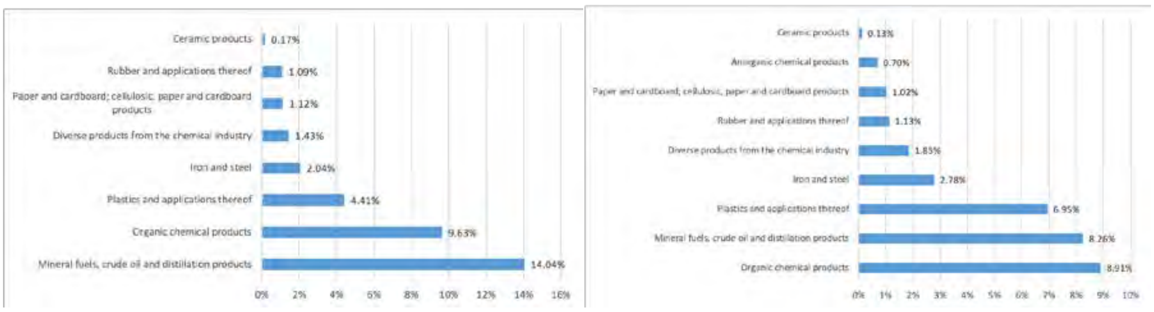


Figure 30: Share of Flemish imports [Left] and exports [Right] in 2015 for selection of products (Sources: FIT and NBB)

Import	EU		non-EU
Netherlands	17.38%	US	9.12%
Germany	12.28%	China	4.42%
France	9.12%	Russia	2.63%
UK	5.23%	Japan	2.54%
Ireland	4.93%	Singapore	1.86%
Italy	2.83%	Norway	1.52%
Sweden	2.01%	India	1.38%
Spain	1.73%	Switzerland	1.10%
Poland	1.13%	Turkey	1.02%
Czech rep	0.98%	Canada	0.97%
Finland	0.67%	UAE	0.97%
Total	**58.29%**		**27.53%**

Export	EU		non-EU
Germany	17.08%	US	6.03%
France	12.67%	India	2.54%
Netherlands	11.94%	China	2.10%
UK	9.13%	Turkey	1.36%
Italy	5.07%	UAE	1.11%
Spain	2.43%	Japan	1.02%
Poland	1.89%	Switzerland	1.40%
Sweden	1.64%	Russia	0.93%
Luxembourg	1.13%	Hong Kong	0.74%
Austria	0.99%	Brazil	0.70%
Total	**63.97%**		**17.93%**

Figure 27: Top 10 EU and non-EU countries for Flemish import [Left] and export [Right] in 2015 (source: FIT)

The overwhelming majority of Flemish trade (imports and exports) takes place within the EU. Flanders' most important trade partners in the EU are Germany, The Netherlands, France, and the UK, while the US is the top external trade partner.

In order to assess the trade with major partners for the selected industrial sectors in Flanders, the UN Comtrade database was consulted through the data visualisation tool GED VIZ (developed by the Global Economic Dynamics Project)[24]. Data on trade flows is only available at Belgian level, however for iron and steel and basic chemicals this should be representative for Flanders too.

In 2000, Belgian iron and steel[25] exports stood at EUR 7.55 Bn, 90% (or EUR 6.8 Bn) of which was exported to other EU countries. In 2014, Belgian iron and steel exports stood at EUR 9.38 Bn, 87.3% (EUR 8.23Bn) of which was exported to the rest of the EU. The relative share of Belgian iron and steel as part of EU countries imports dropped from 45.6% in 2000 to 31% in 2014.

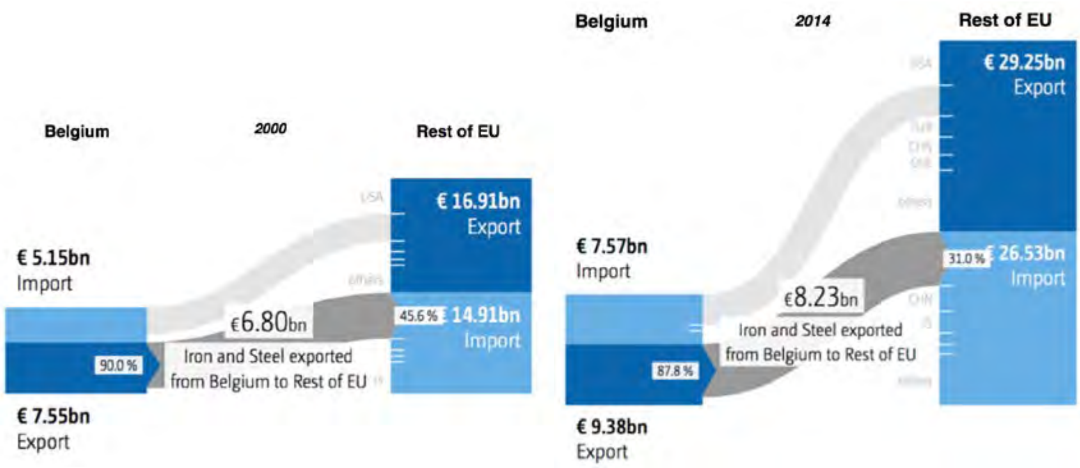


Figure 28: Iron and Steel exports and imports between Belgium and rest of the EU in year 2000 [Left] and 2014 [Right] (source: GED VIZ and UN Comtrade)

[24] https://viz.ged-project.de
[25] Iron and steel as defined in the Standard International Trade Classification, Rev.3 (SITC) 67 https://unstats.un.org/unsd/cr/registry/regcs.asp?Cl=14&Lg=1&Co=671

In 2000, Belgian (basic) chemicals[26] exports stood at EUR 27.35 Bn, 79.2% (or EUR 21.66 Bn) of which was exported to other EU countries. By 2014, Belgian chemicals exports had more than doubled from their 2000 figures standing at EUR 68.53 Bn, 78.5% (or EUR 53.78 Bn) of which was exported to the rest of the EU. The relative share of Belgian chemicals as part of EU member states' imports rose from 27.7% in 2000 to 29.8% in 2014. The export to countries outside the EU should normally follow world growth figures, in particular due to the growing economies of emerging countries, the export share to economic region's outside EU should have increased more significantly. This has not been the case according to the figure 33 below which resulted in a declining market share in international (ex-EU) trade.

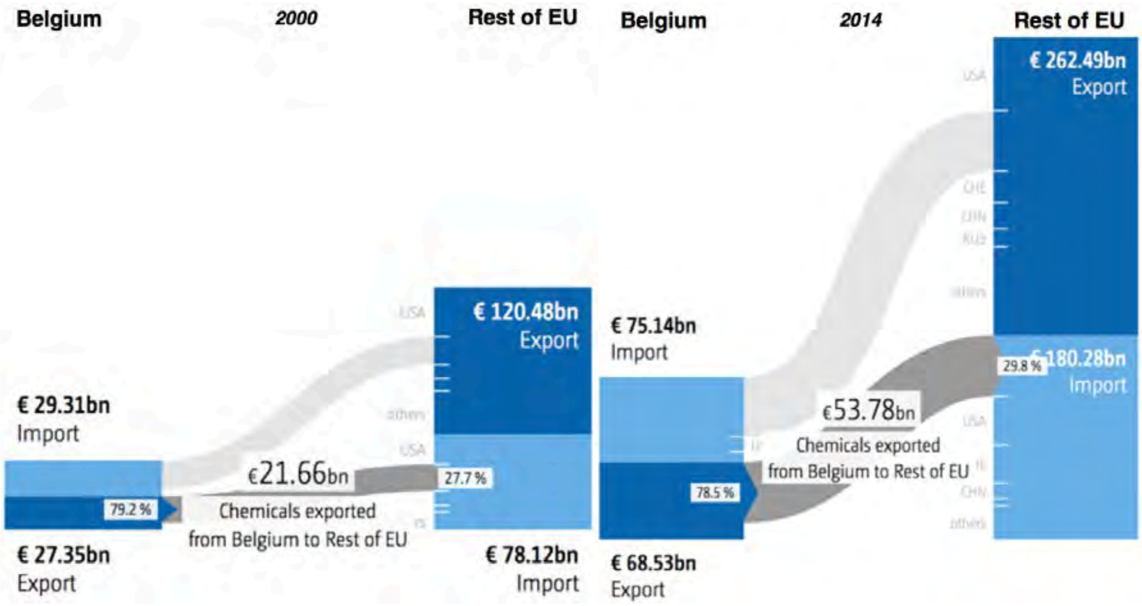


Figure 29: (Basic) chemicals exports and imports between Belgium and rest of the EU in year 2000 [Left] and 2014 [Right] (source: GED VIZ and UN Comtrade)

The above assessment of trade flows confirms that for iron and steel and basic chemicals produced and consumed in Belgium/Flanders, the trade intensity with EU partners is (even) higher in comparison to the overall Flemish trade flows (as shown in figure 30). It thus emphasises the importance of intra-EU value chains for the Flemish industry. Almost a quarter of the export and its associated welfare is created through the export outside the EU which clearly has not been following the world growth pace. From the figure (Figure 33) above it is also seen that the import intensity (e.g. from USA) has increased significantly indicating the effect of the availability of abundant and affordable shale gas in the US improving the competitiveness of the US chemicals industry.

The share of Belgian produced imported by the rest of the EU declined from 45.6% in 2000 to 31% in 2014. For chemicals, the share of Belgian produced chemicals imported by the rest of the EU increased from 27.7% to 29.8%. For both sectors the imports from outside the EU have increased, with notable growth in imports from China (and for chemicals also from the US).

[26] Basic chemicals as defined in the Standard International Trade Classification, Rev.3 (SITC) 5 https://unstats.un.org/unsd/cr/registry/regcst.asp?Cl=14

3.8 RELEVANT RESEARCH, PROJECTS AND POLICY IN FLANDERS

3.8.1 Introduction

This section briefly maps current or recent Flemish initiatives in relation to industrial GHG mitigation, innovation, energy-system transition and road-mapping in general. This information positively informed the exercise of developing steps towards a Flemish industrial low-carbon framework or the facilitation of an industrial low-carbon transition in Flanders. In particular, a non-exhaustive list of examples from three areas will be briefly discussed below:

- Recent studies relevant for low-carbon industrial development
- Projects and initiatives in Flanders
- Policies and strategies

For each of these examples, the possible relevance for future industrial low-carbon transitions or roadmap will be mentioned.

3.8.2 Recent research

Over the past years, highly relevant studies have been published which will be able to support the development and implementation of a Flemish industrial low-carbon framework. In the area of energy-system transitions, the study '*Oplossingsrichtingen voor het energiesysteem (towards solutions for the energy system) (VMM, VITO, Energyville, SEB – 2017)*' formulates a list of technological solutions for significant GHG emissions reductions in industrial sectors. Most of these options are also mentioned in the technology assessment in chapter 6 of this report. The above-mentioned study is relevant as it considered technologies in the Flemish industrial and energy systems.

The *possible application of CCU in Flanders*, including the enabling conditions, has also recently been assessed[27]. The policy recommendations made by the study towards further deployment of CCU in Flanders include:

- Further support for the development of Life Cycle Assessments of CCU technologies;
- Support for CCU demonstration projects in Flanders;
- Promotion of CCU products and services;
- Support for (industrial) cluster development around CCU;
- Tapping into EU Funds (e.g. EU ETS innovation Fund) and Renewable Energy Directive provisions;
- Ensuring that CCU has a place in EU circular economy action plans.

The *potential for renewable hydrogen in the Flemish economy* has been recently assessed[28]. This study investigated the possible use of H_2 in transport, buildings and industrial sectors. For the industrial sectors, the study used the latest insights from an IEA study and EU roadmaps (e.g. the CEFIC and Dechema roadmaps) and linked H_2 technology pathways to demand from the Flemish refining, chemicals and steel sectors. The main conclusion was that demand for H_2 in industry can be high and hence requires significant investments in both electricity generation and electrolysers. It is possible that H_2-based ammonia production in the future, provided electricity prices are very low, can become competitive against current natural gas-based production. However, large capital

[27] *Onderzoek naar mogelijk ondersteuningsbeleid m.b.t. nieuwe toepassingsmogelijkheden van CO_2 als grondstof/feedstock (LNE en VITO, 2016)*
[28] *H2Vlaanderen: Potentieel voor groene waterstof (VEA, Waterstofnet Vlaanderen, Hinico, 2018)*

expenditure (CAPEX) will be required. This study's assessment on the techno-economic use of H_2 in industrial processes in Flanders will prove relevant for scenario developments (incl. cost estimates for technology pathways) in a future Flemish industrial low-carbon transition framework.

The *'KET roadmap – Advanced materials in Flanders (2014)'*[29] offers a broader perspective on advanced materials and processes in industrial sectors (e.g. chemicals (plastics), metals, ceramics). Of particular interest is the value chain-based approach in this study, which can be used as an example or template for an industrial low-carbon roadmap development in Flanders.

Finally it is worth mentioning that while an EU sectoral roadmap for the food and beverages industry has not been developed yet, there has been a study on '*a CO_2, waste and water neutral food-industry by 2030 (2013)'*[30] for Flanders. This study and its approach form a highly interesting template for a broader industrial low-carbon roadmap for Flanders. This comes from the fact that the food-sector roadmap not only tackles GHG emissions but also addresses waste and water resources in an integrated manner (including an assessment across food-sector related value chains). The food roadmap furthermore sets very specific ambition levels (e.g. KPI's) in each of these areas and has developed a toolbox of possible actions. While the roadmap shows a theoretical high potential for achieving 'neutrality' targets, it also highlights major barriers for practical implementation. The report further highlights possible conflicts between energy and raw materials demand (for instance, the energetic use of organic waste vis a vis their use as a circular resource in other sectors). ***Both, the highly interesting scientific approach and the integrated assessment across GHG emissions, waste (circular economy) and the energy system, make this roadmap's approach a good example for replication in a broader industrial low-carbon framework for Flanders***. Importantly, the know-how for the implementation of such an approach resides within Flemish research institutes and should hence be easily accessible.

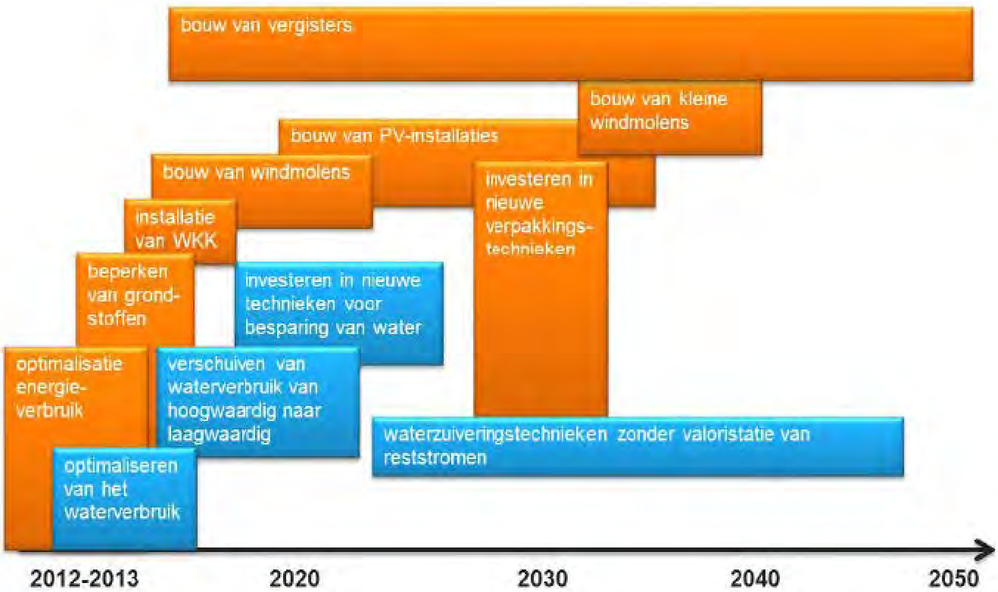


Figure 30: List of activities and timeline towards a CO_2, water and waste neutral food sector in Flanders (Source: LNE, VITO et. al, 2013)

[29] 'KET Roadmap – geavanceerde materialen in Vlaanderen/Advanced materials in Flanders' (FISCH, SIM, 2014)

[30] 'Een CO_2-, water- en afvalneutrale Vlaamse voedingsnijverheid tegen 2030: onderzoek naar haalbaarheid en uitwerking mogelijke aanpak' (LNE, VITO, IDEA, KU Leuven, 2013)

Other relevant studies and reports include the FISCH roadmap for renewable chemicals (2014)[31], which includes a still highly relevant SWOT analysis with regard to the deployment of bio-based chemicals and the chemical valorisation of waste streams in Flanders, and a 2016 study commissioned by the Flemish government on sustainable value creation from renewable feedstock for bio-based industrial production[32].

Study	Relevance for Flemish industrial low-carbon
'A CO_2, waste and water neutral food industry by 2030 for Flanders' (2013)	Template for integrated assessment for tackling GHG emissions reductions alongside resource management
Onderzoek naar mogelijk ondersteuningsbeleid m.b.t. nieuwe toepassingsmogelijkheden van CO_2 als grondstof/feedstock (LNE en VITO, 2016)	Possible application of CCU in Flanders
'Oplossingsrichtingen voor het energiesysteem (VMM, VITO, Energyville, SEB – 2017)'	List of technological solutions or significant greenhouse gas emission reductions in relevant industrial sectors of Flanders.
'H2Vlaanderen: Potentieel voor groene waterstof' (VEA, Waterstofnet Vlaanderen, Hinico, 2018)	Assessment on the techno-economic use of H_2 relevant for scenario developments
'KET roadmap – Advanced materials in Flanders' (2014)	Value chain based approach can serve a as template
'Roadmap Hernieuwbare Chemicalien, FISCH' (2014)	highly relevant SWOT analysis with regard to the deployment of bio-based chemicals and the chemical valorization of waste streams in Flanders
'Duurzaam gebruik van en waardecreatie uit hernieuwbare grondstoffen voor de biogebaseerde industriële productie zoals biomaterialen en groene chemicaliën in Vlaanderen' (2016)	Sustainable value creation from renewable feedstock for bio-based industrial production

Table 1: Overview of recent relevant studies and reports in Flanders for the development of an industrial low-carbon roadmap.

3.8.3 Projects and initiatives

Next to studies and reports related to the transition to a low-carbon economy, some interesting projects have (or are currently) taken place in Flanders that could prove relevant for a future industrial low-carbon transition.

BlueChem incubator for sustainable chemistry

BlueChem, located at the Blue Gate site in Antwerp will be a future incubator for sustainable chemistry in Flanders. The goal of the incubator is to enable new and innovative projects in sustainable chemistry and as such secure and strengthen the future of the chemicals sector in Antwerp and Flanders. The BlueChem building will offer a mix of facilities including laboratories for SME's and (knowledge) sharing projects for large corporations and research institutes. As such, it will be able to identify and guide promising innovation projects. It is expected to open by 2020. BlueChem is a public-private partnership (PPP) between Essenscia, Bopro (BSI) and DEC (DEME Environmental contractors) and public partners - City of Antwerp, VITO, POM Antwerpen, PMV and AG VESPA. It is supported by the European Fund for Regional Development (EFRD), the Flemish government and the city of Antwerp.

[31] Roadmap Hernieuwbare Chemicalien, FISCH, 2014

[32] Duurzaam gebruik van en waardecreatie uit hernieuwbare grondstoffen voor de biogebaseerde industriële productie zoals biomaterialen en groene chemicaliën in Vlaanderen. 2016. EWI. VITO, Clever Consult en UGent.

The CAPTURE initiative[33]

The Centre for Advanced Process Technology for Urban Resource Recovery (CAPTURE) initiative, opened in 2015. The initiative follows an integrated approach based on clustering of expertise, infrastructure and stakeholders. It seeks to develop solutions from waste to resource to final application. The initiative also seeks to enhance the adoption and application of knowledge and technologies among industry and society, including through training of multidisciplinary professionals.

Two important flagship projects of CAPTURE are CAPRA (CO_2 to product) and REFOIL (plastics to resource). The CAPRA project, a three-year Catalisti-ICON project (2018-2020), aims to develop an anaerobic biological process technology for the conversion of un-distilled syngas fermentation products (ethanol and acetic acid) to a bio-oil of medium-chain carboxylic acids, that can serve as a feedstock for the production of added-value chemicals with high market potential. This project brings together three industrial partners (ArcelorMittal, OWS, Proviron) and three academic partners (CMET (Ghent University), EnVOC (Ghent University), VITO). The CAPRA project fits in with the ambition of ArcelorMittal to further valorize waste gases (syngas) produced during steel-making, into valuable products. Syngas fermentation effluent, produced via the Steelanol process at ArcelorMittal, is now only valorised via ethanol distillation, while alternative routes, possibly leading to higher value products, are possible. A biological process technology to convert syngas fermentation effluent to medium-chain carboxylic acids will be developed jointly by CMET and OWS, by focusing both on strategic basic research aspects (CMET), and process upscaling (OWS). Proviron will consequently upgrade these basic products to marketable chemicals. A life-cycle assessment (EnVOC and OWS) and techno-economic assessment (VITO) will further strengthen the research approach, and highlight the feasibility and environmental benefits of the CAPRA process technology.

The objective of the ReFOIL (Recycling or multilayer Foils') project is to develop methods for the effective and efficient mechanical recycling of multi-layer plastic packaging wastes (shells and foils). Films for packaging of products are composed of multiple layers of different polymer materials, each contributing its own functionality to packaging. In ReFOIL, industrially relevant case studies are developed in which some of the common streams of multi-layered packaging wastes (consisting of polyesters, polyolefins, polyamides, intermediate layers, etc.) will be studied.

Flanders bio-based valley

Flanders Biobased Valley is a non-profit organisation supporting the development of bio-based activities and the resulting economic growth in Flanders. It promotes the development of the bio-based economy of the future through collaborative programs, joint initiatives and synergy creation between the partners in the fields of R&D, structural measures and policy, logistics and communication towards the general public. Specific activities are:

- Technological innovation: building R&D expertise in the field of bio-based products and bio-energy by coordinating and facilitating national and international collaborative projects with and for industry;
- Cluster & Integration: building synergies between industrial partners through networking and joint initiatives;
- Communication: informing the public, industry, academia and government about the bio-based economy, improving general and specialized understanding and raising awareness through communication (workshops, site visits, public debates, information campaigns,...);

[33] *http://capture-resources.be/capture-initiative*

- Customised services: technological advice, partner matching, assistance with project proposal submission, …

The public sector partners of the Flanders bio-based valley are UGent, city of Ghent, North Sea Port and the Province Oost-Vlaanderen. Industrial members include AEP polymers, Alco biofuel, ArcelorMittal, biopark terneuzen, Oleon and Storaenso.

Catalisti (formerly Flanders Innovation Hub for Sustainable Chemistry (FISCH))

Catalisti is the spear-point cluster for chemistry and plastics in Flanders. The cluster seeks to bridge the gap between fundamental research and production by:

- Identifying and initiating innovation opportunities
- offering expertise and access to resources and
- catalysing the cooperation between companies and knowledge centers.

Figure 31: List of research projects enabled by catalisti (Source: catalisti)

Catalisti is active in research domains related to renewable chemicals, side-stream valorisation, process intensification and advanced sustainable products. Catalisti (Fisch) has also been leading the development of roadmaps on renewable chemicals and on industrial bio-technology.

3.8.4 Policies and strategies

Flanders is already familiar with a few strategies and policies covered in this study which impact industries. The following will be briefly discussed here:

- The Flemish energy vision (Vlaamse energievisie)
- The Flemish action plan on the circular economy (Vlaanderen circulair)
- Voluntary agreements on industrial energy efficiency (Energiebeleidsovereenkomsten)
- Flemish innovation and investment support
- Financing vehicles (PMV)

Vlaamse energievisie

The ‘Vlaamse Energievisie’, published in May 2017, is a concept note outlining a long-term vision for the Flemish economy with regards to the energy system toward 2030. This vision should lay the basis for future policies. With regard to energy intensive industries the strategy recommends to continue the voluntary agreements on energy efficiency (energiebeleidsovereenkomsten). It further recommends stimulating innovation and the transition to a circular economy. The vision calls for the support of private sector driven demonstration projects. These innovative activities of the public, research and private sectors can be concentrated in well outlined clusters. Finally, the strategic document mentions industry achievable commitments with quantifiable results (e.g. on energy-efficiency) while maintaining competitiveness. Additionally, according to the vision, it can be investigated if roadmaps could be developed or published.

Vlaanderen circulair
'Vlaanderen circulair'[34], established in January 2017, is the masterplan to successfully achieve Flanders' transition to a circular economy. The plan consists of six core activities:

- The creation of partnerships, co-creation and shared ownership
- Financial support for pioneering innovators
- Sharing of knowledge and policy relevant research support
- Supporting policies and coordination between different branches of government
- Support and accelerate innovation and entrepreneurship towards a circular economy
- Anchoring and scale up of best practices on circular economy.

Government support is driven by the needs of stakeholders who will take the initiative in this area. Main work programmes are the Green Deal on circular public and private procurement, the circular city and circular entrepreneurship.

Voluntary agreements on energy efficiency in industry (Energiebeleidsovereenkomsten)
The voluntary agreements on energy efficiency for EU ETS companies started in 2015 (and were a continuation of previous programmes on energy-efficiency benchmarking covenant and auditing covenant). The main goal of these voluntary agreements is to have energy intensive companies strive towards or maintain excellence in the area of energy efficiency. The latest results from the implementation of the voluntary agreements show an aggregated list of efficiency measures by these companies leading to a reduction of energy use of 17.4PJ in 2018 compared to the year 2014.

Flemish innovation and investment support
The Flemish government has a range of instruments to support innovation and investments in large industrial companies. The maintenance and coordination of these initiatives is done by VLAIO (the Flemish Agency for Innovation and Entrepreneurship). The initiatives include[35] support for extending research activities in companies, multidisciplinary demand oriented research, innovation clusters and clean-tech innovation.

An important catalyst for innovative investments in Flanders is Participatiemaatschappij Vlaanderen (PMV). PMV[36] provides finance for promising businesses from the very start through their various growth stages and even on to operating internationally. Working with and for the government and other partners, PMV implements projects that are important for prosperity and wellbeing in Flanders. PMV played an important role in financing the forthcoming innovative bio-based plastic plant in the Antwerp harbour (a joint venture between BASF and Avantium). As mentioned above PMV is also financing the Bluechem sustainable chemistry incubator.

[34] https://www.vlaanderen.be/nl/vlaamse-regering/transitie-circulaire-economie https://www.vlaanderen.be/nl/publicaties/detail/transitieprioriteit-de-transitie-naar-de-circulaire-economie-doorzetten-startnota
[35] https://www.vlaio.be/nl/subsidies-financiering/subsidiedatabank/zoek?thema=28
[36] http://www.pmv.eu/en

It is almost certain that an industrial low-carbon transition in Flanders will require access to risk mitigating capital. Organisations such as PMV will have to play an important role here also because of their ability to leverage other EU de-risking instruments (e.g. via the European Investment Bank (EIB)).

3.9 CONCLUSIONS: ASSETS AND CHALLENGES OF FLEMISH INDUSTRY

3.9.1 General findings

Since 2008, emissions from EU ETS companies have remained relatively flat, with a slight increase over past years. At the same time most of the industrial sectors increased (absolute) value added to the economy (and hence improved their CO_2 efficiency) but show a decrease in their share of value added in the Flemish economy although they kept investments at a high level. Under the 'energiebeleidsovereenkomsten' important energy savings are still happening in Flemish EU ETS (and non-EU ETS) companies.

Flemish industry contributes strongly to exports and, in particular, to value chains in neighbouring countries and the rest of the EU. On the other hand, Flemish companies operate on a global market with competitors such as USA and China. The volume and share of imports from these latter countries in the EU has increased over the past decade and the market share in international trade (outside of the EU) has decreased.

Bringing down emissions from energy intensive industries further, as a contribution to the European goal of -80 to -95% by 2050, will hence be a major challenge. The incremental evolutions as seen in the emissions and energy consumption profiles will not suffice to reach a deep level of decarbonisation. Energy is vital for industrial production in Flanders and since a lot of efforts have already been made to improve energy-efficiency (as shown from the results in the covenants), breakthrough technologies will be needed for further decarbonisation. This points to the need for major industrial innovations over the next decades, and indicates that an intelligent approach on industrial transformation for Flanders must be designed to avoid risking the erosion of competitiveness of the industry even further since delocalisation of production and investments will negatively impact welfare in Flanders and merely shift emissions to more competitive regions

The technological innovations that can assist in achieving a low-CO_2 transition will be considered later in chapters 5 (industrial roadmaps) and 6 (low-carbon technologies).

It is also important to establish a brief SWOT analysis of Flemish energy intensive industries in the context of the transition to a low-carbon economy using information gathered in the process of researching the profile of Flemish energy intensive industry sectors. The next sections will briefly touch upon the assets & strengths, possible weaknesses, threats & challenges and opportunities for these industrial sectors.

3.9.2 Assets & Strengths

Industrial sectors in Flanders possess many strengths demonstrated by their significant contribution to the Flemish GVA. One of the most important assets is related to the geographic location of industry in Flanders. At the centre of Western-Europe and at the same time connected by ports, railroads, roads and waterways to the rest of Europe, Flemish industry occupies a prime spot for the production of materials at different stages of the value (and supply) chains. Furthermore, not only are basic materials produced in Flanders, but those products are further advanced on the value chain (e.g. there are around 400 plastic convertors[37] (mostly small and medium sized enterprises (SMEs)) in Flanders, employing around 18,000 people[38]). As shown in the previous section, a high proportion of Flemish exports consists of products that flow into value chains in neighbouring (and other EU) countries, demonstrating cross-border industrial integration.

A key strength of, in particular the chemicals and refining industry, is the clustering of different production plants. The integration of world-class stream cracking installations and the availability of surplus coking in the largest Flemish refining installations give these a 'must-run' status as compared to other refineries in Northwest Europe that don't have these capabilities, under different future scenarios[39].

Raw Materials		C/Cl	Feedstocks	Building blocks	Commodities	intermediates	Final products
Natural gas/Crude oil/Condensate	Produced in chemical cluster	C1	Methane/ refinery residue	Synthesis Gas	Ammonia, Nitric Acid	Urea, AN, CAN, UAN	Fertilisers
	Not produced in chemical cluster	*C1*			*Methanol*	*Formaldehyde*	*Glues, Resins*
Natural gas/Crude oil/Condensate	Produced in chemical cluster	C2	C2-C3/ Naphtha	Ethylene	PE, EDC, VCM, Ethylene oxide	PVC, Glycols, EVOH, Ethyl NBO, Glycol Ethers	
	Not produced in chemical cluster	*C2*					*Polymers, EPDM, Copolymers*
Natural gas/Crude oil/Condensate	Produced in chemical cluster	C3	C2-C3/ Naphtha	Propylene, propane	Polypropylene, Propylene Oxide, Acrylic Acid	Polyols, SAP	Polymers (e.g. Polyurethane)
	Not produced in chemical cluster	*C3*					
Crude Oil	Produced in chemical cluster	C4	Refinery off-gas/Naphtha	Mixed C4	Butadiene	Polybutadiene	Acrylonitrile, Butadiene, Styrene
	Not produced in chemical cluster	*C4*					
Crude Oil	Produced in chemical cluster	C6	Naptha	Benzene, Toluene	Cyclohexane, Caprolactam, Aniline	BPA, Nylon 66, MDI	Polycarbonate, Polyurethane
	Not produced in chemical cluster	*C6*					
Crude Oil	Produced in chemical cluster	C7,8	Naptha	Mixed Xylenes	O, P-Xylene	PA, PTA	PET
	Not produced in chemical cluster	*C7,8*					
Sea water/Brine	Produced in chemical cluster	Cl	Chlorine, NaOH	EDC, Phosgene		PVC, MDI, Hypochlorites	Plastics, Polyurethane, Bleach
	Not produced in chemical cluster	*Cl*			*VCM*		

Figure 32: The Flemish (Antwerp) chemical cluster of petrochemical building blocks, intermediates and final products (Source: EPCA, Results of the Think Tank Sessions, 2007)

Flanders has a highly skilled work force and strong local research institutes and universities. A significant share (around 70% in 2015) of the Flemish gross expenditures on R&D (Government Expenditures on R&D (GOVERD)) is taken up by the private sector (Business Expenditure on R&D (BERD))[40]. The Flemish chemicals industry (including pharmaceuticals and plastics and rubber production) provided around 33% of the BERD in Flanders in 2015. Most of the chemicals sector's R&D (75%) was spent in the areas of pharmaceutical and bio-tech research[41]. It is interesting to note that, similar to employment and GVA generation, most of Flemish business R&D ensues from a small number of companies. In 2015, the top 50 R&D-active companies represented 58% of business R&D expenditure in Flanders[42].

[37] These are companies that convert or process basic plastic ingredients coming from a.o. the olefins industries into semi-finished and finished plastic products.
[38] Advanced Materials in Flanders (2014), p. 47
[39] 'Long term prospects for Northwest Europe refining', CIEP (2016), p. 30
[40] 'Totale O&O intensiteit in Vlaanderen. 3% nota', Debackere et al. (2017), p. 7
[41] 'Chemie, kunststoffen en life-sciences: kerncijfers 2015, Vlaanderen', Essencia (2016), p. 2
[42] 'Totale O&O intensiteit in Vlaanderen. 3% nota', Debackere et al. (2017), p. 7

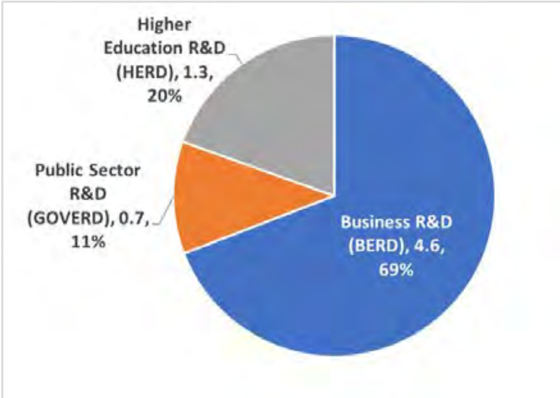


Figure 33: Relative R&D expenditures (% and EUR Bn) of Business, Public and Higher education sectors in Flanders in 2015 (Source: Totale O&O intensiteit in Vlaanderen. 3% nota', Debackere et al. (2017))

3.9.3 Weaknesses

The weaknesses of the industrial sectors considered here relate to their energy intensity and dependence on the import of fossil fuels, as well as the uncertainty surrounding the evolution of electricity production and markets in Flanders and Belgium. Other regions in the world which have access to cheap feedstock (and electricity) might be at a (structural) cost advantage. Also, labour costs tend to be relatively high in Flanders. Regulatory complexity in Belgium (in particular for multinational companies operating in the different regions of Belgium) can have a negative impact on investments.

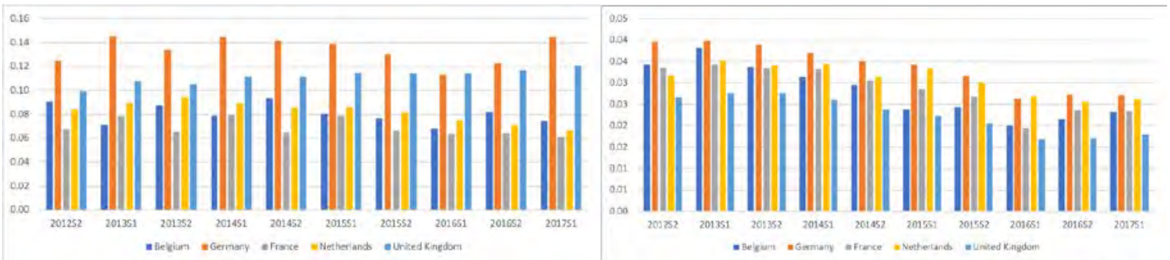


Figure 34: [Left] Average electricity prices (70,000 MWh<consumption<150,000 MWh) and natural gas prices (1,000,000 GJ<consumption<4,000,000 GJ) [Right] in EUR/kWh all taxes and levies included (Sources: Eurostat nrg_pc_205 and nrg_pc_203)

The Belgian open economy and location, while being a major asset can at times also be a (temporary) weakness. Disruptions in international trade (e.g. Brexit or global trade wars) can disproportionately affect Belgian industrial sectors. Furthermore, being at the centre of a major logistics hub makes the industry dependent on an adequate level of public investments to maintain, expand or diversify transport infrastructure.

Finally, from a governance perspective, the fact that most energy intensive companies are multinationals with headquarters outside Flanders can be seen as a weakness. This is, in particular, since it can strengthen the impact of the previously mentioned negatives on investments decisions in Flanders. On the other hand, these large companies can create large positive spill-overs for smaller (local) companies that are part of the industrial clusters. With regard to the transition to a low-CO_2 industry in Flanders, the previous sections have shown that these companies (due to their disproportionate importance on GVA, employment, investments and R&D expenditure) will be pivotal. Hence, the importance of the future investment and R&D climate in Flanders.

3.9.4 Threats & challenges

With regard to global challenges and threats, some relatively recent evolutions may negatively impact Flemish industrial sectors (in particular keeping in mind the weaknesses listed above)[43]. These include the continuous exploitation of abundant shale gas (and shale oil) in the US which has led to new investments in petrochemical installations in America and subsequently to the production of basic chemicals at a very competitive price. A similar structural point can be made with regard to (new) investments in the Middle East. There is a risk that other parts of the chemicals value chain (beyond basic petrochemicals) will be developed in these regions. Finally, the increased demand in growing markets such as India and China has led to an increased level of investments in basic production capacities in these regions. This has reduced the European (global) market share significantly. Furthermore, a decline in domestic demand in China can force Chinese producers to dump more on the international market in order to compensate for domestic production capacity surpluses (which happened with steel during the economic global recession that started in 2008-2009).

As mentioned before, Flemish industry (due to its location and being part of a very open economy), can be more vulnerable to events that disrupt trade. Examples of such events are a possible hard exit of the UK out of the EU (i.e. without a free trade agreement) or trade barriers being introduced by an increasingly mercantilist US administration (including the responses by other trade partners).

Other challenges or threats have a more local or regional dimension, in particular, in relation to the transition to a low-carbon society. In particular, disruptions that could happen in the transport and power sector low-carbon transitions might impact basic materials industries significantly. The energy/power sector transition in particular will be extremely relevant for energy/electro-intensive industries. Close coordination between the future industrial low-carbon transition and the ones already happening in the power sector will be necessary, in particular to ensure that (increasing) energy costs do not lead to a competitive distortion. It is also highly likely that low-carbon technologies to be deployed in industrial sectors over the next decades[44] will lead to a (significantly) higher electricity demand, hence increasing the demand for investments in low-carbon power production. Also, according to the impact assessment of the European Commission's energy roadmap 2050[45], non-energetic energy use will not significantly go down by 2050.

The (road) transport sector is likely to see major disruptions over the next decades. In the short-term, there may be a probable shift away from diesel engines in cars (due to air quality concerns and standards). In the longer-term electric vehicles may gradually replace internal combustion engine vehicles. The rate at which this will happen is still uncertain. Both evolutions can impact the refining industry and hence the petrochemical cluster. As shown in the figures in section 3.3.2. the Flemish refining industry's output is mostly diesel oil (vis a vis gasoline), and a sudden drop in demand for diesel might lead to additional investments (or change in crude oil inputs) to meet higher demand for gasoline.

Changes to future oil demand in Europe can be substantial as it may decrease by over 32% by 2040[46]. Depending on the scope and speed of such transition, Flemish refineries could be affected.

[43] Vlaamse Regering, 2018, Nota aan de Vlaamse Regering: Trilaterale strategie voor de chemische industrie

[44] This can be concluded by looking at the industrial roadmaps that have been developed so far and the low-carbon breakthrough technologies that are being researched at the moment (see chapters 5 and 6 of this report).

[45] European Commission's communication 'Energy roadmap 2050' - Staff Working Paper., 2011. P. 168-179 https://ec.europa.eu/energy/sites/ener/files/documents/roadmap2050_ia_20120430_en_0.pdf

[46] CIEP, 2018, Refinery 2050: Refining the clean molecule. p. 16

Finally, there are indicative future shifts and policies that are directly linked to energy intensive industries. Plans for full circularity of plastics and higher consumer awareness can lead to a significantly lower demand for plastics and/or (some) polymers. This can have an important impact on the whole chemicals value chain in Flanders but can also lead to new business models.

The EU ETS will (likely) over time see higher CO_2 prices and lead to more carbon exposure for energy intensive industries. While there is a level playing field in the EU, it is not certain that this will be the case on a global level. It's also possible that sectors in other EU Member States that have access to sufficient R&D support, finance and a conducive regulatory environment might develop the required low-carbon processes and value chains faster and hence gain a competitive advantage.

3.9.5 Opportunities and relevance for Flemish industrial low-carbon framework

The major challenges that are likely to occur also offer opportunities for the energy intensive industry sectors in Flanders.

The industrial clusters in Flanders are well placed to further explore industrial symbiosis and hence create economic resilience in a low-carbon context. This can include options for CCU for instance or biomass (waste) streams. The circular economy will offer important opportunities for new business models along the value chains of different sectors, with the option to save materials and energy costs. With these changes in mind it is possible that the current sectoral boundaries (as used in the previous sections) become less relevant (even across borders). The opportunities in the context of a circular economy could lead to a focus on higher value-added products and services.[47]

The identification of existing and future opportunities, linked with the strengths of Flemish industrial sectors, should hence form an important element in the development and implementation of a possible future Flemish low-carbon framework for industry.

[47] 'The essential cluster for the Belgian economy', Noels G. (2017)

Strengths	Weaknesses
• Central geographical location • Excellent connectivity (logistics) • At the core of European value (& supply) chains • Clustering of production plants/processes and process optimisation (esp. Chemicals & Refining) • Strong presence of large multinationals creates positive spill-overs for smaller (local) companies in industrial clusters • Refining has due to Integration of world-class stream cracking installations and availability of surplus coking a 'Must Run' status • Highly skilled labour force • Strong reputation for research and business expenditure on R&D (BERD)	• High energy cost related to EU policy (exposure to prices) • Most (large) investment decisions are taken by multinational companies with decision making centres outside of Flanders. • Relatively high labour costs • Regulatory complexity especially for multinationals • Open economy and location → vulnerable to international trade disruptions • Need for more and updated infrastructure given status as a major logistics hub
Threats	**Opportunities**
• Global sectoral developments (US shale gas & shale oil, new investments in Middle East, overproduction in emerging economies like China) • EU & global trade disruptive events (e.g. Brexit, US mercantilism) • Disruptions during transport and power sector low-carbon transition • Industrial low-carbon technologies deployment → (significantly) higher electricity demand → demand for investments in low-carbon power production • Circularity → lowered demand of basic products/materials • EU ETS → (future) higher CO_2 prices → more carbon exposure → uneven global playing field	• Energy/power-sector transition → industrial demand response/storage opportunities • Well placed industrial clusters offer opportunities for industrial symbiosis and better economic resilience in a low-carbon economy • Circularity → new business models and higher value-added products and services

Table 2: SWOT analysis of Flemish energy intensive industries in the context of a low-carbon and energy transition.

4 INDUSTRY IN NEIGHBOURING COUNTRIES AND REGIONAL CLUSTERS

4.1 INTRODUCTION

This section will draw a comparison of industry in Flanders with that of four key neighbouring European countries - Germany, France, The Netherlands and the UK - along three parameters: GHG emissions, GVA and employment (sections 4.2, 4.3 and 4.4 respectively). The sectors assessed here are the same NACE 2 level industrial sectors' aggregates as used in section 2, allowing a direct comparison between Flemish industries and those of the neighbouring countries.
These sectors are:

- Manufacture of food products, beverages and tobacco products (10-12)
- Manufacture of textiles, wearing apparel and leather products (13-15)
- Manufacture of wood and of products of wood and cork (except furniture); manufacture of articles of straw and plaiting materials (16)
- Manufacture of paper and paper products (17)
- Manufacture of coke and refined petroleum products (19)
- Manufacture of chemicals and chemical products (20) and manufacture of rubber and plastics products (22)
- Manufacture of other non-metallic mineral products (23)
- Manufacture of basic metals (24)

All the data presented in this chapter has been extracted from the European Commission's EUROSTAT statistics database[48] unless stated otherwise.

Section 4.5. moves beyond the direct comparison of Flanders and its neighbouring countries and presents the industrial clusters and the links to Flemish industry, including the new trilateral strategy of the governments in the region. As example of new cluster developments, the Flemish Dutch bio-based energy/economy delta is briefly presented.

4.2 GREENHOUSE GAS EMISSIONS

In comparison with France, UK, Germany and The Netherlands, the energy intensive industries in Flanders represents a significantly higher share of GHG emissions, both as share of economy-wide emissions and as share of the emissions covered by the EU ETS. In Germany, the industrial sectors represent 17% of economy-wide emissions and 34% of the emissions of installations (i.e. industry and power production) in Germany covered by the EU ETS (2016 figures). This can (partially) be explained by the presence of high CO_2 intensity power production in Germany (e.g. through coal and lignite). In France, the overall share of industrial emissions is 15% but the share under the EU ETS is much higher (69%) (2016 figures). The latter can be explained by the high share of nuclear energy in

[48] Extracted from http://ec.europa.eu/eurostat/data/database (GVA figures: nama_10_a64, Employment: nama_10_a64_e, GHG emissions: env_ac_ainah_r2)

France (leading to a relatively lower share of power sector emissions). In the UK the overall share of industrial emissions is relatively small (14%) (2016 figures). The UK industry EU ETS' share of GHG emissions stands at 46%. This higher figure can be explained by the presence of nuclear energy in the UK and the decline of coal-based power generation. The Netherlands has a higher share of industrial emissions as part of the overall economy (22%) and industrial emissions' share under the EU ETS is 46% (2016 figures).

In Flanders, the industrial share of economy-wide emissions is 29%, the highest among neighbouring countries (2016 figures). Also, Flemish industry's emissions as part of the EU ETS (71%) are significantly higher compared to (most) neighbouring countries. Both figures combine the effect of a relative high presence of industry in Flanders (also reflected in GVA figures), a high share of nuclear energy in Belgium and no presence of coal-based power production (i.e. a low share of power sector emissions under the EU ETS).

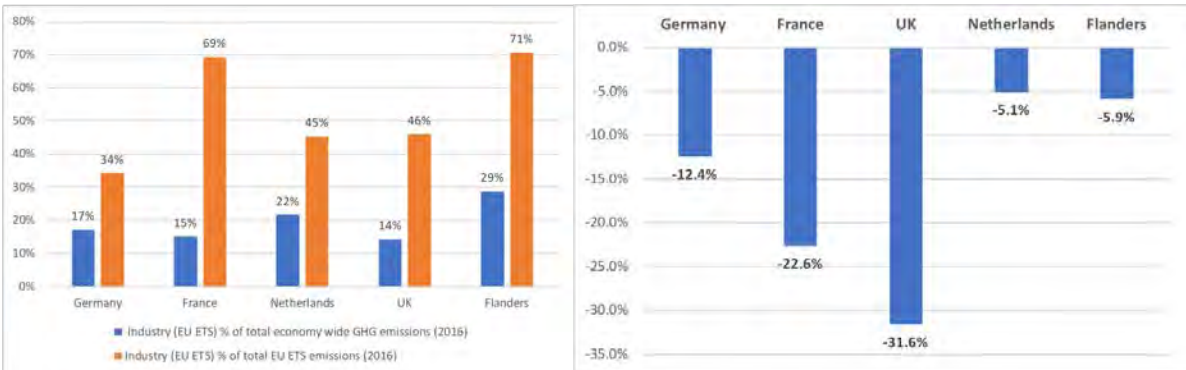


Figure 39: [Left] share of industrial (EU ETS) emissions as part of total economy and the EU ETS in Flanders and neighbouring countries in 2016 (sources: European Environment Agency, Sandbag, Vlaamse Overheid). [Right] Relative change in GHG emissions from industrial sectors between 2008 and 2016 (Sources: Eurostat and Vlaamse Overheid)

Between 2008 and 2016 the emissions from industrial sectors[49] declined the most in the UK (-31.6%), followed by France (-22.6%) and Germany (-12.4%). The Netherlands saw the smallest decrease (-5.1%), while in Flanders they dropped 5.9%. The significant decline in the UK and, to a lesser extent, France's industrial emissions is related to major industrial closures that ensued over that period. Three large-scale UK refineries (Teesside (Petroplus), Coryton (Petroplus) and Milford Haven (Murco) closed in 2009, 2012, and 2014 respectively. There has also been a reduction of capacity through mothballing of primary distillation[50] while others have registered large losses[51]. Large integrated iron and steel plants in the UK closed in 2010 and 2015 (which included the second largest blast furnace in Europe) in addition to two of three aluminium smelters[52]. In France, there was a large industrial closure in steel production in 2011 (Florange). In Germany, a significant reduction took place in the chemical sector's non-CO_2 emissions, likely similar (catalytic) reduction measures that were taken a bit earlier in Flanders. Flanders did not see industrial closures of large, single source emitters in the period 2008-2016. While there were important industrial closures in textiles, ceramics and automotive in that period in Flanders, these had a relatively limited impact on overall industrial GHG emissions.

[49] For all neighbouring countries Eurostat data (env_ac_ainah_r2) was used covering NACE 10-12, 13-15, 16, 17, 19 , 20, 22, 23 and 24. For Flanders actual sectoral data from the EU ETS was used. This likely means a higher share of industrial emissions compared to Flanders because the NACE sector codes can also include emissions from smaller emitters not covered by the EU ETS.

[50] https://assets.publishing.service.gov.uk/government/uploads/system/uploads/attachment_data/file/652109/oil-refining-decarbonisation-action-plan.pdf

[51] https://www.telegraph.co.uk/finance/newsbysector/energy/oilandgas/11866733/Britain-faces-diesel-drought-following-refinery-closures.html

[52] https://onlinelibrary.wiley.com/doi/full/10.1002/wene.212

Germany

Emissions from industrial sectors stood at 148 Mt CO_2-eq in 2016, a decrease of 12.43% since 2008 (169 Mt CO_2-eq). Between 2008 and 2016, emissions have dropped across all the sectors considered, with the exception of food products, beverages and tobacco industries which registered a slight increase of 0.31%. Emissions in the chemicals industry decreased 25% between 2008 (38.4 Mt CO_2-eq) and 2016 (28.6 Mt CO_2-eq), a significant part of which came about due to reductions of N_2O emissions.

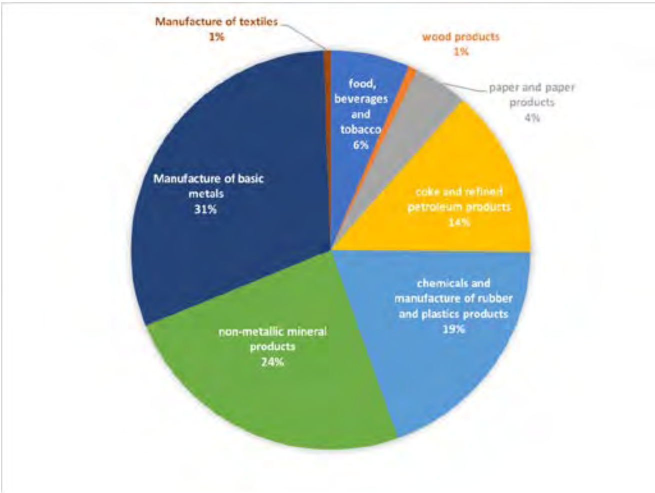


Figure 35: Relative shares of GHG emissions of industrial sectors (mentioned in chart) in Germany in 2016 (Source: Eurostat)

As expressed in the figure 40 above, the basic metals industry was the largest emitting sector accounting for 31% of total industrial emissions in 2016, followed by the non-metallic mineral products industry (24% of total industrial emissions), chemicals industry including rubber and plastic products (19%), coke and refined petroleum products industry (14%), food, beverages and tobacco industries (6%) and paper products industry (4%). The manufacture of textiles and wood products industries each accounted for 1% of total industrial emissions.

France

Emissions from industrial sectors stood at 89 Mt CO_2-eq in 2016, a decrease of 22.61% since 2008 (115 Mt CO_2-eq). Between 2008 and 2016, emissions have dropped across all the industries considered. The chemicals, plastics and rubber production industry was the largest emitting industry accounting for 24.38% of total industrial emissions and 6.6% of total French economy-wide GHG emissions in 2016. Emissions in the chemicals, plastics and rubber production industry decreased 24.13% between 2008 (28.6 Mt CO_2-eq) and 2016 (21.7 Mt CO_2-eq). Coke and refining industry sectors' emissions decreased 29% and that of the basic metals industry by 18% in same period. Between 2008 and 2016, the paper and paper products industry was the only one to have registered a rise in emissions as a percentage of total French emissions (from 0.87% to 0.91%).

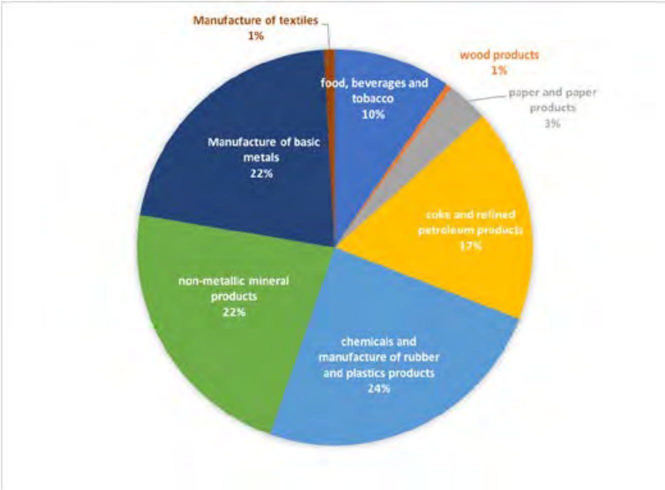


Figure 36: Relative shares of GHG emissions of industrial sectors (mentioned in chart) in France in 2016 (Source: Eurostat)

Figure 41 above illustrates the distribution of total industrial emissions (amongst sectors assessed) in France, in 2016, the chemicals industry including rubber and plastics products formed the largest share (24%) followed by the basic metals and non-metallic mineral products industries (22% each) and coke and refined petroleum products industry (17%). The food, beverages and tobacco industry accounted for 10% of total industrial emissions, paper and paper products industry for 3% and the manufacture of textiles and wood products industries 1% each of total industrial emissions.

UK

Emissions from industrial sectors stood at 65 Mt CO_2-eq in the same year, a decrease of 32% since 2008 (95 Mt CO_2-eq). Between 2008 and 2016, emissions have dropped across all the industries considered. However, there has been an interesting decrease across three industries between 2008 and 2016: the chemicals, plastics and rubber production industry (-33%); basic metals industry (-54%) and coke and refining industry (-25%).

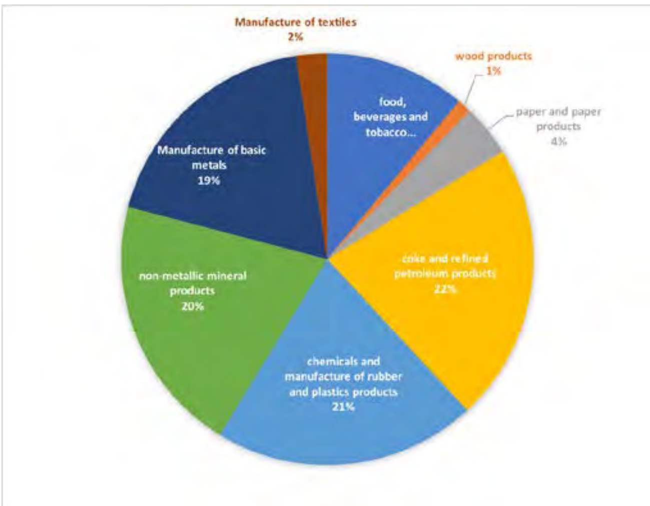


Figure 37: relative shares of the GHG emissions of industrial sectors (mentioned in chart) in the UK in 2016 (Source: Eurostat)

The figure 42 above shows that four industries accounted near-equally for almost 80% of total industrial emissions (amongst sectors assessed) in 2016: coke and refined petroleum production industry (22%), chemicals including rubber and plastics products industry (21%), non-metallic mineral products industry (20%) and the basic metals industry (19%). They were followed by the food beverages and tobacco industry (11%), paper and paper products industry (4%), textiles industry (2%) and wood products industry (1%).

Netherlands

Emissions from industrial sectors stood at 44 Mt CO_2-eq in 2016, a decrease of only 5% since 2008 (46 Mt CO_2-eq). Between 2008 and 2016, emissions have dropped across all the industries considered, with the exception of two: food products, beverages and tobacco industry which grew by 3.15% (from 39.94 Mt CO_2-eq in 2008 to 41.20 Mt CO_2-eq in 2016) and chemicals, plastics and rubber production industry which grew 1.13% (from 19.23 Mt CO_2-eq in 2008 to 19.45 Mt CO_2-eq in 2016).

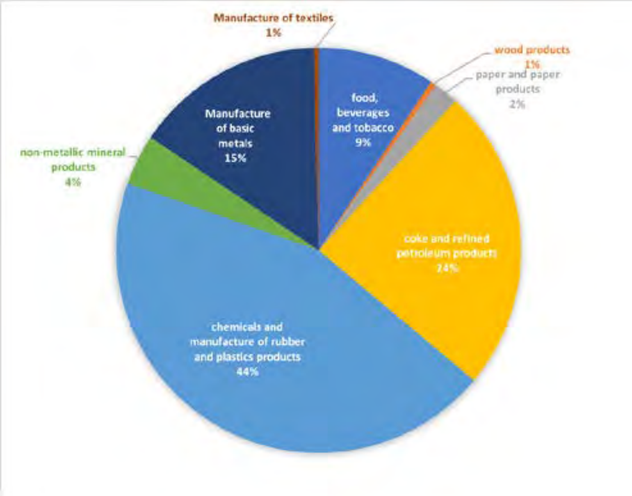


Figure 38: relative shares of GHG emissions of industrial sectors (mentioned in chart) in the Netherlands in 2016 (Source: Eurostat)

The chemicals including rubber and plastic products industry accounted for 44% of total industrial emissions (amongst sectors assessed) in 2016 (see figure 43 above). This was followed by the coke and refined petroleum products industry (24%), food, beverages and tobacco industry (9%), non-metallic mineral products industry (4%), paper and paper products industry (2%) and textiles and wood products industries (1% each). The basic metals industry with 15% emissions represents the lowest share of total industrial emissions (amongst sectors assessed) as compared to the UK, France and Germany. Out of all countries assessed here, the industrial emission profile of Flanders is most similar to the one presented for The Netherlands. This does not imply that the overall industrial profile itself is fully comparable between Flanders and The Netherlands.

4.3 GROSS VALUE ADDED

The GVA % for all the industrial sectors together in Flanders (followed by Belgium as a whole) is higher than in all the neighbouring countries selected for this assessment. GVA as a percentage of the economy has dropped across all countries (Belgium: 9.07% in 2003 to 7.07% in 2014, Germany: 7.61% in 2003 to 6.76% in 2014, France: 6.47% in 2003 to 5.17% in 2014, Netherlands: 6.77% in 2003 to 5.27% in 2014, UK: 5.5% in 2003 to 4.07% in 2014, but most as concerns Flanders: 12.75% in 2003 to 9.74% in 2014).

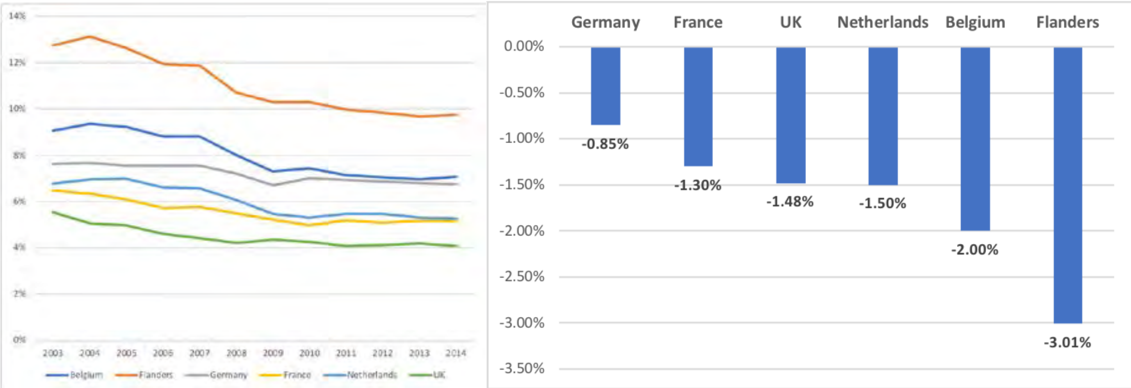


Figure 39: [Left] Evolution of GVA (of selected industries as aggregate) % to economy wide GVA of countries and [Right] difference in share of industrial GVA between 2003 and 2014 (Source: Eurostat and NBB)

Germany

In the period 2003-2015, the economy-wide total GVA (current prices) increased by nearly 735 Bn (or 37%) from EUR 2 Trillion (Tn) to EUR 2.74 Tn. The value added of the industrial sectors as aggregated increased nearly 25% in same period (from EUR 153 Bn to EUR 191 Bn). However, the contribution of these sectors to the overall German GVA decreased slightly from 7.61% in 2003 to 6.96% in 2015.

Just as in Flanders, the chemicals, plastics and rubber production industry offers by far the largest GVA (current prices) as compared to other manufacturing industries, standing at EUR 75.78 Bn in 2015, up 36% from 2003 (EUR 55.80 Bn). The industry's contribution to the overall German GVA (also the largest as compared to other manufacturing industries) remained more or less the same in 2015 at 2.76% as compared to 2003 at 2.78%.

France

In the period 2003-2015 the total GVA (current prices) registered a rise of 33% or EUR 487 billion having increased from EUR 1.48 Tn to EUR 1.96 Tn. The value added of the industrial sectors as aggregated however increased only 7% in same period (from EUR 95.5 Bn to EUR 102.5 Bn). The contribution of these industries to the overall French GVA too decreased more than a percent point from 6.47% in 2003 to 5.22% in 2015.

Unlike in Germany and Flanders, the food products, beverages and tobacco industry offers by far the largest GVA (current prices) as compared to other manufacturing industries, at EUR 46.77 Bn in 2015, up nearly 19% from 2003 (EUR 39.32 Bn). The chemicals, plastics and rubber production industry registered the second largest GVA at EUR 29 Bn in 2015, increasing a little more than 13% from 2003 (EUR 25.6 Bn). Every industry's contribution to the overall French GVA decreased between 2003 and 2015.

UK

Between 2003 and 2015, the economy-wide UK GVA increased by EUR 700 billion having risen from EUR 1.62 Tn in 2003 to EUR 2.32 Tn in 2015 (+43%). The value added of the industrial sectors as aggregated increased a little more than 10% in same period (from EUR 90.1 Bn to EUR 99.4 Bn). The contribution of these industries to the overall UK GVA too decreased from 5.55% in 2003 to 4.28% in 2015.

Similar to France (and unlike in Flanders), the food products, beverages and tobacco industry in the UK offers by far the largest GVA (current prices) as compared to other manufacturing industries, at EUR 37.08 Bn in 2015, an increase of 7.92% from 2003 (EUR 34.36 Bn). Once again, analogous to France, the chemicals, plastics and rubber production industry registered the second largest GVA at EUR 28.17 Bn in 2015, increasing almost 4% from 2003 (EUR 27.12 Bn). Interestingly, the coke and refined petroleum products industry registered an impressive growth in GVA of 134.26% growing from EUR 1.80 Bn in 2003 to EUR 4.22 in 2015. The industry's contribution to the overall UK GVA increased from 0.11% in 2003 to 0.18% in 2015 while every other industry's contribution decreased over the same period.

Netherlands
Between 2003-2015, the total GVA (current prices) increased by EUR 162.1 Bn from EUR 452.9 Bn in 2003 to EUR 615 Bn in 2015 registering a rise of nearly 36%. The value added of the industrial sectors as aggregated increased 13.36% in same period (from EUR 30.7 Bn to EUR 34.8 Bn). The contribution of these industries to the overall Dutch GVA however decreased from 6.77% in 2003 to 5.65% in 2015.

Similar to France and the UK (and unlike in Flanders or Germany), the food, beverages and tobacco industry offers the largest GVA (current prices) as compared to other manufacturing industry, at EUR 14.14 Bn in 2015, an increase of almost 21% from 2003 (EUR 11.70 Bn). Again, as in the UK and France, the chemicals, plastics and rubber production industry registered the second largest GVA at EUR 12.16 Bn in 2015, increasing almost 18% from 2003 (EUR 10.32 Bn). The relative contribution to the overall Dutch GVA declined across all sectors.

4.4 DIRECT EMPLOYMENT

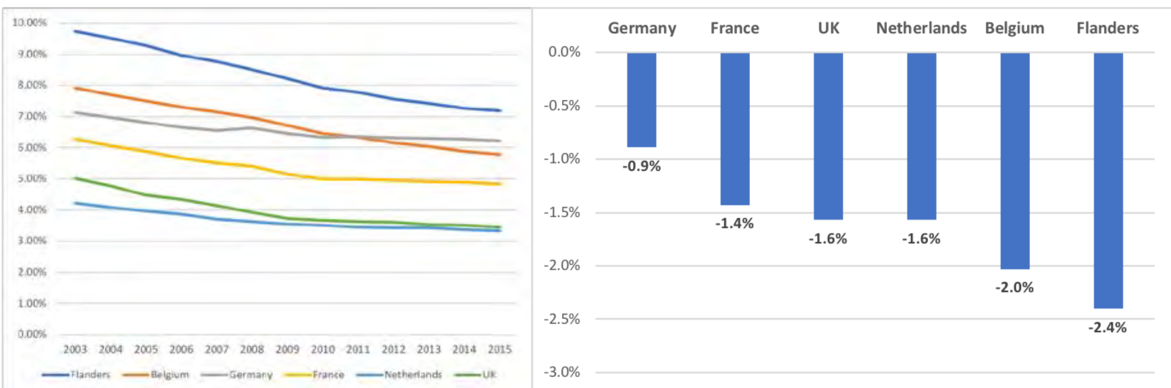


Figure 40: Change of employment in (selection of) industrial sectors as share of total employment between 2003 and 2014 (Sources: Eurostat and NBB)

Across all selected countries the share of industrial sectors' employment, as part of total employment in the economy, declined between 2003 and 2014. The indirect employment generated by these industries wasn't taken into account. In Germany this decline in employment share was the smallest (-0.9%), while in Belgium and Flanders it was the most notable (respectively -2% and -2.4%). In the other countries considered, the declines were 1.4% (France) and 1.6% (UK and Netherlands).

Germany

In the period 2003-2015 the total employment (number of persons) employed increased by almost 10% from 39.2 Mn to almost 43.1 Mn. Similar to Flanders (albeit less so), the industrial sectors (as aggregate of listed NACE codes) saw a decline in employment of 4% from 2.79 Mn to 2.68 Mn between 2003 and 2015. This downward trend is consistent amongst all manufacturing industries covered. The share of number of people employed in these subsectors compared to total German employment decreased to 6.21% in 2015 from 7.1% in 2003.

The manufacture of food, beverages and tobacco industry was the largest employer within the industries considered, mirroring Flanders, having employed 930,000 people in 2015, slightly down from 936,000 people in 2003. The share of number of people employed in this industry compared to total German employment decreased from 2.39% in 2003 to 2.16% in 2015. The chemicals, plastics and rubber production industry was the second most important employer with 783,000 employees in 2015 and was the only industry to register a growth in employment, up 2.1% from 767,000 employees in 2003. Yet, the share of number of people employed in the chemicals, plastics and rubber products industry compared to total German employment decreased from 1.82% in 2003, to 1.96% in 2015 despite being the only sector to pick up following the financial crisis (from 1.76% in 2010 steadily rising to 1.83% in 2014).

France

In the period 2003-2015, the total economy-wide employment (number of persons) increased by nearly 5% from 26.16 Mn to almost 27.43 Mn. Similar to Flanders and Germany, the industrial sectors (as aggregate of listed NACE codes) saw a decline in employment of 19% between 2003 (1.64 Mn) and 2015 (1.33 Mn). All manufacturing industries covered registered the decline. The share of number of people employed in these industries compared to total French employment decreased from 6.27% in 2003 to 4.84% in 2015.

Just as in Flanders and Germany, the food products, beverages and tobacco industry was the largest employer within the industries considered, having employed 645,000 people in 2015, a meagre decrease from 652,000 people in 2003. The share of number of people employed in this industry compared to total French employment decreased from 2.49% in 2003 to 2.35% in 2015. The chemicals, plastics and rubber production industry was the second largest employer with 267,000 employees in 2015, registering a significant decrease in employment of 25.63% from 359,000 employees in 2003. The textiles, wearing apparel, leather and related products industry underwent the largest change between 2003 and 2015 with employment halving from 210,000 people in 2003 to 106,000 people in 2015. Its share of number of people employed compared to total French employment too halved from 0.80% in 2003 to 0.39% in 2015.

UK

In the period 2003-2015 the total economy-wide employment (number of persons) increased by 10.8% from 28.22 Mn to 31.28 Mn. Similar to Flanders, France and Germany, the industrial sectors (as aggregate of listed NACE codes) saw a decline in employment of nearly 24% between 2003 (1.41 Mn) and 2015 (1.08 Mn). Employment declined across all manufacturing subsectors covered. The share of number of people employed in these industries compared to total UK employment decreased from 5.01% in 2003 to 3.44% in 2015.

Alike Flanders, France and Germany, the food products, beverages and tobacco industry was the largest employer within the industries, having employed 413,000 people in 2015, declining from 455,000 people in 2003. The share of number of people employed in this industry compared to total

French employment decreased from 1.61% in 2003 to 1.32% in 2015. The chemicals, plastics and rubber production industry was also the second largest employer with 264,000 employees in 2015 – a fall in employment of nearly 30% from 373,000 employees in 2003. Like France, the textiles, wearing apparel, leather and related products industry underwent the largest change between 2003 and 2015 with employment decreasing 43% from 188,000 people in 2003 to 107,000 people in 2015. Likewise, similar to France, its share of number of people employed compared to total UK employment too almost halved from 0.67% in 2003 to 0.34% in 2015.

Netherlands

Between 2003 and 2015 the total economy-wide employment (number of persons) increased by 6.32% from 8.38 million to 8.91 million. Similar to Flanders, France, the UK and Germany, the industrial sectors (as aggregate of listed NACE codes) saw a decline in employment of nearly 17% between 2003 (354 thousand) and 2015 (294 thousand). Employment declined across all manufacturing subsectors covered with the exception of the manufacture of coke and refined petroleum products subsector which remained consistent at 6 thousand throughout the period. The share of number of people employed in these subsectors compared to total Dutch employment decreased from 4.22% in 2003 to 3.34% in 2015.

Akin to Flanders, France, UK and Germany, the food products, beverages and tobacco industry was the largest employer within the industries considered, having employed 127,000 people in 2015, declining from 140,000 people in 2003. The share of number of people employed in this industry compared to total Dutch employment decreased from 1.67% in 2003 to 1.44% in 2015. The chemicals, plastics and rubber production industry was also the second largest employer with 74,000 employees in 2015 with employment declining around 13% from 85,000 employees in 2003.

4.5 NEIGHBOURING INDUSTRIAL CLUSTERS CONNECTED TO FLANDERS

While a comparison with industrial developments in neighbouring countries can give insights into the relative performance of industry in Flanders, it is also relevant to consider how some of the industrial clusters in neighbouring countries are linked to those in Flanders. In particular the chemical and refining industry form part of a broader Northwest European cluster.

In the Netherlands, three major industrial clusters are closely related to Flanders: the chemical cluster in Terneuzen/Zeeland, the chemical cluster around Maastricht/Geleen and the large industrial activities surrounding the port of Rotterdam. There are ethylene and propylene pipelines connecting Rotterdam, Antwerp and Terneuzen. An ethylene pipeline connection exists between Antwerp and Geleen. In Germany, there is a large variety of industrial activity in Northrhein Westfalen (Ruhr), and connected by (ethylene) pipeline to Antwerp and next down to other industrial areas in Germany around Frankfurt and Ludwigshafen. In Belgium, there exists an ethylene/propylene pipeline connection from Antwerp to chemicals production in and around Feluy. In Northwest France, there’s large industrial activity in Dunkirk (steel, pharma/chemicals) and around Lille.

Figure 41: Illustration of a selection of industrial clusters in and around Flanders

© Appe - Association of Petrochemicals Producers in Europe 2004

Figure 42: Major refining, steam-cracking operations and related pipelines in Northwest Europe (Source: Petrochemicals Europe)

The Trilateral region

The trilateral region (Flanders, Netherlands and Nordrhein Westfalen) delivers 17% of the European turnover in the chemicals sector. It employs 350,000 people (11% of total EU chemicals sector employment). Finally, the trilateral region is one of the biggest R&D investors in the EU (EUR 38 Bn in 2015)[53].

In the period 2013-2017 a trilateral strategy for the chemicals industry was developed between the governments of Flanders, Netherlands and Nordrhein Westfalen. This strategy has five overarching goals[54] for the regions to jointly become the global engine for a sustainable and competitive chemicals industry by 2030:

- Facilitating the transformation of the value chain to a digital, sustainable and circular chemicals industry.

[53] 'Nota aan de Vlaamse Regering: Trilaterale strategie voor de chemische industrie', Vlaamse Regering (2018).
[54] Ibid

- Increasing the quality and integration of the trilateral education and qualification systems towards the development of a regional labour-pool for a knowledge-based chemicals industry.
- Improving the weakened competitiveness with regard to energy costs of the trilateral region and ensuring a level playing field for the use of sustainable feedstock.
- Ensuring the development of critical infrastructure for the chemicals industry and making progress in developing a chemicals logistics 4.0 system.
- Improving the quality and effectiveness of policy coordination in the trilateral region with regard to issues of high cross-border priority for the chemicals industry.

North Sea Port and Smart Delta Resources
Significant examples of regional industrial cooperation are the 'North Sea Port' and the related 'Smart Delta Resources' (SDR) platform. North Sea Port is the fusion of the Port of Ghent and Zeeland Seaports on 8th December 2017, which allowed it to become the third largest port in Europe (in value added) after the ports of Rotterdam and Antwerp. The merger strongly benefits both Flemish and Dutch economies by allowing the creation of a sustainable increase in employment, added value, transhipment (both maritime and inland), knowledge and resources and by fostering innovation. North Sea Port is now planning to further development of the multimodal infrastructure and further accessibility of the port as well as collaborate on sustainability. They actively work with all the partners involved in order to achieve their existing ambitious objectives in terms of sustainability more quickly.

The SDR platform on the other hand is a collaborative initiative of eleven energy and feedstock intensive companies that constitute the industrial cluster of the Schelde Delta (a river delta in the Netherlands and Belgium) to reduce their use of energy and feedstock though industrial symbiosis. The industrial cluster includes 6 chemicals companies (Sabic, Yara, ICL-IP, Trinseo, Dow Benelux and Zeeland Refinery), 3 food companies (Cargill, LambWeston and Suiker Unie), 1 energy company (Engie Electrabel), and 1 steel company (Arcelor Mittal).

In April 2018, SDR published a foresighting Roadmap: '*Roadmap towards a climate neutral industry in the Delta region'* (SDR, 2018) which provides an ambitious yet feasible actionable plan for the industrial cluster through joint collaboration to reduce 85-95% emissions (or become climate neutral) by 2050 compared to 1990 (current emissions – 20 Mt CO_2). The companies themselves identified five methods to reduce GHG emissions from industrial processes: 1) Reduction of energy demand by application of new technologies, 2) Circular feedstock, 3) CO_2 capture usage and storage (CCU and CCS), 4) Climate-neutral energy carriers (H_2 gas and electricity), and 5) CO_2-free energy sources, such as geothermic energy and renewable energy from solar or wind. From these methods, the roadmap developed eight concrete projects which maintain competitiveness and carbon neutrality.

The '*Robust and cost-effective electricity network infrastructure*' project seeks to ensure a robust and cost effective electricity network via access to wind energy (inclusion in the regional high-voltage grid), large-scale electrification in industry (power2heat, power2products, etc) and developments of the existing power generation in the region (e.g. Doel and Borssele) as well as on-site gas-fired CHP units. The '*Power2Hydrogen*' project will create a regional facility that provides clean H_2 produced from renewable energy (range of 10-20 MW) by means of a H_2 network in the SDR region by 2025 addressing the existing gap between the size of the current electrolysis plants (6-12 MW, i.e. 300-720 ton H_2) and the amount of H_2 consumed in the region (about 405,000 ton H_2). The project would cost around EUR 40-70 Mn. The '*Region H2 open network infrastructure*' project consists of an open infrastructure H_2 network (like the current natural gas network) connecting H_2 and oxygen production capacity to the major H_2 and oxygen users in the Delta region by 2030. This carbon-free H_2 used by SDR companies as a feedstock and an energy source replacing natural gas would potentially mitigate 3.1-5 Mt CO_2 emissions per year. The project would cost around EUR 70 Mn.

Similar to the on-going regional SolventLoop project that recycles expanded polystyrene (EPS) foam and recovers bromine, the '*Circular feedstock supply*' project seeks to construct, by 2030, a regional circular plastics plant (pyrolysis unit with a capacity of 250,000 tonnes of mixed waste plastic) to create recycled plastics feedstock for plastics, as well as a network of pyrolysis units for waste plastics or polystyrene over the whole of north western Europe producing a naphtha-like pyrolysis oil suitable for the production of PE and PP or PS. The project would cost around EUR 150 Mn. The main objective of the '*Regional CO_2 network*' project is the creation of a CO_2 network connecting CO_2 sources in the Delta region to a network for storage (CCS) and/or to users of CO_2 (CCU). Given the absence of suitable storage options in the Delta region, one option could be the development of infrastructure (pipelines and storage facilities) as exist in Rotterdam for example. The project would cost around EUR 120 Mn.

With the help of heat pump technologies, the '*Stimulation of heat-pump technology at SDR companies*' project seeks, by 2030, to reduce 20% of the current energy used for heat supply at SDR companies resulting in a reduction of energy costs and mitigation of around 1,600 thousand tonnes GHG emissions. The '*Geothermic potential in Bergen op Zoom*' plant project, operational by 2035 in the Bergen op Zoom Region, will supply carbon-free geothermic heat of 110-180°C to SDR companies in the western Brabant region most of whom require less high temperatures than the chemical industry. The project would cost between EUR 2-12 Mn. The '*Steel2Chemicals*' project is under preparation will see ArcelorMittal deliver its residual gases to Dow Benelux allowing ArcelorMittal to reduce its emission of CO and CO_2 and Dow Benelux to not only becomes less dependent on oil but also avoid the need to build feedstock production infrastructure for its plastics production. The project would cost around EUR 300 Mn.

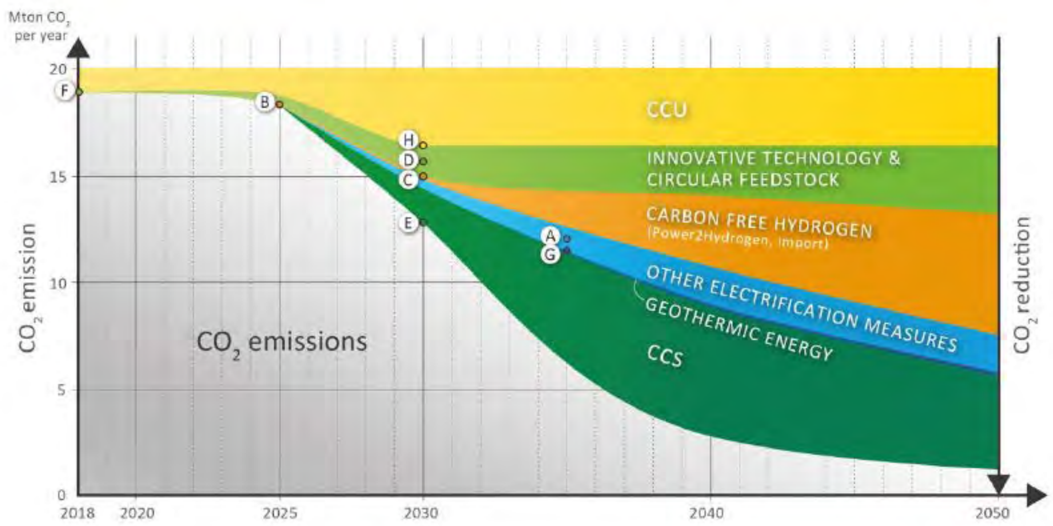


Figure 48: Low-carbon technology pathways from the 'Roadmap towards a climate neutral industry in the Delta region' (Source: SDR and CE Delft, 2018)

The manpower and budget to start the projects will be provided by the companies themselves while other actors (North Sea Port, development agency Impuls Zeeland, the province of Zeeland and probably at a later stage the provinces of Oost-Vlaanderen and Noord Brabant) will facilitate their ambitions with manpower effort and financial support. Additional actions will be taken by other parties.

4.6 CONCLUSIONS

It is clear that, in Flanders, energy intensive industries have a larger share in added value creation and higher GHG share as part of the overall economy and as share of the emissions under the EU ETS compared to all neighbouring countries. This is due to the presence of large industrial sectors in a small region and the low CO_2 intensity of electricity production in Flanders/Belgium. As relevant is the high contribution of the energy intensive industries to the Flemish gross value added. In Flanders these sectors still contribute almost 10%, while in the neighbouring countries the contribution is between 4% (UK) and 7% (Germany). Flanders did see the most significant decline in the energy intensive industries' contribution to the GVA (-3% in the period 2003-2014) while in the neighbouring countries the figure was between -0.85% (Germany) and -1.5% (Netherlands) over the same period. As stated before, Flanders started from a much higher baseline and its energy intensive industries still have the largest contribution to the GVA. Furthermore, the absolute GVA of industry is still increasing albeit at a smaller rate compared to other sectors in the economy. The important contribution of industrial value added to the overall economy in Flanders shows the necessity of an intelligent approach towards industrial low-carbon transformation.

Amongst the neighbouring countries, Flanders together with The Netherlands saw the smallest reduction in GHG emissions from the energy intensive industries between 2008 and 2016 (-5.1% and -5.9% respectively). Some neighbouring countries saw a dramatic reduction in industrial emissions over the same period (e.g. UK -33% and France -23%). However, these reductions are mostly due to major closures of large industrial plants (e.g. steel and refining) over that period. While Flemish industry did see closures in that period, these mostly happened in the textiles, ceramics and automotive industries with a much lower CO_2 intensity. No large steel, refining and chemicals plants closed in Flanders over that period. Some smaller chemical production plants did however cease production in Flanders. The larger emission reductions in Germany (-12.4% between 2008-2016) can be partially explained by mitigation of N_2O emissions in the chemicals industry which happened a bit after similar measures were taken in Flanders (partially before 2008).

The overall comparison of Flemish energy intensive industries with the neighbouring countries shows a high level of similarity with The Netherlands when it comes to the type of main energy intensive industrial sectors present. In particular, the similarity between the relative shares of GHG emissions between the different sectors is striking (e.g. large shares of emissions of refining and chemicals industries). The parallel between The Netherlands and Flanders goes deeper through the presence of two large harbour areas with major industrial presence (i.e. Antwerp and Rotterdam). However there are also some important differences between Flanders and The Netherlands. First of all there is a big difference in the energy mix (coal versus nuclear) and the availability of gas supplies. This also sets a direction for possible technology priorities set in The Netherlands that are less likely for Flanders.

It is also clear that in particular the Flemish chemicals and refining industries do not operate physically isolated from the rest of Europe. There are major infrastructure links (i.e. pipelines) between the industrial clusters in The Netherlands and the Nordhrhein Westfalen region in Germany. Hence, the transition to low CO_2 emissions from these industrial sectors will require coordination between these regions. In this context the recently established Trilateral region strategy between the respective governments of these regions can prove a highly relevant venue to discuss supranational energy infrastructure and coordination of R&D towards a low-carbon economy.

Finally, practical interregional cooperation is already taking place between industry in the Ghent harbour region and the Dutch Terneuzen area, in the shape of the new Northsea Port venture. A group of companies in this area (united under Smart Delta Resources) recently presented what likely is the first interregional low-carbon roadmap. It clearly shows the benefits (but also challenges) of cooperation between neighbouring industrial clusters. These international processes deserve specific attention in the development of a Flemish industrial low-carbon transition framework.

5 ANALYSIS OF INDUSTRIAL ROADMAPS

5.1 INTRODUCTION

This chapter provides an overview of the key findings from the analysis conducted of European sectoral and other relevant industrial low-carbon roadmaps published since 2010. The selection of roadmaps to be analysed was based on two criteria. First, EU industrial roadmaps that represent sectors with important presence in Flanders were selected. Secondly, other roadmaps that can offer additional insights (e.g. similar region or broader scope) for the development of a Flemish industrial roadmap were selected.

The following European industrial low-carbon roadmaps were analysed for this report:

- Eurofer, 2013. A Steel Roadmap for a low-carbon Europe 2050.
- Accenture for CEFIC, 2016. Taking the European Chemical industry into the circular economy.
- DECHEMA for CEFIC, 2017.Low-carbon energy and feedstock for the European Chemical Industry.
- CEPI, 2011. Unfold the future: The Forest Fibre Industry, 2050 Roadmap to a low-carbon bio-economy
- CEPI, 2017. Investing in Europe for Industry Transformation (2050 Roadmap to a low-carbon economy).
- Ecofys for CEFIC, 2013 European Chemistry for Growth: Unlocking a competitive, low-carbon and energy efficient future.
- CONCAWE, 2018. Low-carbon pathways CO_2 efficiency in the EU refining system 2030/2050.
- CERAEUMUNIE, 2013. Paving the way to 2050, the ceramic industry roadmap

Due to the similarities between the Flemish and Dutch industrial sectors, including the major concentration of (petro-)chemical companies in respectively the Antwerp and Rotterdam harbour, three important Dutch low-carbon roadmaps were also reviewed:

- Wuppertal Institut for the Port of Rotterdam, 2016. Decarbonisation Pathways for the Industrial Cluster of the Port of Rotterdam.
- McKinsey & Company, 2017. Energy Transition: mission (im)possible for industry? A Dutch example for decarbonisation.
- Ecofys and Berenschot for VNCI, 2018. Chemistry for Climate, Acting on the need for speed. Roadmap for the Dutch Chemical Industry towards 2050

Finally, key findings in relation to the low-carbon transition for energy intensive industries from the latest version (2017) of the highly relevant Energy Technology Perspectives (ETP) published annually by the International Energy Agency (IEA) are presented. While the scenarios in the IEA's ETP address low-carbon transitions from a global perspective, they are also embedded in broader low-carbon scenarios that deal with the transition of the other major sectors in the economy.

The chapter concludes with the relevance of the roadmaps considered here towards the development of a Flemish industrial low-carbon framework.

5.2 A STEEL ROADMAP FOR A LOW-CARBON EUROPE 2050 (EUROFER, 2014)

The roadmap focuses on the EU steel industry and develops four scenarios using 1990 and 2010 as baselines. It estimates that by 2050 the sector can achieve 63% decarbonisation compared to 1990 levels by combining all technologies that are currently under development, including CCS. Along the four scenarios – 'Economic Scenario', 'Theoretical-Maximum Abatement Scenario without CCS', 'Theoretical-Maximum Abatement Scenario With CCS' and 'Hypothetical Emission Reduction Scenario' relying on breakthrough technologies in combination with CCS – the roadmap envisages maximum CO_2 emission reductions (between 2013-2050) of 13%, 38%, 57%, and 80% respectively.

The Economic Scenario is described as the one which achieves the best balance between emission reduction and economic viability. It assumes continued decarbonisation of the power sector, increased scrap availability, underscores sharing of best practices and the implementation of cost-effective incremental technologies. It requires, however, access to scrap and energy at competitive prices, incentives and full offset of distortive CO_2 costs until an international level-playing field is restored. The Theoretical-Maximum Abatement Scenario without CCS is to be achieved by shifting from Blast Furnace – Blast Oxygen Furnace (BF-BOF) to DRI-EAF and requires that natural gas-based DRI becomes competitive in Europe. The Theoretical-Maximum Abatement Scenario with CCS can be achieved through the use of BF-Top Gas Recycling technology in combination with CCS and requires support for demonstration and deployment of BF-TGR, access to CCS widespread at competitive prices. The Hypothetical Emission Reduction Scenario' relying on breakthrough technologies in combination with CCS which aims for the highest CO_2 reduction is largely based on circularity and implies industrial symbiosis but requires support for R&D, demonstration and deployment of breakthrough technologies.

The roadmap (EUROFER, 2014) does not include any detailed economic analysis but assesses that the highest emission reduction possible while maintaining economic viability is 0-15%. Higher emission reductions will result in uneconomic scenarios, given large investments in infrastructure and higher operating costs. The roadmap makes the following key assumptions: increased scrap availability (from 96 Mt in 2010 to 136 Mt in 2050), greater share of EAF steelmaking (44% by 2050), continuous decarbonisation of power sector, and continuous market growth (0.8% annually or 236 Mt EU crude steel production in 2050). Key technologies underscored are BF-TGR, ULCORED/HIsarna, CCS on all emission sources, Electrification of heating, H_2-based reduction, and Electrolysis.

A 14 point policy recommendations list envisages a strong role by the EU (policy support and coherence, trade shepherding, transparency and predictability, and global climate leadership), and underscores fairness, competitiveness, the need for differentiation, R&D support, energy prices, financial price stability, support for development and deployment of new technologies, CO_2 sequestration into products, value chain approach, and circularity.

5.3 EUROPEAN CHEMISTRY FOR GROWTH, UNLOCKING A COMPETITIVE, LOW-CARBON AND ENERGY EFFICIENT FUTURE (CEFIC & ECOFYS, 2013)

This roadmap focuses on the European (EU 27) chemicals industry consisting of the sub-sectors petrochemicals, basic inorganic chemicals, polymers, specialty chemicals and consumer chemicals. It takes into account the CO_2 and N_2O emissions during the production process (scope 1) of these chemicals and GHG emissions related to the production of electricity and heat for these processes (scope 2). With 1990 as a baseline, the roadmap develops four different scenarios to 2050 (beginning 2013): *'Continued Fragmentation Scenario', 'Isolated Europe Scenario', 'Differentiated Global Action Scenario', and 'Level Playing Field Scenario'*.

In the Continued Fragmentation scenario, there is continuation of current European policies along with an ambition of 40% emission reduction target as compared to 1990 in the absence of global action against climate change. In the Isolated Europe scenario, the current fragmentation in energy and climate policies with a low global ambition continues, but Europe intensifies its policy ambitions striving for an 80% reduction in GHG emissions by 2050 as compared to 1990, even in the absence of a global agreement. In the Differentiated Global Action scenario, differentiated global action and limited policy convergence in key economic regions results in an 80% GHG emissions reduction target for Europe and global GHG emission reduction of approximately 50% between 1990 and 2050. Finally, in the Level Playing field scenario there is around 50% emission reduction between 1990 and 2050 due to a global climate change mitigation agreement and therein policies fostering a level playing field for the global manufacturing industry via a uniform global carbon price signal.

The roadmap makes key competitiveness assumptions. In all the scenarios with the exception of the Level Playing Field scenario, energy price differences between Europe and the rest of the world persist and there is a negative impact on production for basic chemical industries which also affects Specialty Chemicals and Consumer Chemicals. In the Continued Fragmentation and Isolated Europe Scenario, CO_2 price signal between Europe and the rest of the world in 2050 increases over time to ± EUR 30 per tonne of CO_2 (/t CO_2), while that in the Differentiated Global Action Scenario increases to ± EUR 200/t CO_2. However, in the Level Playing Field scenario, global energy and feedstock prices as well as industry electricity costs converge over time, there is a similar CO_2 price signal worldwide, and value chains are fully integrated in Europe. Under the level playing field scenario, the roadmap sees EU chemicals sales almost double between 2010 and 2050 (from around EUR 500 Bn to around EUR 1000 Bn). In the scenario where the EU undertakes unilateral climate action the figure would barely change in 2050. The net trade ratio (as % of demand) would rise from 10% to almost 15% between 2010 and 2050 in the level playing field scenario, but would drop dramatically to -20% by 2050 in a unilateral action scenario (CEFIC, 2013, pages xi-x).

The roadmap does provide detailed cost calculations such as CAPEX or OPEX, and delves little into demand side (addressed partially), circularity, new business models and industrial symbiosis. It underscores the following technological options: bio-based feedstock; valorisation of waste and recycling of plastics; CCS; greater process energy efficiency; changes in heat sources, use of renewable energy and CHP; end of pipe emission abatement; reduction of emissions in nitric acid productions; and mitigation options for ammonia, cracker products and chlorine.

The roadmap formulates policy recommendations on global climate action and the role of the EU, EU energy policy, the link with GHG mitigation in other sectors and the EU's and national R&D frameworks.

5.4 LOW-CARBON ENERGY AND FEEDSTOCK FOR THE EUROPEAN CHEMICAL INDUSTRY - TECHNOLOGY STUDY (DECHEMA & CEFIC, 2017)

This roadmap focuses on technological enablers for a low-carbon EU chemical sector which upon implementation can allow for an estimated 210 Mt CO_2/year (max) emissions reduction in 2050. It quantifies the emission reduction potentials of low-carbon production technologies for high volume petrochemical/chemical products in Europe, such as methanol, ethylene and propylene, benzene, toluene, xylenes (BTX), ammonia and urea, and chlorine. Process routes yielding other chemical products are also discussed. For the production of synthetic fuels for the transport sector, the product range covers the production of methanol as substitute and/or additive in gasoline, bioethanol as gasoline additive, synthetic diesel as drop-in fuel, and synthetic kerosene as drop-in jet-fuel.

The roadmap develops four scenarios: Business as Usual (BAU), Intermediate, Ambitious, and Maximum. The BAU scenario assumes a freeze in the current state of play (2015) with no implementation of new technology options, no further advancement of efficiency measures and no further progress in power sector decarbonisation (relative to electricity-based chlorine production). It assumes a 1% per annum (p.a.) growth of the European chemical industry (total production volume grows 100 Mt in 2015 to 140 Mt in 2050). BAU CO_2 emissions increase proportional to production volumes, from 85 Mt CO_2 to 119 Mt CO_2 but with the introduction of energy efficiency measures, CO_2 emissions would be reduced by 14.34 Mt CO_2-eq.

The intermediate scenario assumes continuous process efficiency measures (via retrofits and optimizations), slow yet steady deployment of breakthrough technologies, steam generation by electricity and steam re-compression implemented at full scale by 2050, supportive policy measures for 1) an increasing biofuel quota including synthetic fuels from CO_2, 2) incentivizing investments in chemical production, and 3) weaning off established fossil feedstock based processes) and a 1% p.a. replacement rate of existing chemical production capacities (35% new production facilities by 2050). CO_2 emission reductions in the intermediate scenario are 117 Mt (70 Mt or 59% decrease for the chemical industry and 47 Mt for synthetic fuels by 2050).

In the ambitious scenario, by 2050, the share of low-carbon chemical production increases to 50% (via strong societal and policy support including financial incentives for substitution of fossil feedstock, and economically competitive low-carbon technologies), the share of renewable (including CO_2-based) fuels increases to 40%, energy efficiency measures are implemented, electrical steam generation and recuperation is fully deployed, the replacement rate of old plants increases from 1% to 1.5% p.a. (or 50% substitution of old plants by BPT level production plants), lighthouse demonstration projects are realized at around 5000 tonnes per annum (t/a) scale and industrial symbiosis potentials are valorised. Total chemical production is at 130 Mt in 2050 while fuel production is at 60 Mt in 2050. CO_2 emission reductions in 2050 amount to 216 Mt (101 Mt chemical industry only, corresponding to the abatement target of 80 to 95% of CO_2 emissions for the chemical sector in Europe by 2050 and 115 Mt for fuels). Combined, the potential emission reductions are at 80% above the chemical sector's BAU emissions in 2050.

In the maximum scenario, there is 100% deployment of all new technologies. H_2 (preferred) and biomass yield 100% of the production in 2050. This is the case for methanol and olefin production, but also the share of methanol in gasoline and the bioethanol share are complementary and add up to 100%. The scenario results in 100% new production facilities (assuming a 2.85% p.a. replacement rate) (hence extremely low impact of energy efficiency measures) while the deployment of electric steam generation and steam re-compression reaches 100% in 2050. There is a high amount of low-carbon methanol production for chemicals while the production of synthetic fuels is relatively low as compared to chemicals and diesel, gasoline and jet-fuel consumption decreases (from 14,000 PJ to 5,300 PJ in 2050). CO_2 emission reductions are the highest: 498 Mt in 2050 (chemicals: 210 Mt; synthetic fuels: 288 Mt).

The roadmap assumes 1) increased demand for low-carbon power, 2) increased demand for CO_2 as feedstock, 3) increased demand for biomass as feedstock, and 4) extensive additional investments.

As a technologies-focused roadmap, the technologies included are those which are at least proven and demonstrated on pilot plant scale, i.e. available at technology readiness levels (TRL) 6 and higher. Low TRL technologies, i.e. technologies at TRL 2-4 investigated in fundamental and lab research activities are not considered to constitute a commercial production pathway by 2050 and to contribute to real emission reduction within the envisioned timeframe. The roadmap underscores the following: Energy efficiency, H_2 and CO_2 based production routes, biomass and biomass waste streams to chemicals, electricity-based processes, industrial symbiosis and circular economy, other technologies, CCU. In this regard, three aspects are combined: i) improvement of energy efficiency in conventional production plants, ii) transition of the feedstock base towards alternative carbon sources, i.e. CO_2 originating from various industrial point sources, biomass as a renewable feedstock and carbon-containing products reused in recycling processes, and iii) the use of low-carbon electricity (renewable electricity and nuclear power) for energy supply (and electrons as reducing agent) in chemical transformations.

The roadmap addresses demand-side measures (through recycling of polymers and the use of polymer waste as feedstock for chemical processes which could save 57 Mtoe by 2050 energy for feedstock, not taking into account the energy for recycling) and industrial symbiosis (collaboration with the steel industry), but does not explore new business models.

Policy recommendations of the roadmap focus on the need for a large and ambitious R&I program, Public-Private-Partnerships (PPPs) to focus RD&I efforts and to enable risk sharing for investments for demonstration of innovative technologies, abundant low-carbon electricity in much larger volumes and at competitive prices, innovation and research into new chemical technologies that help overcome the challenges, enabling fiscal structure to modernise ageing production facilities and equipment or build new plants, enhanced cross-sectorial collaboration and exploration of industrial symbiosis opportunities, dialogue with policy makers and the generation of a central European database of CO_2 sources and infrastructures, available sustainable biomass and lifecycle data that would foster industrial symbiosis. In terms of R&I priorities a strong focus has to be provided on technologies for H_2 generation.

5.5 TAKING THE EU CHEMICALS INDUSTRY INTO THE CIRCULAR ECONOMY' (ACCENTURE & CEFIC, 2017)

The roadmap focuses on the impact of a partial/full circular economy on material needs, energy consumptions and economics of the EU 27 chemical industry, including downstream value chains (e.g. automotive, packaging). It does not directly address GHG emissions but looks at enhancing circularity in the EU's chemical sector and models. The roadmap develops five linked scenarios or *'Loops'* with increasing levels of materials circularity: 'Loop 1: Substituting raw materials', 'Loop 2: Increased re-use of end-user products', 'Loop 3: Mechanical recycling',' Loop 4: Chemical recycling', and 'Loop 5: Energy recovery and carbon utilization'. Together they can bring 66 Mt of chemicals (out of a total of 106 Mt) back in circulation, but would require an additional 509 TeraWatt Hours (TWh) of energy and CAPEX between EUR 160-280 Bn. However lesser production of virgin chemicals would save around 250 TWh of energy.

Loop 1 scenario involves the substitution (to a certain extent) of fossil feedstocks with renewable feedstocks such as biomass which in turn would require investment into new feedstock infrastructure and conversion assets. However, given biomass' low energy intensity compared to fossil resource, production would require 14% of total European agrarian land rendering the scenario a non-standalone option. It results in 12 Mt looped chemicals in a full circular economy, requires 0.03 Million Tonnes of Oil Equivalent (Mtoe) and 0.30 TWh of energy and CAPEX between EUR 20-40 Bn. Loop 2 scenario focuses on developing full suites of new products and solutions that can essentially be re-used "as is". It requires industry-led establishment of "design to reuse" partnerships involving stakeholders. It results in 17 Mt looped chemicals in a full circular economy. Loop 3 implies re-using existing materials without modifying their chemical bonds. It demands focus on research, development, and new product design to use mechanically recycled molecules; and on developing reverse logistics capabilities; and on establishing processing partnerships. It results in 19 Mt looped chemicals in a full circular economy, requiring 12 Mtoe and 135 TWh of energy and CAPEX between EUR 30-80 Bn.

Loop 4 scenario suggests molecular bond modification to recover hydrocarbons and would require industry investment in further R&D (in cracking and gasification processes) and large scale assets. It results in 8 Mt looped chemicals in a full circular economy, requires 3 Mtoe and 40 TWh of energy and CAPEX between EUR 10-20 Bn. Loop 5 scenario involves molecular energy recovery, capture and reconstruction of new chemical feedstocks via a catalytic reaction which is highly complicated and would require new assets for creating dense CO_2 sources and for the re-synthesizing of carbon into hydrocarbons. This requires the establishment of H_2 supply at scale. It results in 10 Mt looped chemicals in a full circular economy, requires 29 Mtoe and 334 TWh of energy and has CAPEX between EUR 100-140 Bn. This scenario is the most difficult, energy-and capital-intensive, and expensive one.

The roadmap does not make policy recommendations but advises European chemical companies to 1) gain greater knowledge of circular economy growth potential and shift capital and operating expenses accordingly, 2) shift focus from volume to value, 3) explore new business models, 4) increase resilience and deepen integration with customer value chains and 5) decrease dependence on oil and gas. An important consequence highlighted by the roadmap is the shrink effect on fossil-based feedstock and basic chemicals due to extensive re-use of molecules.

5.6 THE FOREST FIBRE INDUSTRY 2050 ROADMAP TO A LOW-CARBON BIO-ECONOMY (CEPI, 2011)

The roadmap focuses on building a low-carbon European (EU 28) forest fibre industry and offers a pathway to achieve up to 80% decrease in sectoral CO_2 emissions by 2050 (12 Mt CO_2 for pulp and paper in 2050 with 1990 as a baseline – no data for wood products) whilst accounting for competitiveness and future consumer demand. The roadmap does not develop its own scenario but adopts the European Commission (EC) Roadmap's *Global Action Scenario With Available Technologies* and evaluates three technologies pathways (Best Available Technologies or BAT, Emerging Technologies or ET, and Breakthrough Technologies or BTT) to achieve the goal. However, in contradiction to the EC, the roadmap predicts emissions reductions up to 2050 to be non-linear rationalised by the assumption that CO_2 reductions under ET will be gradual.

The roadmap estimates CO_2 emission reductions by 2050 of 25% with the BAT pathway, 50% with the ET pathway under current investment patterns, and 80% with the BTT pathway (BTT commercially available by 2030 allowing 10 years of optimization). The BAT pathway implicates upgradation of equipment to more efficient and commercially available models by 2050. While CHP is recognised as a key BAT, CCS or new solutions are also highlighted as necessary. Assumptions include a continuing trend for more electricity-based and less heat-based production equipment. In the ET pathway, the pulp and paper industries focus on improving efficiency of existing processes. The pathway also looks at new products, such as for the production of nano-cellulose. Other ET like energy conversion, biomass and waste/residue gasification, torrefaction, carbonisation and pyrolysis are also considered. For wood products, the ET pathway promotes new laser cutting technologies, material savings, wood drying concepts and the development of glues, paints, coatings and further treatment for increasing the durability of wood. The BTT pathway provides solutions for improving resource efficiency, energy efficiency, conversion efficiency, and product efficiency. The roadmap envisages CCS as a BTT, albeit, with delayed application.

It is further recognised that emission reductions can be met through increased recycling and improved sorting through technology-based, social and policy measures. The roadmap underscores integration of new markets, new bio-based products, recycling concepts, waste, energy and the vital impact of consumer preference for the bio-economy. It also explores other non-technological energy saving solutions and value adding options: fuel mix change, production of transport fuels, development of improved species, new harvesting techniques, improved sustainable forest practices and production of forest residues. Industrial symbiosis can be found with the waste sector. CCS facilities moreover can render these sites carbon-free.

The roadmap does not use economic modelling but assents factors that condition the EC's scenario: expected decarbonisation of electricity, carbon neutrality of biomass, availability of CCS, realisation of energy efficiency targets, projected rise in CO_2 price (from EUR 17 /t in 2010 to EUR 190 /t in 2050) driving coal replacement and boosting wood-for-energy demand (by 35% from 2010-2050). The EC roadmap's PRIMES modelling envisages a 20% rise in sectoral final energy demand. However, the roadmap contradicts the EC's prediction that imports of biomass or wood will not increase to meet demand for large-scale electricity production. Sectoral growth is expected to be in line with EU GDP of 1.5%/year until 2050, with 50% more added-value by 2050.

The roadmap's policy recommendations include: sector-specific industrial policy packages beyond carbon pricing, EU ETS auctioning revenues as an innovation finance tool, multi-stakeholder sector transformation partnerships, include sector specific innovation support systems in Horizon 2020, a dedicated recycled materials policy, policy support for a shift towards a bio-based economy and a sustainable biomass supply policy.

5.7 INVESTING IN EUROPE FOR INDUSTRY TRANSFORMATION: 2050 ROADMAP TO A LOW-CARBON BIO-ECONOMY (CEPI, 2017)

The roadmap addresses the forest fibre and paper industry's path to 80% GHG emission reductions relative to 1990 levels by 2050 (reducing carbon emissions from 60 Mt to 12 Mt of which 10 Mt direct emissions, 1 Mt transport emissions and 1 Mt emissions from purchased electricity). The roadmap models six actions through which 48 Mt of carbon reduction could be achieved by 2050. These are: Energy Efficiency Improvements, Demand-Side Flexibility, Fuel Switch, Emerging and Breakthrough Technologies, Carbon Reduction from Purchased Electricity and Transport Improvements.

Energy efficiency improvements include a combination of process improvements, including transition to industry 4.0, as well as investment in state-of-the-art production technologies and can reduce 7 Mt CO_2. Demand-side flexibility includes leveraging on-site cogeneration assets to engage on the energy market and adapt energy sourcing to profit from low prices, in particular, from surpluses of intermittent renewable energy. This action can reduce 2 Mt CO_2. Fuel switch through further conversion of industrial installations to low-to no-carbon energy sources can reduce CO_2 emissions by 8 Mt. Emerging and breakthrough technologies both under development and other innovative and disruptive solutions can reduce CO_2 emissions by 5 Mt. As the European power sector decarbonizes, a carbon reduction of 11 Mt from purchased electricity (indirect emissions) can be achieved. Finally, improvements in transport through greater fuel and transport efficiency, improved infrastructures, inter-modality and use of alternative transport fuels, such as biogas, advanced biofuels, electricity or fuel cells' can reduce CO_2 emissions by 4 Mt.

The roadmap stresses the importance of commercial availability of ET and BTT (approximated abatement from BTT being 5 Mt CO_2). It estimates that for the 80% decarbonisation scenario by 2050, 40% more investment than 2010 levels would be needed, with an estimated EUR 24 Bn extra investment. A further investment of EUR20 billion would be needed for the production of new bio-based products. Projected costs refer to CAPEX only and not R&D expenditures. The roadmap does not employ any economic modelling but estimates the industry's value added compared to 2010 to increase by 50% (approximately EUR 25 Bn by 2050). It underscores a shift to the circular bio-economy by building on the assets of forest fibres such as renewability, carbon sequestration and recyclability. The potential for industrial symbiosis is identified with the waste sector.

The roadmap outlines policies needed to embed a pro-investment approach in four areas: reducing regulatory costs, addressing investment risk profiles, matching investment life cycles and preventing regulatory uncertainty. These require policy focus on: building a vibrant bio-economy (at the centre of the EU framework for R&I and other EU policies), European R&D focus on development and deployment of ET and identification of BTT, elimination os policy measures encouraging low-efficient energy and prioritising recycling, greater electricity market design to complete EU market integration and remove regulatory barriers to unleash the potential of industrial demand-side flexibility, cost and resource efficient reduction of transport emissions, development of skills and education, and facilitating access to finance particularly for SMEs.

5.8 THE CERAMIC INDUSTRY ROADMAP: PAVING THE WAY TO 2050 (CERAME-UNIE, 2012)

The roadmap focuses on the decarbonisation of the European (EU 27) ceramic industry and develops two scenarios: 65% decrease in CO_2 emissions and 78% decrease in CO_2 emissions. The 65% scenario centres on current and identified future technologies, and assumes that barriers to alternative fuels are overcome. It bears the caveat that regulators treat syngas and biogas as net-zero sources. The 78% scenario underscores conversion of half of all kilns to electric from 2030 to 2050, with the remainder fuelled by syngas or biogas co-fired with natural gas.

Scenario 1 costs are not estimated. However, Scenario 2 estimates capital costs (EUR 90 Bn) (given BTT in in electric kiln efficiency require further investments) and running costs to be extremely high, and thus not feasible for the European ceramic industry to remain economically-viable and globally competitive. Kilns are a significant capital cost and have long life cycles which render them financially ineffective to replace before end-of-life. The model predicts EUR 40 Bn to write off plants and for lost sales during times of kiln modification. OPEX are also expected to rise. The roadmap estimates energy costs for a typical tile factory to increase approximately 2.5 times the current rate and the cost of biogas to be 2-3 times that of natural gas, even at current prices. The roadmap recognises that rising cost of raw materials from Asia will prove problematic for European ceramics and the industry's global competitiveness. The roadmap assumes a constant level of production with a similar product mix between 2010 and 2050.

The roadmap underscores energy efficiency to reduce fuel emissions but cautions that achieving the 80% target will be possible only with breakthrough technology, securing alternative fuel sources and financial assistance. Energy efficiency measures include installation of upgradable equipment (such as kilns, dryers, thermostats and seals), application of automated controls, and heat saving through improvements in thermal insulation. Moreover, with smart design of facilities, integrated process efficiencies can be exploited through the capture of excess heat to be used in other production processes. Alternative fuel sources include changes to the fuel mix, such as the electrification of kilns and using low-carbon electricity (albeit an unfeasible option given lower cost of natural gas). However, the roadmap promotes methods of cogeneration through CHP. The roadmap cites CCS as the only BTT that can reduce process emissions.

The roadmap highlights that the majority of ceramic products can be recycled and reused, either within the sector, to create new products, or by other industries and provides examples of current ceramic recycling practices, without however offering insight into how recycling and reuse could be enhanced on the pathway to 2050.

Policy recommendations made by the roadmap include: a shift to lifecycle view of emissions and product profile, use of green public procurement to encourage more sustainable consumption, action against unfair trade practices (including secure and fair access to raw materials), access to affordable finance for capital projects with longer payback periods, supporting a shift to renewable energy installations, a consistent/predictable legal framework across the EU's climate and energy policies, financial support to facilitate transition to low-carbon fuel sources (through BTTs), and public-private partnerships (PPPs) dedicated to innovation.

5.9. LOW-CARBON PATHWAYS CO_2 EFFICIENCY IN THE EU REFINING SYSTEM. 2030 / 2050 EXECUTIVE SUMMARY (INTERIM REPORT) (CONCAWE, 2018)

The study focuses on the EU refining sector (*Scope 1 and 2 emissions*) and develops two scenarios (baselines unclear): 2030 and 2050, wherein via a combination of three technological options, emissions can be reduced between 20-30% and up to 70% respectively. The three options adopted via a top-down approach include: 'Energy Efficiency (EE)', 'Use of Low-carbon Energy Sources (LCE)', and 'CO_2 Capture (CC)'.

The EE option comprises refinery process efficiency (continuous improvement through implementation of a combination of measures and small projects for example catalyst improvements and hardware improvements; major capital projects which provide larger efficiency improvements for example new process plants; and Inter-unit heat integration), energy management systems (which combine equipment with strategic planning, organisation and culture), and increased recovery of refinery low-grade heat for export and electricity production.

The LCE option encompasses benefits arising from decarbonisation of the gas and electricity grid, reduction of liquid fuel burning, improved recovery of H_2 and LPG from fuel gas, and increased use of imported low-carbon electricity (which includes a partial replacement of own generation by imported low-carbon electricity, increased use of electricity for general operations a/o rotating machines, substitution of fired heaters by electric heaters and production of H_2 with electrolysers using imported renewable electricity).

The CC option sees the capture of a portion of the total CO_2 emitted by refineries. In the CC option, a combination of CCS and steam reforming plants (SMR) to produce low-carbon intensity H_2 is explored.

The study assesses that by 2030, the bulk of the CO_2 savings will stem from process energy efficiency and improvement measures while the impact of external opportunities becomes prominent only in the 2050 horizon. Achievable energy efficiency improvements are quantified at 0.7% per year on average by 2050 (15% by 2030, 25% by 2050). The study stresses that without CCS, total 2050 emission reductions would be 50% with a large degree of uncertainty surrounding CCS penetration. The study emphasizes that progressive availability of low-carbon electricity in the average EU mix (at affordable price for industrial users) could reduce EU refinery emissions up to 25% by 2050 (bringing the total electricity consumption of the sector close to 180 TWh/annum, or around 5% of European current electricity generation). The potential contribution of the recovery of low-grade heat to either internal production of electricity or export is deemed insignificant.

R&D is identified as a key enabler for technological development to make the potential a reality at reasonable pace within the time horizons (2030 and 2050). The study highlights multiple areas where cross-sectorial collaborative R&D may be required to accelerate the development and integration of technologies including green H_2 and CCS. However, it warns that despite such collaborative R&D, refineries will need to attract investments to revamp existing or build new plant and required infrastructure to integrate the developing technologies which will necessitate a supporting regulatory framework and a favourable economic environment.

CAPEX is estimated at minimum EUR 40 Bn (generic cost of the different technologies and opportunities identified) with actual implementation costs variable per individual asset. The study assumes constant refining capacity in the EU at the 2030 level, when all options are exercised, different rates of deployment of technology, energy prices and the of degree of decarbonisation of the electricity grid.

5.10 ENERGY TRANSITION: MISSION (IM)POSSIBLE FOR INDUSTRY? - A DUTCH EXAMPLE FOR DECARBONISATION (MCKINSEY & CO & VEMW, 2017)

The roadmap focuses on the Dutch industrial sector and develops six decarbonisation measures and three scenarios (from a combination of the six decarbonisation measures) for the sector to lower its CO_2 emissions by 60% by 2040 and by 80% and 95% by 2050 (with baseline 1990 emissions 45 Mt direct and 22 Mt indirect). The six decarbonisation measures are: 'Energy efficiency', 'Electrification of heat demand', 'Change of feedstock', 'Develop routes to reuse and recycle materials', 'Decide on steel production route(s)', 'Develop CCS/U'. The scenarios as of 2014 are: 'Cheaper route: 60% reduction until 2040', 'Steeper route: 80% reduction until 2040', and 'Steeper route: 95% reduction until 2050'. This reduction can in theory be achieved without reducing industrial output, by creating, refining, and applying new processes, technologies, and feedstocks on a large scale. As a reference scenario, the roadmap finds that the BAU scenario would lead to -40% (ref 1990) until 2030, but with no significant reductions after that.

The six decarbonisation measures combined offer a mitigation of 20 Mt CO_2 in the 60% scenario, 36 Mt CO_2 in the 80% scenario and 46 Mt CO_2 in the 95% scenario. Although electrification of heat demand and development of CCS/U capabilities are the two most significant options, the roadmap recommends a combination of all six options as the most economically beneficial. This combination would increase the electricity demand by 215 PJ (renewable power supply expanded by 6 Gigawatts (GW) to 64 GW), and cost between EUR 21-23 Bn by 2040 for the 60% scenario with a viable business case for only about 20% investments while 80% would have a negative payback at current commodity and technology prices. In the 80% scenario, the cost would rise to about EUR 55 Bn by 2050 and in the 95% scenario, the cost would be as high as EUR 71 Bn until 2050. Implementation of a different selection of options could increase CAPEX further. The main factor dictating the relative contributions of the six different options is the pricing of electricity (base and peak pricing), especially with regards to the business case.

The 60% scenario implies energy demand (including feedstock) be reduced by 12% while direct CO_2 emissions be reduced by 46%. The scenario also implies industrial indirect CO_2 emissions to increase by 11 Mt CO_2 by 2040 unless an 80% renewable energy supply is available. The 80% scenario implies industry energy demand (including feedstock) reduced by 17% and industrial direct CO_2 emissions reduced by 74%. The 80% and 95% scenarios will have implications like a shift from fossil-based electricity generation to renewables (from 16 Mt CO_2-eq to 0-6 Mt CO_2-eq), electrification of industry amidst growing electricity demand (up to 560 PJ in 2040 including an additional 6 GW renewable energy and other sources such H_2), and future electricity price.

The main factors determining the relative contributions from each option on each scenario were the future price of energy (most influential factor), commodity prices, equipment costs and the extent to which industrial companies pursue other priorities. Under each scenario, the key parameters taken into account were: CO_2 emissions (direct and indirect) per industrial sector, energy source per sector and correlated CO_2 emissions, regional mapping clusters of emissions and energy demand. The roadmap scenarios clearly distinguish between efficiency improvements, system developments and technological innovations. Demand side measures focus strongly on circular economy (reuse, remanufacturing and recycling) influenced by the 'Nederland circulair in 2050'. Two of the six decarbonisation measures directly involve circularity: 'Develop routes to reuse and recycle materials' (mitigation potential of 1 Mt CO_2) and 'Develop CCS/U' (mitigation potential of 3 Mt CO_2).

The roadmap lists three key policy recommendations: develop a master plan for decarbonisation, optimise planning for long-term economic value, and structure public incentives to support the master plan.

5.11 DECARBONISATION PATHWAYS FOR THE INDUSTRIAL CLUSTER OF THE PORT OF ROTTERDAM, (WI & PORT OF ROTTERDAM, 2016)

The roadmap has a regional scope and focuses on decarbonisation by 2050 of the industrial cluster of the Port of Rotterdam whose annual CO_2 emissions range over 30 Mt. With a baseline of 1990, the roadmap develops four scenarios: 'Business As Usual (BAU)', 'Technological Process', 'Biomass and CCS (BIO)', and 'Closed Carbon Cycle (CYC) scenario and the Closed Carbon Cycle Earlier Closure (CYC-ECE)'.

The BAU scenario targets 30% CO_2 emission reductions: emissions remain stable until 2020, and then gradually decline amidst technical improvements and declining refinery production. The TP scenario targets around 75% CO_2 emission reductions with wide implementation of BAT and tightening of the Emissions Trading System (ETS), expanded renewable electricity for heat generation and H_2 production "at models scale", energy efficiency improvements in all sectors, and CCS at industrial scale. The BIO scenario targets 98% CO_2 emission reductions through major breakthroughs, especially CCS. A key challenge for the scenario is sustainable and affordable sourcing of biomass. The BIO scenario assumes energy-related emissions in the EU to be near-zero by 2050, nearly 100% market share of renewable electricity, that heat and mechanical energy is delivered by electricity, and that remaining thermal power plants connect to a CO_2 grid instead of using fossil fuels. Strong policy instruments such as carbon tax, support for implementation of CO_2 grids and CO_2 storage sites pro, and construction of CO_2 pilot grids of 2020 will be needed.

The CYC and CYC-ECE scenarios target around 98% CO_2 emission reductions and are identical, with the except that the CYC scenario counts on earlier closure of coal-fired power plants (2019-2025). The CYC and CYC-ECE scenarios are similar to the BIO scenario, but makes different assumptions regarding CCS and biomass: CYC scenario assumes CCS as economically unviable, and sustainable biomass sourcing unnecessary. The CYC scenario is well-suited for Rotterdam harbour given the port's advanced circular and almost carbon-neutral economy status. However, the scenario will require extensive investments to enable technical viability (e.g. methanol-based feedstock, Fischer-Tropsch wax).

The underlying assumptions of the modelling are largely based on EU decarbonisation scenarios and emphasise expected changes in three crucial areas for the port's current industrial cluster: European transport sector fuel demand, final industrial sector energy demand mix and Europe's electricity mix. The roadmap addresses technologies for the energy sector, crude oil refining and transport fuel supply, petrochemical sector, building sector and the transport and logistics sector. It however underscores emission reduction strategies for two vital sectors - petrochemicals (*energy efficiency improvements both in processes and in cross sectional strategies; renewable energy as a fuel or heat source; electrification; change in feedstock from mineral oil to natural gas and to carbon feedstock; and CCS/CCU*) and buildings (*energy efficiency improvements of buildings and technical systems; renewable energy as a fuel, electricity or heat source; and integrated concepts creating synergy effects*). Industrial symbiosis implies strong value chain integration and is emphasized in the vertical integration of the petrochemical sector. Demand side reduction measures highlight seven new economic activities and industries: Offshore wind, Bio-based chemistry, Demand-side-management and energy storage, CO_2 transport and storage, Synthetic fuels, Carbon-neutral primary steel production and Use of waste.

The roadmap makes the following recommendations to both industry and policy makers: the need for a decarbonisation roadmap, support for the ROAD project, adjustment to the port's business model, emphasizing strategic networking, identifying low-risk and robust investments, providing policy predictability, increase in Carbon Price, schedules for the phase-out of CO_2-intensive technologies and subsidised R&D and investments in new low-carbon technologies and infrastructure.

5.12 CHEMISTRY FOR CLIMATE, ACTING ON THE NEED FOR SPEED. ROADMAP FOR THE DUTCH CHEMICAL INDUSTRY TOWARDS 2050 (ECOFYS, & BERENSCHOT, & VNCI, 2018)

The Roadmap focuses on the Dutch chemicals sector - *scope 1 (direct emissions), scope 2 emissions (purchased electricity and heat), scope 3 emissions (end-of-life treatment of sold products)* - and targets 80-95% emission reduction compared to 1990 (constructed baseline - 58 Mt CO_2-eq) by 2050 (60-70 Mt CO_2-eq reduction in absolute terms) and an intermediary target of 49% by 2030 (15 Mt CO_2-eq reduction). Between 2030-2050, the remaining 56 Mt CO_2-eq consists of end-of life emissions (38 Mt CO_2-eq) and energetic and non-GHG emissions (18 Mt CO_2-eq).

The Roadmap proposes six solution themes: closure of the materials chain (or circularity), alternative feedstock, energy efficiency, renewable energy, CCS, and sustainable products. From them, it explores thematic three transition pathways each targeting 80-95% GHG and energy-related emissions in a value-chain approach: Circular & Biobased pathway, Electrification pathway and CCS pathway. From these three transition pathways, the Roadmap develops two combination transition pathways that pick up the best elements while avoiding the extremes: 'Pathway 1: 2030 compliance at least costs' and 'Pathway 2: direct action and highvalue applications'. Both pathways aim at 49% of energy and other GHG emission reductions in 2030 and all GHG emissions by 80-95% in 2050. In Pathway 1, all emissions are reduced by 14% in 2030 and 95% in 2050. It aims to achieve the 2030 target at the lowest cost for the chemical industry. In Pathway 2, all emissions are reduced by 25% in 2030 and 95% in 2050. It is a more balanced approach which starts with reducing end-of-life emissions up to 2030, whilst using energy and feedstock resources optimally. In both pathways, energy efficiency improves at 1%/year after 2005, implying 22% improvement in 2030 and 36% in 2050. However, while end of life emissions are reduced by 25% by 2030 in Pathway 1, they are reduced by 1% in 2030 in Pathway 2 (93% by 2050 in both). Investment costs are also the same in both pathways (EUR 16 Bn in the chemical industry, and EUR 25 Bn outside the chemical industry).

The roadmap develops detailed technological options for each of the six solution themes, three transition pathways and two combination pathways. Circularity includes reuse, mechanical recycling (recycling of polymers, rubbers and other organics and of inorganic material through ground water filtration), and chemical recycling (Solvolysis, Pyrolysis, Low Temperature Gasification, High Temperature Gasification). Alternative feedstocks include bio-based feedstocks (Fermentation, Transesterification, Gasification and Pyrolysis) and H_2 (through Alkaline electrolysis, PEM electrolysis and High-temperature solid-oxide electrolysis). Energy efficiency can be achieved through process intensification and efficiency as well as electrification with high COP technologies (such as Mechanical Vapour Recompression and high temperature heat pumps). Renewable energy includes renewable electricity and renewable heat (electric and hybrid boilers, biomass, geothermal energy). CCS with a potential to capture 14 Mt CO_2/year includes pre and post combustion capture and oxy-fuel combustion.

The Circular & Biobased pathway involves the use of 700 PJ of sustainable biomass in 2050 with 2050 Investment Costs of EUR 24.5 Bn mainly for alternative feedstocks and EUR 10.1 Bn for the energy sector. The Electrification pathway relies largely on H_2 from electrolysis in combination with CCU as alternative feedstock (requiring around 980 PJ of electricity or around 62 GW of offshore wind development) and costs EUR 91.3 Bn mainly for electrolysis and EUR 152.4 Bn for the energy sector - offshore wind capacity and related infrastructure costs. The CCS pathway relies overwhelmingly on CCS to mitigate around 11.4 Mt CO_2/year with minimal deployment of other solutions (2.3 Mt for mechanical recycling, 0.5% per year energy efficiency improvement and 2.3 Mt reduction from functionality driven bio-based feedstock). The pathway costs up to EUR 12.4 Bn Eur for abatements for energetic and other GHG emissions and EUR 15.9 Bn for CCS (waste incinerators).

The roadmap develops a detailed analysis of the two combination pathways' technological inputs. In Pathway 1, there is heavy reliance on heat from bio-based boilers (requiring 70 PJ of biomass by 2030 and 435 PJ by 2050), followed by energy efficiency measures and mechanical recycling. Renewable energy comes from electric boilers (0 PJ in 2030 and 65 PJ in 2050) and biomass boilers (26 PJ in 2030 and 67 PJ in 2050). After 2030, the focus will be on closing the material loop with both mechanical and chemical recycling while functional bio-based materials will be implemented to the full potential. Further reduction of feedstock related emissions will be achieved by making bio-diesel and producing plastics. CCS will employed after 2030 and by 2050 will capture 2.4 Mt CO_2 of process emissions and 1.2 Mt CO_2 of energy-related emissions while waste incineration with 85% efficiency will capture 8.5 Mt CO_2. Total CAPEX would be EUR 16 Bn investments in the chemical sector, and EUR 25 Bn investments outside the chemical industry. OPEX would be EUR 10 Bn/year for energy and feedstock

In Pathway 2, the maximum amount of biomass is 140 PJ in 2030 and 280 PJ in 2050. Biomass is first used for the highest value applications. Functional bio-based materials will be implemented to the full potential is this pathway and the remainder of the biomass will be used for the production of BTX and bioplastics. Circularity is maximized and CCU is implemented to its full potential. Methanol, and part of C2/C3, are produced on the basis of H_2 (in combination with CCU); the total electricity use is 170 PJ or 11.4 GW off shore wind. The rate of energy-efficiency improvement is set at 1% a year. Maximum heat is sourced from geothermal sources, with the remaining demand provided by electrical boilers. The pathway omits the use of bio-based boilers. CCS will be used to capture 0.82 Mt CO_2 by 2030 and 2.4 Mt CO_2 by 2050 of process emissions and 5.1 Mt CO_2 of energy-related emissions by while waste incineration will capture 8.5 Mt CO_2 by 2050. The pathway requires additional 600 Kilo Tonnes (Kt) of H_2 by 2050. Total CAPEX would be EUR 27 Bn investments in the chemical sector, and EUR 37 Bn outside the chemical industry. However, OPEX for Pathway 2 (EUR 9 Bn/year for energy and feedstock) would be lesser by 1 Bn/yr in 2050.

Cost-effectiveness of the abatement measures only includes investments cost and energy and feedstock OPEX based on current prices. The roadmap uses the Energy Transition Model (ETM). As a basis for parameters outside the chemical sector, the 95% scenario for 2050 made for the Raad voor de Leefomgeving (RLI, 2015) was used. Demand side and circularity play an important role in the roadmap. Industrial symbiosis too has been addressed in detail with the following sector: agrifood, transport sector, power sector, industry, and residential and tertiary sector; representing a potential of 50 Mt CO_2/annum avoided emissions in 2030. New business models have not been identified but certain pathways are more conducive to their development.

The Roadmap makes the following policy recommendations: large-scale access to affordable and reliable renewable energy carriers, closing of carbon loops, introduction of renewable sources of carbon, an effective global carbon price in the longer term, coherent and wide-scale implementation of existing and innovative solutions, underscoring infrastructure, active cooperation between government and industry leadership, and creation of a stable policy framework with targets and support for a longer timeframe aligned with EU and where possible global initiatives.

Separate roadmap implementation recommendations are made and underscore the establishment of a joint task force (government – industry– energy sector), joint industry/government far-reaching technological innovation program targeting reliable deployment full scale, development of the energy system and the associated infrastructure alongside the industry transition, long-term regional implementation programs, establishment of new partnerships and speeding up implementation via regional long-term implementation programs.

5.13 ENERGY TECHNOLOGY PERSPECTIVES 2017 (IEA, 2017)

The roadmap focuses on global energy systems (energy efficiency, decarbonisation, transformation and clean technologies) but only industry sectors (*chemicals and petrochemicals*, *iron and steel*, *cement, aluminium* and *pulp and paper)* are considered in this analysis. With 2014 as a baseline, three mitigation scenarios up to 2060 are developed: 'Reference Technology Scenario (RTS)', '2DS', and 'B2DS'.

In the RTS scenario direct CO_2 rises 0.6%/year through to 2055 peaking at 10.4 Giga Tonnes of CO_2 ($GtCO_2$) then slightly declining to 2060. Fossil fuels account for 64% of energy demand in industry in 2060 compared with 72% in 2014 (electricity's share rises from 20% to 23%). In the 2DS (compatible with 2°C by 2100), direct CO_2 emissions are reduced by 44% by 2050 and halved by 2060. BAT and energy efficiency account for 55% and CCS accounts for 37 $GtCO_2$ of cumulative direct CO_2 emission reductions compared with the RTS. The B2DS represents a dramatic shift in direct CO_2 emissions to "well below 2°C". Direct CO_2 emissions are reduced by 69% by 2050 and 80% by 2060. Innovative technologies account for 42% of cumulative emissions reductions while energy efficiency and BAT deployment account for 37% (of which CCS accounts for 90 $GtCO_2$ and BECCS account for 4.5 $GtCO_2$). Structural shifts in industry and redefining product value chains are significantly more ambitious in 2DS than in the RTS, and most ambitious in the B2DS.

In the chemicals and petrochemicals industry, direct CO_2 emissions reductions are 975 Mt CO_2/year in 2060 in 2DS and 321 Mt CO_2/year in 2060 in B2DS (30% of current levels). B2DS reductions are achieved by reducing the SEC/tonne of product to produce ammonia to 10.7 Giga Joules per Tonne (GJ/t) 2060 and direct CO_2 footprint by 96% to 0.1 t direct CO_2/tonne of ammonia production; a 10% decrease in process energy intensity and a 94% decrease in direct CO_2 emissions from current levels in Methanol production. In addition, process energy intensity would improve by 21% and direct CO_2 intensity more sharply by 89% by 2060 in HVC production. Direct CO_2 intensities of primary production are seen reduced 24% - 62% by 2030 in the B2D driven by: energy efficiency improvements, advances towards BAT-level processes, shifts to lower-carbon fuels and feedstocks, and deployment of CCS. Decreased Demand in both 2DS and B2DS is at -4% (17.8 EJ) or 1.3 $GtCO_2$ cumulative savings compared with the RTS achieved through material efficiency, improving collection and processing rates of plastic-based consumer products which means less ammonia (70 Mt), methanol (68 Mt), and HVC (1,292 Mt).

In the iron and steel industry, direct CO_2 emissions reductions in 2DS are more or less 1000 Mt CO_2/year while in the B2DS are 208 Mt CO_2/year (9% of current levels or one-fifth of emission levels in the 2DS). Direct CO_2 intensities of primary production are reduced by 50% by 2030 while aggregated energy intensity is seen reduced by 32% by 2030 in B2DS compared with 2014. Decreased demand for crude steel stands at -12% or 11Gt, equivalent to 99 EJ or 7.7 $GtCO_2$ cumulative savings compared with the 2DS (26% less over the period to 2060) achieved through additional material efficiency, significant reduction of internal scrap and pre-consumer scrap production, and production of steel with less material loss.

In the cement industry, direct (residual) CO_2 emissions reductions, in B2DS are 485 Mt CO_2 in 2060, equivalent to 32% of the 2DS level by 2060, 18% below 2DS level by 2030. A fourth of the annual emission reductions in 2030 come from energy efficiency and fuel switching compared with 9% in the 2DS. Direct CO_2 intensities of primary production in B2DS drops 82% below 2014 level and 73% below the level of the 2DS (mainly due to CCS). Aggregated energy intensity in B2DS increases to 2.9 GJ/t cement in 2060, 11% above 2014 and 24% above the 2DS level, due primarily to the energy penalty associated with CO_2 capture (regardless, shift towards higher share of low-carbon fuels occurs in 2DS and B2DS). By 2060, the shares in the energy mix: of coal decreases to 25% from 63% in 2014, of biomass increases from 2% to 11%, and waste fuels increases from 3% to 12%.Overall, fossil fuels drop from 83% to 59% and natural gas makes up 48% of fossil fuels, compared with 11% in 2014.

In the aluminium industry, direct CO_2 emission reductions in the RTS are 124 Mt CO_2/year by 2060 (equivalent to 54% of current emission levels), 244 Mt CO_2/year by 2060 in 2DS, and in B2DS the process related CO_2 emissions are 12% of total cumulative process-related CO_2 emission reductions. Direct CO_2 intensities of primary production and aggregated energy intensity in B2DS decrease 59% to 1.7 tCO_2/t aluminium and 18% to around 84 GJ/t by 2060 compared with current levels respectively. In addition, that of recycled production would need to halve to reach current BAT levels by 2060 in both cases. Cumulative recycled production of aluminium is 57% in RTS and 61% in 2DS of total aluminium production. In B2DS, production of aluminium increases by only 59% by 2060 due to material efficiency strategies, including improved manufacturing and semi-manufacturing yield rates and post-consumer scrap reuse. The reduction in demand more than offsets the increase in primary production (cumulative net energy savings of 43 GJ and emissions savings of 1.9 $GtCO_2$ between 2014-60) achieved through further material efficiency, reducing the availability of internal and new scrap by 24% compared with 2DS, and shifting the composition of scrap toward post-consumer scrap.

In the pulp and paper industry, aggregate direct CO_2 intensities of primary production decrease significantly - by 78% in 2060 compared with RTS levels in 2DS and by 93% in 2060 compared with RTS levels in B2DS. Aggregated energy intensity in 2DS sees a 28% reduction by 2060, and reduces by 4.5 GJ/t paper and paperboard (30% below 2014 levels) by 2060 in B2DS.

Estimated cumulative investment needs between 2017 and 2060 are USD 6.8-8.0 Tn for RTS, USD 6.3-7.3 Tn for 2DS (30% chemicals and petrochemicals, 24% iron and steel, 20% pulp and paper, 15% cement and 12% aluminium) and USD 7.0-8.7 Tn for B2DS. The 2DS is the least costly scenario while the B2DS is the most costly (given early replacement of capacity, deployment of more costly carbon abatement options and the rapid deployment of CCS, equipment costs offset these effects).

Four main groups of technologies and strategies enable the 217 Gt cumulative direct CO_2 emission reductions in the B2DS: energy efficiency and BAT deployment (42%), innovative processes and CCS (37%), lower carbon fuels and feedstocks (13%) and material efficiency strategies (8%). Low-carbon processes and technologies have been systematically detailed along three groups: 1) Commercial low-carbon process technologies, 2) Innovative low-carbon process technologies at the demonstration phase and 3) Low-carbon innovative process technologies at the R&D phase.

The roadmap makes a list of policy findings: lack of performance standards and fiscal incentives, continuation of fossil fuel subsidies and lack of effective internationally coordinated carbon pricing schemes, poor RD&D, lack of sufficient material efficiency strategies, lack of mapping and integrated assessments, lack of programmes that collect technology-specific energy performance statistics and lack of co-operative frameworks. The roadmap also lists technology, low-carbon innovation and low-carbon energy system-focused short and long term recommendations.

Finally, the roadmap makes specific policy implications for the B2DS scenario which includes: more aggressive deployment of policy levers, unprecedented climate policy ambition, higher carbon pricing, stronger incentives, additional support for RD&D, strengthened cross-sectoral and cross-regional co-ordination on energy technology and carbon mitigation options, long-term stability and visibility of the policy framework for investment decision making and rapid policy actions to support a more rapid scale-up and deployment of innovative low-carbon technologies, de-risking and incentive mechanisms to ensure competitiveness and viability.

5.14 ROADMAPS AND STUDIES OVERVIEW

Table 3 on the next pages gives a summary of the main elements of the roadmaps and studies analysed above.

Sector	Steel	Chemicals				Refining	Forest Fibre (Pulp, Paper, Wood)	Ceramics	Industrial Cluster	Multiple Industrial Sectors	
Name	A Steel Roadmap for a Low-carbon Europe 2050	European Chemistry for growth, unlocking a competitive, low-carbon and energy efficient future	Low-carbon energy and feedstock for the European chemical industry	Taking the EU chemicals industry into the circular economy	Chemistry for Climate, Acting on the need for speed. Roadmap for the Dutch Chemical Industry towards 2050	Low-carbon Pathways CO2 efficiency in the EU Refining System. 2030 / 2050	Investing in Europe for Industry Transformation : 2050 Roadmap to a low-carbon bio-economy	The Ceramic Industry Roadmap: Paving the way to 2050	Decarbonisation Pathways for the Industrial Cluster of the Port of Rotterdam	Energy transition: mission (im)possible for industry? - A Dutch example for decarbonisation	Energy Technology Perspectives
Release Date	2014	2013	2017	2017	2018	2018	2011 & 2017	2012	2016	2017	2017
Author	EUROFER	ECOFYS & CEFIC	DECHEMA	ACCENTURE	ECOFYS & BERENSCHOT	Concawe	CEPI	Cerame-Unie	WI	McKinsey and Co.	IEA
Commissioned By	EUROFER	CEFIC	CEFIC	CEFIC	VNCI		CEPI	Cerame-Unie	Port of Rotterdam	VEMW	
Scope	EU 2013→ 2050	EU 27 2013→ 2050	EU 2015→ 2050	EU 27 NA → 2030	The Netherlands 1990 → 2050	EU 28 NA → 2030/2050	EU 28 1990 → 2050	EU 27 1990 → 2050	Port of Rotterdam 1990 → 2050	The Netherlands 1990 → 2030/40/50	Global 2014 → 2060
Scenarios, Mitigation and Costs	**Economic** -13%	**Continued Fragmentation Scenario** -40%	**Business as Usual** ↑ From 85Mt CO_2 to 119 Mt CO_2	**Substituting raw materials** 12 Mt looped chemicals *EUR 20-40 Bn CAPEX*	**Compliance at least cost** -49% (→2030) -80-95% (→2050) *EUR 41 Bn CAPEX*	**2030 Scenario** -20-30% (→2030)	**Scenario** -80% *EUR 44 Bn CAPEX (+annual Investments)*	**Scenario 1** -65%	**Business as Usual** -30%	**Business as Usual** -40% (→2030)	**Reference Technology** +0/6%/yr to (→2055 - peak) *USD 6.8-8.0 Tn Investment*
	Maximum theoretical Abatement w/o CCS -38%	**Isolated Europe Scenario** -80%	**Intermediate** -117Mt CO_2	**Increased re-use of end-user products** 17 Mt looped chemicals | *CAPEX NA*	**Direct action and high value applications** -49% (→2030) -80-95% (→2050) *EUR 64 Bn CAPEX*	**2050 Scenario** -70% (→ 2050 with CCS, -50% w/o CCS) *EUR 40+ Bn CAPEX*		**Scenario 2** -78% *Capital costs (EUR 90 Bn) + Running Costs*	**Technological Progress** -75%	**Cheaper Route** -60% by 2040| *EUR 21-23 Bn CAPEX*	**2DS (2 degrees)** -44% (→2050) -60% (→2060) *USD 6.3-7.3 Tn Investment*
	Maximum theoretical Abatement with CCS -57%	**Differentiated Global Action Scenario** -80%	**Ambitious** -216 Mt CO_2 (-80%)	**Mechanical recycling** 19 Mt looped chemicals *EUR 30-80 Bn CAPEX*			-		**Biomass and CCS (BIO)** -98%	**Steeper route** -80% (→2040) *EUR 55 Bn CAPEX*	**B2DS (below 2 degrees)** -69% (→2050) -80% (→2060) *USD 7.0-8.7 Tn Investment*
	Emissions Reductions with BTT -80%	**Level Playing Field Scenario** -50%	**Maximum** - 498 Mt CO_2	**Chemical recycling** 8 Mt looped chemicals *EUR 10-20 Bn CAPEX*					**Closed Carbon Cycle & Closed Carbon Cycle Earlier Closure** -98%	**Steeper route** -95% (→2050) *EUR 71 Bn CAPEX + further*	
				Energy recovery and carbon utilization 10 Mt looped chemicals *EUR 100-140 Bn CAPEX*							

Sector	Steel	Chemicals				Refining	Forest Fibre (Pulp, Paper, Wood)	Ceramics	Industrial Cluster	Multiple Industrial Sectors	
Key Technologies	BF-TGR, ULCORED/HIsarna, CCS, Electrification of heating, H_2-based reduction, Electrolysis	Bio-based feedstock; valorisation of waste and recycling of plastics; CCU/CCS; greater process energy efficiency; changes in heat sources, renewable energy and CHP; end of pipe emission abatement; reduction of emissions in nitric acid productions; mitigation options for ammonia, cracker products and chlorine.	Energy efficiency, H_2 & CO_2 based production routes, Biomass & biomass waste streams to chemicals, Electricity-based processes, Industrial symbiosis & circular economy, CCS	Biomass, new products and solutions that can essentially be re-used "as is", mechanically recycled molecules; reverse logistics capabilities, processing partnerships, cracking and gasification processes, molecular energy recovery, capture and reconstruction of new chemical feedstocks	Circularity, reuse, mechanical recycling, chemical recycling, bio-based feedstocks, H_2, process intensification and efficiency, electrification with high COP technologies, renewable electricity and renewable heat, CCS	Energy Efficiency, Low-carbon Energy Sources, CO_2 Capture (combination of CCS and steam reforming plants)	Energy Efficiency Improvements, Demand-Side Flexibility, Fuel Switch, Emerging and Breakthrough Technologies, Carbon Reduction From Purchased Electricity, Transport Improvements.	Energy efficiency (such as kilns, dryers, thermostats and seals, application of automated controls, and heat saving through improvements in thermal insulation), breakthrough technology, alternative fuel sources (such as the electrification of kilns and using low-carbon electricity), smart design of facilities, integrated process efficiencies gas), cogeneration through CHP, CCS	Petrochemicals (energy efficiency improvements; renewable energy as a fuel or heat source; electrification; change in feedstock from mineral oil to natural gas and to carbon feedstock; and CCS/CCU), Buildings (energy efficiency improvements; renewable energy as a fuel, electricity or heat source; and integrated concepts creating synergy effects)	Energy efficiency' Electrification of heat demand, Change of feedstock, Develop routes to reuse and recycle materials, Decide on steel production route(s), CCS/CCU	B2DS Scenario: Energy efficiency & BAT deployment (42%), Innovative processes & CCS (37%), Lower carbon fuels & feedstocks (13%), Material efficiency strategies (8%)
Assumptions	Increased scrap availability, greater share of EAF steelmaking, continuous decarbonisation of power sector, continuous market growth	Competitiveness, energy price, impact on production, CO_2 price, feedstock prices, value chain integration	Increased demand for low-carbon power, increased demand for CO_2 as feedstock, increased demand for biomass as feedstock, extensive additional investments	Lesser production of virgin chemicals would save around 250 TWh of energy		Constant refining capacity (EU, 2030 level), all options are exercised, different rates of deployment of technology, energy prices & degree of electricity grid decarbonisation	Value added compared to 2010 to increase by 50%, shift to the circular bio-economy	Energy costs 2.5x current rate, cost of biogas 2-3x that of natural gas, rising cost of raw materials from Asia, Constant level of production with a similar product mix.	European transport sector fuel demand, final industrial sector energy demand mix, Europe's electricity mix	future price of energy (most influential factor), commodity prices, equipment costs, extent to which industrial companies pursue other priorities	

5.15 RELEVANCE FOR FLEMISH INDUSTRY

In general the roadmaps considered in this study show that across a range of industries (steel, chemicals, ceramics and paper) but also across multiple industrial sectors in a country (Netherlands) or region (Port of Rotterdam) in theory deep emission reductions are possible but challenging. In most cases the mitigation can in theory go beyond 80% compared to different historical baselines. In most cases, the deep emission reductions depend on breakthrough technologies that still need to be proven commercially (e.g. CC(U)S and H_2 based feedstock/synthetic fuels). In all cases deeper mitigation will require high levels of CAPEX (e.g. EUR 55 Bn for McKinsey & Co scenario to reduce emissions in Dutch industry by 80% in 2040). Often the OPEX of the new technologies is higher compared to those currently used. It is also clear that a mix of different technologies will have to applied within and across industrial sectors. The specific mix of technologies will likely depend on local circumstances (e.g. the availability of pure CO_2 streams and storage locations, affordable and reliable biomass and/or H_2 (via renewable electricity), waste streams from one sector as input for another production process, etc.). It is highly likely, when looking at the roadmaps and the modelled technologies that electricity demand will rise significantly in most decarbonisation scenarios bringing extra challenges to the energy system .

For Flanders, this implies that all the technological options and scenarios presented in the roadmaps will have to be applied and calibrated to the specific regional context (e.g. availability of affordable biomass and H_2, electricity demand).

The roadmaps considered in this report are useful in the sense that they look at the bigger picture and international context important for competitiveness. They offer interesting but limited insights into the specific decarbonisation options for Flanders. In combination with Flemish specific studies such as the CCU, H_2 and renewable based chemicals mentioned in section 3.8 they can form a starting point for further explorations of breakthrough technologies in the Flemish industry.

Some roadmaps, like EUROFER (2014) and CEFIC (2013) in particular, are less useful for Flanders in term of the latest technological innovation trends. Both these roadmaps are almost 5 years old and in the process of being updated by a new European Steel Masterplan and a Mid-Century Strategy for the European Chemical industry. These new studies are expected in the course of 2018. The more recent and highly technologically focussed DECHEMA roadmap on the other hand gives a comprehensive and detailed overview of future technological options for deep emission reductions in the chemicals industry, including the expected economics (investment needs) of these options.

In addition, the Accenture study on the chemicals industry and the circular economy and in particular its methodology to assess the increased looping of chemicals can prove very relevant for use in Flanders on the condition that cross-country cooperation and interactions are included, in particular due to the importance of plastics in the Flemish chemical sector value chain.

The CEPI (EU paper industry) roadmap's approach which links the ambition level to double the value added of the industry to generate the capital to invest in low-carbon technologies offers an extremely strong (but also realistic) logic. It is therefore recommended to evaluate such dual track (value added and investments for mitigation) in Flanders.

The similarity between the Dutch and Flemish industrial emission's profile (e.g. as shown in chapter 4) invites a closer look of the recent roadmaps developed there (e.g. McKinsey & Co, Wuppertal/Port of Rotterdam and VNCI/Ecofys) and an analysis of the different solution pathways and the relevance for Flanders. More information on industrial low-carbon transition and implementation thereof in The Netherlands is likely to become available soon given the ambition of the current government to reduce emissions by almost 50% by 2030. It presents two main scenarios with a different strategic vision. One which seeks to meet (short-term) targets at lowest cost and one that seeks more upfront CAPEX in new technologies. While the (short-term) lowest cost scenario might seem attractive it comes with a higher cost on the longer term in the form of higher OPEX beyond 2030 and dependence on foreign developed know-how and technologies.

Finally, there is high level of consistency between the policy recommendation across most of the roadmaps considered in this report. They show a clear need for a mission oriented research, development and, most importantly, demonstration and deployment policy framework. This includes facilitating finance or access to capital. Often the matter of urgency is stressed given the high CAPEX of most low-carbon investments and the fact that investment cycles for energy intensive industries cover a period of 20-30 years, and hence leave limited time towards 2050. Most roadmaps also argue for a coherent and stable regulatory framework for industrial competitiveness and see a strong link with the ongoing energy transition in Europe.

6 TECHNOLOGY ANALYSIS

6.1 CURRENT DEVELOPMENTS IN LOW-CO_2 CHEMICALS PRODUCTION TECHNOLOGIES

6.1.1 Introduction

The most comprehensive and recent analysis of EU chemicals production technologies is the DECHEMA report[55], which was launched in June 2017. The report assesses breakthrough technologies in four different routes: direct use of low-carbon electricity, H_2/CO_2-based production routes (including ethylene and propylene via H_2 based methanol), biomass as feedstock and, syngas to ethanol. The information in this chapter is largely based on the DECHEMA report and has been complemented with primary sources (e.g. corporate information, EU-sources on publicly funded projects and interviews).

6.1.2 Direct use of low-carbon electricity

Direct use of low-carbon electricity is mainly investigated through two routes: electricity-based steam production and advanced heat management via steam recompression. Electricity-based steam production (TRL 7) enables decarbonisation by use of renewable energy, since chemicals production's process energy demand is mainly in the form of heat (steam). 60% of total fuel used in chemicals production is used to generate steam. Advanced heat management via steam recompression (TRL 6-7) has the potential for significant energy savings through major upgrades of residual steam by mechanical vapour recompression (MVR). Potential emission reductions through application of these technologies can be significant, with energy savings estimated at around 50%. Potential savings in energy for heat demand is estimated to around 15-20%.

6.1.3 H_2/CO_2-based production routes

The fundamental transformational processes in the chemicals industry are largely based on reactions that involve carbon and H_2. In the synthesis gas-based route, reactions with mixtures of H_2, CO and CO_2 lie at the core of the industry's value chain. The main role of H_2 in these reactions is to act as a high-carrier to enable the conversion of CO_2. It is therefore essential to investigate different technologies for the production of low-carbon H_2 for the chemical industry to achieve decarbonisation. Different pathways can be designed using H_2 from low-carbon electricity as a reactant.

Production through methane pyrolysis, thermochemical processes and photocatalytic processes have lower TRLs (2-5), whereas low-carbon ammonia (H_2-based), hybrid ammonia production (H_2 with CH_4) and low-carbon methanol production (CO_2 + H_2) have TRLs around 7. The emission mitigation potential of these technologies range significantly, with abatement potential as high as 90%. Low-carbon ammonia (H_2-based)

[55] DECHEMA (2017). Technology study: Low-carbon energy and feedstock for the European chemical industry. Commissioned by CEFIC. Available at: https://dechema.de/dechema_media/Technology_study_Low_carbon_energy_and_feedstock_for_the_European_chemical_industry-p-20002750.pdf

production, for example, has direct CO_2 emission reduction potential of 1.33 tCO_2/tNH_3 compared to the conventional production route. These technologies have fairly high electricity demand and can use CO_2 as feedstock (Figure 49 and

Figure 50).

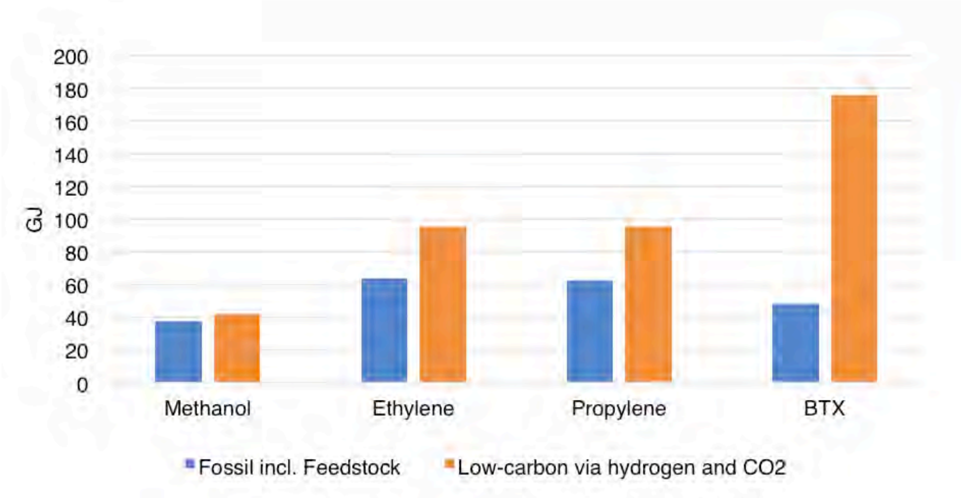


Figure 49: Demand for electricity and CO_2 as feedstock in the low CO_2 H_2-CO_2 route (Source: IES, 2018)

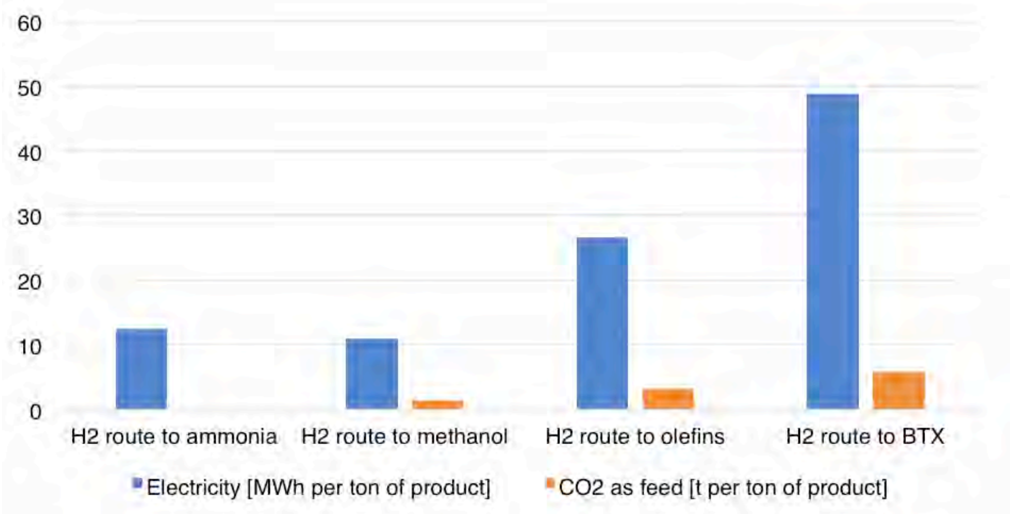


Figure 50: Energy demand per ton of product for the fossil route (including feedstock) versus the low-CO_2 H_2-CO_2 route. (Source: IES, 2018).

The three most important routes for electrolysis H_2 production are Alkaline Electrolysis (TRL 7-9), PEM-Electrolysis (TRL 7-8) and High-Temperature Solid-Oxide Electrolysis (TRL 6-7). For these technologies, the OPEX per kW are expected to almost halve by 2050. The technologies have significant variations in energy demand, TRL and CAPEX, as illustrated in the figures (51 and 52) below. Alternative ways to produce low-CO_2 H_2 include methane pyrolysis (TRL 4-5).

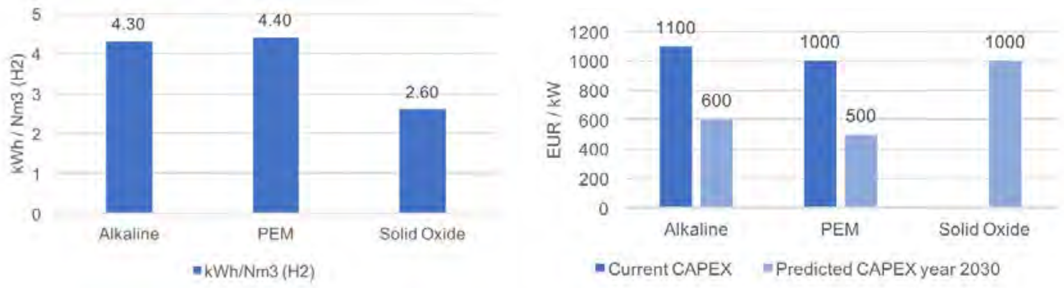


Figure 51: [Left] energy demand for the three H_2-electrolysis routes (Source: IES, 2018); [Right] current CAPEX and predicted CAPEX for year 2030 for the three H_2-electrolysis routes (Source: IES, 2018)

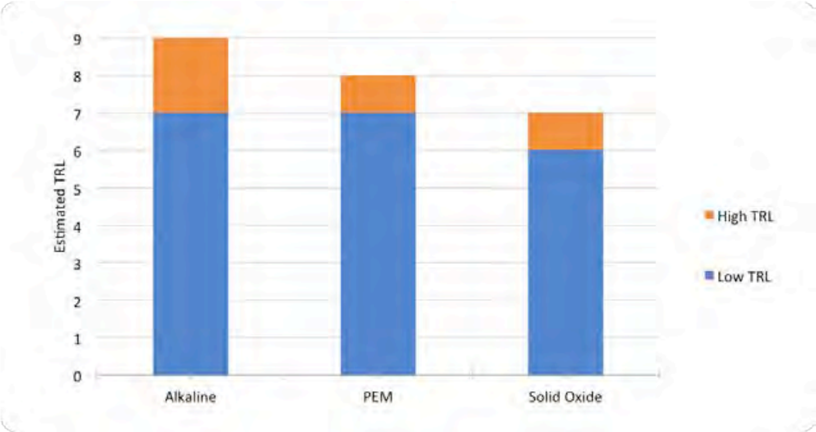


Figure 52: Estimated TRLs for the three H_2-electrolysis routes (Source: IES, 2018)

The H_2/CO_2-based production routes also include production of ethylene and propylene via H_2-based methanol. Several technologies are currently being investigated for this route. Processes at lower TRL levels (1-4) are olefins out of H_2 and CO_2 in single system, dimethyl ether DME (direct synthesis from CO_2), sodium acrylate from ethylene and CO_2 and electro-catalytic processes to convert CO_2 to ethylene. The more advanced technologies (TRL 7-9) are: benzene, toluene and xylenes (BTX) via H_2 based methanol, poly(propylene)carbonate and polycarbonate etherols using CO_2 and formic acid (using electrochemical CO_2 reduction), and low-carbon ethylene and propylene via MTO (Methanol to Olefins) where methanol is made using H_2 and CO_2. Some of these technologies enable significant emission reductions, but demand a higher amount of energy than conventional production. For example, the MTO process causes 0.4 tCO_2eq/t high value chemicals (HVC) compared to 0.76 tCO_2eq/t HVC when olefins are produced through catalytic cracking of naphtha, whereas the specific energy consumption of the low-carbon process is 40% higher.

6.1.4 Biomass as feedstock

Using biomass as feedstock is a low-carbon alternative to conventional production methods. Biomass however is a fairly limited resource, and is largely used in many different sectors - such as for food and animal feed, energy, fuel and as raw material - which limits its availability. Biomass also largely depends on specific geographical conditions, which means that environmental factors affect the extent to which using biomass as feedstock can be considered sustainable. Today, biomass contributes 10% of total carbon feedstock in the EU chemicals industry.

Production of bio-ethanol and bio-ethylene has a high TRL (7-9). The TRL is slightly lower (6-7) for production of bio-methanol, bio-propylene and BTX from biomass. For most of the bio-based breakthrough chemicals processes, the output (e.g. yield, production cost, process efficiency, CO_2 emissions, energy demand) is largely dependent on the feedstock used (e.g. lignocellulosic biomass, or sugar and starch containing crops), as well as local circumstances (e.g. infrastructure). In general, both production costs and plant costs are significantly higher for the bio-based route. For example, production of bio-methanol from forest residues enables around 24% emission reduction (0.2 tCO_2-eq/t methanol) compared to the conventional route using natural gas, even though the energy demand is 17% higher (around 14.6 GJ/t methanol from dry wood biomass, compared to 12.5 GJ/t methanol from natural gas).

6.1.5 Syngas to ethanol

The syngas to ethanol route is currently under development in the Steelanol project by Lanzatech and ArcelorMittal, at ArcelorMittal's steel plant in Ghent. The Steelanol technology investigates conversion of CO/CO_2 to ethanol, and is described in further detail in section 6.2.3. *(Carbon Capture and Utilisation (CCU) in iron- and steelmaking).*

6.1.6 Current state of play

A summary of the estimated TRLs of the mapped technologies is available below (Figure).

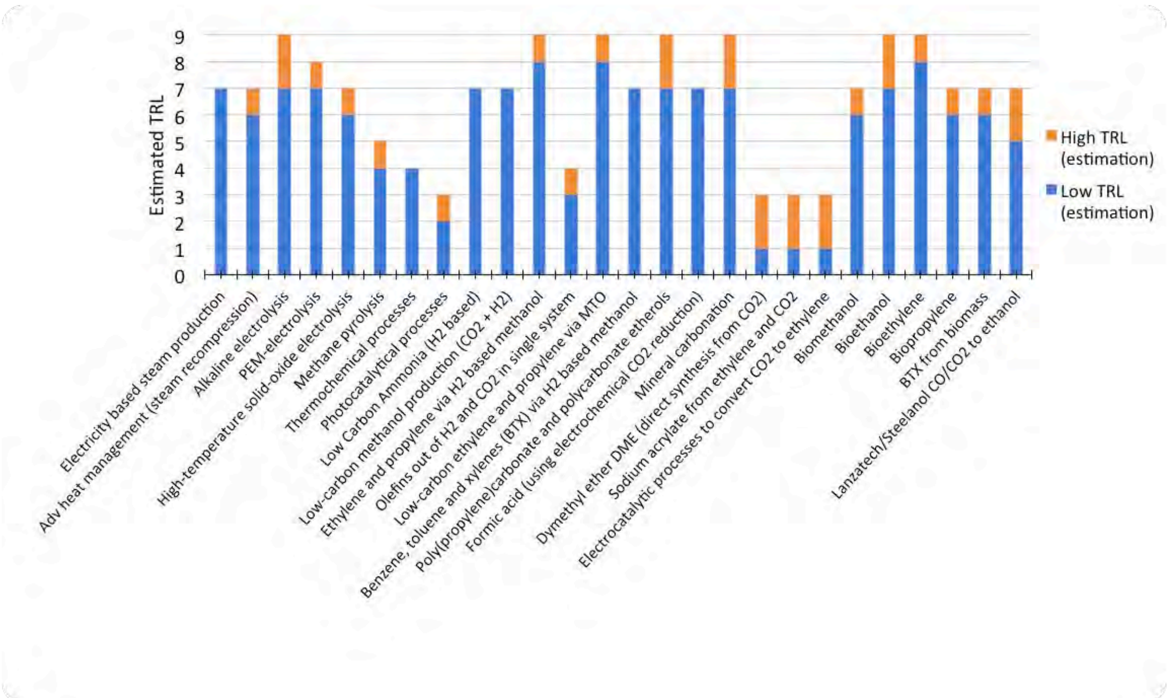


Figure 53: Estimated TRL ranges for select breakthrough technologies in chemicals production (Source: IES, 2018)

The estimated CO_2 emission mitigation potential of select breakthrough technologies is presented in Figure (excluding biomass) and Figure 55 (biomass), with the values adjusted to present conventional fossil-based production as the baseline. Figure 56: shows the net avoided tons of CO_2 per ton of biomass used in the biomass path.

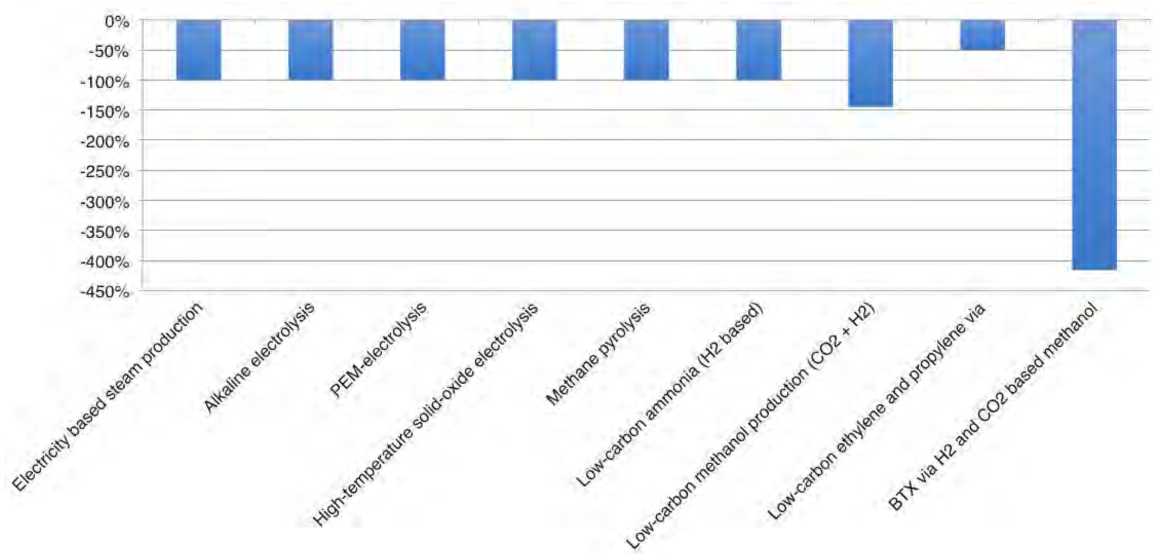


Figure 54: Estimated CO_2 emission mitigation potential of select breakthrough technologies (biomass route excluded compared to the fossil route. The baseline equals the emissions of the fossil route for the different chemicals. (Source IES, 2018)

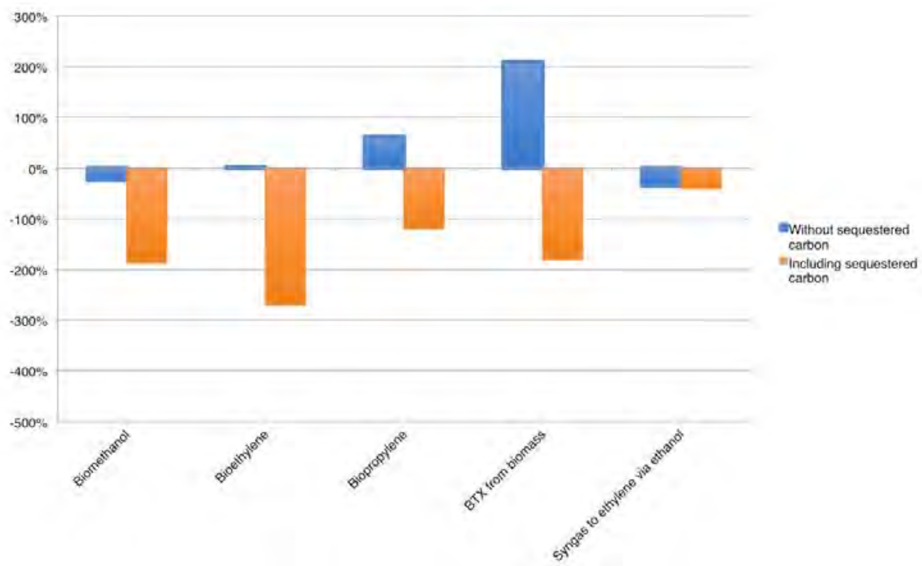


Figure 55: Estimated CO_2 emission mitigation potential of select breakthrough technologies in the biomass route compared to the fossil route. The baseline equals the emissions of the fossil route for the different chemicals. NB: for bioethylene, the non-sequestered emissions are the same as the fossil-based route. (Source: IES, 2018)

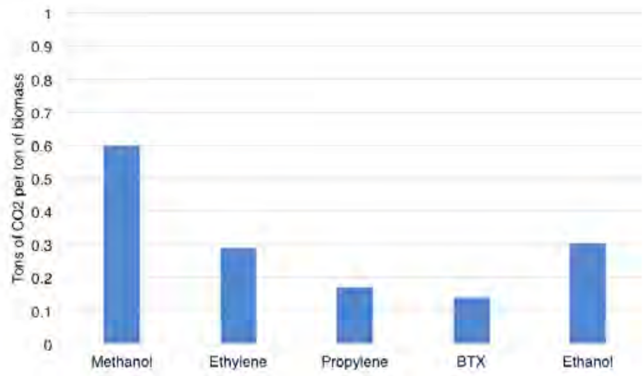


Figure 56: Net avoidance (i.e. sequestration minus emissions) of CO_2 per ton of biomass used in the biomass route. (Source: IES, 2018)

The estimated energy demand of select breakthrough technologies is presented below (Figure). The values are adjusted to present conventional fossil-based production as the baseline, meaning that while smaller bars may indicate less energy demand than the other low-CO_2 technology options, all alternatives have a higher energy demand than the conventional route. For the biomass route, the energy demand (GJ) is measure per ton of product (Figure 58).

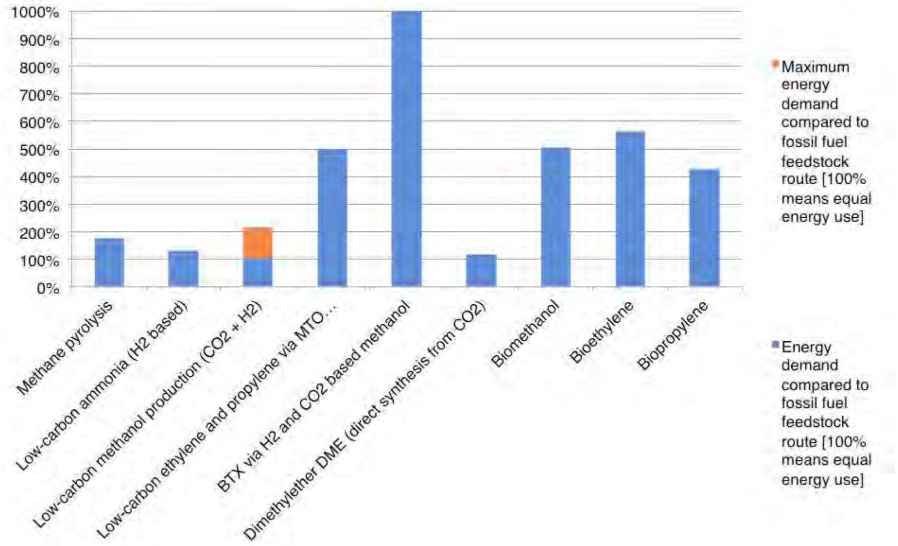


Figure 57: Estimated energy demand for low-CO_2 chemical production technologies. (Source: IES, 2018)

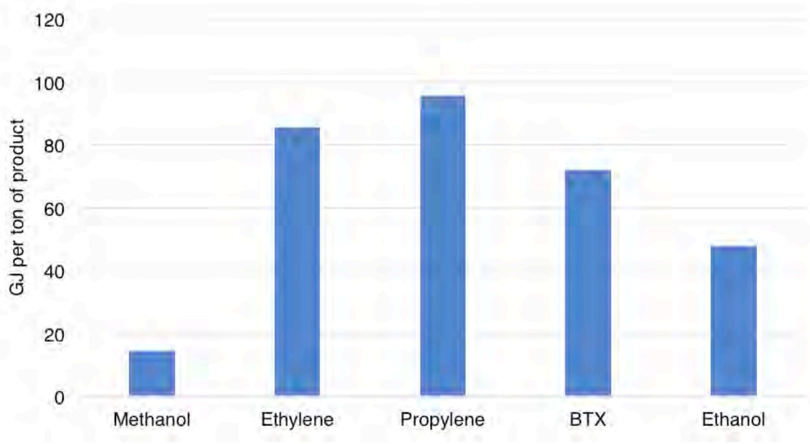


Figure 58: Estimated energy demand (including use as feedstock) per ton of product (e.g. methanol, ethylene etc.) in the biomass route. (Source: IES, 2018)

For the analysis of the economic parameters, Figure 59 presents the estimated cost of production of low-CO_2 chemicals through the H_2-route and the biomass route.

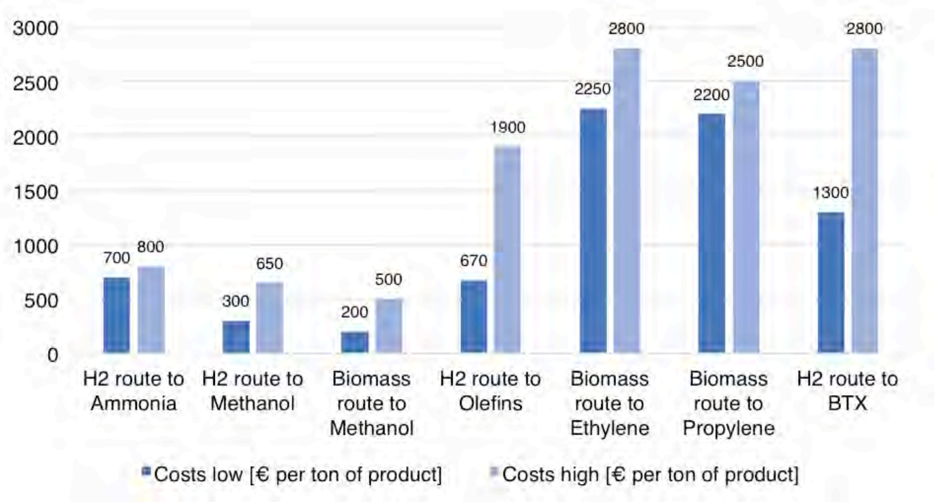


Figure 59. Estimated cost comparison for the production of low-CO_2 chemicals through the H_2 route and the biomass route. (Source: IES, 2018)

Figure 60 below presents the same data set, compared to conventional chemical production. The bars indicate the estimated cost of the low-carbon route (highest and lowest value) (source: Dechema, 2017), and the triangles indicate current price of the product through conventional production (sources: ICIS[56] and S&P Global Platts[57]). For the H_2-route to Olefins, the two triangles refer to the ethylene price and the propylene price. For BTX, the two triangles refer to the prices of

[56] S&P Global Platts (2018). Available at: https://www.platts.com/news-feature/2014/petrochemicals/pgpi/benzene
[57] ICIS (2018). Independent Chemical Information Service. See:

- https://www.icis.com/resources/news/2018/01/10/10181799/tight-market-pushes-us-spot-propylene-sharply-higher/
- https://www.icis.com/resources/news/2017/11/24/10167628/global-ammonia-prices-firm-again-on-flurry-of-spot-sales/
- https://www.icis.com/resources/news/2017/01/06/10068252/europe-methanol-spot-price-support-rolls-into-2017/
- https://www.icis.com/resources/news/2018/04/12/10211217/european-pvc-april-prices-rise-5-10-tonne-for-cis-markets-on-ethylene-hike/

benzene (lowest) and toluene (highest). The biomass route to BTX has an estimated cost of EUR 3000/tonne and higher.

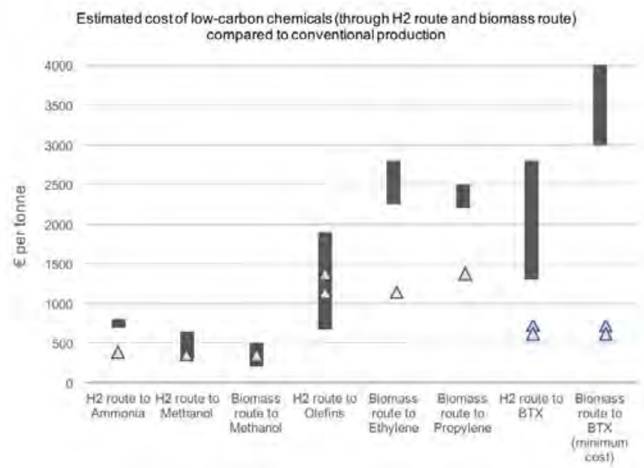


Figure 60: Estimated cost comparison of production of low-carbon chemicals through the H_2-route and the biomass route, compared to conventional chemicals production. (Sources: Dechema, ICIS and S&P Global Platts)

Figure 60 shows that the H_2 route is more cost-efficient than the biomass route for the production of low-CO_2 olefins (ethylene and propylene) and for low-CO_2 BTX. The cost of the two routes is similar for methanol production and close to methanol market price.

6.1.7 Implications of findings

There are several routes to emission reductions in the chemicals industry and a collection of fairly advanced technologies.

The energy demand (Figure 57 and 58) of some of the technologies is substantially higher than conventional processes, meaning that widespread application will depend on available and affordable renewable energy and/or biomass. Likewise, technologies that depend on renewable energy for production of H_2 will require high volumes at competitive prices. Technologies for the production of low-CO_2 H_2 production therefore need to be advanced. This will require capital and infrastructure investments.

In the biomass route, availability of biomass can be restricted by its demand in many different industries. Also, the sourcing of biomass affects the extent to which biomass is considered sustainable.

6.2 CURRENT DEVELOPMENTS IN EU LOW-CO_2 STEEL PRODUCTION TECHNOLOGIES

6.2.1 Introduction

To a large extent, low-carbon production technologies in the steel sector are driven by projects led by some of the largest steelmaking firms. The technological developments in the EU steel industry are therefore analysed at project level, divided into three routes: the H_2 path, the CCU path and the path for other sustainable steelmaking processes (including electrolysis and other breakthrough furnace innovations). Additionally, several enabling technologies for application in EU steelmaking are also discussed.

6.2.2 H_2-based steelmaking

In the H_2 path, reduction of iron ore is conducted through the use of H_2 instead of fossil fuels (coal) as is conventionally used in BF-BOF steelmaking. It is based on the direct reduction of iron (DRI), in a DRI furnace instead of a blast furnace. The output product is sponge iron, which in turn can be melted into steel in an electric arc furnace (EAF). The main sustainability gain of this process is that the by-product is water, rather than CO_2. A vast amount of H_2 is needed in the process, and the first step for EU steel firms who pursue this path is to attempt to successfully produce green H_2. Three different low-CO_2 H_2 making technologies are considered here: Proton Exchange Membrane (PEM) electrolysis, solid oxide electrolysis and alkaline electrolysis, as further discussed in section 6.1.3**.** Apart from the (theoretically) significant emission reductions of 80-95%, one of the benefits of the H_2 path is that it can stabilise the electricity grid and simultaneously act as a reverse generator.

Three main H_2-based steelmaking projects are currently under development in the EU: Hybrit, SALCOS and SUSTEEL. To meet H_2 requirements, these projects are also pursuing green H_2 through one of three H_2-based electrolysis routes. As an enabling technology, SALCOS uses GrInHy (based on solid oxide electrolysis), SUSTEEL uses H2Future (based on PEM) ,while for Hybrit the enabling technology remains undecided[58]. An additional H_2 making technology using methane pyrolysis is also currently being investigated by BASF-Linde-ThyssenKrupp.

The H_2 path has a relatively low TRL compared to the other two paths. As illustrated in the TRL graphs (see section 6.2.5 below) the H_2-making component of the technologies (e.g. GrInHy and H2Future) is currently more advanced than the steelmaking component (e.g. SALCOS and SUSTEEL). A major barrier to the H_2 path is cost and scalability. The path entails a high future demand for low-cost, sustainable H_2 and has a high additional electricity demand which must be supplied through renewable energy sources to ensure sustainability benefits.

[58] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695

6.2.3 Carbon Capture and Utilisation (CCU) in iron- and steelmaking

The CCU path implies strong industrial symbiosis, especially between the steel industry and the chemical industry. The path does not directly avoid emissions from the industry but can reduce emissions through utilisation and valorisation of industrial waste gases from steel production. The path also indirectly reduces emissions, by (assuming a similar demand) replacing primary production of chemicals with products made from recycled waste gases from steel production. Four main projects in the CCU path are currently under development in the EU - Carbon4PUR, Steelanol, Carbon2Chem and FReSMe. The Steelanol technology is currently under development at ArcelorMittal's steel plant in Ghent.

The projects STEPWISE and MefCO2 are developing enabling technologies to FReSMe. STEPWISE captures blast furnace gases and processes them through an advanced water-gas shift technology. This enables a higher carbon capture rate and lower energy consumption. MefCO2 uses H_2 from water hydrolysis as reactant. The TRL of STEPWISE is estimated to be 3-4, and for MefCO2 1-3.

The technologies in the CCU path are available at slightly higher TRLs (2-6) than the H_2 path. A significant barrier to the CCU path is uncertainty of mitigation for which reliable LCA-based carbon accounting tools will be required to measure net emission reductions. The path also requires significant sectoral coordination to enable successful industrial symbiosis, as well as electricity supplied through renewable sources to ensure sustainability in energy demand.

6.2.4 Other emerging sustainable steelmaking processes

Four other steelmaking technologies that are not based on H_2 or CCU and currently under development are: HIsarna, SIDERWIN, IGAR and PEM.

HIsarna

HIsarna is a new type of furnace in which iron ore is directly injected, and liquefied in a high-temperature cyclone so that it drips to the bottom of the reactor where it reacts with powder coal. With the addition of pure oxygen (instead of air) these react to form liquid iron. The gas that leaves the HIsarna reactor is concentrated CO_2, suitable for use or storage. One of the main challenges for sustainable implementation of the technology is the cost of CCS. Estimated emission mitigation is 20%, which could increase to 35% in combination with high scrap steel use or even to 80% in combination with CCS. The technology is already in its third development stage as it was initially developed under the ULCOS consortium[59]. The current TRL is estimated to be around 7, with a focus on upscaling in the current phase[60].

SIDERWIN (previously ULCOWIN)

The SIDERWIN project is based on CO_2-free steelmaking through electrolysis. The electrolysis process transforms iron oxide (e.g. hematite) into a steel plate (at the cathode) and oxygen (anode); the latter can be used in the blast oxygen furnace at a later stage. The system operates close to thermodynamic optimum and the overall energy consumption is estimated to be 3.6 Mega Watt

[59] IEA (2018). *Tracking Clean Energy Progress*. [online] Available at: http://www.iea.org/tcep/
[60] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695

Hour Per Tonne (MWh/tonne) or 13 GJ/tonne. Due to the exceptionally low temperature (around 100˚C) needed in the process, the technology also enables flexible steel production at a very small scale. With renewable electricity sources, this technology reduces most of the emissions compared to current integrated steel making routes. Expected emission mitigation of direct emissions is 87%, and of the direct energy use is 31%. The technology is already in its third development stage as it was initially developed under the ULCOS consortium. The current TRL level is estimated to be 4-5.

IGAR

The IGAR technology is based on process-integrated CO_2 capture through top-gas recycling in a blast furnace. A significant benefit of this technology is that it can be installed in existing blast furnaces. The project is a continuation of the European ULCOS top gas recycling blast furnace (TGR-BF) process project. The technology has been researched much over the past decade. However no current TRL data is available[61].

PEM (Primary Energy Melter)

The PEM project explores melting of low-quality scrap steel in a shaft vessel. Potential CO_2 savings amount to 1 tCO_2/ton of melted scrap. No TRL data is currently available for the PEM technology.

6.2.5 Current state of play of technologies

A summary of the estimated TRLs of the mapped technologies is available in figure 61 below.

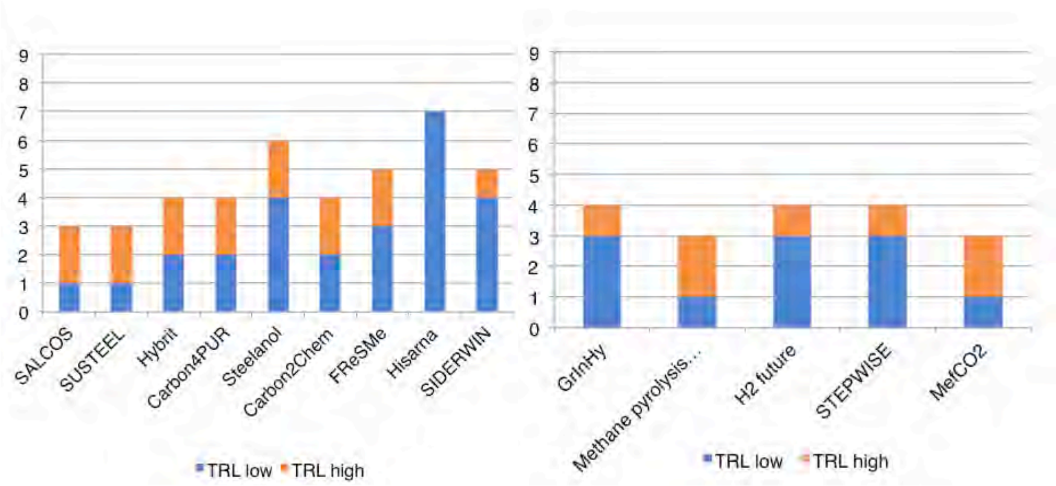


Figure 61: Estimated TRL ranges for select breakthrough technologies in steelmaking (Source: IES, 2018)

The CO_2 abatement potential of the technologies is predicted to be high (Figure 62) especially if combined with renewable energy. In particular, the H_2- and electricity-based technologies would benefit from electricity decarbonisation and high availability of renewable electricity. The CO_2 reduction potential of HIsarna depends on the availability of CCS, with which 80% emission reductions can be achieved[62].

[61] Ibid
[62] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695

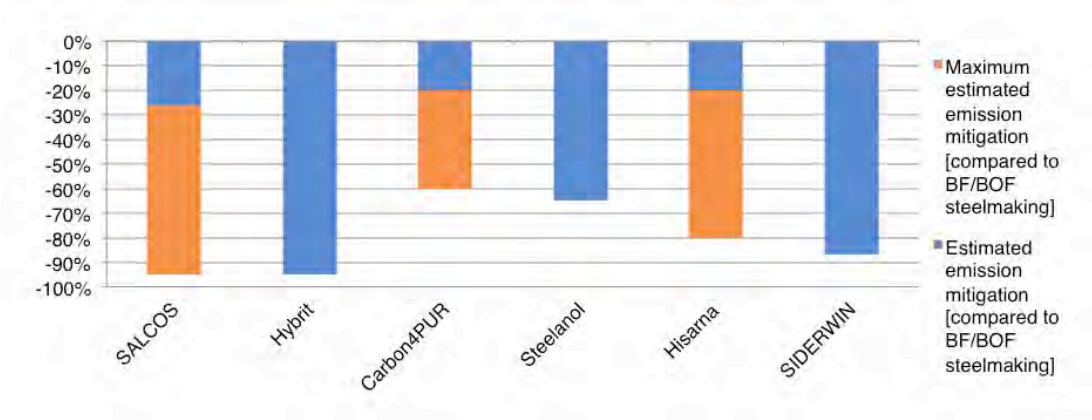


Figure 62: Estimated emission mitigation potential of select breakthrough technologies in steelmaking. (Source: IES, 2018)

6.2.6 Implications of findings

In the EU steel sector, short-term CO_2 emission reductions can be achieved through increased EAF-based scrap recycling and energy efficiency improvements. In the long run, breakthrough technologies in primary steelmaking can deliver deeper emissions reductions.

Low-CO_2 innovation in the steel sector is constrained by long investment cycles, which do not allow for rapid development of new technologies). It can be reasoned therefore that the technologies under development today will likely be those that contribute to climate targets in 2050. However, many of the aforementioned technologies currently have low TRLs and require significant funding for further development. Alongside private investments and corporate commitments, EU mechanisms such as financial assistance, risk sharing and lower administrative burdens, are expected to play a key enabling role in technological advancement.

Several of the technologies imply strong symbiosis with other industries. This is particularly true for the CCU path which underscores a connection between the steel industry and the chemicals industry and for which the success rate of several steelmaking technologies will depend on breakthroughs in chemical production.

6.2.7 Policy recommendations from EUROFER

Several of the above-mentioned technologies are featured in the EUROFER publication 'towards an EU masterplan for a low-carbon competitive European steel value chain'[63]. This document claims that a complete transition to these breakthrough steelmaking technologies would require up to 500 TWh of additional electricity demand in the EU. This electricity will have to come from renewable sources in order for the processes to be carbon neutral, requiring significant investment by member states and their industry sectors.

The development, up-scaling and commercial deployment of low-carbon innovations are risk- and capital-intensive activities. EUROFER estimates that up to EUR 10 Bn over the next decade would likely be needed to if all the technologies mentioned above are to be implemented at industrial scale.

[63] EUROFER, 2018, Towards an EU masterplan for a low-carbon competitive European steel value chain.

Financing instruments should focus mainly on 'de-risking' by combining several tools, such as access to public grants and preferential credit.

Energy costs also represents a similar risk. CCU processes and H_2 steelmaking will require low-CO_2 electricity which must be available at fixed and low prices over extended periods of time. EUROFER also states that EU State Aid rules should be flexible on the financing of projects, and that EU regulations should support industrial synergy and circularity, and reduce EU and national regulatory costs that depress the steel industry's R&D capacity.

6.3 CURRENT DEVELOPMENTS IN EU LOW-CO_2 PULP AND PAPER PRODUCTION TECHNOLOGIES

6.3.1 Introduction

This section contains an analysis of a number of technologies for low-CO_2 pulp and paper production, largely based on a report by the Confederation of European Paper Industries (CEPI), the Two Team Project[64], and innovations of the sector as mapped by the IEA's tracking clean progress (2018). If not provided by the sources, TRLs are estimated based on technological descriptions and information provided.

6.3.2 Breakthrough technologies in EU low-carbon pulp and paper production

Use of Deep Eutectic Solvents (DES) in pulping
Deep Eutectic Solvents (DES) are a class of plant-based solvents that can be used to fractionate biomass into its constituent parts - lignin, hemicellulose and cellulose - to be further processed. Using DES in pulping means that the process can take place at atmospheric pressure and low temperatures. The technology is therefore considered to be more energy efficient than its chemical and mechanical counterparts, producing fewer emissions and residues while maintaining the production of high-quality cellulose fibres. Using DES can add value for producers who sell pure lignin as fuel or as a raw material.

It is predicted that the cross-sectoral application of DES pulping technology could reduce carbon emissions by 20% between 2011 and 2050, and administer energy savings of 40% over the same period. Further savings in transport costs and emissions could be delivered through the use of annual crops. Compared to conventional chemical pulping methods, application of DES also has the potential to reduce investment costs by 50%.

Since publication of the CEPI report (2013), research into the development of DES for pulping has taken place under the industry-led PROVIDES project, co-funded by H2020 and the project's 18 industrial partners. The current TRL of DES is around 5-6, and with project funding coming to an end

[64] CEPI (2013). *The two team project report.* [online] Available at: http://www.cepi.org/publication/two-team-project-report

in 2018, additional financial support is imperative to ensure commercial viability of the technology by 2025-2030[65].

Flash condensing with Steam

Flash condensing with steam enables significant water and hence energy savings (drying) in paper production. These savings are achieved by blasting predominantly dry, high-consistency fibres with agitated steam into a forming zone where the combination of condensation and steam expansion enables bonding to create paper sheets. As the volume of water used in the production is very low, this also means that less additional heat is required to dry the paper in subsequent processes.

Application of this method throughout the sector is expected to reduce carbon emissions by 50% between 2011 and 2050, and enable 20% primary energy savings over the same period. This method is also expected to cut operating costs due to reduced need for water and energy, and by using smaller production units that cost less as regards capacity.

While this method of production is completely novel, the concept is expected to fit nicely with existing technology; and industry can draw on research and practices from other sectors on high temperature refining. However, the TRL remains particularly low (estimated 1-3) due to further research required in: 'the fluidising of fibres in water vapour', 'the process to achieve inter-fibre bond formation during condensing/drying' and, 'cleaning steps required in the dry recycling process' (CEPI, 2013: p.19). The Two Team Project Report estimated a minimum of 10 years (ref 2013) before the technology could be available at industry level. Given negligible progress in recent years, this technology is unlikely to be commercially available before 2025[66].

Use of steam in paper drying process

Replacing air with pure steam in the paper drying process allows for improvements in energy efficiency as the full power of steam enables total recovery of thermal energy, which can be used in subsequent processes. As such, the use of superheated steam is also extended to papermaking, where steam and heat-boosted forming and pressing take place within an air-free paper machine.

Full application of the technology would reduce the sector's energy consumption by 25%, with largest savings in the drying process. By 2050, this could reduce CO_2 emissions by 50% compared to 2011. At mill level, full application could reduce overall costs by at least 30%. Further cost reductions may arise due to reduced paper weight, reduced water handling and treatment costs. CAPEX would also diminish as forming and drying sections would be shorter, and faster production speeds would increase machine output. Further savings could be achieved in raw materials and energy, as sheet stratification would present opportunities for recycling.

The TRL for superheated steam drying is estimated to be 1-3, and the technology has not shown significant progress in recent years[67].

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[65] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695
[66] Ibid
[67] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695

Dry-pulp for cure-formed paper
This innovation is based on two technologies that enable waterless paper production: 1) DryPulp and 2) cure-forming. DryPulp is where a high concentration of fibres treated with a bio-based protective layer and suspended in a viscous solution are pressed during cure-forming to remove the viscous solution, forming a thin sheet.

It is estimated that under this technology the industry can gain from a reduction in energy demand of 25%, and a 55% reduction in CO_2 emissions between 2011-2050. Lower energy demand would reduce operating costs for the entire manufacturing chain and due to simplification of the process, losses would also be minimised. CAPEX would be 20 times less due to smaller production units.

This concept is based on new production processes and even though the technology is founded on existing knowledge, fundamental R&D is still needed to advance the innovation further. The TRL is therefore estimated to be 1-2.

Supercritical CO_2
Substitution of steam-heated cylinders with supercritical CO_2 ($scCO_2$) in the "extraction drying" process in addition to the decontamination properties of $scCO_2$- removing contaminants, adhesives and mineral oils in the recycling process) - could theoretically reduce CO_2 emissions by 45% and enable 20% energy savings in the pulp and paper industry between 2011-2050.

The TRL of scCO2 is around 1-3. Recently, the process has been discarded in drying application for being economically non-viable on a commercial scale. The technological and economic feasibility of using scCO2 to remove contaminants as a stand-alone technology has not been assessed.

100% electricity for papermaking
This concept is based on 1) the use of electricity-based, energy efficient technologies in place of fossil fuel-based alternatives and 2) developing capacity to store cheap surplus energy from the grid that has been generated by intermittent renewable sources. In practice, a switch to 100% electricity for the paper industry would require implementation of electric/hybrid boilers in place of gas-fired boilers and, eventually, various electro-thermal technologies in the drying processes.

If by 2050, 100% of electricity is generated carbon-free, papermaking could be expected to decarbonise within the same period. This concept has high CAPEX - for investments in new machines and because it is expensive to replace existing machinery. However, energy-savings could reduce OPEX by 8%.

Technologies based on electrification are generally advanced, however no data on the specific TRL for electricity-based papermaking is available because the innovation is co-dependent on the development and implementation of various other technologies[68].

[68] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695

Black Liquor Gasification (BLG)
Recovery and gasification of black liquor, a by-product from the conversion of wood into pulp, can be used to generate energy or as a feedstock in the synthesis of liquid fuels and chemicals. Gasification of black liquor is expected to improve mill efficiency and be a key technology in the decarbonisation of the sector. For commercialisation of the two designs currently under development (TRL 8 for the low temperature steam reforming and TRL 7 for the high temperature entrained flow reactor), significant R&D will be needed in the coming 5 years[69].

Lignin extraction
Extraction of lignin from wood pulp can enable its use as a petroleum substitute in new industrial products, or as biofuels in boilers of limekilns. TRLs of technologies for lignin extraction range from 5-8. But to provide economically feasible solutions to fossil-based alternatives at an industrial scale, focus in the coming years needs to be on up-scaling technologies[70].

6.3.3 Current state of play

A summary of the estimated TRLs of the mapped technologies is available in the figure below (Figure 63). The estimated CO_2 mitigation potentials are also illustrated in Figure 64. The energy demand of all mapped technologies is expected to be lower than that under conventional production methods (Figure 65).

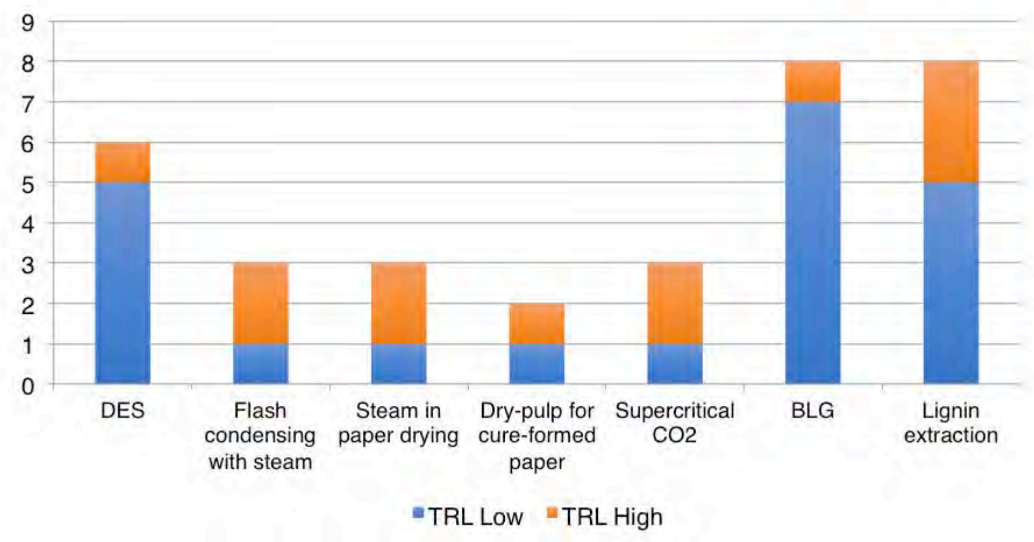

Figure 63: Estimated TRL ranges for select breakthrough technologies in pulp and paper (Source: IES, 2018)

[69] IEA (2018). *Tracking Clean Energy Progress*. [online] Available at: http://www.iea.org/tcep/
[70] Ibid

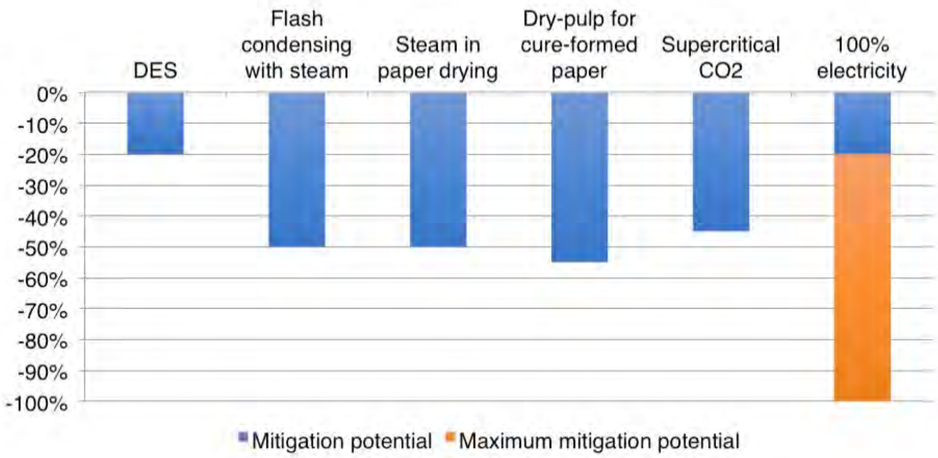

Figure 64: Estimated CO_2 mitigation potential for low-CO_2 pulp and paper production technologies. (Source: IES, 2018)

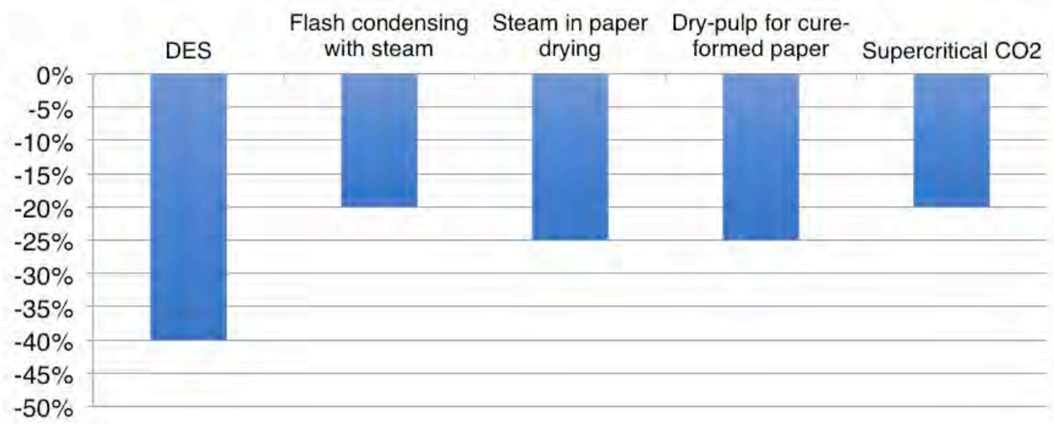

Figure 65: Estimated energy demand for low-CO_2 pulp and paper production technologies (Source: IES, 2018)

6.4 CURRENT DEVELOPMENTS IN EU LOW-CO_2 CERAMICS PRODUCTION TECHNOLOGIES

6.4.1 Introduction

The on-going low-CO_2 technological development in the ceramics industry is divided into three paths: new kiln design, energy alternatives and heat recovery, and end-of-pipe processes[71].

New kiln design

This path includes: electric kilns, hybrid kilns and radically improved architecture for kiln efficiency gains. Electrification of kilns and substitution of natural gas as fuel for low-CO_2 electricity has the largest CO_2 mitigation potential of all the low-CO_2 options - up to 80% depending on the status of overall electricity decarbonisation. Hybrid kilns are expected to reduce fuel consumption by 35% and also reduce emissions with a simultaneous electricity grid decarbonisation. Practically, implementation of these two technologies will depend on electricity prices or the practicalities of on-site CHP, in the case of hybrid options. Electric kiln technology is expected to have a TRL of 6-8, while that of hybrid kiln technology is estimated to be slightly lower at TRL 1-4 (estimation based on the hybrid-ring tunnel kiln with flue-gas-based combined heating system).

Radically modified kiln design for energy efficiency improvements is another route to CO_2 abatement. The Dream project (Design for Resource and Energy efficiency in CerAMic kilns, under H2020/SPIRE), for example, is exploring the benefits of kiln restructure by combining improvements in hardware furnace components and hardware-software kiln parts. The project (TRL 4-6) estimates that these changes could reduce energy consumption by 20%.

Energy alternatives and heat recovery

CHP systems concurrently produce electricity and thermal energy in an integrated system. Heat that would have otherwise have been lost can be used to supply demand directly. Energy efficiency in ceramic production can be achieved through the restructuring of ceramic industrial furnaces - by including new modules or sub-systems such as a CHP unit in the existing furnace architecture. CHP technology has been applied to recover waste heat from the cooling stage of ceramic tile production by channelling hot air from the drying stage to be used in the cogeneration system via a heat exchanger placed in the kiln cooling zone (Delpech, Axcell and Jouhara, 2017). Integration of CHP can contribute to emission reductions given that valorisation of waste heat reduces energy consumption. There are an estimated 250 CHP ceramic plants in operation in EU member states (Italy, Spain and Portugal), giving the technology an estimated TRL of 7-9.

Application of heat pumps in the production of ceramics enables waste heat recovery and therefore improves efficiency. In the brick industry, the project DryFiciency (under H2020/SPIRE) is currently developing a closed-loop heat pump for air-drying processes, with the plan to demonstrate at industrial sites (including at a German brickwork organisation)[72]. The expected performance targets

[71] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695

[72] DryFiciency (2018). *Key performance targets*. [online] Available at: http://dry-f.eu/About/Key-performance-targets

of this project are potential CO_2 emission reductions between 57-73%, energy savings of 60-80%, and production cost reductions of up to 20%/Kg.

Biomass can act as an alternative feedstock to fossil-based inputs in the ceramics sector, facilitated by the application of an on-site biomass gasifier technology for conversion of biomass into fuel. It is reported that biomass gasification (TRL 5-6) could reduce emissions by 29% in the Heavy Clays subsector at a cost of (CAPEX) EUR 17 Mn per site[73]. The UK ceramics roadmap highlights biomass gasification for its decarbonisation potential[74], and alternative feedstock and biofuels are considered areas of interest in European research and innovation trends.

End-of-pipe procedures

While carbon capture might be practically more challenging in the ceramics sector than in other energy intensive industries (because of the sector's high percentage of SMEs)[75], the technology is still a possible option in EU ceramics production if the production site is part of a larger industrial cluster. The TRL of CCS for ceramic manufacturing is currently estimated at 5-6, and 3-6 for CCU[76].

It is estimated that CCS technology in kiln exhausts could reduce CO_2 emissions in the Heavy Clays subsector by 50%[77] at a CAPEX of EUR 11.3 Mn per site[78]. The EU funded LIFE Zef-tile (zero emissions firing) project (under the Life+ program) estimates 90% capture of CO_2 from flue gases, and 10% reduced energy consumption (for CCU)[79].

Potential economic advantages of CCU include OPEX gains from end-of-pipe procedures that lower fuel consumption, higher productivity, and greater ease to treat exhaust gases (e.g. CO_2, NO_2 and particulate matters)[80].

6.4.2 Current state of play

An overview of the estimated TRLs (Figure 66) and CO_2 emission mitigation potential (Figure 67) for low-CO_2 ceramic production technologies are presented below.

[73] Department for Energy and Climate Change and the Department for Business, Energy and Skills (2015b).
[74] Department for Energy and Climate Change and the Department for Business, Energy and Skills (2015a).
[75] Cerame-Unie (2012), p. 14
[76] Department for Business, Energy and Industrial Strategy (UK) (2017), p. 20
[77] Ibid., p64
[78] Ibid., 70
[79] Ceramica Alta (2018)
[80] Ibid

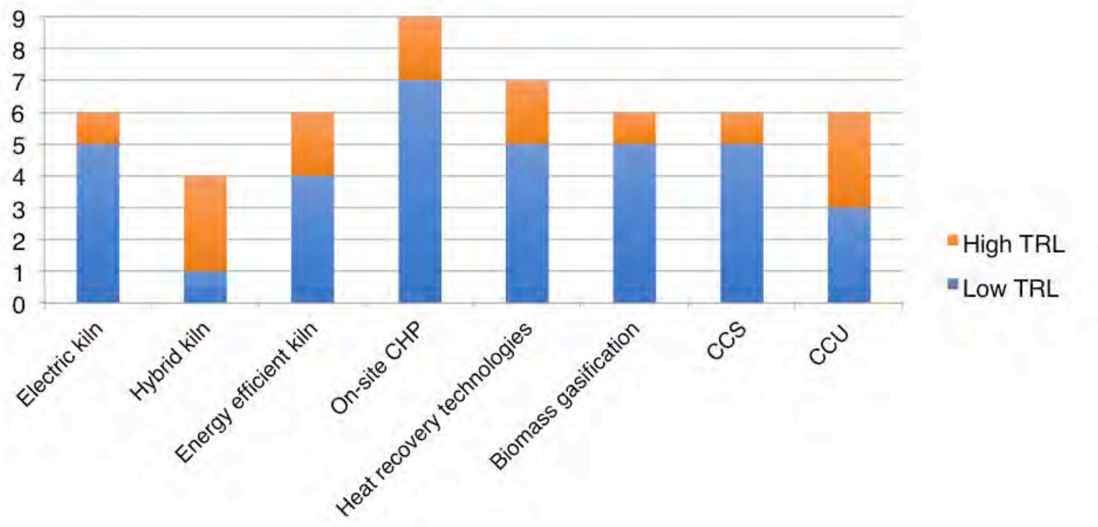

Figure 66: Estimated TRLs for low-CO_2 ceramic production technologies. (Source: IES, 2018)

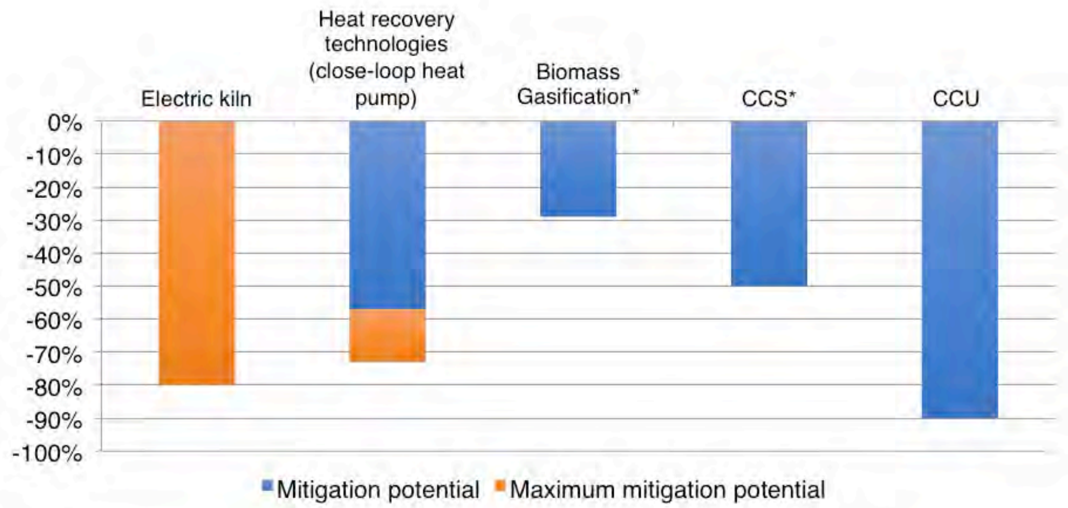

Figure 67: Estimated CO_2 mitigation potential for low-CO_2 ceramic production technologies. (*in the Heavy Clays subsector only). (Source: IES, 2018)

6.4.3 Implications of findings

The analysis shows that there are indeed some promising technologies on the horizon for decarbonisation of the ceramics industry, in particular, the on-site CHP which has been implemented in several EU member states. Other technologies that offer significant CO_2 reduction potential (e.g. CCS/CCU) require more R&D. In the case of electrification, renewable electricity would need to be available at a competitive price.

Development and deployment of (high CAPEX) breakthrough technologies can be a challenge due to the high percentage of SMEs in the ceramics industry. Financially, it may be less feasible for small companies to invest in large-scale R&D or new machines. Government/EU-led initiatives could help overcome some of the challenges that smaller organisations face in advancing low-CO_2 technology innovation[81].

6.5 CARBON CAPTURE AND STORAGE (CCS) TECHNOLOGIES

CCS is an end-of-pipe emission abatement technology. The technology is currently not available at large scale in the EU, with only a few on-going projects. One of the main CCS projects is being developed in the Rotterdam harbour area[82]. Another one is a pilot project called LEILAC (Low Emissions Intensity Lime & Cement), hosted by Heidelberg Cement at Lixhe in Belgium[83].

For CCS to become operational, significant infrastructure must be in place, which comes with high cost barriers. Most processes entail transportation of the captured CO_2 (for storage or for usage), ideally through pipelines or shipping, which in turn requires purification and compression/liquefaction of the CO_2 prior to transportation. However, for some processes, the captured CO_2 could be directly utilised on-site, as is already common practice, for example in production of urea from ammonia[84]. Application of CCS technology (in Flanders and elsewhere) should therefore ideally be prioritized at large-scale plants (which limits its application to large-scale industrial sites or industrial clusters) and with access to pipelines or shipping infrastructure. In Flanders, CCS is therefore expected to be relevant mainly for the chemical industry and the steel industry.

Some of the technologies previously discussed in this report can be successfully combined with CCS and, in particular, production processes that generate highly concentrated CO_2 streams. The typical CO_2 concentration in source gases from the EU steel industry is around 14-27%, which is comparable with the cement industry's figure of 13-33% CO_2 concentration[85]. One low-CO_2 steelmaking production technology with particularly high and pure CO_2 concentration at the end of the process is the HIsarna technology, which makes it suitable for application in combination with CCS. The emission abatement potential of HIsarna steelmaking increases from around 20% to around 80% if combined with CCS. For successful implementation, the previously mentioned cost barriers to CCS must be overcome.

For the chemical industry, CCS can be successfully combined with ammonia production, due to the high availability (around 23 Mt in the EU) and highly concentrated CO_2 stream generated through the process (close to 100% CO_2 concentration in source gas)[86]. Also, source gas from ethylene production has very high CO_2 concentration and is suitable for CCS. Notably, the Dechema report (2017) assesses that under such advanced technology deployment, the chemical industry in particular will have a large demand of CO_2 as feedstock, and is therefore more likely to evolve as a net importer of CO_2.

[81] Institute for European Studies (VUB-IES) (2018). *Breaking Through – Industrial low-CO2 technologies on the horizon*. [online] Available at: https://www.ies.be/node/4695
[82] Wuppertal Insitute (2016).
[83] LEILAC (2018). Low Emissions Intensity Lime & Cement. Available at: https://www.project-leilac.eu/
[84] Ecofys & CEFIC (2013).
[85] Dechema (2017).
[86] Mckinsey & Co & VEMW (2017).

Such development would hence make CCS technology counterproductive[87]. A report by McKinsey (2017) discusses that development of alternative technologies may make CCS less economically beneficial in the future. For example, at low electricity prices, electrification might be more economical than CCS for production of ethylene and ammonia. Meanwhile, the same report expects CCS to play a key role in enabling the industry to reach EU decarbonisation targets for 2050, since it facilitates mitigation of emissions that cannot be reduced by any other means[88].

6.6 RELEVANCE FOR FLANDERS

One of the lessons learnt from the technologies mapped above is that several of the technologies have received significant EU funding for basic research at low-to-medium TRLs. Some of the more advanced breakthroughs have taken time to reach their current TRL. HIsarna, for instance, a project of ULCOS started in 2001, necessitated 15 years to reach the current pilot stage. Also, regional funding plays an integral role in the development of some of the technologies.

In the steel industry, the promising Steelanol and CCU technology in general can play a significant role in Flemish industrial decarbonisation given its high potential to reduce emissions in petrochemicals production (e.g. ethylene, propylene, …). Therefore, a future industrial transition framework for Flanders should explore the potential of integration of industrial value chains. H_2-based steelmaking shows promise for major emission reductions but its commercial viability will largely depend on low-cost (and renewable energy based) H_2 production. It might also not be compatible with existing production of steel in Flanders because the process is a change from the current integrated steel production route.

For the Flemish chemicals industry new low-carbon processes that replace naphtha (for ethylene, propylene, butadiene and BTX) and methane (in ammonia synthesis) are relevant. However, many of the breakthroughs depend (for commercial success) to a large extent on the availability of low-cost low-carbon H_2. The overall electricity demand and the necessary installed capacity (and costs) are likely to rise significantly. Especially considering the synthetic fuel route. When CO_2 is used as a feedstock, additional energy demand will be even higher.

The use of syngas, in particular from steel production (e.g. steelanol technology), for production of basic chemicals looks promising due to the presence of a large integrated steel plant in Ghent and the demonstration of blast furnace gas based ethanol production.

Investing in bio-based chemicals, in particular if bio-based inputs can be used to produce high value chemicals, can be relevant for Flanders. However, there will need to be sufficiently large and stable supply chains of biomass and at an economically viable price.

As shown in section 6.1.6, most of the breakthrough technologies in the areas of H_2 and biomass-based chemicals can, at this moment in time, not compete with existing fossil fuel-based

[87] Dechema (2017).
[88] Mckinsey & Co & VEMW (2017).

technologies. It will require more R&D and optimisation to bring these processes into a competitive area. Furthermore, the main requirements for these alternatives to challenge existing processes will be the availability of cheap, abundant and secure (green) electricity and biomass.

Research in advanced circular economy technologies and techniques, allowing the recovery of basic chemicals and plastics or to allow waste to be converted, will be crucial to make the transition to low-carbon chemicals possible because most of the above mentioned technological options on their own will likely strain electricity generation and biomass supply in Flanders.

For the paper industry, most of the technologies will have an important impact on electricity consumption but can over-all reduce the energy consumption and GHG emissions. The application of these technologies will likely depend on the specific type of paper production plant. The relevance of the Deep Eutectic Solvents (DES) technology for Flanders will probably depend on the type of pulp used by the paper mill. DES is understood as an alternative for chemical pulping, currently not applied in Flanders.

For ceramics there are still options to optimise the heat use in kilns (e.g. CHP). Applying breakthrough technologies can be a challenge for smaller ceramics producers in Flanders due to the high CAPEX of the investments in relation to the turnover of the plants.

7 SCOPE AND DESIGN OPTIONS FOR A FLEMISH INDUSTRIAL TRANSITION FRAMEWORK

7.1 INTRODUCTION

7.1.1 Options to design a low-carbon roadmap/framework

The development of the possible scope and design of a future Flemish industrial low-carbon process transpired through a process with systemic stakeholder input. The goal of this process was to identify preferences and priorities among stakeholders in the following five areas:

- The operational scope and function of a future Flemish industrial low-carbon roadmap/framework
- Other ambitions/goals that can be part of a roadmap/framework next to the contribution to a move to a low-carbon economy
- The sectoral scope of a future roadmap/framework
- The policy scope of a future roadmap/framework
- Future stakeholder engagement in the process of developing a roadmap/framework

7.1.2 Stakeholder consultation process

The stakeholder consultation process on the above mentioned areas started with a general discussion in the 1st advisory group meeting on 14 March 2018.

The main feedback received from this stakeholder meeting was:

- That there is a need for the facilitation of low-carbon technologies and investments (e.g. R&D, finance, …).
- The need/relevance of a new, additional Flemish industrial low-carbon roadmap itself was questioned given the existence of EU level roadmaps for numerous industries concerned here, and because investment and innovation decisions are often not taken in Flanders.
- A strong link between future evolutions in the power sector and other sectors and the likely impact (e.g. energy/electricity prices) on energy intensive industries was acknowledged and underscored .
- The relevance of a pure sector by sector based approach was limited given that some sectors in Flanders are represented by only a very limited amount of companies.
- An inclusive and fair approach that takes into account the limited number of large companies/emitters and the larger number of smaller companies/sectors would be needed.

The next step sought to gain specific insight into the scope and design of future Flemish industrial low-carbon roadmap(s) or other processes. An electronic survey for all members of the advisory group was thus conducted. The purpose of this survey was to gain additional but indicative insight into the preferences of the stakeholders the 5 above mentioned areas. The result of the survey and first conclusions were presented and discussed at the second advisory group meeting, held on 18 April 2018.

The questions in the survey do indeed leave a lot of room for interpretation. **The results of the survey can therefore not be seen as the conclusion of the advisory committee and were used as a first step and guidance for further discussions.** The survey result are presented in section 7.2. General conclusions from this survey and next steps in the process are presented in section 7.3.

Subsequent stakeholder meetings took place on 16th May and 21st June 2018. During these meetings three additional essential views of industry stakeholders were discussed:

- The need to further clarify the added value of a new additional Flemish industrial low-carbon framework complementary to the EU-ETS regulation and existing sectoral European roadmaps.
- The need for more articulation on the role of the Flemish government in this process as to avoid causing fragmentation of industrial policy or duplication with the European framework.
- The need for unambiguity on the outcome/purpose and binding nature of such an exercise with a 2050 perspective, while keeping the international economic context in mind.

In September and October 2018 these elements were further developed by an ad hoc working group consisting of a selection of members of the advisory committee. The results of this work are presented in chapter 8 (Construction of a Flemish industrial transition framework) of this report. This approach (chapter 8) was approved by the advisory committee on 24 October 2018.

7.2 STAKEHOLDER SURVEY QUESTIONS AND ANSWERS

7.2.1 Introduction to survey process

The questions formulated in this survey were based on the feedback gathered during the first advisory group and informed by the profiling of Flemish industry (Chapter 3). Each of these questions contained multiple options for which stakeholders could express relative preference. The following questions were presented to the advisory group stakeholders:

- What will be the operational scope and function of the low-carbon industrial roadmaps?
- What can be the additional goals of a possible industrial transition roadmap?
- What can be the sectoral scope of the roadmaps?
- What can be the policy scope of the roadmaps?
- How can stakeholders be involved in the development process (of the roadmap(s))?

For each question/statement, the stakeholders consulted could choose between the following answers:

1. Fully disagree (-2)
2. Partially disagree (-1)
3. Neither agree nor disagree (0)

4. Partially agree (+1)
5. Fully agree (+2)

Each answer carried a weight (as shown in brackets above). The answers to the survey were then aggregated by giving by calculating the average weight of all answers. Stakeholders could further express themselves more elaborately through a comments section provided in each survey question.

The survey was sent to all members of the advisory group on Friday 30th March 2018 with request to send in answers by Friday 13th April 2018. In total 14 answers were received:

- 7 from sector federations representing industrial sectors
- 3 from other sectoral/technology federations
- 2 from the governmental sector
- 1 from a harbour authority
- 1 from an environmental non-governmental organisation

7.2.2 "What will be the operational scope and function of the industrial low-carbon roadmap(s)?"

The survey's answers showed that there no need for a classical roadmap with singular focus on (scenarios for) a low-carbon industry. Also, the need for additional Flemish low-carbon roadmaps (in general) gathered little support. However, there was a more favourable attitude towards an industrial transition plan that took into consideration a wide range of elements that are of importance to industrial sectors, beyond simply the mitigation of GHG emissions.

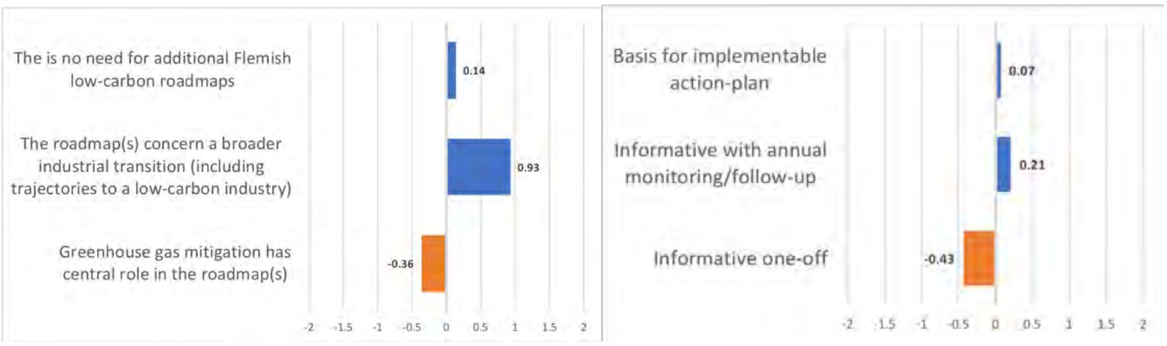

Figure 68: Survey results for - *"What will be the operational scope and function of the industrial low-carbon roadmap(s)?"*

At the time, there was no pronounced opinion on the exact function of a possible roadmap. It was however clear that a document on the lines of a purely one-off informative study had the least interest. There was a visibly more favourable view towards a process with regular follow-ups and monitoring.

7.2.3 "What can be the additional goals of a possible industrial transition roadmap?"

Covering a broader industrial transition (including trajectories to a low-carbon industry) emerged, as mentioned above, the preferred option with regard to the operational scope of a future roadmap. The survey also queried about other elements that could be considered in such a broader transition.

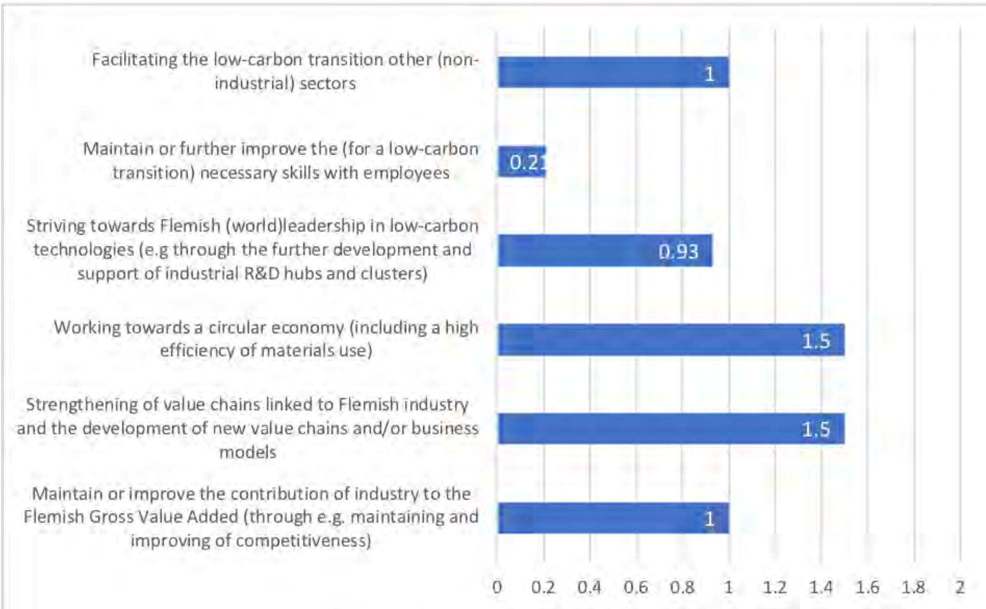

Figure 69: Survey results for – *"What can be the additional goals of a possible industrial transition roadmap?"*

The answers displayed a preference for including the transition towards a circular economy and strengthening value chains linked to Flemish industry. Goals to maintaining or improving the industry's GVA contribution to the Flemish economy (competitiveness), facilitating the low-carbon transition in other sectors and Flemish R&D leadership in low-carbon technologies received forthright support. Employee-led workforce skills development, necessary for a low-carbon transition, got lesser support. Via the comments section, stakeholders clarified that they considered optimising skills to be a general concern and not one specifically related to the transition to a low-carbon industry.

7.2.4 "What can be the sectoral scope of the roadmap(s)?"

With regard to the possible scope of a Flemish industrial low-carbon roadmap/framework, multiple (non-mutually exclusive) options were presented. From the preferences expressed, little to no interest in the development of Flemish (industrial) sector specific low-carbon roadmaps was visible. Instead, an approach that assesses the transition on the basis of industrial clusters (e.g. harbour industrial areas or industrial concentration zones) seemed to be preferred. There was greater interest in a roadmap that maximised synergies (i.e. through value chains, industrial symbiosis and between industry and non-industrial sectors). Also, the possibility of linking the Flemish industrial low-carbon transition (for some sectors) with those in neighbouring countries was positively considered for inclusion in the scope.

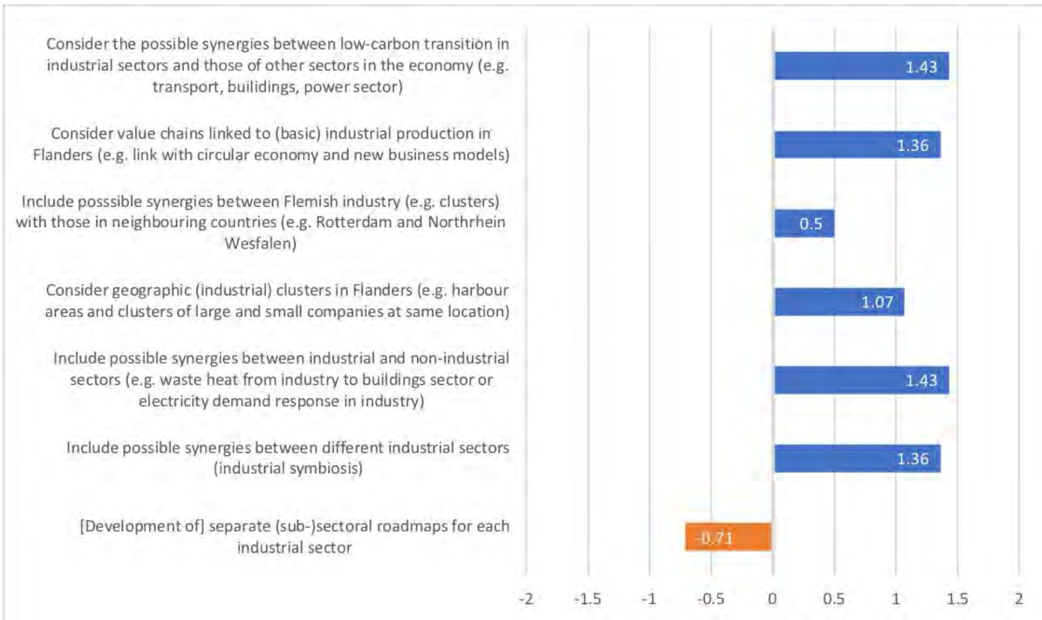

Figure 70: Survey results for – "What can be the sectoral scope of the roadmap(s)?"

7.2.5 "What can be the policy scope of the roadmap(s)"

Vis-à-vis policy areas or activities deemed relevant for consideration in a future roadmap there was large interest in (the development of) a 'mission oriented' policy framework that supports both the R&D and deployment of low-carbon breakthrough technologies in Flanders. The survey's results showed broad interest in a roadmap that identified current and future regulatory (or other) barriers (e.g. electricity prices) for a low-carbon industrial transition and the optimisation of the coherence of policy instruments. Finally, facilitating access to capital for investment in low-carbon technologies and the identification of related opportunities in EU funds were deemed important. There was, at the time of the survey, little interest in new longer-term policy instruments.

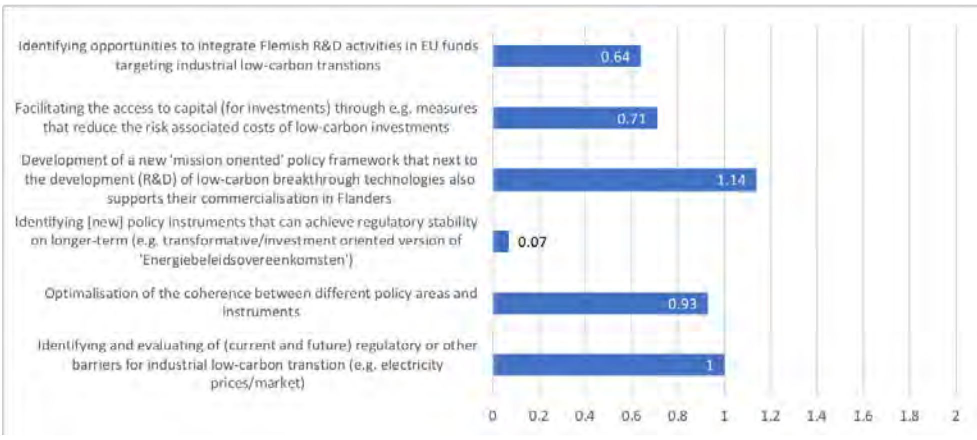

Figure 71: Survey results for – "What can be the policy scope of the roadmap(s)?"

7.2.6 "How can stakeholders be involved in the development of the roadmap(s)"

The survey showed interest in the construction of a future Flemish industrial low-carbon roadmap through a so-called co-creation process consisting of relevant stakeholders and the government. However, some stakeholders expressed the need for more clarity with regard to the overall future process before they could provide a more affirmative answer. The survey underscored no interest amongst stakeholders for sectors to develop their own roadmaps or to participate in a limited consultative role in the creation of a Flemish roadmap/framework.

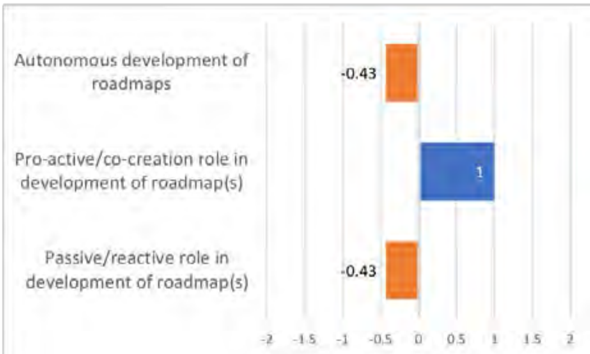

Figure 72: Survey results for –"How can stakeholders be involved in the development of the roadmap(s)"

7.3 A FACILITATING FLEMISH INDUSTRIAL TRANSITION FRAMEWORK TOWARDS A LOW-CARBON ECONOMY

The survey results and discussions with the advisory group indicated no need for a Flemish industrial low-carbon roadmap (or multiple sectoral roadmaps) that focussed on scenarios, technologies and costs of transition to a low-carbon economy. There was however interest in an approach that considered the facilitation of a broader industrial transition. This approach could be defined as a facilitating Flemish industrial transition framework towards a low-carbon economy related to innovation, infrastructure and financing. Based on the feedback received during the stakeholder process, the following elements are to be taken into account when considering such an approach:

- It is important to avoid duplication and fragmentation of industrial policy. Therefore, EU sectoral roadmaps (and forthcoming initiatives) and international influences need to be taken into account.
- The energy transition in Belgium and Flanders can have important impacts on industrial competitiveness and the industrial low-carbon transition and vice versa. Both processes therefore need to be(come) well aligned.
- The transition framework is meant to facilitate (in particular innovation, financing and infrastructure) and should not be seen as an instrument to place additional GHG mitigation targets or trajectories on specific industrial sectors.
- The term 'low-carbon' while commonly used in this context can be confusing. The transition is not meant to reduce the presence of the chemical element 'carbon' in products or processes and shall not prevent the utilisation of CO_2 in industrial processes.

The Flemish industrial framework can look at (existing) industrial clusters, value chains and possible synergies between companies, industrial and non-industrial sectors.

In accordance with stakeholder feedback, a transition framework should focus on constructing an enabling or facilitating environment through innovation, financing and infrastructure and foster synergies and symbiosis between companies, sectors, regions and policies. This could include enabling (removal of policy hurdles) higher levels of circularity along the value chains of basic industries and the alignment of the industrial and ongoing energy transitions.

Furthermore, the detailed design of the framework will require meeting certain standards to avoid burdening stakeholders, eschew duplication of work in other processes and towards a meaningful output. The basic framework conditions will need to address the following fundamental questions put forth by industrial stakeholders:

- Clarification of the need for/added value of a new Flemish industrial low-carbon framework complementary to the EU-ETS regulation and existing sectoral European roadmaps.
- Clarification on the role of the Flemish government in this process in order to avoid causing fragmentation of industrial policy or duplication with the European framework.
- Clarification on the outcome/purpose and binding nature of such an exercise with a 2050 perspective and the international economic context in mind.

With regards to the process and design of a Flemish industrial framework towards a low-carbon economy the following elements will need to specified in close consultation with industrial stakeholders:

- The expected outputs of the transition framework
- The process towards constructing such framework
- The framework conditions and the engagements of the public sector and industrial sectors during and after the process towards developing an industrial framework

Finally, developing such transition framework will require the support of multiple stakeholders (e.g. industrial companies, sectors, specialised scientific institutions, innovation actors in Flanders, unions, environmental NGO's, the financial sector, technology providers, industrial suppliers, customers, energy suppliers and network operators and governmental administrations competent in these areas). Ideally, the overall governance of such a process happens through a constructive dialogue system between the public sector and the industrial sectors.

8 CONSTRUCTION OF FLEMISH INDUSTRIAL TRANSITION FRAMEWORK / OPBOUW VLAAMS INDUSTRIEEL TRANSITIEKADER NAAR EEN LAGEKOOLSTOFECONOMIE

8.1 ENGLISH VERSION

Important note: The English version is a translation of the original in Dutch (see Section 8.2) for informational purposes only. In case of a discrepancy, the Dutch original will prevail.

8.1.1 The need for a Flemish industrial transition framework

The Paris climate agreement and accompanying ambitious EU greenhouse gas reduction targets (-80 to -95% by 2050 compared to 1990) imply that Flemish industry faces enormous challenges.

The latest review of the European Emissions Trading Scheme (EU ETS) tightened the emission space, and in the run up to 2030, the price of emission rights can be expected to further increase systematically. This means that the challenges will become increasingly acute for Flemish ETS companies. Despite the measures taken to protect industry from the risk of carbon and investment leakage, a higher CO_2 price may constitute an economic risk, particularly in the absence of analogous policies in regions outside Europe. **It is therefore important that the Flemish industry prepares for this transition with a 2050 perspective and focuses on innovation, to remain competitive even and especially, during the transition.**

The way in which the Flemish government responds to these challenges can have a positive impact on the competitiveness of Flemish companies. Innovation processes can accelerate the development of technologies, know-how and infrastructure. This can provide industry with an additional competitive edge and greater economic opportunities, including the exports of those technologies to other countries**. The Flemish government must respond in the most optimum way by developing a specific framework that guarantees the competitiveness of Flemish companies.** This can provide Flanders with a competitive advantage as destination for future investments as well as guaranteeing and protecting the competitiveness of existing investments.

Flanders **cultivates excellent knowledge of low-carbon technologies** (via knowledge institutions and the business sector) and the current research and innovation policy already supports the transition to a low-carbon economy (via for example the spearhead clusters) for which different and more performing technologies will be required. This means that there are already many progressive projects ongoing amongst Flemish industry. The challenges for the Flemish energy-intensive industry are great and there is a need for additional innovation and technological breakthroughs, especially considering the long investment cycles of these energy-intensive industries. It is therefore **necessary to not only foster existing knowledge and experience, but to further develop, focus, expand and**

accelerate where necessary. A facilitating transition framework, elaborated in cooperation with the actors involved, can contribute by assisting industry in innovation and research.

At the European level, a significant amount of resources (and processes) will be available as of 2020 to help advance industrial low-carbon innovation. Particular attention will be paid to financing industrial low-carbon demonstration projects (for example via the EU ETS innovation fund). Furthermore, European innovation policy (Horizon Europe) will focus on major socio-economic challenges such as the transition to a low-carbon economy. European industrial sector federations (e.g. CEFIC and EUROFER) have already anticipated this by developing their own master plans. It will be important for Flanders to prepare for these opportunities. **Countries and regions that proactively develop a vision, strategic innovation excellence, and provide the necessary co-financing will be more likely to acquire European funding.**

As a result of continued devotion on energy and raw materials efficiency, significant technological progress has been made in the development of industrial processes with (much) lower greenhouse gas emissions (see chapter 6). In order to make further progress, breakthrough technologies will be needed. R&D and demonstration projects will be essential to get these technologies market-ready. Various sectoral European roadmaps have already detected and extensively studied the most promising technologies (see Chapter 5). These roadmaps provide important input for the transition framework.

Many of the technologies highlighted by European roadmaps identified in this study are not yet commercially available and / or economically viable. Technologies that are already in an advanced stage of development and have the potential of scalability will have to be identified. Developing demonstration and pilot projects in Flanders, that match with these findings, is necessary to realize a roll-out on a larger scale. **It is then essential to ascertain within Flanders, where opportunities exist to develop such demonstration projects and to determinate the appropriate funding channels. Next, it should be examined how these projects can be scaled up, which barriers hamper the initiation of the projects and further roll-out, and which kind of support is needed.**

Circular economy and the energy transition play an important role in this transition. The industry already actively contributes by developing more efficient processes, and by providing products and services to other consumers within society, that lead to more circular applications and a reduction in emissions. A smart carbon policy, that goes beyond sectoral boundaries, should be considered carefully. Therefore, further optimization of material and energy flows is necessary. For Flanders, this can result in identification of possible modifications of legislation (and if needed at European level) and **synergies between companies and even with *hors* industry sectors are possible**.

The Flemish industrial transition framework must - without being too rigid and within the specific context of the Flemish industry - identify which high-level breakthrough technologies and solutions can be relevant or economically applicable. Once it is clear which technologies will or can play an important role within Flanders, it **will be possible to examine the opportunities (for example in terms of circular economy and GHG reduction potential) and the innovation, infrastructure and investment requirements**. Flemish policy can then respond to stimulate and support the transition.

The **goal of a transition framework** is to create a facilitating framework for the industry to enable a low-carbon industrial transition. The framework will therefore have to gather information that can be useful to remove barriers and to facilitate synergies. On the other hand, it is important that know-how and experience with innovative technologies can be used efficiently in order to become a driving force in the innovation landscape. Finally, a competitive framework is needed to attract more investments in Flanders to achieve a win-win between climate ambitions and prosperity.

Given the scale of the transition, broader public interest and the large number of parties involved, it is important that the preparation **for this transition is executed in a coherent manner, supported by the government, the business community and other relevant stakeholders**. After all, this is a long-term transition that involves a high level of uncertainty and risk (on a technological and economic level). The transition framework must make it clear to the parties involved what their role and commitment can be. The whole process must therefore be transparent and, in addition, adjustments during the process must be possible.

8.1.2 Context of the Flemish industrial transition framework

The Flemish industrial transition framework concurs to the opportunities and challenges identified for the Flemish industry in "Vision 2050. A long-term strategy for Flanders."

Moreover, it forms the first interpretation of action 5.2.2 'Transition framework for the transition to a low-carbon economy' from the preliminary draft Flemish Climate Policy Plan 2021-2030 that was approved by the Flemish Government on 20 July 2018. This plan establishes the blueprint for a climate policy in the period 2021-2030 in the Flemish Region and, together with the Flemish Energy Policy Plan 2021-2030, forms the Flemish input to the design of the Belgian integrated energy and climate plan.

In this action of the preliminary draft climate policy plan the following was included:

"Industry plays an important role in the climate and energy transition. New technologies, products, raw materials and production processes will be needed in the coming decades. The business community, the research community and the government can strengthen each other in this. That is why, together with industry and research institutes, it is being investigated whether and how a transition framework for low-carbon technologies can be drawn up, in addition to the roadmaps that have already been drawn up by the spearhead clusters and IBNs. In this transition framework, it is possible to map out the greatest opportunities for Flemish research institutes to participate in the necessary system innovations to enable the climate and energy transition. In doing so, it can be investigated which supporting flanking policy is needed in terms of innovation, financing and infrastructure in order to mobilize effective investments in climate innovation."

The Flemish transition framework can also contribute to the interpretation of articles 4 and 14 of the Regulation on the Energy Union and Climate Action that require the formulation of a long-term strategy.

8.1.3 A multidisciplinary approach to tackle the research questions

In the development of a Flemish transition framework, there will be a clear need for technological, business, economic and policy-based knowledge and support. In addition, a wide range of topics will have to be explored, each assuming specific knowledge and experience (e.g. low-carbon technologies for different sectors, circular economy / material flows, energy systems, impact, barriers, ...). Therefore, it will be required to have important points of contact between competencies from different scientific disciplines and knowledge institutions and initiatives (for example the spearhead clusters) with the research questions.

Presumably, such knowledge is not present in a single institution, and this multidisciplinary approach will therefore probably require collaboration between various Flemish research institutions, public actors and other relevant economic actors (sector federations, companies, ...). Ideally, there will be a focused collaboration that brings together state-of-the-art knowledge about most of the above-mentioned domains. It must be kept in mind that there are many multi-national companies in Flanders, where knowledge about innovation is concentrated in the headquarters which are not necessarily located in Flanders. A first step in the drafting of the transition framework can be to detect sectors in which Flanders has a key position in innovation.

This approach could provide added-value for Flanders to develop further know-how and information about low-carbon technologies at industry and knowledge centers.

8.1.4 Research questions for the development of a Flemish industrial transition framework

The starting point in the creation of an industrial transition framework will be the existing knowledge in Flanders (and outside Flanders) and the current economic landscape in Flanders; and will therefore rely on input from:

- Flemish sector federations and employers organisations and their spearhead clusters
- Relevant innovative industrial networks
- Flemish research institutions and their relevant research activities
- Relevant governmental institutions (including port boards)
- Companies (insofar as information is available and can be shared)
- Roadmaps and studies that have already been carried out (e.g. at European level)
- Other relevant social stakeholders (NGOs, trade unions, etc.)

It is important to note that all these actors have to be involved in a useful way. Who, when and how this should be done will be examined later.

In consultation with the relevant stakeholders, the transition framework must find a way to address the following research questions:

- How can existing knowledge and experience be further focused, possibly expanded and shared?
- How can the development and dissemination of this knowledge be accelerated?

- How can a transition framework strengthen the learning process at policy level?
- What barriers and requirements exist for the industry to realize the transition to a low-carbon economy? This can include barriers and preconditions regarding R&D, financing, the regulatory framework, necessary competences and skills, infrastructure and energy and material costs, and competitiveness.
- Which policy measures can mitigate the above-mentioned barriers and ensure the implementation of the necessary preconditions? These include infrastructure, investment, competitiveness and financing measures for the Flemish government in collaboration with the business community.
- How can levers be generated for additional funding of industrial low-carbon pilot / demonstration projects and infrastructure, in particular through new EU funds (e.g. the EU ETS innovation fund and Horizon Europe)?
- How can the practical monitoring of the implementation of the transition framework be arranged?

In support of the above-mentioned research questions, insights obtained from a techno-economic analysis of the different types of high-level technologies and their opportunities, **for example in terms of circular economy and greenhouse gas reduction potential, and from a competitiveness analysis** of the investment framework in Europe / Flanders versus other regions can be used as possible inputs. Such analysis will be based on input from companies and economic actors (e.g. sector federations, port regions, etc.) in Flanders (insofar as this information is available and can be shared) and existing information (e.g. scientific literature, European low-carbon roadmaps and relevant research in Flanders), and can include the following questions:

- What are the possible low-carbon technologies that are most suitable for application in Flanders (without being excessively rigid) and their possible opportunities where the estimates (such as impact on CAPEX, OPEX and energy demand) are dependent on preconditions and transparent assumptions of future economic and technological developments in Europe and in the rest of the world?
- What possible options exist for industrial symbiosis (in terms of materials, waste, energy and CO_2 flows)? What impact do they have in terms of opportunities, infrastructure needs and investment costs?
- What possible synergies between industrial companies and sectors outside industry are possible (e.g. energy storage, circular economy, waste re-use, CCU, ...)?
- What opportunities exist for developing demonstration and pilot projects? Which barriers can hamper the start-up of projects and the further roll-out of technologies? What kind of support is needed for this?
- What are the economic requirements - also in the long term - for the above elements, in an international context?
- What infrastructure requirements exist and what impact do they have in terms of opportunities?
- What is the impact of (and the interaction between) the identified options on the broader energy system?

8.1.5 Next Steps

In this study the relevance of a Flemish facilitating transition framework is clarified (in consultation with various stakeholders). The study also identified research questions which should be considered during the development of an industrial transition framework.

No agreement on how the transition framework will be developed, or how the transition framework must deal with these research questions, was reached between the parties involved during this study. The following steps can contribute to furthering this:

- Interdepartmental coordination between the Department of Economy, Science and Innovation (EWI) and the Department of the Environment (Omgeving) about a future approach. The aim is to finalize this alignment through a proposed action plan before the end of 2018.
- Identification of involved actors.
- Finalisation of the plan on how to develop a Flemish industrial transition framework in consultation with the actors involved.

In carrying out the above steps, it will be ensured that:

- Continuation of existing cooperation between various actors involved remains crucial.
- Generic aspects are discussed at the Flemish level to the extent possible to avoid fragmentation and duplication of consultation. Typical local aspects (such as infrastructure and logistics and local bottlenecks / barriers) can be discussed at local level.
- The workload for the companies and the actors involved in dealing with the research questions is kept to a minimum.

8.2 NEDERLANDSTALIGE VERSIE

8.2.1 Waarom een Vlaams industrieel Transitiekader?

Het klimaatakkoord van Parijs, en de hierbij gepaard gaande ambitieuze EU-broeikasgas reductiedoelstellingen (-80 tot -95% 2050 t.o.v. 1990) maken dat ook de industrie in Vlaanderen voor enorme uitdagingen staat.

Onder het Europees systeem van verhandelbare emissierechten (EU ETS) werd de emissieruimte aangescherpt in de laatste EU ETS review. Dit betekent dat de uitdagingen ook voor Vlaamse ETS-bedrijven steeds scherper worden. Er wordt verwacht dat in de periode tot 2030 de prijs van emissierechten systematisch zal stijgen. Ondanks de maatregelen die genomen werden ter bescherming van het risico op carbon leakage, kan de hogere CO_2 prijs een economisch risico vormen, in het bijzonder bij afwezigheid van gelijkwaardig beleid in regio's buiten Europa. Het is dan ook van belang dat de Vlaamse industrie zich voorbereidt op deze transitie en inzet op innovatie om competitief te blijven tijdens de transitie met perspectief 2050.

De manier waarop de Vlaamse overheid hierop inspeelt kan een positieve impact hebben op de competitiviteit van de Vlaamse bedrijven. Innovatieprocessen kunnen de ontwikkeling van technologieën, knowhow en infrastructuur versnellen, hetgeen voor deze bedrijven een bijkomend competitief voordeel en bijkomende economische opportuniteiten kan opleveren, inclusief export van deze technologieën naar andere landen. De Vlaamse overheid moet hier optimaal op inspelen door een concreet kader uit te werken om de competitiviteit van de Vlaamse bedrijven te garanderen. Dit kan Vlaanderen een concurrentieel voordeel opleveren voor de locatiekeuze van toekomstige investeringsbeslissingen alsook het behoud van de competitiviteit van bestaande investeringen garanderen.

Vlaanderen beschikt over uitstekende kennis inzake low carbon technologieën (via kennisinstellingen en het bedrijfsleven) en het huidige onderzoeks-en innovatiebeleid ondersteunt ook reeds de transitie naar een koolstofarme economie (via bv. de speerpuntclusters) waarvoor er andere en meer performante technologieën vereist zullen zijn. Dit maakt dat er reeds tal van vooruitstrevende projecten in Vlaanderen plaatsvinden in de Vlaamse industrie. De uitdagingen voor de energie-intensieve industrie zijn groot en er is de nood aan bijkomende innovatie en doorbraken, ook rekening houdend met de lange investeringscycli binnen de energie-intensieve industrie. Het is daarom noodzakelijk om bestaande kennis en ervaring niet alleen te bestendigen, maar nog verder te ontplooien, te focussen, en verder uit te breiden en te versnellen waar nodig. Een faciliterend transitiekader dat de industrie bijstaat onder andere in innovatie en onderzoek, en uitgewerkt in samenwerking met de betrokken actoren, kan daartoe bijdragen.

Op Europees niveau zal er vanaf 2020 een aanzienlijke hoeveelheid middelen (en processen) ter beschikking komen om deze industriële innovatie vooruit te helpen. Veel aandacht zal gaan naar het financieren van industriële low-carbon demonstratieprojecten (bijvoorbeeld via het EU ETS innovatiefonds[89]). Voorts zal het Europees innovatiebeleid (Horizon Europe) zich toespitsen op grote socio-economische uitdagingen zoals de transitie naar een low-carbon economy. Europese industriële sectorfederaties (e.g. CEFIC en EUROFER) anticiperen hierop door de ontwikkeling van eigen masterplannen. Voor Vlaanderen zal het belangrijk zijn zich voor te bereiden op deze opportuniteiten. Landen en regio's die proactief een visie en strategische innovatie-excellentie ontwikkelen en de nodige cofinanciering voorzien, zullen een grotere kans hebben om Europese financiering te krijgen.

Dankzij de continue aandacht voor energie- en grondstoffen-efficiëntie is er belangrijke technologische vooruitgang geboekt in het ontwikkelen van industriële processen met een (veel) lagere broeikasgasemissie (zie hoofdstuk 6). Om verdere stappen te kunnen zetten zullen er breakthrough technologieën nodig zijn, O&O en demonstratie om deze technologieën marktrijp te krijgen. De verschillende sectorale Europese roadmaps hebben de meest beloftevolle technologieën reeds uitvoerig bestudeerd en beschreven (zie hoofdstuk 5). Deze roadmaps leveren een belangrijke input voor het transitiekader.

Veel van de technologieën uit de Europese roadmaps, geïdentificeerd in deze studie, zijn nog niet commercieel beschikbaar en/of economisch rendabel. Er zal eerst verder gedetecteerd moeten worden welke technologieën die reeds in een ver gevorderd stadium van ontwikkeling zijn, het potentieel hebben om op grote schaal te ontwikkelen. Demonstratie- en pilootprojecten die op deze bevindingen aansluiten, zijn noodzakelijk om een uitrol op deze grotere schaal te kunnen verwezenlijken. Het is nodig om binnen Vlaanderen na te gaan waar er opportuniteiten zijn om demonstratieprojecten op te starten en welke financieringskanalen hiervoor aangesproken kunnen worden. Daarna dient bekeken te worden hoe die verder opgeschaald kunnen worden, welke barrières de opstart van de projecten en verdere uitrol bemoeilijken en welke ondersteuning hiervoor verder nodig is.

Binnen deze transitie spelen circulaire economie en de energietransitie een belangrijke rol, waaraan de industrie actief bijdraagt door enerzijds zelf in te zetten op efficiëntere processen te ontwikkelen en anderzijds producten en diensten aan te leveren die leiden tot meer circulaire toepassingen en daling van emissies bij andere verbruikers in de maatschappij. Er moet dus aandacht zijn voor een smart carbon beleid dat over de maatschappelijke sectorgrenzen heen gaat. Het verder optimaliseren van materiaalstromen en energiestromen is dan ook noodzakelijk. Voor Vlaanderen kan bekeken waar er aanpassingen aan de wetgeving nodig zijn, zo nodig op Europees niveau en waar synergiën tussen bedrijven onderling en buiten de industrie mogelijk zijn.

Het Vlaams industrieel transitiekader moet – zonder daarin al te rigide te zijn – binnen de specifieke context van de Vlaamse industrie identificeren welke high-level breakthrough technologieën en oplossingen relevant of economisch toepasbaar kunnen zijn. Wanneer duidelijk is welke technologieën binnen Vlaanderen een belangrijk rol zullen/kunnen spelen, kan ook nagegaan worden waar de opportuniteiten (bijvoorbeeld op vlak van circulaire economie en BKG-reductiepotentieel) liggen en welke innovatie-, infrastructuur- en investeringsnoden er zijn. Het Vlaams beleid kan hierop inspelen om zo de transitie te stimuleren en ondersteunen.

[89] https://ec.europa.eu/clima/events/articles/0115_en

Het doel van een transitiekader is een faciliterend kader voor de industrie te scheppen om de low carbon transitie van de industrie mogelijk te maken. Het kader zal dus enerzijds informatie dienen te capteren die nuttig kan zijn om barrières te verwijderen en om synergiën te faciliteren. Anderzijds is het belangrijk dat de knowhow en de ervaringen met innovatieve technologieën op een efficiënte manier aangewend kunnen worden om een stuwende kracht te krijgen in het innovatielandschap. Tot slot is een competitief kader nodig om de investeringen te kunnen aantrekken in Vlaanderen om tot een win-win te komen tussen klimaatambities en welvaart.

Gezien de omvang van de transitie, het maatschappelijk belang en het grote aantal betrokken partijen is het belangrijk dat de voorbereiding op deze transitie op een coherente wijze gebeurt, gedragen wordt door overheid, bedrijfsleven en andere relevante stakeholders. Het gaat hier immers over een lange termijn transitie waaraan veel (technologische en economische) onzekerheden en risico's verbonden zijn. Het transitiekader moet voor de betrokken partijen duidelijk maken wat hun rol en engagement hierin kan zijn. Het hele proces moet dan ook transparant zijn en bovendien moet bijsturing mogelijk zijn.

8.2.2 Context van het Vlaams industrieel transitiekader

Het Vlaams industrieel transitiekader speelt in op de kansen en uitdagingen die voor de Vlaamse industrie werden geïdentificeerd in "Visie 2050. Een langetermijnstrategie voor Vlaanderen."

Bovendien vormt het een eerste invulling van actie 5.2.2 'Transitiekader inzake de omschakeling naar een koolstofarme economie' uit het voorontwerp van Vlaams Klimaatbeleidsplan 2021-2030 dat op 20 juli 2018 door de Vlaamse Regering goedgekeurd werd. Dit plan legt de krijtlijnen vast voor het klimaatbeleid in de periode 2021-2030 in het Vlaamse Gewest en vormt samen met het Vlaams Energiebeleidsplan 2021-2030 de Vlaamse inbreng voor het ontwerp van Belgisch geïntegreerd energie- en klimaatplan.

In deze actie van het voorontwerp van klimaatbeleidsplan werd het volgende opgenomen:

"De industrie speelt een belangrijke rol inzake de klimaat- en energietransitie. Nieuwe technologieën, producten, grondstoffen en productieprocessen zullen nodig zijn de komende decennia. Het bedrijfsleven, de onderzoekswereld en de overheid kunnen elkaar daarin versterken. Daarom wordt samen met het bedrijfsleven en onderzoeksinstellingen onderzocht of en hoe een transitiekader inzake koolstofarme technologieën (low carbon technologies) kan worden opgesteld, in aanvulling op de roadmaps die reeds door de speerpuntclusters en IBN's worden opgesteld. In dit transitiekader kan in kaart worden gebracht waar de grootste mogelijkheden liggen voor Vlaamse onderzoeksinstellingen om mee te werken aan de nodige systeeminnovaties om de klimaat- en energietransitie mogelijk te maken. Daarbij kan worden onderzocht welk ondersteunend flankerend beleid nodig is op vlak van innovatie, financiering en infrastructuur om effectieve investeringen in klimaatinnovatie te mobiliseren."

Het Vlaams transitiekader kan bovendien bijdragen aan de invulling van artikels 4 en 14 van de Verordening inzake de Energie-Unie en Klimaatactie die de opstelling van een langetermijnstrategie vereisen.

8.2.3 Een multidisciplinaire aanpak voor onderzoeksvragen

Bij de opzet van een Vlaams transitiekader is er een duidelijke nood aan technologische, bedrijfseconomische en beleidsmatige kennis en ondersteuning. Voorts zal een breed scala aan onderwerpen onderzocht moeten worden die elk, specifieke kennis en ervaring veronderstellen (e.g. low-carbon technologies voor verschillende sectoren, circulaire economie/materiaalstromen, energiesystemen, impact, barrières, …). Gezien de omvang van deze thematiek zullen competenties uit verschillende wetenschappelijke disciplines en kennisinstellingen en initiatieven (bijvoorbeeld de speerpuntclusters) die belangrijke raakpunten hebben met de onderzoeksvragen, nodig zijn.

Vermoedelijk is zulke kennis niet aanwezig in een enkele instelling, en deze multidisciplinaire aanpak zal daardoor hoogstwaarschijnlijk een samenwerking tussen verschillende Vlaamse onderzoeksinstellingen, publieke actoren en andere betrokken economische actoren (sectorfederaties, bedrijven, …) noodzakelijk maken. Idealiter vormt zich een gerichte samenwerking dat Vlaamse state of the art kennis over de meeste van bovenvermelde domeinen samenbrengt. Hierbij moet in rekening gebracht worden dat er vele multi-nationale bedrijven zijn in Vlaanderen, waar de kennis over innovatie geconcentreerd wordt in de hoofdkwartieren, die zich niet noodzakelijk in Vlaanderen bevinden. Een eerste stap bij de opstelling van het transitiekader kan detecteren voor welke sectoren Vlaanderen een sleutelfunctie heeft in innovatie.

Deze aanpak kan een meerwaarde betekenen voor Vlaanderen om knowhow en informatie over low-carbon technologieën op te bouwen bij industrie en kenniscentra.

8.2.4 Onderzoeksvragen voor de ontwikkeling van een Vlaams industrieel transitiekader

Het startpunt van de opmaak van een industrieel transitiekader is de kennis die reeds aanwezig is in Vlaanderen (en buiten Vlaanderen) en het bestaande economisch landschap in Vlaanderen en zal zich daarom baseren op input van/uit:

- Vlaamse sectorfederaties- en-werkgeversorganisaties en hun speerpuntclusters
- De relevante innovatieve bedrijfsnetwerken
- Vlaamse onderzoeksinstellingen en hun relevant onderzoek
- Betrokken overheidsinstellingen (inclusief havenbesturen)
- Bedrijven (voor zover deze informatie beschikbaar is en gedeeld kan worden)
- Roadmaps en studies die reeds uitgevoerd zijn (b.v. op Europees niveau)
- Andere relevante maatschappelijke stakeholders (NGO's, vakbonden,….)

Bij deze is het belangrijk te noteren dat al deze actoren op een nuttige manier betrokken moeten worden. Wie, wanneer en hoe dit moet gebeuren zal nog worden onderzocht.

In samenspraak met de relevante stakeholders moet het transitiekader een manier vinden om volgende onderzoeksvragen te behandelen:

- Hoe moet de reeds bestaande kennis en ervaring verder gefocust, eventueel uitgebreid en gedeeld worden?
- Hoe kan de ontwikkeling en ontplooiing van deze kennis versneld worden?
- Hoe kan een transitiekader het leerproces op beleidsniveau versterken?
- Welke barrières en randvoorwaarden bestaan er voor de industrie om de transitie naar een lage koolstofeconomie te verwezenlijken? Hierbij kan gekeken worden naar barrières en randvoorwaarden inzake O&O, financiering, het regelgevend kader, noodzakelijke competenties en skills, infrastructuur en energie- en materiaalkosten en competitiviteit
- Welke beleidsmaatregelen kunnen bovenvermelde barrières mitigeren en zorgen voor de invulling van de noodzakelijke randvoorwaarden? Deze omvatten onder andere infrastructuur-, investerings-, competitiviteits- en financieringsmaatregelen voor de Vlaamse overheid in samenwerking met het bedrijfsleven.
- Hoe kunnen hefbomen genereerd worden voor bijkomende financiering van industriële low-carbon piloot-/demonstratieprojecten en infrastructuur, in het bijzonder via nieuwe EU middelen (e.g. EU ETS innovatiefonds, Horizon Europe)?
- Hoe kan de praktische opvolging van de implementatie van het transitiekader geregeld worden?

Ter ondersteuning, kunnen inzichten verkregen uit een techno-economische analyse van de verschillende high level technologieën en hun opportuniteiten, bijvoorbeeld op vlak van circulaire economie en broeikasgasreductiepotentieel, en uit een competitiviteitsanalyse van het investeringskader in Europa/Vlaanderen versus andere regio's als mogelijke inputs gebruikt worden voor bovenstaande onderzoeksvragen. Zulke analyses zullen zich baseren op input van bedrijven en economische actoren (e.g. sectorfederaties, havenregio's, …) in Vlaanderen (voor zover deze informatie beschikbaar is en gedeeld kan worden) en bestaande informatie (e.g. wetenschappelijke literatuur, Europese low-carbon roadmaps en relevant onderzoek in Vlaanderen) en kan volgende vragen bevatten:

- Wat zijn mogelijke low-carbon technologieën die het meest geschikt zijn voor toepassing in Vlaanderen (zonder daarin al te rigide te zijn) en hun mogelijke opportuniteiten waarbij de inschattingen (zoals impact op CAPEX, OPEX en energievraag) afhankelijk zijn van randvoorwaarden en transparante assumpties over toekomstige economische en technologische evoluties in Europa en in de rest van de wereld?
- Welke mogelijke opties bestaan er voor industriële symbiose (op vlak van materiaal-, afval-, energie en CO_2-stromen)? Welke impact hebben deze op vlak van opportuniteiten, infrastructuurnoden en investeringskosten?
- Welke mogelijke synergiën tussen bedrijven onderling en buiten de industrie zijn er mogelijk (e.g. energieopslag, circulaire economie, waste re-use, CCU, …)?
- Welke opportuniteiten bestaan er om demonstratie- en pilootprojecten te ontwikkelen? Welke barrières bemoeilijken de opstart van de projecten en verdere uitrol? Welke ondersteuning is hier voor nodig?

- Welke de economische randvoorwaarden - ook op de lange termijn - zijn voor bovenstaande elementen, in een internationale context?
- Welke infrastructuurnoden bestaan er en welke impact hebben deze op vlak van opportuniteiten?
- Wat is de impact van (en de wisselwerking tussen) de geïdentificeerde opties op het bredere energiesysteem?

8.2.5 Volgende stappen

In deze studie wordt de relevantie van een Vlaams faciliterend transitiekader in samenspraak met verschillende stakeholders verduidelijkt. Er worden ook onderzoeksvragen geïdentificeerd, waar het transitiekader een manier moet vinden om deze te behandelen.

- Over hoe het transitiekader zal worden opgebouwd, of hoe het transitiekader deze onderzoeksvragen moet behandelen is nog geen overeenstemming gevonden binnen de betrokken partijen. Volgende stappen kunnen hiertoe bijdragen: Interdepartementale afstemming tussen het Departement Economie, Wetenschap en Innovatie (EWI) en het Departement Omgeving over de verdere aanpak. Er wordt gestreefd deze afstemming met een voorstel van plan van aanpak voor eind 2018 te finaliseren.
- Identificatie van betrokken actoren.
- Finaliseren van het plan van aanpak in samenspraak met de betrokken actoren.

Bij de uitvoering van bovenstaande stappen zal er over gewaakt worden dat:

- Verderzetting van de bestaande samenwerking tussen verschillende betrokken actoren cruciaal blijft.
- Generieke aspecten in de mate van het mogelijke op Vlaams niveau besproken worden om versnippering en ontdubbeling van het overleg te vermijden. Typisch lokale aspecten (zoals infrastructuur en logistiek en lokale knelpunten/barrières) kunnen op lokaal niveau besproken worden.
- De werklast voor de bedrijven en betrokken actoren bij het behandelen van de onderzoeksvragen tot een minimum beperkt wordt.

9 REFERENCES

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6 LIST OF ABBREVIATIONS

2DS	2 degrees Celsius scenario
B2DS	Below 2 degrees Celsius scenario
BAT	Best available technology
BAU	Business as usual
BECCS	Bio-energy with carbon capture and storage
BERD	Business expenditure on R&D
BF-BOF	Blast furnace - blast oxygen furnace
BF-TGR	Blast furnace - top gas recycling
BIO	Biomass and CCS
BLG	Black liquor gasification
Bn	Billion
BPT	Best practice technology
BTT	Breakthrough technology
BTX	Benzene, toluene, xylenes
C1/C2/C3	Hydrocarbons with either 1 (methylene), 2 (ethylene) or 3 (propylene) carbon atoms
CAPEX	Capital expenditure
CCS	Carbon capture and storage
CCU	Carbon capture and utilisation
CH_4	Methane
CHP	Combined heat and power generation
CO	Carbon
CO_2	Carbon dioxide
COP	Coefficient of Performance
CYC	Closed carbon cycle
CYC-ECE	Closed carbon cycle earlier closure
DES	Deep eutectic solvents
DME	Dimethylether
DRI	Direct reduction of iron
DRI-EAF	Direct reduction of iron - electric arc furnace
EAF	Electric arc furnace
EC	European Commission
EE	Energy efficiency
EJ	Exajoule (1018 J)
EPS	Expanded polystyrene
ET	Emerging technology
ETM	Energy transition model
ETP	Energy technology perspectives
ETS	Emissions trading system
EU	European Union

EUR	Euro
GHG	Greenhouse gases
GJ	Gigajoule
GJ/t	Gigajoule per tonne
GOVERD	Government expenditures on R&D
$GtCO_2$	Giga tonnes of CO_2
GVA	Gross value added
GW	Gigawatts
GWh	Gigawatt Hour
H_2	Hydrogen
HVC	High value chemicals
IBNs	Innovative business networks
KPI	Key performance indicator
Kt	Kilotonnes
kWh	Kilowatt hour
LCA	Life cycle assessment
LCE	Low-carbon energy sources
LPG	Liquefied petroleum gas
Mn	Million
Mt	Megatonnes
Mt CO_2-eq	Million tonnes CO_2 equivalent
Mt CO_2	Million tonnes CO_2
MTO	Methanol to olefins
Mtoe	Million tonnes of oil equivalent
MVR	Mechanical vapour recompression
MW	Megawatt
MWh	Megawatt hour
N_2O	Nitrous oxide
NGO	Non-governmental organisation
NH_3	Ammonia
OPEX	Operational expenditure
p.a.	Per annum
PE	Polyethylene
PP	Polypropylene
PS	Polystyrene
PEM	Proton exchange membrane
PEM	Primary energy melter
PJ	Petajoules
PPP	Public-private partnership
R&D	Research and development
R&I	Research and innovation
RD&D	Research, development and demonstration
RD&I	Research, development and innovation

RTS	Reference technology scenario
$scCO_2$	Supercritical CO_2
SDR	Smart delta resources
SEC/tonne	Tonne per second
SMEs	Small and medium-sized enterprises
SMR	Steam reforming plants
t/a	Tonnes per annum
tCO_2	Total CO_2
Tn	Trillion
tNH_3	Total NH_3
TP	Technological progress
TRL	Technology readiness level
TWh	TeraWatt Hours
USD	United States dollar
w/o	Without