WORLD ENERGY COUNCIL | THE NETHERLANDS

VALUING INDUSTRIES:
THE TRADE-OFFS OF INDUSTRY STRATEGIES IN A CHANGING ENERGY LANDSCAPE

ABOUT

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EXECUTIVE SUMMARY

One year ago, a study for the World Energy Council Netherlands (WEC NL), performed by PwC, concluded that the energy-intensive industry (EII) in Northwest-Europe (NW Europe) is facing heavy consequences from higher energy prices and energy transition costs versus competitors producing in other parts of the world. Since then, discussions on the future of the EII in NW Europe have intensified. This is driven particularly with recent global trade shifts and the sector's vulnerability becoming more apparent, marked by decreasing production and plant closures. It is generally acknowledged that we are living in a pivotal era, in which the competitiveness consequences of high energy prices and the ongoing energy transition in Netherlands and NW Europe, among other factors, are beginning to create existential challenges for businesses. Relocation of EII activities to other parts of the World is therefore a trend that is not inconceivable at all right now. This begs the question whether this possible relocation is a good or a bad thing for long-term welfare creation of the region, and if there is societal merit in trying to prevent that from happening, by a least retaining substantial parts of it. The central question is thus what value to society there is in having, versus not having, the sort of EII present in NW Europe today.

Relocation of economic activities is in itself an inherent part of economic development. In free market economies like ours, there are limitations to the degree in which the future industry composition is makeable. Yet a choice can be made either to let a certain development happen without interference, or to create conditions and incentives to try to correct for an increasingly uneven playing field. This is especially true as much of the grounds for relocation are the consequence of our societal choices to accelerate the energy transition, almost unilaterally in the global context.

Deciding whether there is merit for retaining the EII turns out to be complex. This is witnessed by the many arguments that are brought forward in the debate. This year's WEC NL study suggests that societal discussions about the EII's future should be grounded in a thorough, empirical social cost-benefit analysis (SCBA). Simplistic answers that overlook sectoral differences and only focus on isolated parts of the story or lack empirical support should be avoided. Instead, it is important to define relevant scenarios for the industry's future, identify the full range of private and societal costs and benefits to be analysed, and quantify and qualify these as comprehensively as possible.

In this WEC NL study, we discuss the methodologically critical choices that need to be addressed and outline a number of necessary components for such a SCBA. As it will turn out, thinking along the methodological principles reveals insights that are currently overlooked, not well understood or in some cases even misrepresented in the debate. As in all SCBA's, the conceptual phase is as important as the eventual outcomes.

A SCBA for the energy-intensive industry in NW Europe requires three methodological choices:

Scenarios: First, a SCBA requires clear definitions of scenarios: the counterfactual scenario versus the alternative scenario(s). The central question the SCBA should contribute to is what the societal value is of having versus not having the sort of EII as present in NW Europe today. In this study, this question is operationalized by comparing the scenario of full retention versus full relocation, assuming European decarbonisation ambitions remain intact. An important consideration is the destination to which the EII relocates. This study reflects on the potential different implications, depending on destination. Moreover, this study suggests that relocation of EII can mean different things. For some sectors, it seems plausible to split the decarbonised production process, according to their energy-intensity. This creates room for a potential middle scenario, where only specific parts of the EII relocate. Finally, this study notes that the energy-intensive industry can decarbonise in NW Europe through different decarbonisation methods and suggests that their socioeconomic implications may vary.

Scope: Second, a SCBA requires a clear market demarcation. The current debate seems to focus on “the energy-intensive industry” in a Dutch context. Ultimately, the scope and level of detail depends on the level at which policies will be designed, but in this study we highlight crucial differences per sub-industry (i.e. ammonia, steam cracking, refineries and steel) and the fact that the EII operates in a NW European context. Failing to recognize these dynamics, makes the conclusions too high-level to be meaningful and practical.

Cost and benefit elements: Third, a SCBA requires a selection and precise definition of both the private and societal costs and benefits. In the current debate various cost and benefit components are brought forward, but the debate could use the sound basis of a comprehensive and structured set of public and private costs and benefits. In this study, we suggest considering a framework based on the Trilemma model, which is widely used - also by the EC- to assess broader energy and energy transition policy. In this study the pillars of assessment are economic, environmental and strategic autonomy impact.

This study is not a complete SCBA. Instead, it is merely a first attempt to operationalise the aforementioned steps. Nonetheless, some first qualitative and quantitative analyses give useful insights and considerations on an economic, environmental and strategic autonomy level:

ECONOMIC INSIGHTS:

The decarbonisation of the EII involves broader adjustments to the energy system, which depend on the decarbonisation technology. The decarbonisation of the EII requires more than just transforming the industrial production process; it also necessitates investments in renewable energy generation, electricity and hydrogen transport, as well as flexibility enhancements. The chosen technological options for decarbonising industrial production processes, energy generation, transportation, and flexibility are interdependent. For example, a decarbonisation route based on electrification and hydrogen demands significant electricity grid expansions, sufficient hydrogen production and the development of a hydrogen transport network. Alternatively, a route based on natural gas combined with Carbon Capture and Storage (CCS) requires investments to enhance CCS infrastructure. This route could potentially lead to ~€27-53 bln. lower investments in the Dutch energy grid.

Decarbonisation costs for Europe remain when production relocates outside of Europe, though they may differ from local levels. European demand for EII products is likely to stabilize or grow in the future, meaning relocated production will still be consumed, and will therefore be imported. Regions receiving relocated production can only absorb extra demand if they invest in decarbonised capacity, both for producing the products, and for producing the required energy system. The combined effect of those costs affects product prices. Thus, European consumers committed to climate goals will ultimately bear these costs, which could be higher, similar, or lower depending on the receiving area's decarbonisation costs compared to decarbonisation costs in Europe.

The relocation of competitive local industries due to temporary distortions of the level playing field causes a negative social impact. Higher costs from policies, such as energy transition goals, may compel industries to relocate, not because of any comparative disadvantage but due to increased local expenses compared to countries with less ambitious goals. The relocation of efficient industrial activity results in economic losses due to competitive distortions caused by a lack of level playing field regarding policy. There are no corresponding social or environmental benefits. Relocating efficient industries due to temporary transition policy issues thus negatively impacts society.

The relocation of non-competitive industry might lead to positive or negative societal impact. Maintaining inefficient industry on the other hand involves economic costs associated with the higher local production expenses. In this case, public investments to retain inefficient industry is only warranted if relocation leads to greater societal costs, such as increased emissions and decreased supply security.

Since the industry's future competitiveness is key to welfare outcomes, it must be well understood and studied. Conceptually, it is important to differentiate between cost disadvantages arising from policy decisions, such as higher transportation costs due to investments in energy transition grids, compared to countries with lower ambitions, and cost disadvantages stemming from inherent long-term inefficiencies in production processes, such as structurally higher energy and decarbonisation costs. The former can be viewed as an obstacle during the transition phase, while the latter may indicate long-term competitive challenges.

Existing research on the future competitiveness of the EII in NW Europe offers useful insights but remains inconclusive. There are currently a limited number of studies regarding the long-term competitiveness of the EII in NW-Europe. These studies provide useful insights, though they are not definitive. The PwC-WEC study from last year[1] indicated that relatively high energy prices in NW-Europe could persist in the long term when the energy mixes are dominated by renewables. This poses a challenge to the competitiveness of energy-intensive industries such as ammonia, steel, and high-value chemicals production. However, this study also highlighted important caveats regarding the interpretation of the results. First, the results differ greatly between sectors, so generalisations at the level of EII should not be made. Second, the study primarily focused on energy cost differences, while location choices depend on more than just energy costs. The distribution of renewable energy capacity across the world will not only be based on cost differences, but also on e.g. institutional factors, availability of infrastructure, availability and qualifications of workforce, proximity to demand, and international connectiveness. Third, assumptions on future cost levels are inherently uncertain and dependent on assumed learning effects. Fourth, last-year's PwC-WEC study only compared competitiveness for green decarbonisation options and did not consider blue decarbonisation scenarios. Another study recently assessed the competitiveness of refineries in NW Europe vis-à-vis other regions and showed that when assuming that there is a level playing field, NW European traditional refineries may in fact be competitive towards 2040.[2] This is especially true in case refineries decarbonise primarily through CCS. Finally, a recent study conducted by TNO shows that if all costs are included, the cost delta's with other regions in the world may in fact be small, much smaller than the deltas of the costs of renewable energy production suggest. **See also Appendix D for further discussion on this topic.**

The argument that the relocation of the EII can free up scarce resources and thus lead to social benefits, overlooks the economic principle that scarcity is best allocated by market mechanisms. In the current debate, it is suggested that relocating the EII could address resource scarcity, which is a concern in countries with limited space, such as the Netherlands. This viewpoint assumes that it is up to the state to determine the distribution of scarce resources by identifying which sectors should have access to those resources. This perspective does not align well with the established economic principle that markets are effective tools for allocating scarce resources, provided that externalities are included in market prices to align market outcomes with societal goals. The EU emissions trading system (ETS) sets a price on emissions and allocates emission capacity to sectors and companies based on their willingness to pay, without bias towards or against specific sectors. Although it is accurate to assert that scarcity necessitates allocation, there is no definitive economic foundation to claim that the state will make superior decisions compared to the market regarding allocation. Furthermore, there is no justification for pre-emptively excluding specific sectors, such as the EII, from the allocation process.

Relatedly, the argument that moving the EII can free up scarce resources like labour, land, and capital overlooks the principle that these factors are best allocated by markets. In the current debate it is also suggested that relocation of the EII will lead to economic welfare as relocation will free-up production factors for economic activities that yield higher productivity. The argument implies that labour-, land-, and capital markets are not working as they allocate resources to these industries and that there is need for state intervention to reallocate resources between different sectors. Once again, such assumptions seem to be inconsistent with the proven economic principle that resource allocation is best achieved by market mechanisms.

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[1] World Energy Council (2024), Preserving the NW European industry is a balancing act for the government (link)

[2] PwC Strategy& (2024), Future of refining in the Netherlands, prepared for VEMOBIN (link)

ENVIRONMENTAL EFFECTS:

The climate and environmental effects of relocation versus local production will depend on the destination of relocation. NW European producers are among the most efficient in CO_2 emissions globally. Relocating these industries to countries with less ambitious climate goals could lead to carbon leakage, thereby increasing global greenhouse gas emissions. Moving NW European production to other European countries is unlikely to harm the climate. Other harmful emissions can cause local health risks and biodiversity loss. Relocation to less populated areas or those with fewer biodiversity concerns might be beneficial globally but could be detrimental if moved to densely populated or biodiverse regions.

Assumptions regarding decarbonisation technologies are key drivers of climate impact. For example, decarbonisation through CCS can reduce large volumes of CO_2-emissions relatively quickly, but may also lead to higher CO_2-emissions by 2040 compared to fully green decarbonisation, as post-combustion carbon CCS only captures between 70 and 95% of all emitted CO_2. However, capture and storage of biogenic CO_2 can enable negative emissions, which are considered necessary in order to limit global warming.

STRATEGIC AUTONOMY:

Growing geopolitical tensions and trade disputes may justify keeping EII, even if local production costs more. With increasing geopolitical tension and the weaponization of international trade, energy and product autonomy (defined as the degree of control over the production of goods, demanded by the European consumer) is becoming increasingly important. Even in cases where production in other countries or continents is cheaper, completely outsourcing the production of strategic products such as steel, fertilizer, chemicals and fuels can pose fundamental risks to the functioning of the (Northwestern) European society. However, any inefficiencies must be justified by showing that their costs are less than those of losing strategic autonomy and that import diversification is insufficient. It should also be clear how retaining NW EII fits within Europe's strategic autonomy strategy.

Quantifying the impact of (partially) retaining EII on the degree of product autonomy requires detailed studies per subsector and depends on the destination of relocation. How the degree of product autonomy compares between scenarios is highly dependent on the number of countries that will produce these products and on the relationship with these countries. As the homogeneity of products increases when a larger part of the value chain is relocated to other countries, it seems likely that product autonomy is highest in a scenario with local production. The extent of product autonomy, however, largely relates to the question whether production will move within Europe or move outside of Europe, which requires more detailed analyses at subsector-level.

Although retaining and decarbonizing all EII in NW Europe significantly increases the industry demand for green hydrogen and/or natural gas, this not automatically means lower energy autonomy. There are practical limits to the capacity of local energy production in case the EII decarbonises locally. These practical limitations make it unlikely that the Netherlands can be self-sufficient in terms of energy in any of the decarbonisation scenarios. However, imports of green hydrogen and/or natural gas not automatically leads to lower energy autonomy compared to the level we have today, as currently the industry is also highly dependent on import of e.g. natural gas, oil and coal. Furthermore, it cannot just be assumed that energy autonomy will be greater when the EII (partially) relocates. Assuming lower energy autonomy due to local decarbonisation of the EII oversimplifies the autonomy issue, ignoring the impact of energy demand on the relative competitiveness of local energy production and the interconnectedness of European energy markets. Finally, imports of energy impacts emission levels. Therefore, import strategies should take both import dependency and emissions into account, next to cost considerations.Based on the insights discussed above, some first conclusions can be drawn on what directions authorities should be aiming for.

POLICY IMPLICATIONS

From an economic perspective, market mechanisms should play a central role in determining the allocation of scarce resources and production factors, rather than relying on central planning. Economic principles show that markets are effective tools for allocating scarce resources. To ensure market mechanisms lead to the preferred societal outcome, externalities such as CO_2 emissions should be priced by the government, by introducing pricing mechanisms.

Implement climate policies at the European level to avoid distortions and correct for differences with the rest of the world. Location shifts due to climate policy distortions diminish social welfare. Climate policies for the industry should be coordinated at the European level to prevent discrepancies among member states. Instruments like the EU Carbon Border Adjustment Mechanism, which are crucial for protecting European industry from unfair global competition, must be designed effectively. Given the challenges of establishing a fully equitable playing field globally concerning regulatory measures (such as the EU ETS) and standards (such as purchase obligations for green hydrogen), subsidies will likely be necessary in the overall mix of instruments. Ideally, these subsidies should be allocated through market mechanisms, such as tenders, to ensure the efficient use of taxpayer funds.

The allocation of taxpayer funds to support the industry can be more effectively justified when there is long-term competitiveness of the relevant industries in Europe. There is ongoing debate about the long-term competitiveness of the energy-intensive industry in NW Europe. Further quantitative research is needed to gain more insights into its future relative competitiveness.

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1. CONTEXT

THE EII IN NW EUROPE IS UNDER PRESSURE, DUE TO RELATIVELY HIGH ENERGY, GRID AND CARBON PRICES, DECREASING DEMAND AND GLOBAL OVERCAPACITY

The recent Draghi report[3] signals that high energy, grid and carbon prices in Europe, decreasing demand and global overcapacity have led to decreasing production volumes for the energy-intensive industry in the EU. These challenges threaten the competitiveness of the European EII and create a risk of deindustrialisation. The same challenges are also evident in the Netherlands and neighbouring EU countries (such as Belgium and Germany: Northwestern Europe or NW Europe for short). For example, production levels of the chemicals, basic metals and rubber & plastics have dropped by more than 10% since 2022. Production levels of building materials and glass even dropped by more than 20%.[4]

EII MIGHT CONSIDER LEAVING NW EUROPE AS THE COMPETITIVE ENVIRONMENT CONTINUES TO DETERIORATE

The EII is – and has been for many decades – present in NW Europe for many reasons. One was clearly the proximity to affluent and growing markets. But a favourable investment climate has contributed to the flourishing of the industries. The factors affecting the investment climate mentioned in literature and in surveys invariably point at the stability and reliability of government policy, trusted authorities and institutions, well-developed infrastructure, and an open and well-educated workforce. These dimensions of a favourable investment climate are not a static given. As Draghi's report suggests, several of these factors are eroding in one form or another, particularly when compared to other blocks in the world. That creates huge challenges for Europe in its ambition to sustain welfare and prosperity in the changing dynamic world order.
As a consequence of the erosion, companies that are operating in an international competitive landscape see the business cases of operations in NW Europe worsen. Increasingly, CEOs are announcing their worry about the trends, and some have already actually voted with their feet.

SHOULD THEY STAY OR SHOULD THEY GO?

Until only a few years ago, apart from some incidences, industry's licence to operate was not subject of great societal or political debate – and energy-intensive industries were no exception. Industry's presence was taken for granted, and even applauded, as witnessed by their high scores on rankings of great places to work, for instance. In recent years however, especially in Europe we have seen the emergence of demands for companies to explain their position and choices more publicly. The CSRD legislation is a reaction by EU's politicians to structure the demands for transparency and accountability that should and could be expected from companies.
One significant turn that the evolving debate has produced is the question why it might be good to have industry in the first place, and how bad it would be if industry vanished – relocated elsewhere for example. A next question immediately follows: is there a desirable level and intensity of presence for industry, from a societal welfare point of view, and if so, is that a makeable option at all.

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[3] European Commission (2024), The Future of European Competitiveness (link)
[4] PwC Strategy& (2025), *De sociaaleconomische bijdrage van 6 sectoren binnen de basisindustrie* (link)

THE PRESENCE OF ENERGY-INTENSIVE INDUSTRY ON THE TERRITORY BRINGS SIGNIFICANT ECONOMIC, ENVIRONMENTAL AND STRATEGIC AUTONOMY IMPLICATIONS

Industry may have not felt the need to be explicit about their contributions to society until recently, but there is no doubt that industry – energy-intensive industry included – brings significant economic benefits. In the recently published Industrial Clean Deal[5], the European Commission recognizes that the energy-intensive industry contributes to three distinct pillars. First, the energy-intensive industry has historically fuelled economic growth and has put Europe at the forefront of technological progress. Second, as Europe is grappling with rising geopolitical tensions, the European Commission argues that a robust industrial component is required for a resilient economy. Finally, the European Commission earmarks decarbonisation as an opportunity to increase the competitiveness of the energy-intensive industry and as a growth opportunity for the sustainable technologies industry. At the same time, industry's presence and its activities also generate other societal implications, broadly classified as environmental and strategic. In economics jargon: energy intensive industry incurs private costs and benefits, as well as societal costs and benefits.

TO DECIDE ON THE VALUE TO SOCIETY OF HAVING ENERGY-INTENSIVE INDUSTRY ON THE TERRITORY, A SOCIOECONOMIC EVALUATION FRAMEWORK IS REQUIRED

As the emerging debate on the place and role of industry shows, the number of potential private and social cost and benefit items of energy-intensive industry is broad and multifaceted. The tool that economists have at their disposal for such a mixed private and social valuation is the Societal Cost Benefit Analysis.

THIS REPORT IS A FIRST ATTEMPT AT IDENTIFYING AND QUANTIFYING THE COSTS AND BENEFITS OF DIFFERENT FUTURE SCENARIOS FOR THE ENERGY-INTENSIVE INDUSTRY IN NW EUROPE

This study can be seen as a first step towards a socioeconomic evaluation framework, which aims to provide a balanced view, identifying and quantifying the impacts—both positive and negative—of having the energy-intensive industry, or the flip side of the coin: not having it, through multiple lenses: the economy, the environment, and strategic autonomy. These three categories correspond to the concept of the Trilemma of broad objectives that the European Commission has been using to assess energy and energy transition policies: affordability, sustainability, and security of supply.

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[5] European Commission (2025), *Clean Industrial Deal* (link)

THIS REPORT IS STRUCTURED ALONG FIVE CHAPTERS

In Chapter 2 we present some of the methodological choices that need to be made before a SCBA can be employed. In Chapter 3, we present important considerations that need to be taken into account when deciding on these methodological choices and demonstrate that in-depth insights into the sub-industries' characteristics is key for a solid understanding of (policy)options and outcomes. In Chapter 4, we look at a shortlist of societal costs and benefits that, in our view should be included in the scope of a SCBA. In this chapter we show how the causal argumentations to arrive at outcomes for the different benefit and cost elements for each of the scenarios can be quite nuanced.

IN THE APPENDICES, THE UNDERLYING DETAILED RESEARCH CAN BE FOUND

In Appendix A we do a deep-dive in the sub-sectors of the EII considered in this report and we discuss the current and future production processes. In Appendix B, we discuss the operationalisation of the scenarios, which elements to consider there and the energy requirements in the various scenarios. In Appendix C, we focus on one large cost element that attracts much of the current debate: the costs of infrastructure and energy production capacity that is needed for the energy transition, and the implications for these investments from having or not having energy-intensive industry. Infrastructure investments are, as it were, one of the societal costs, and a material one. We demonstrate again that detailed know-how is needed to arrive at meaningful conclusions. Appendix D discusses what needs to be considered when comparing production costs between various locations.

2. METHODOLOGICAL CHOICES

Scenario definition, sectoral and geographical demarcation, and private & societal benefit and costs elements are the three fundamental methodological decisions before a SCBA can be conducted. An SCBA is in essence a societal business case, containing at its centre the private business case of the companies directly and indirectly involved, augmented with the broader societal implications, both positive and negative, and as far as possible, expressed in monetary terms. As is the case with private business cases, the exercise of scoping, assuming, defining, and forecasting the key variables is perhaps as valuable as the numbers eventually arrived at. In our case, this exercise contributes to structuring and validating the debate on the future of the energy-intensive industry in NW Europe. Before a SCBA can be conducted, three methodological decisions are fundamental. These methodological decisions are depicted in table 1.

Table 1. Methodological choices in a SCBA

Decision	Key question
1. Scenario definition	Which scenario(s) should be included and against which counterfactual should these scenarios be measured?
2. Sectoral and geographical demarcation	At which level (macro, sectoral or company) should the analysis be conducted? And what is the geographical scope?
3. Private & societal benefit and costs elements	Which private and societal benefit and costs should be considered?

- A crucial element in a societal cost benefit analysis is the definition of the different scenarios. The current debate seems to be dominated by two scenarios; retaining the energy-intensive industry versus relocation of the energy-intensive industry. However, when evaluating the future of the energy-intensive industry in NW Europe, there are more plausible scenarios.

- Another element in a societal cost benefit analysis is to determine the sectoral and geographical demarcation. For example, the analysis could be conducted on a macro-level (i.e. “the energy-intensive industry”), at sector-level (e.g. Chemical sectors) or at specific company-level. Geographically, the SCBA could be scoped to a specific region (e.g. Rotterdam harbour), a country (e.g. NL), an industrial cluster (e.g. the Antwerp-Rotterdam-Rhine-Ruhr Area, or ARRRA-cluster), an economic region (e.g. NW Europe or EU27) or a continent (E.g. Europe). The current debate is often conducted on a macro- (and sometimes sector-) level within the Dutch context.

- The third step is to select and define the private and social benefit and cost elements to be included in the study. In the current debate, various cost and benefit components are brought forward, but the debate could use the sound basis of a comprehensive and structured set.

Chapter 3 discusses these methodological choices that need to be addressed. As it will turn out, thinking along the methodological principles reveals insights that are currently overlooked, not well understood or in some cases even misrepresented in the current debate.

3. METHODOLOGICAL INSIGHTS

3.1. ELEMENT 1: SCENARIO DEFINITION

This study introduces four different scenarios for 2040, differentiating between the extent to which the energy-intensive industry is retained and what technological decarbonisation route is taken. Across scenarios the decarbonisation goal to reach net zero by 2050 is maintained. For the ‘retention’ scenarios, we explore two distinct technological routes on the trajectory to net-zero: one focusing on a pathway based on renewable energy and green hydrogen, and a second one that relies more on natural gas and CCS. In the third scenario the energy-intensive industry is partly retained, a middle-scenario as it were. The fourth scenario considers full relocation of the EII. This leads to the following four distinct scenarios:

1. Full retaining - with a focus on renewable energy and green hydrogen
2. Full retaining - with a focus on natural gas and CCS
3. Partial relocation
4. Full relocation

3.1.1. ‘RETAINING GREEN’ - FULL RETAINING WITH A FOCUS ON RENEWABLE ENERGY AND GREEN HYDROGEN

In this scenario, energy-intensive industries across NW Europe are retained and successfully undergo a green transformation. Governments are leading the way with an orchestrator role, actively steering the transition towards both sustainability and product autonomy. The region takes responsibility for reducing its own green-house gas (GHG) emissions. This transformation requires large investments and customized government support is used to enable companies to make the necessary investments in an international competitive context. Within the span of 15 years – our sight-year is 2040 –, the existing fleet of energy-intensive industrial production assets undergo a fast transformation from fossil-based energy carriers, towards production technologies that run on renewable electricity and green hydrogen. This leads to massive renewable energy demand in the region. Local energy production is maximized, but in all likelihood also significant energy imports from other countries are required to meet the energy demand.

A thriving industrial sector within the region results in a high degree of product autonomy. While the region continues to rely on raw materials and imports of renewable energy from other countries, it maintains self-control over production processes. The industry can swiftly adapt to the evolving demands of its domestic market, ranging from consumer goods to defence industry, and drives significant R&D spin-off effects that benefit the welfare-creating potential of the region. This scenario will drive the development of the clean and green technology sector.

3.1.2. ‘RETAINING BLUE’ - FULL RETAINING OF ENERGY INTENSIVE INDUSTRY WITH A FOCUS ON NATURAL GAS AND CCS

In this alternative retain scenario the EII in NW Europe is also guided towards net zero, but then with a strong reliance on natural gas and CCS technologies to reduce GHG emissions. This approach entails substantial natural gas imports, resulting in a reliance on external suppliers on the (already existing) global market. Furthermore, the region benefits from the already existing natural gas infrastructure, thereby reducing the need for part of the extensive infrastructure development that is required in the Green scenario. Nonetheless, significant investments are still required to develop and enhance CCS capabilities.

Product autonomy is maintained similarly to the Retaining Green scenario. However, the development of clean technologies is likely limited due lower demand within the region than in the Green scenario. The development of CCS technologies and the application thereof, for which NW Europe in general and the Netherlands in particular is well-located, are a possible economical upside under this scenario.

3.1.3. PARTIAL RELOCATION

In this ‘middle’ scenario, industrial energy needs and added value are balanced by relocating the most energy-intensive parts of the production chains. If one takes a closer look at the intricate production chains of the energy-intensive industries, some stages of the chain are much more energy-intensive than others. In this ‘middle’-scenario, the most energy-intensive production stages of industries relocate outside NW Europe. We elaborate on the extent to which that would be conceivable from a technological, logistic, and economic point of view. Alternatively, if partial relocation of a production chain is not possible, for some processes full retaining or full relocation is considered. The partial relocation scenario would see a significantly lower domestic energy demand, while less energy-intensive production steps with their corresponding added value remain in the region. Governments take a leading role in enabling a level playing field for those segments of the industrial chains that remain.

Dependency shifts from energy to intermediate or semi-finished goods. Although this transition still requires significant scaling up renewable energy and infrastructure, the demand is notably less than in the green scenario focused on retaining all industry sectors in their entirety. Consequently, the region is better positioned to meet its own energy needs. Nonetheless, this shift creates a new dependency on the import of intermediate or semi-finished goods, highlighting that in each of the scenarios here are trade-offs involved of balancing energy independence with industrial integration.

Control over GHG emission reductions is limited under this scenario. As the region exports its most energy-intensive production process under this scenario, it limits the ability to take control of reducing emissions. This scenario thus also means that NW Europe will be relying on other countries for a sustainable future. Global emissions might even not be reduced if the competing regions may have less ambitious reduction targets than Europe has.

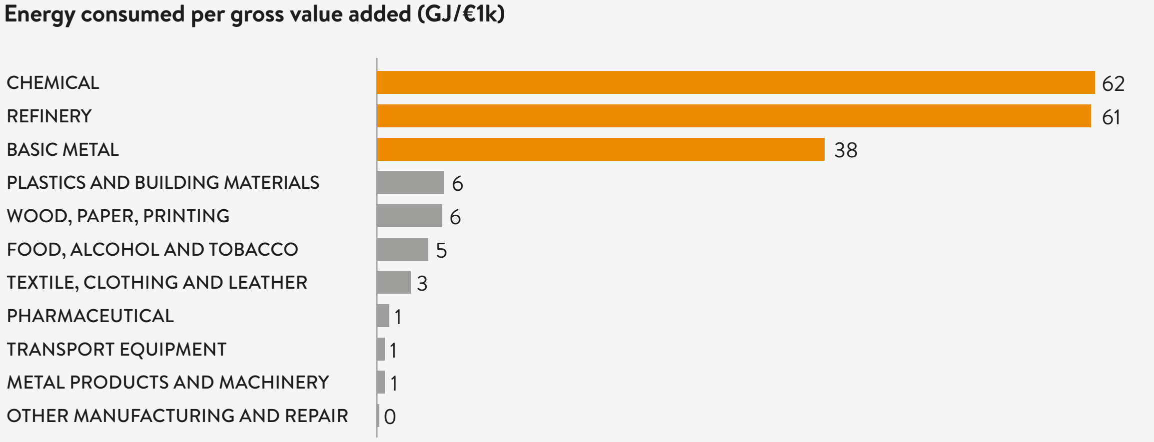
3.1.4. FULL RELOCATION

In this scenario, the energy-intensive industry in NW Europe completely disappears, at the cost of product autonomy. In this scenario the NW European economy will see a large-scale transformation towards existing or potentially new, less energy-intensive sectors. As a result, the regions energy demand significantly decreases compared to scenarios focused on retention. However, this shift comes at the cost of product autonomy, as the country becomes heavily reliant on imports for a wide range of products. While energy self-sufficiency is achieved, the dependency on external manufacturing underscores new vulnerabilities in the national economy. Compared to the partial relocation scenario, the dependency on other countries for realizing emission reductions further increases.

3.2. ELEMENT 2: SECTORAL AND GEOGRAPHICAL DEMARCATION

To operationalize the four scenarios, a good understanding of the "energy-intensive industry" is required. The definition of the energy-intensive industry of the European Commission comprises sectors such as basic metal, chemicals, refineries, building materials, glass and ceramics, pulp and paper. In this study a subset of the energy-intensive industry is investigated in more detail. Within the Netherlands, the chemical, refinery and basic metal industry can be classified as the most energy-intensive industry. As becomes clear from figure 1, the chemical, refinery and basic metal industry currently require 62, 61 and 38 GJ for every €1.000 of gross value added. Hence, these sectors are the focus for this study.

Figure 1. Energy-intensity of industry in the Netherlands, energy consumption (GJ) per gross value added (€1k)) [6]



Chemical - The chemical industry encompasses a vast and highly integrated network of companies and the relocation of a part of the chemical sector may have serious knock-on effects for the rest of the sector.[7] To quantify the renewable energy that the chemical sector would require after large-scale decarbonisation, this study focusses on two energy-intensive processes within the chemical sector.

- The first energy-intensive process is steam cracking, where fossil-based products are converted into olefins, which are essential building blocks for manufacturing plastics and other carbon-based materials. In the Netherlands, steam crackers alone are responsible for roughly 23% of total energy consumption within the chemical sector.
- The second energy-intensive process included is synthetic fertilizer production. Synthetic fertilizers are used within the agricultural sector, to increase the yield of agricultural land. In the Netherlands, this production process requires roughly 85 PJ per year[7], representing roughly 20% of the Dutch chemical energy consumption.[7]

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[6] CBS (2024), Energiebalans; aanbod en verbruik per sector (link) en CBS (2023), Productie- en inkomenscomponenten bbp (link)

[7] PwC Strategy& (2025), De sociaaleconomische bijdrage van 6 sectoren binnen de basisindustrie (link)

Refinery - Although demand for fossil-based fuels is expected to decline, fossil-based fuels are expected to still be required by 2040, across scenarios.[9] Therefore, traditional refineries will need to be decarbonised, and this will continue to require significant volumes of energy. Since the refining steps are difficult to split, refineries are included in full. Additionally, spurred by EU regulations, the transition to sustainable fuels will continue. This study deep-dives on the production of e-SAF, one of the potential future synthetic fuels, as this is expected to be an energy-intensive process and there are plans to produce e-SAF in NW Europe.

Basic Metal - Production activities within the basic metals sector encompass primarily steel, zinc and aluminium. Notably, steelmaking accounts for 98% of the sector's total energy consumption in the Netherlands. Consequently, this study focuses on the process of steel production.[10]

The remainder of this section explores some of the key conclusions regarding the "energy-intensive industry". Please refer to Appendix A for a more detailed description of each sector.

The Netherlands, Germany and Belgium host considerable production capacity within chemicals, refinery and basis metal. In NW Europe, Germany hosts the largest production capacity for all considered sectors. The Netherlands hosts a relatively large production capacity of ammonia, steam crackers and refineries.

Table 2. Production capacity of selected energy-intensive processes in NW Europe. For refineries, input capacity is used.

Process	Germany	Netherlands	Belgium
Ammonia (Mton)	3.1	3.1	1.1
Olefins (Mton)	8.6	6.1	3.3
Refineries (Mn barrels)	767	447	236
Steel (Mton, primary)	25.7	7.5	5.0

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8 Project MIDDEN (2022), Decarbonisation options for large volume organic chemicals production (link), (link), (link)
9 IEA (2024), World Energy Outlook (link)
10 Source CBS and NEa, corrected for emissions of Vattenfall IJmond and Vattenfall Velsen

All energy-intensive industries can decarbonize primarily through hydrogen, CCS and/or electrification. Synthetic fertilizer production currently involves “grey” hydrogen. Therefore, production of synthetic fertilizer production can primarily be decarbonised by replacing the current “grey” hydrogen with low-carbon hydrogen, such as green or blue hydrogen. For olefins production, the most notable alternatives are electric steam crackers, hydrogen-powered steam crackers, and steam crackers with post-combustion CCS. For traditional refineries, a combination of decarbonisation technologies is required, such as CCS, hydrogen and electrification, but also utilisation of residual heat and energy efficiency. The production of steel can be decarbonized primarily through hydrogen or CCS, both combined with electrification. Important note is that although there are alternative technologies for all processes, the maturity of these technologies is still relatively low as they have not been scaled yet.

Although there may be potential to split ammonia and steel production according to energy-intensity, other chemical and traditional refinery production methods seem to be tightly integrated. Ammonia and steel production consist of several steps, that can be split according to their energy-intensity. Both products have a very energy-intensive first step which is required to produce the intermediary good (i.e. ammonia and pig iron). A series of lower energy-intensive steps is then applied to convert the intermediary good to the end-product. Given that the EII step is the first step and the intermediary good can be transported, these production processes could be split to create a ‘middle scenario’. Nevertheless, splitting the production process introduces several considerations, such as energy-inefficiencies (e.g. cooling and re-heating the product) and safety issues (e.g. ammonia). Both the traditional refining and chemical sector are highly integrated and the traditional refining process is generally not characterized by a highly energy-intensive first step and a lower energy-intensive second step. Due to these circumstances, a middle scenario with relocation of production processes based on energy-intensity seems to be less logical for the (petro-)chemical sector.

With the energy transition, new carbon feedstocks for chemical processes and renewable transport fuels are required. Next to decarbonizing the production process of the traditional refining and chemical sector, new decarbonized products and feedstocks will be needed. Transport fuels are shifting from fossil-based sources to renewable ones. Similarly, as the processing of fossil fuels decreases, the feedstock for chemicals, such as plastics, will also need to transition from fossil-based naphtha to renewable alternatives. There are multiple alternatives, and this study explores the production of e-SAF and pyrolysis oil based on plastic waste, respectively. Important finding of this study is that, unlike traditional refining, there is a middle scenario conceivable for e-SAF production, highly impacting energy requirements. Moreover, plastic waste is not sufficient in NW Europe to sustain current production levels of steam crackers.

3.3. ELEMENT 3: PRIVATE AND PUBLIC COSTS AND BENEFITS

There are numerous criteria that can be used to evaluate the long-term socioeconomic impact of the different scenarios for the energy-intensive industry. In this study we revamp the traditional World Energy Trilemma paradigm of affordability, sustainability and reliability[11] and expand it based on the current (geopolitical) context.

Figure 2: Revamped World Energy Trilemma

1 ECONOMIC EFFECTS	2 ENVIRONMENTAL EFFECTS	3 STRATEGIC AUTONOMY
DECARBONISATION COSTS	USE OF SCARCE LAND AND WATER	ENERGY AUTONOMY
R&D DEVELOPMENT	GREENHOUSE GAS EMISSIONS	PRODUCT AUTONOMY
PRODUCTIVITY	NITROGEN AND OTHER HARMFUL EMISSIONS	
EMPLOYMENT		
GDP		

Economic effects: When conducting a Societal Cost Benefit Analysis (SCBA), it is important to assess all economic effects, both public and private. Therefore, the question of socializing costs or benefits should not be an input of a SCBA. Decarbonizing the energy-intensive industry requires large-scale investments in the energy system, ranging from energy generation, transportation, storage and import to adjustments to industrial installations. All required investments should be included in the SCBA analysis. Next to these investments, the future of the energy-intensive industry has a large impact on how the economic welfare (e.g. GDP, R&D development, productivity, employment) of NW Europe will evolve and this should be explicitly accounted for.

Sustainability: Next to economic effects, the different scenarios can have different (local) environmental effects, such as greenhouse gas emissions, use of scarce land and water and nitrogen and other harmful emissions. These (public) costs should be included in the SCBA. It should be noted that the environmental effects should be considered on a global scale. In principle, relocation of EII should not lead to incremental environmental effects, as relocation of fossil-based EII only leads to carbon leakage and no climate benefits. However, more stringent regulations and different decarbonisation routes (e.g. CCS vs. green hydrogen) may lead to differences in for example greenhouse gas emissions.

Strategic autonomy: With increasing geopolitical tension and the weaponization of international trade, strategic autonomy is becoming increasingly important and should be considered as a public benefit in a SCBA. This study distinguishes two types of strategic autonomy; energy and product autonomy. Energy autonomy is defined as the degree of autonomy that NW Europe has over its energy supply. It is important to note that energy autonomy should not be assessed regionally but should consider the integration of energy markets. Product autonomy is defined as the degree of control over the production of goods (ranging from raw materials, intermediaries to final products), demanded by the European consumer.

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[11] A detailed elaboration on the energy trilemma framework and recent reports of the WEC on this topic (link).

4. QUALITATIVE AND QUANTITATIVE INSIGHTS

IN THIS CHAPTER, THE REVAMPED WORLD ENERGY TRILEMMA FRAMEWORK IS USED TO EVALUATE THE IMPACT OF THE DIFFERENT SCENARIOS FOR THE NETHERLANDS. WE SHOW HOW THE CAUSAL ARGUMENTATIONS TO ARRIVE AT OUTCOMES FOR THE DIFFERENT BENEFIT AND COST ELEMENTS FOR EACH OF THE SCENARIOS CAN BE QUITE NUANCED. FOR SOME ELEMENTS OF THE FRAMEWORK, A FIRST ESTIMATION OF THE QUANTITATIVE IMPACT HAS BEEN MADE.

4.1. ECONOMIC EFFECTS

4.1.1. REQUIRED SOCIETAL INVESTMENTS TO DECARBONISE

The decarbonisation of the EII requires broader adjustments to the energy system than just transforming the industrial production process; it also necessitates investments in renewable energy generation, transportation, as well as flexibility enhancements (e.g. storage, flexible demand. The chosen technological options for decarbonising industrial production processes, energy generation, transportation, and flexibility are interdependent. For example, a decarbonisation route based on electrification and hydrogen demands significant electricity grid expansions, sufficient supply of renewable electricity and hydrogen and the development of a hydrogen transport network. Alternatively, a route based on natural gas combined with CCS requires investments to enhance CCS infrastructure.

Between the four identified scenarios for the EII, the required investments in the energy grids in the upcoming decades can differ strongly, especially related to offshore wind. The required investments until 2040 in the Dutch energy grids (electricity, natural gas, heat and hydrogen) for example have recently been estimated at ~€219 bln, of which ~€197 bln relates to the electricity grid.[12] These costs are estimated based on the NPE, which assumes a large share of the EII is retained and decarbonized via electrification and hydrogen. However, relocation of the energy-intensive industry will likely have a significant impact on the required infrastructure investments, especially on the required offshore electricity grid (see Appendix C for more details). Compared to the 50GW offshore wind ambition for 2040 in the NPE, full relocation would potentially require 12-25GW lower offshore wind capacity. The investments for the offshore grid are estimated at approximately 2 bln euros per GW offshore wind,[13] which would imply that the full relocation scenario could lead to a reduction of ~€24-50 bln in offshore grid investments.[14]

Whether an offshore hydrogen network is required in case of full relocation of EII depends on choices with regard to import and self-sufficiency. The EII is the main driver of hydrogen demand in the Netherlands, as the demand from these industries accounts for ~40-60% of the total hydrogen demand in the Netherlands as per 2040 (see Appendix C for more details). Therefore, partial or full relocation of industry has a significant impact on the hydrogen demand and could potentially also have a significant impact on the required (offshore) electrolysers. Full relocation of EII could even imply that offshore electrolysers and an offshore hydrogen grid are not necessarily required, which could lead to a reduction of ~€3 bln euros for the offshore hydrogen grid

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[12] Netbeheer Nederland, Financiële Impact Energietransitie voor Netbeheerders (16 December 2024)

[13] Based on EUR 88 bln investments on the offshore grid from 2025 until 2040, as estimated in the report 'schakelen naar de toekomst', IBO bekostiging elektriciteitsinfrastructuur and the ambition for 2040 to have 50 GW offshore wind capacity connected via the grid as included in the underlying II3050 scenario's.

[14] See chapter 5 for incremental grid investment effects in other scenarios

alone[15]. Note however that this also highly depends on the import strategy, as imports from e.g. Norway could also require an offshore hydrogen grid (versus imports via ships from e.g. Oman). Alternatively, in case priority is given to energy independency, relatively more imports could be reduced in the relocation scenarios rather than pro-rata reducing supply sources. In that case, offshore electrolysers and an offshore hydrogen network are also required in the full relocation scenario to meet remaining hydrogen demand. An onshore hydrogen transport network, as developed in the actual Gasunie "Uitrolplan", is required in every modelled scenario to connect supply with (remaining) demand.

A decarbonisation route based on natural gas combined with CCS could lower the required infrastructure costs, while keeping the benefits of having a local industry. In the scenario where the industry follows a decarbonisation route based on natural gas and CCS, similar reductions of electricity and hydrogen costs could be obtained as in the full relocation scenario, e.g. ~€27-53 bln. Decarbonization through CCS can reduce large volumes of CO_2-emissions in a short time (e.g. the maximum annual capacity of Aramis is estimated at 22 million ton CO_2.), while keeping the benefits of having a local industry.

The cost estimations for renewable energy generation, flexibility enhancements and transforming the industrial production processes are less well known. Currently, no publicly available estimates for the total required investments (including investments in renewable energy generation and adjustments to industrial facilities) for the energy transition towards 2040 are available, but the required investments are significant. For the middle and relocate scenario, also the required investments in renewable energy generation and adjustments to industrial facilities are lower. (Partial) relocation of the energy-intensive industry would lead to a decrease in required renewable energy generation capacity and also (some) costly adjustments to production processes do not have to be made (for example switching to DRI-based steel-making and synthetic fertilizer production based on green hydrogen is not required in both the middle and relocate scenario).

However, the required investments to decarbonise the EII do not disappear when industry relocates, though they may differ from local levels. European demand for EII products is likely to stabilize or grow in the future, meaning relocated production will still be consumed, and will therefore be imported. Regions receiving relocated production can only absorb extra demand if they invest in decarbonised capacity, both for producing the products, and for producing the required energy system. The combined effect of those costs affect product prices. Thus, European consumers committed to climate goals will ultimately bear these costs, which could be higher, similar, or lower depending on the the decarbonisation costs in the receiving area compared to those in Europe..

The three industries considered contribute 5.0% of GDP and 3.0% of total employment to the Dutch economy. The energy-intensive industries included in this study account for €17.9 billion, or 2.1% of GDP, approximately 79,500 jobs representing 0.8% of total employment, and €789 million—equivalent to 6.3%—of national R&D investments.[16] However, the industry's impact goes beyond direct employment. It supports an additional 2.1% of GDP (€18.1 billion) and 1.5% of jobs (138,700) through indirect effects, which include employment and economic activity across the supply chain—such as suppliers, logistics services, and other related businesses. In addition, the industry creates induced effects, as wages earned in both the industry and its supply chain are spent on goods and services, further stimulating sectors like retail, hospitality, and local services. These induced effects account for another 0.8% of GDP (€6.9 billion) and 0.7% of total

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[15] Based on expected investments on the offshore hydrogen grid until 2040, as was calculated by Netbeheer Nederland, Financiële Impact Energietransitie voor Netbeheerders (16 December 2024)

[16] VEMW & Strategy&. (2025, February 17). The socio-economic contribution of 6 sectors within the basic industry. PricewaterhouseCoopers Advisory N.V

[17] QBIS. (2020). Socio-economic impact study of offshore wind (Final Technical Report). Danish Shipping, Wind Denmark, and Danish Energy

employment (58,700 jobs). Taken together, the direct, indirect, and induced effects mean that the three industries under investigation contribute €42.9 billion, or 5.0% of GDP, and 267,000 jobs, or 3.0% of total employment, to the Dutch economy. The current contribution of the EII may serve as a proxy for the contribution in 2040 for the full retain scenario.

This proxy is likely an underestimation, as the energy transition itself will stimulate substantial economic activity. For instance, a report on the socio-economic impacts of offshore wind estimates that producing 1 GW of offshore wind capacity generates roughly 3-9k full-time jobs (FTEs) across all phases, depending on whether generators are produced locally or not.[17] This dynamic presents both an opportunity and a risk for the Dutch labor market: an opportunity when labor supply is sufficient, but a challenge under tight conditions, where increased demand—particularly in technical roles—may intensify shortages and crowd out other economic activity.

The relocation of competitive local industries due to temporary distortions of the level playing field causes a negative social impact. Higher costs from policies, such as energy transition goals, may compel industries to relocate, not because of any comparative disadvantage but due to increased local expenses compared to countries with less ambitious goals. The relocation of efficient industrial activity results in economic losses due to competitive distortions caused by a lack of level playing field regarding policy. There are no corresponding social or environmental benefits. Relocating efficient industries due to temporary transition policy issues thus negatively impacts society.

The relocation of non-competitive industry might lead to positive or negative societal impact. Maintaining inefficient industry on the other hand involves economic costs associated with the higher local production expenses. In this case, public investments to retain inefficient industry is only warranted if relocation leads to greater societal costs, such as increased emissions and decreased supply security (see 4.2 and 4.3).

Since the industry's future competitiveness is key to welfare outcomes of the various scenario's it must be well understood and studied. Conceptually, it is important to differentiate between cost disadvantages arising from policy decisions, such as higher transportation costs due to investments in energy transition grids, compared to countries with lower ambitions, and cost disadvantages stemming from inherent long-term inefficiencies in production processes, such as structurally higher energy and decarbonisation costs. The former can be viewed as an obstacle during the transition phase, while the latter may indicate long-term competitive challenges.

Existing research on the future competitiveness of the EII in NW Europe offers useful insights but remains inconclusive. There are currently a limited number of studies regarding the long-term competitiveness of the EII in NW Europe. These studies provide useful insights, though they are not definitive. The PwC-WEC study from last year[18] indicated that relatively high energy prices in NW Europe could persist in the long term when the energy mixes are dominated by renewables. This poses a challenge to the competitiveness of energy-intensive industries such as ammonia, steel, and high-value chemicals production. However, this study also highlighted important caveats regarding the interpretation of the results. First, the results differ greatly between sectors so generalisations at the level of EII should not be made. Second, the study primarily focused on energy cost differences, while location choices depend on more than just energy costs. The distribution of renewable energy capacity across the world will not only be based on cost differences but also on e.g. institutional factors, availability of infrastructure, availability and qualifications of workforce, proximity to demand, international connectiveness. Third, assumptions on future cost levels are inherently uncertain and dependent on assumed learning effects. Fourth, last-year's PwC-WEC study only compared competitiveness for green decarbonisation options and did not consider blue decarbonisation scenarios. Another study recently assessed

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[18] World Energy Council (2024), Preserving the NW European industry is a balancing act for the government (link)

[19] PwC Strategy& (2024), Future of refining in the Netherlands, prepared for VEMOBIN (link)

the competitiveness of refineries in NW Europe vis-à-vis other regions and showed that when assuming that there is a level playing field, NW European traditional refineries may in fact be competitive towards 2040.[19] This is especially true in case refineries decarbonise primarily through CCS. Finally, a recent study conducted by Nobian shows that if all costs are included, **the cost delta's with other regions in the World may in fact be small, much smaller than the delta's of the costs of renewable energy production suggest. See also Appendix D for further discussion on this topic.**

Economic replacement effects: lessons from practice

Early 2024, VDL Nedcar shutdown, which led to unemployment of ~4,000 employees. However, a year after the shutdown of VDL Nedcar, approximately 90% of the displaced workers found new employment.[20] Many remained in the technical sector, while others used the opportunity to transition into different industries such as logistics, manufacturing, landscaping, and even healthcare.[21] This demonstrates that while industrial shifts may cause short-term disruptions, they could also lead to economic reallocation, job creation, and long-term gains in labor market efficiency.

However, while economic reallocation can mitigate negative impacts or even lead to net-positive outcomes, (large-scale) relocation may also pose long-term risks, as illustrated by the closure of the coal mines in the Dutch province of Limburg between 1965 and 1975. Throughout this period, approximately 45,000 direct and 30,000 indirect jobs were lost, damaging the regional economy. The transition was not immediately followed by sufficient alternative employment opportunities, leading to persistent unemployment and economic stagnation, particularly in towns that had been economically dependent on mining.[22, 23]

While several intervention programs were introduced—including retraining schemes, early retirement, business subsidies, and the relocation of government services—many failed to deliver long-term economic resilience. A key exception was the relocation of the civil service pension fund (ABP) to Heerlen in 1973. Of the roughly 1,200 jobs created, only about 200 went to former miners—mainly above-ground staff—while most positions were filled by young local school-leavers trained through internal ABP programs. Though not specifically designed to re-employ miners, ABP became deeply embedded in the region, partnering with local institutions, outsourcing to Limburg-based companies, and investing heavily in housing and infrastructure. Now operating as APG, it remains one of the largest employers in Limburg, with over 2,500 staff—an example of durable job creation in a post-industrial region.

Yet to this day, unemployment and poverty levels in the former mining region remain higher than in the Randstad.A similar phenomenon is now unfolding in the UK: the closure of Port Talbot's blast furnaces is expected to result in 2,800 direct job losses, with severe knock-on effects for the wider local economy.[24]

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[20] NOS. (2024, February 9). *Jaar na massaontslag bij VDL Nedcar heeft bijna iedereen weer werk.* NOS. (link)

[21] UWV. (2024, november). *UWV Magazine – November 2024. Uitvoeringsinstituut Werknemersverzekeringen* (link).

[22] NOS. (2015). *Vies, zwaar en weggestopt: de Limburgse mijnsluitingen* (link).

[23] Etil & Sociaal Historisch Centrum Limburg. (2013). *Na de mijnsluiting in Zuid-Limburg – 35 jaar herstructurering. Stichting Behoud Mijnhistorie.*

[24] Berry, C. (2024, February 16). *Port Talbot shows the need for a just transition to net zero.* LSE Politics and Policy (link).

4.2. ENVIRONMENTAL IMPACTS

4.2.1. CO_2 EMISSIONS

Industrial CO_2 emissions form a significant part of the overall CO_2 emissions in NW Europe; thus reduction thereof is one of the key elements in reaching our climate goals. The Dutch industry for example is responsible for ~25% of the total CO_2-eq. emissions in the Netherlands[25] and the EII (as defined as steel, refineries, ammonia and chemical cracking) is responsible for ~36 Mt, i.e. 74% of Dutch industrial CO_2-eq. emissions. Each scenario leads to a reduction in industrial CO_2 emissions in the Netherlands, but outcomes differ. The main difference is the CCS scenario, where total remaining emissions by 2040 are estimated at ~5 Mt per year (i.e. 14% of current levels). This is driven by the fact that post-combustion CCS only captures between 70 and 95% of all emitted CO_2. Additionally, unlike for synthetic fertilizer, steam crackers and steel production, it is assumed for refineries that reaching net zero by 2040 may become challenging.[26] Therefore, by 2040, ~2 Mt CO_2 (i.e. 6% of current levels) continues to be emitted in the retain and in partial relocation scenarios. In the full relocation scenario, it follows that CO_2 emissions from the EII in the Netherlands are reduced to zero, as the EII has relocated to other regions.

From a climate perspective, production in the country or region where the resulting CO_2 emissions are lowest is most desirable. Demand for the products of the energy-intensive industry will remain and even grow for most sectors.[27] Therefore, these products still need to be produced, leading to CO_2 emissions in the country of production. Since CO_2 emissions are a global problem, scenarios should be compared on a global impact basis, and not on a country level.

Moving production outside of Europe lowers control on CO_2 emissions and may not lead to the desired climate outcomes. Currently, European production facilities are relatively CO_2-efficient and Europe is considered most ambitious in its climate efforts. Looking forward, CO_2-intensity of the energy-intensive industry by 2040 in other regions relative to Europe are difficult to estimate and highly dependent on climate policies, energy prices, technological innovations etcetera. Moreover, other parts of the world are currently reconsidering their climate policies. For example, the United States recently withdrew from the Paris Climate Agreement and abolished many of its climate measures.[28] Thus, with the current geopolitical developments, simply assuming that other parts of the world will decarbonise their energy-intensive industries by 2040 in line with the ambitions of Europe does not seem very realistic. Moving production outside of Europe may not lead to the desired climate outcomes, and, by keeping production within Europe, Europe contains a higher degree of control over the industrial decarbonisation of its consumption.

Relocation of the EII from NW Europe to other regions within Europe can possibly lead to the realization of the EU's climate ambitions at lower costs. More favorable renewable energy conditions, for instance affordable hydropower in Scandinavia or higher solar irradiation in Southern-Europe, may be a reason to consider relocating part of the EII currently located in NW Europe to these areas. In case the climate policies are aligned on the European level, this could lead to welfare creation while maintaining realization of the same climate ambitions.

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[25] PwC Strategy& (2025), De sociaaleconomische bijdrage van 6 sectoren in de basisindustrie (link) – Percentage gecorrigeerd voor uitstoot van Tata Steel bij Vattenfall IJmond en Vattenfall Velsen

[26] PwC Strategy& (2024), VEMOBIN study (link)

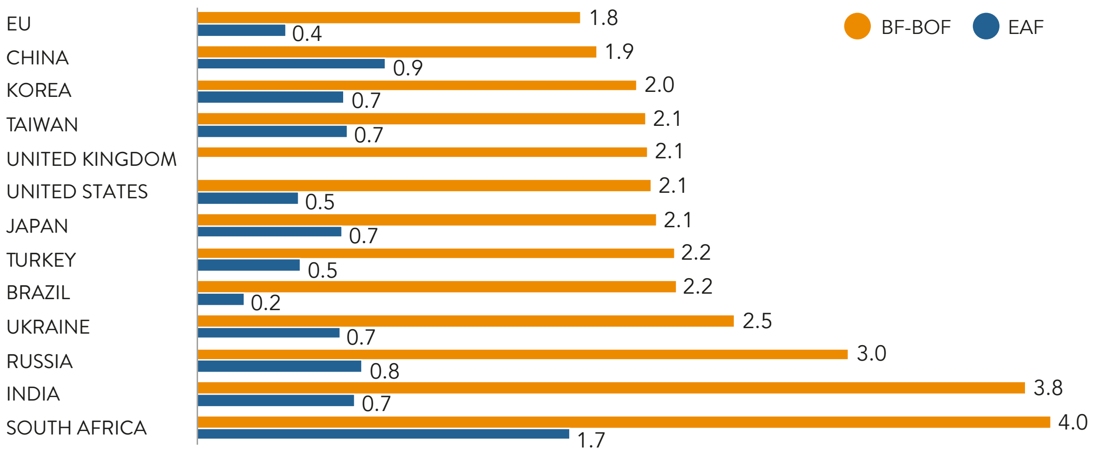
[27] PwC Strategy& (2025), De sociaaleconomische bijdrage van 6 sectoren in de basisindustrie (link)

[28] The White House (2025), Executive order – Unleashing American Energy (link)

Europe’s leading position in low-emission and efficient manufacturing processes

Europe leads in steel manufacturing considering the carbon footprint, with its BF-BOF steel production ranking first, followed by China.[29] Europe holds second place in the carbon footprint for steel production via the EAF route. Here Brazil takes the top spot, benefitting from abundant hydroelectric power.

Figure 3. Emission intensity of the BF-BOF and EAF route (t CO_2 / t of steel)



Europe’s leadership in carbon intensity is demonstrated not only in steel production but also across various industrial sectors. In the fertilizer industry, EU-produced fertilizers are, on average, 50-60% less carbon intensive compared to those produced outside the EU.[30]

In the refinery sector, similar results are found, with the average CO_2-emissions per barrel of refined crude oil at 28 kg, compared to a global average of 41 kg per barrel.[31]

Although some of these differences may be attributed to different configurations (e.g. EU refineries on average use lighter feedstock that emits less CO_2 and on average EU refineries may be less complex than their international counterparts), a large part of the difference in carbon intensity can be attributed to the EU ETS system, which has incentivized decarbonisation of industrial processes.

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[29] JRC (2022), Greenhouse gas intensities of the EU steel industry and its trading partners (link)
[30] Yara (2024), CBAM and exports: a critical path to EU competitiveness (link)
[31] SEB Research (2021), EU refineries on the line of fire (link)

4.2.2. OTHER EMISSIONS

Other emissions can have a more local character, and thus different considerations apply compared to CO_2 emissions. Although other emissions of the EII have decreased significantly over the last decades, they are currently responsible for 8% of particulate matter and 4% of nitrogen emissions in the Netherlands. Moreover, these industries are responsible for the emission of several other harmful emissions such as PFAS (one of the so-called Zeer Zorgwekkende Stoffen). In contrast to CO_2-emissions, other harmful emissions mainly have local implications, such as health concerns. In a densely populated area such as NW Europe, these harmful emissions have a relatively large impact. One might argue that relocation to less densely populated areas might lead to a net-positive effect. Still, this implies relocating the harmful effects of our consumption to other regions, leading to negative health effects there. These replacement effects should be explicitly considered when conducing a SCBA.

4.2.3. REQUIRED LAND AND WATER USE

Land used by the Dutch EII is currently equivalent to roughly 1.5 times the land area of the Rotterdam harbour. Currently, within the Netherlands the different sectors included in the scope of this study occupy ~50 km^2. This is equivalent to the area of cities such as Zeist or Amersfoort, or roughly 1.5 times the land area of the Rotterdam harbour. Although additional land may be required for decarbonised production processes (e.g. Maasvlakte III), the potential for “freeing up” land may be limited.

Lower energy production due to relocation of the EII may lead to land and sea areas becoming available for other purposes. The scenarios lead to differences in required energy generation and transportation networks. This requires scarce space on both land and water (North Sea). In terms of energy generation, it is estimated that in the relocation scenario, ~12-25 GW of the planned 50GW offshore wind might not be required anymore. As a result, multiple potential wind areas would no longer be required, which would free-up space on the North Sea for competing use-cases such as aquaculture, maritime transport and ecological purposes. Also the required area for the energy transportation network would decrease in the (partial) relocation scenario. For example, the required space for the expansion of the electricity grid (e.g. high- and mid-voltage stations, transformers) is estimated at ~8 km2 towards 2050.[32]

The argument that the relocation of the EII can free up scarce resources and thus lead to social benefits, overlooks the economic principle that scarcity is best allocated by market mechanisms. In the current debate, it is suggested that relocating the EII could address resource scarcity, which is a concern in countries with limited space, such as the Netherlands. This viewpoint assumes that it is up to the state to determine the distribution of scarce resources by identifying which sectors should have access to those resources. This perspective does not align well with the established economic principle that markets are effective tools for allocating scarce resources, provided that externalities are included in market prices to align market outcomes with societal goals. The EU emissions trading system (ETS) sets a price on emissions and allocates emission capacity to sectors and companies based on their willingness to pay, without bias towards or against specific sectors. Although it is accurate to assert that scarcity necessitates allocation, there is no definitive economic foundation to claim that the state will make superior decisions compared to the market regarding allocation. Furthermore, there is no justification for pre-emptively excluding specific sectors, such as the EII, from the allocation process.

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[32] Netbeheer Nederland (2025), Stand van de Uitvoering (link) – Assuming one football field is ~0.7 ha

4.3. STRATEGIC AUTONOMY

4.3.1. PRODUCT AUTONOMY

The scenarios differ in the relative dependency on raw materials, half-fabricates and end-products. With increasing geopolitical tension, product autonomy (defined as the degree of control over the production of goods, demanded by the European consumer) is becoming increasingly important. This is recognized by the European Commission and a key pillar of the recent Industrial Clean Deal[33]. Even in cases where production in other continents is cheaper, completely outsourcing the production of strategic products such as steel, fertilizer, chemicals and fuels can pose fundamental risks to the functioning of the (Northwestern) European society. The degree of product autonomy looks different in the four scenarios. In the full retain scenarios, NW Europe remains dependent on raw materials such as iron ore, crude oil, hydrogen and natural gas for the production of steel, refined products, chemicals and synthetic fertilizer. In the partial retain scenario, the dependency shifts to half-fabricates, such as iron, methanol and ammonia, while in the full relocation scenario, NW Europe will be dependent on the delivery of end-products, such as steel, refined products, chemicals and synthetic fertilizer.

Quantifying the impact of (partially) retaining EII on the degree of product autonomy requires detailed studies per subsector. How the degree of product autonomy compares between scenarios is highly dependent on the number of countries that will produce these products and on the relationship with these countries. As the homogeneity of products increases when a larger part of the value chain is relocated to other countries, it seems likely that product autonomy is highest in a scenario with local production. The extent of product autonomy, however, largely relates to the question whether production will move within Europe or move outside of Europe, which requires more detailed analyses at subsector-level.

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[33] European Commission (2025), Clean Industrial Deal (link)

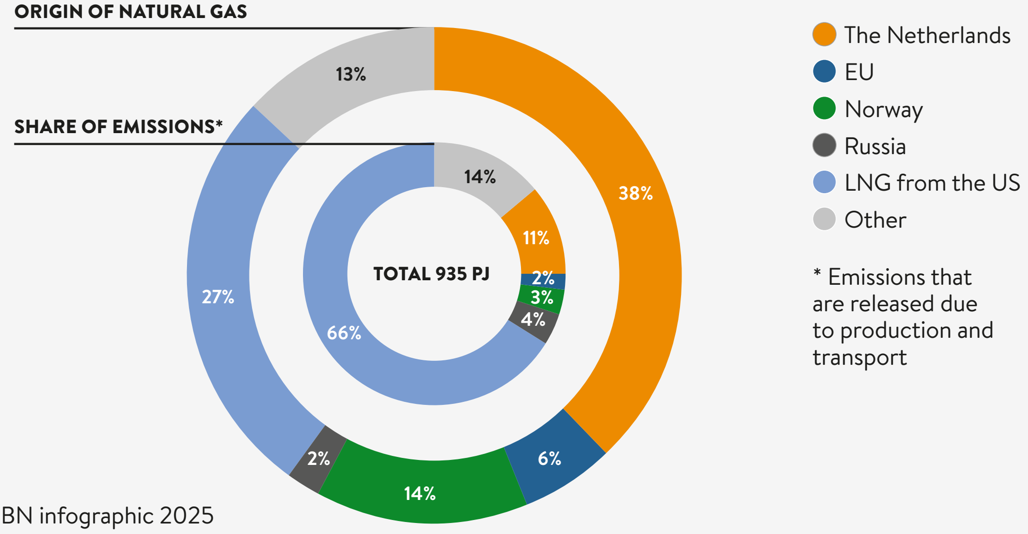
4.3.2. ENERGY AUTONOMY

Energy self-sufficiency is bound to practical limits, both for renewable and non-renewable energy sources. There are practical limits to the capacity of local energy production in case the EII decarbonises locally. For example, in case the EII decarbonizes primarily through renewable electricity and green hydrogen, an estimated 24-36 GW of hydrogen output capacity would be required in the Netherlands by 2040, whereas the current NPE assumes a maximum range of 15-20 GW electrolyser input capacity by 2040.[34] When the EII decarbonises primarily through natural gas and CCS, the required volumes of natural gas for the EII would exceed the available local natural gas in the Netherlands by 2040 tenfold. These practical limitations make it unlikely that the Netherlands can be self-sufficient in terms of energy in these scenarios.

It cannot just be assumed that energy autonomy will be greater when the EII (partially) relocates. As shown in Appendix B, the demand for green hydrogen and natural gas is significantly lower in the (partial) relocation scenarios vis-à-vis the retain scenarios. Consequently, in theory, the Netherlands can achieve a greater degree of self-sufficiency in these scenarios. However, imports of green hydrogen and/or natural gas not automatically leads to lower energy autonomy compared to the level we have today, as currently the industry is also highly dependent on import of e.g. natural gas, oil and coal. Furthermore, assuming lower energy autonomy due to local decarbonisation of the EII oversimplifies the autonomy issue, ignoring the impact of energy demand on the relative competitiveness of local energy production and the interconnectedness of European energy markets. The high-volume, baseload energy demand of the EII inherently affects the attractiveness of local production versus import. Therefore, detailed studies on the interaction between energy supply sources and the EII's energy demand are needed before any conclusion can be drawn on the impact on energy autonomy.

The sourcing of energy impacts emission levels, showing the interdependency between affordability, sustainability and reliability. For example, sourcing natural gas not only creates an import dependency but potentially also leads to higher emissions. E.g. currently 27% of the natural gas is imported from the US, but this accounts for 66% of emissions from producing and transporting natural gas. Therefore, import strategies should take both import dependency and emissions into account, next to cost considerations.

Figure 4. Origins and emissions of natural gas in the Netherlands.



* Emissions that are released due to production and transport

Source: EBN infographic 2025

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[34] Note that NPE given range is stated as electrical input capacity. The 15-20 GW input capacity translates to ~10-14GW output capacity.

5. APPENDICES

APPENDIX A - DEEP-DIVE ON ENERGY-INTENSIVE INDUSTRIES

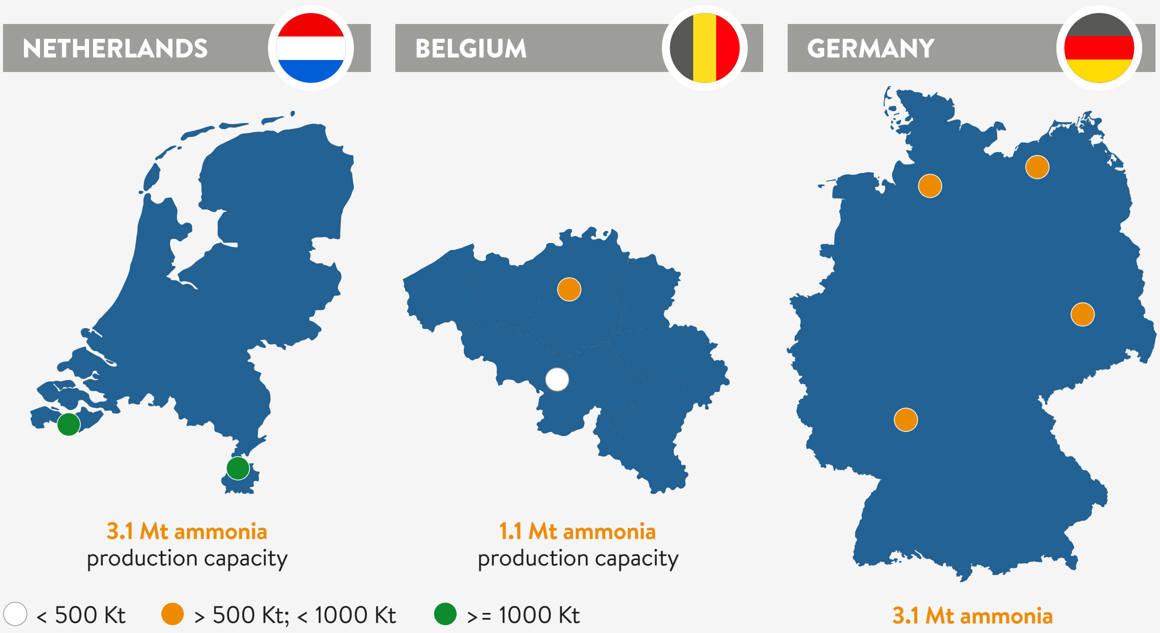
THIS SECTION DETAILS THE CURRENT LANDSCAPE AND PRODUCTION PROCESS AND POTENTIAL NEW PRODUCTION METHODS FOR SYNTHETIC FERTILIZER PRODUCTION, STEAM CRACKING, REFINING AND STEEL PRODUCTION. THESE INSIGHTS ARE USED TO OPERATIONALIZE THE FOUR DIFFERENT SCENARIOS (I.E. RETAINING GREEN, RETAINING BLUE, PARTIAL RETENTION AND FULL RELOCATION) IN APPENDIX B AND DETERMINE THE INFRASTRUCTURAL IMPACT IN APPENDIX C.

A1. CHEMICALS – SYNTHETIC FERTILIZER

Current landscape

In NW Europe, the total annual ammonia production capacity is approximately 7.3 Mt, with the Netherlands and Germany each holding a share of 3.1 Mt, while Belgium contributes 1.1 Mt.[35,36] This production capacity is distributed over 8 ammonia production plants: 2 plants in the Netherlands, 4 in Germany and 2 in Belgium. The leading producers are Yara and OCI in the Netherlands, EuroChem in Belgium, and SKW in Germany. Their production capacities are 1.9 Mt, 1.2 Mt, 0.7 Mt, and 0.9 Mt, respectively.

Figure 5: Ammonia production plants per country in 2023



Source: Fertilizers Europe (2018), ICIS (2023), Yara (2020)

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[35] Fertilizers Europe (2023), Industry facts and figures (link)
[36] Yara (2020), Production capacities (link)
[37] Fertilizers Europe (2018), Map of major fertilizer plants in Europe (link)
[38] ICIS (2023), Insight: poor demand, high costs stifle Europe industry despite falling gas prices (link)

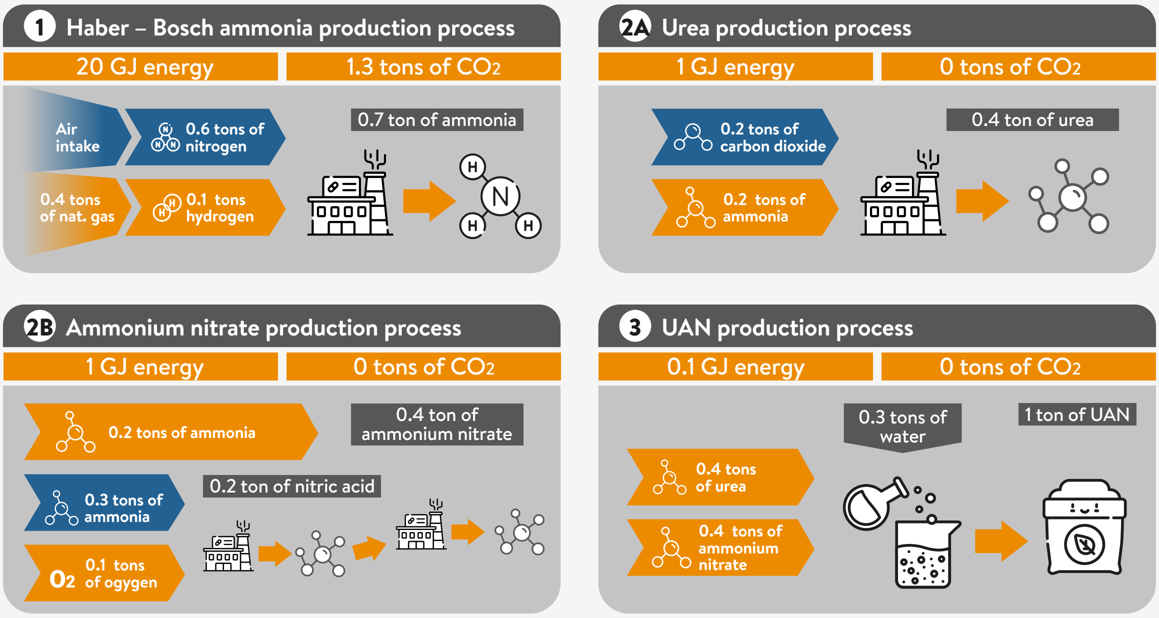
Following the steep increases in natural gas prices since 2022, largely due to the Russia-Ukraine war, synthetic fertilizer production has dropped in NW Europe. This is because the manufacturing process of fertilizers is highly reliant on natural gas (see next section). In 2023, the Netherlands produced 2.0 Mt, down 9% from 2019-2020's 2.2 Mt, while Germany produced 1.5 Mt, a 39% drop from 2.4 Mt.[39,40]

Overview of the process

The production of synthetic fertilizer, defined as urea ammonium nitrate (UAN), involves four simplified steps. The first and most energy-intensive step is the production of ammonia by combining hydrogen with nitrogen. This process emits 1.3 tons CO_2 per ton of UAN[41] and requires 20 GJ of energy including the grey hydrogen production. This step is followed by two parallel production steps, namely that of urea and ammonium nitrate. Relative to the production of UAN, both steps have relatively low emissions and only require around 2 GJ combined, if scaled to 1 ton of UAN. The last step is the production of UAN, which involves mixing urea and ammonium nitrate in water. This step does not emit any carbon dioxide and requires only 0.1 GJ in electricity per ton of UAN.[42]

Figure 6. Synthetic fertilizer production process

Synthetic fertilizer production processes



Source: IEA (2021), Rouwenhorst et al. (2021), Suryanto et al. (2021)

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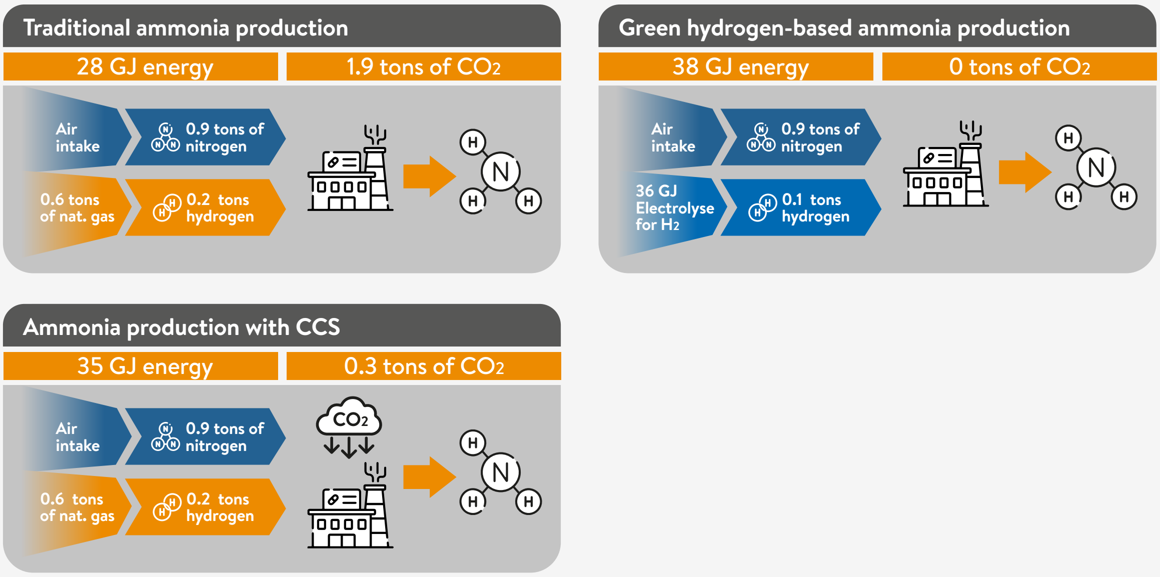
[39] USGS (2024), Mineral commodity summaries (link)
[40] USGS (2021), Mineral commodity summaries (link)
[41] Suryanto et al. (2021), Nitrogen reduction to ammonia at high efficiency and rates based on phosphonium proton shuttle (link)
[42] IEA (2021). Ammonia technology roadmap (link)

New methods

Given the high energy- and CO_2-intensity of the first step of synthetic fertilizer production, i.e. ammonia production, decarbonizing this part of the process requires most effort. Two alternatives are highlighted in this study: green hydrogen-based ammonia production and ammonia production with CCS. The first option changes the energy source for the hydrogen from natural gas to renewable hydrogen, i.e. produced from electricity through electrolysis. The total energy required to produce one ton of ammonia is 38 GJ, comprised of 36 GJ for hydrogen production and 2 GJ of electricity for the associated processes. CCS integrates a post-combustion system to capture 85% of CO_2 from ammonia production, utilizing 'blue' hydrogen but increasing energy consumption. It requires 35 GJ of energy and emits 0.3 tons of CO_2 per ton of ammonia. This is higher than the traditional ammonia production process due to the additional energy requirements for the CO_2 capturing installation.

Figure 7. Synthetic fertilizer production processes

Energy and emissions overview per ton of ammonia



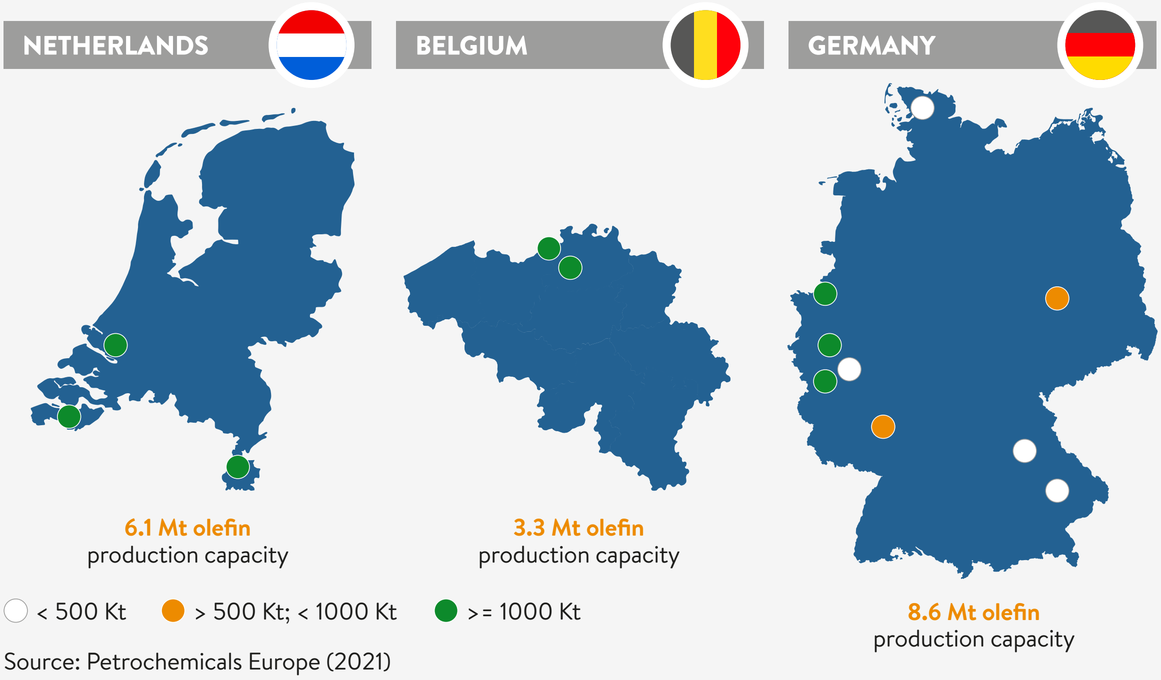
Source: IEA (2021), Rouwenhorst et al. (2021), Smith et al. (2019), Suryanto et al. (2021)

A2. CHEMICALS – STEAM CRACKERS

Current landscape

Various steam cracker plants operate in NW Europe to produce olefins, which are essential components for plastic products.[43] The production capacity in NW Europe is approximately 18.1 Mt.[44] The split of production capacity between the countries is 48% for Germany, 34% for the Netherlands and 18% for Belgium. This split is reflected in the number of steam cracking plants each country has. Germany hosts nine industrial sites across its territory. Among the largest facilities are Ineos in Cologne, which has an olefin capacity of 1.7 Mt, BP in Gelsenkirchen, with a capacity of 1.6 Mt, and LyondellBasell in Wesseling, with a capacity of 1.6 Mt. The Netherlands operates three steam crackers: Shell in Moerdijk, Sabic in Geleen, and DOW in Terneuzen, with olefin production capacities of 1.4 Mt, 2.0 Mt, and 2.7 Mt respectively. Belgium has two major steam cracking plants, Total Olefins Antwerp and BASF, both located in Antwerp.19 The olefin production is 1.7 Mt and 1.6 Mt, respectively.

Figure 8. Olefin production capacity (ethy. & propy.)



Source: Petrochemicals Europe (2021)

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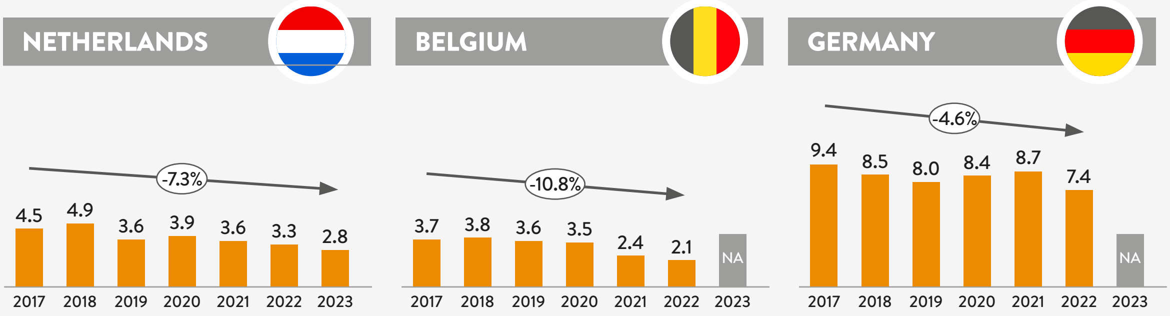
[43] This study uses ethylene and propylene production as proxies to estimate olefins, given they make up most olefins

[44] Petrochemicals Europe (2024), Facts and figures (link)

Olefin production in NW Europe has been decreasing since 2017.[45] The Netherlands' output fell from 4.5 Mt to 2.8 Mt in 2023, averaging a 7.3% annual decline. Belgium's production dropped from 3.7 Mt to 2.1 Mt in 2022, while Germany's production fell from 9.4 Mt to 7.4 Mt in 2022, with significant declines in 2022 for each country. The declining production levels can be largely attributed to high energy prices in NW Europe and global overcapacity.

Figure 9. Steam cracker actual production levels per country

Olefins actual production (in Mt, ethy. & propy.)



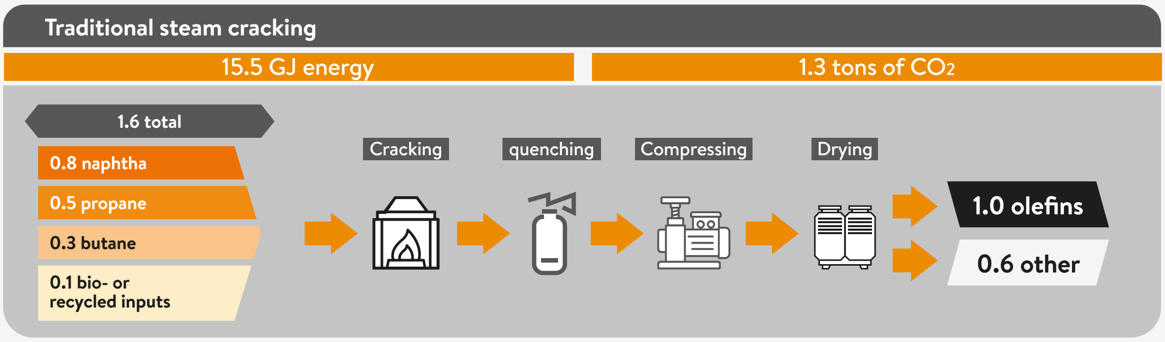
Source: Eurostat (2024)

Overview of the process

A steam cracker produces olefins, which are key precursors for plastics, by breaking down naphtha, a refinery product, and other hydrocarbons. The yield of olefins depends on the feedstock mix; lighter hydrocarbons like propane and butane produce higher concentrations of olefins but reduce the yield of other products such as aromatics. As one of the most energy-intensive industrial processes, it uses steam at high temperatures to crack long hydrocarbon chains into smaller molecules. Currently, most of the required energy comes from byproducts like methane and hydrogen. Producing 1 ton of olefins requires 15.5 GJ of energy and emits approximately 1.25 tons of CO_2.

Figure 10. Traditional steam cracking processes

Traditional steam cracking processes



Source: PBL (2024)

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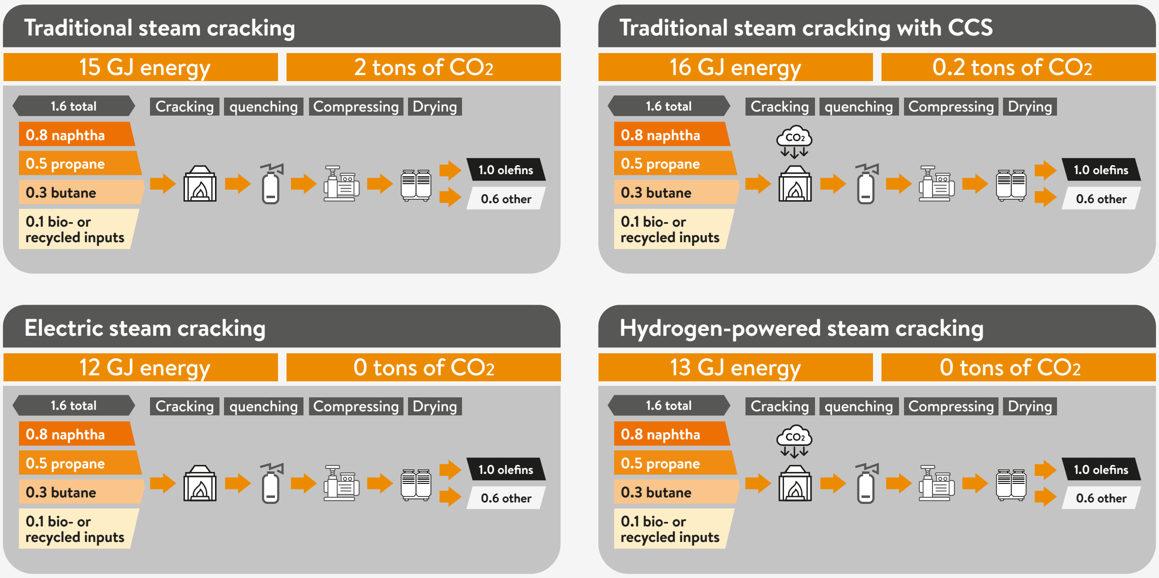
[45] Eurostat (2024), Total production (link)

New methods

There are alternative technologies for the steam cracking process; however, the maturity of these technologies is still relatively low as they have not been scaled yet. The most notable alternatives are electric steam crackers, hydrogen-powered steam crackers, and steam crackers with post-combustion CCS.[46] The electric steam cracker requires 11.6 GJ to produce 1 ton of olefins and does not emit any carbon emissions when using renewable electricity. Hydrogen-powered steam cracker requires 12.7 GJ to produce 1 ton of olefins and also does not emit any carbon emissions. Lastly, the steam cracker with CCS requires 16.5 GJ of energy and emits 0.2 tons of CO_2 per ton of olefins.

Figure 11. Alternative steam cracker processes

Alternative steam cracking processes



Source: Project MIDDEN (2022), PBL (2024)

Next to decarbonizing the production process of olefins, the feedstock for olefins can also be decarbonised. This becomes especially relevant in the context of declining refined fossil fuel products. There are multiple alternatives and this study explores using pyrolysis oil. The benefit of this alternative is that the current cracker installations can be used to convert the pyrolysis oil into olefins. In this study, the conversion rate of plastic waste to pyrolysis oil is assumed to be 80% efficiency[47] and requires approximately 2 GJ per ton of pyrolysis oil.[48]

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[46] PBL (2024), Manufacturing industry decarbonisation data exchange network – the database (link)

[47] Genuino et al (2022), *Pyrolysis of mixed plastic waste: Predicting the product yields* (link)

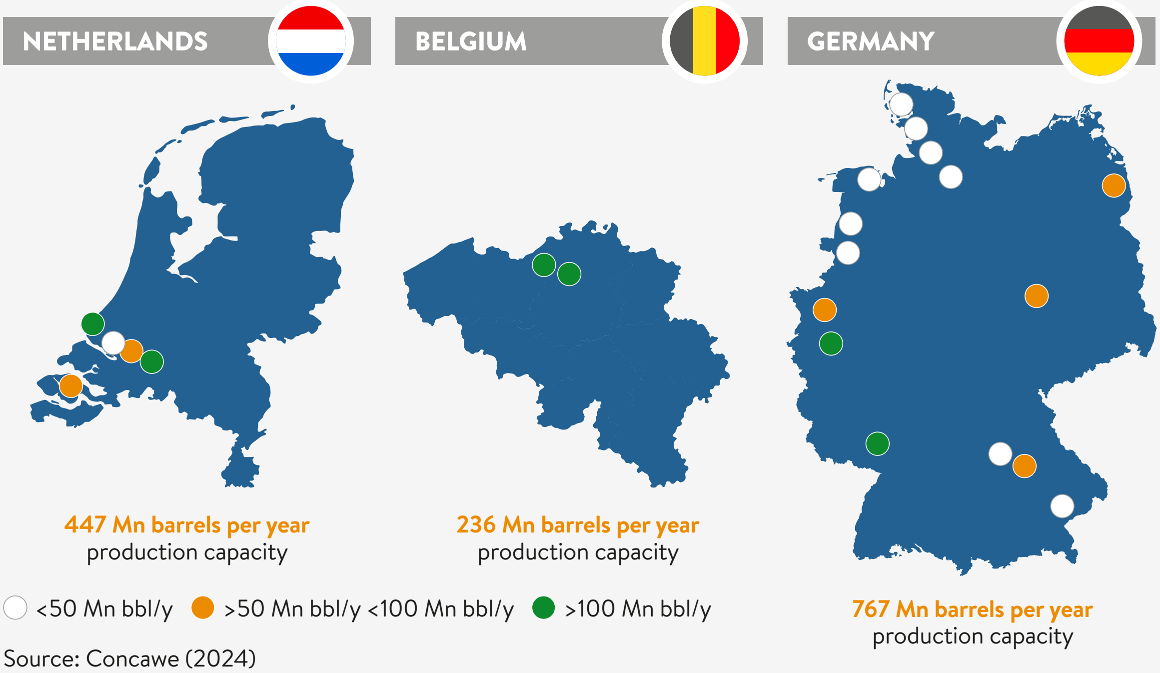
[48] Kodera et al. (2021), *Energy- and economic-balance estimation of pyrolysis plant for fuel-gas production from plastic waste based on bench-scale plant operations* (link)

A3. REFINING

Current landscape

The total refinery capacity of Northwestern Europe is estimated at 1.450 million barrels or 209 Mt of crude oil input per year. The total processing capacity of Germany is ~767 million barrels (53%), while the Netherlands and Belgium can handle 447 and 236 million barrels, respectively.[49] Germany has the highest number of refinery plants, with 15 active refineries. The Netherlands follows with 5 refineries, and Belgium has 2. The six largest refineries by input capacity are Shell (149 Mn barrels per year) and BP (145) in Rotterdam, Netherlands; Total Energies (122) and ExxonMobil (113) in Antwerp, Belgium; and Shell (119) in Rhineland and The Mineral Oil Refinery Oberrhein (MiRO) (105) in Karlsruhe, Germany.

Figure 12. Refinery production per country



Source: Concawe (2024)

The production output in the Netherlands remained relatively stable between 2015 and 2023, with a compound annual growth rate (CAGR) of 0.7%.[50] Germany's refinery sector showed similar stability, with a CAGR of -0.3% from 2015 to 2022. In contrast, Belgium's refinery sector experienced a decline, with a CAGR of -3.5% from 2015 to 2022. As opposed to other EII, refineries are less exposed to high gas prices, as most required energy is sourced from the processed crude oil, which is traded on global markets.

[49] Concawe (2024), Refinery and biorefinery sites in Europe (link)

[50] Eurostat (2024), Supply, transformation and consumption of oil and petroleum products (link)

Although the demand for fossil fuels is expected to experience a significant reduction (~38% as forecasted by the IEA)[51] in Europe, fossil fuels will still be needed by 2040. Hence, there is a need to decarbonise traditional refineries, and the potential impact thereof has been included in this study. Additionally, spurred by EU regulations, the transition to sustainable fuels will continue. One of these sustainable fuels is electro-Sustainable Aviation Fuel (e-SAF), which acts as an alternative to kerosene and is produced from renewable electricity. The forecasted demand for e-SAF in Europe is 6 Mt for 2040. As production of e-SAF is expected to be an energy-intensive process and there are plans to produce e-SAF in the NW Europe, this process has been included in this study.

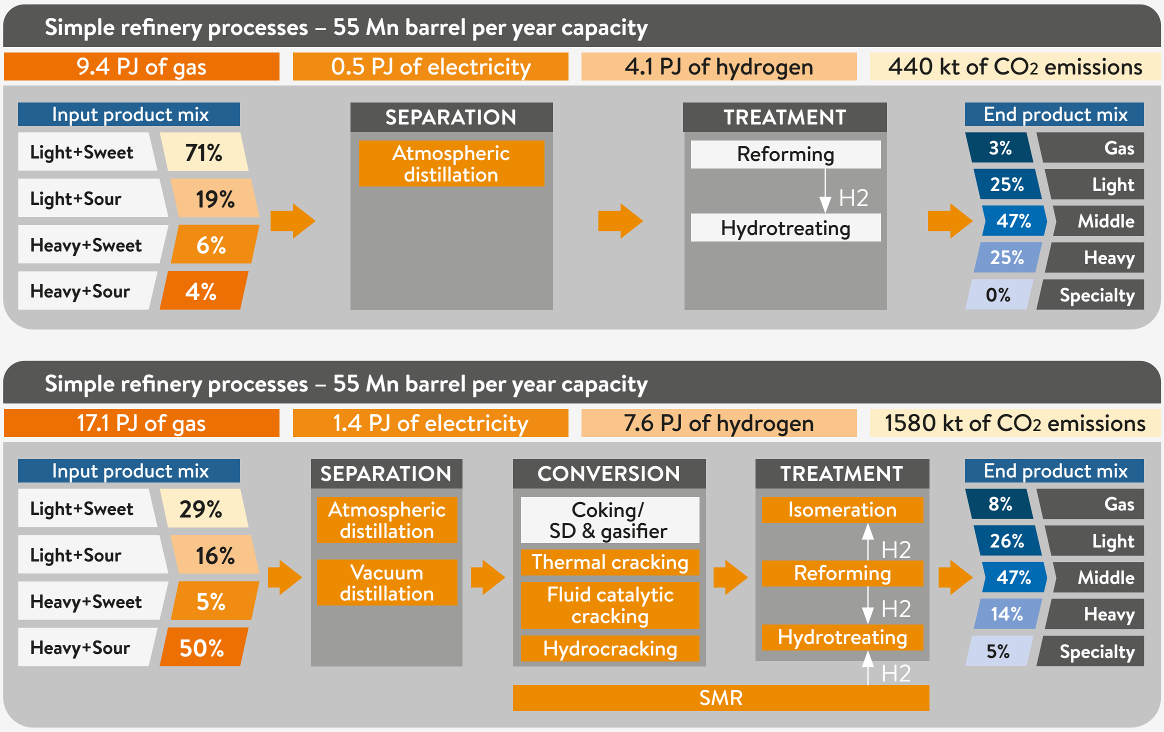
Overview of the process

Crude oil refining can be simplified into two main archetypes: simple and complex refineries. Simple refineries primarily process light crude oil, involving basic separation and limited treatment steps. Atmospheric distillation separates crude oil into fractions like gasoline, kerosene, naphtha, and diesel. Some fractions may undergo additional treatments (e.g. reforming or hydrotreating) to enhance quality. A simple refinery with an annual processing capacity of 55 Mn barrels of crude oil per year, is estimated to consume approximately 9.4 PJ of natural gas, 0.5 PJ of electricity, and 4.1 tons of hydrogen, while emitting roughly 440 kt of carbon dioxide (CO_2).[52]

Complex refineries process heavier crude oils and incorporate additional conversion steps (e.g., catalytic cracking, hydrocracking, coking) to break heavy hydrocarbons into lighter, valuable products. This increases yields of gasoline and diesel but requires more energy. A complex refinery processing 55 million barrels annually uses approximately 17.1 PJ of natural gas, 1.4 PJ of electricity, and 7.6 PJ of hydrogen and emits roughly 1.580 kt of CO_2 each year.

Figure 13. Refinery processes

Input and output processes of refineries per year



Source: PwC Strategy& (2025) ● Certain part of the configuration ○ Optional part of the configuration

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51 IEA (2024), World Energy Outlook (link)
52 Vemobin study

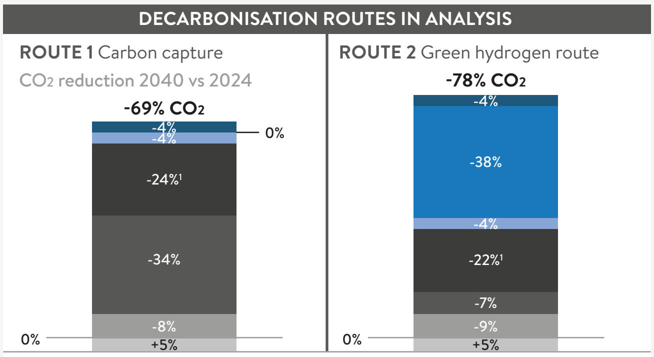
New methods

Refineries have various options to reduce carbon emissions in their operations. This study examines two primary routes for both simple and complex refinery models: the CCS route and the green hydrogen route.

The green hydrogen route overlaps with the CCS route and the differences are only in focus. Both routes assume CCS, electrification, utilisation of residual heat and energy efficiency measures, but the green hydrogen incorporates hydrogen as fuel in furnaces (in addition to feedstock purposes), reducing the need for CCS on the refinery process. In this case, gas consumption and carbon emissions drop by 43% and 78%, while electricity and hydrogen demand increase by 134% and 168%. This translates to a new gas consumption of 5.4 PJ, electricity demand of 1.1 PJ, hydrogen requirement of 10.9 PJ and carbon emissions of 96 Kt per year for a simple refinery. For a complex refinery, the gas consumption is 9.7 PJ, electricity demand is 3.3 PJ, hydrogen need is 20.3 PJ and carbon emissions are 345 Kt.

The CCS route involves CCS on the Steam Methane Reformer and on the refinery process, electrification, utilisation of residual heat and energy efficiency measures, potentially reducing emissions by 69% to 135 kt for a simple refinery or 485 kt for a complex refinery per year. To enable this CO_2 reduction, electricity usage will increase by 183% to 1.4 and 4.0 PJ per year for simple and complex refineries, respectively.

Figure 14. New refinery methods



ROUTE 1		ROUTE 2	
Gas usage	+ 0%	Gas usage	- 43.0%
ELectricity usage	+ 182.9%	ELectricity usage	+ 134.3%
Hydrogen usage	+ 0%	Hydrogen usage	+ 168.3%
CO_2-reduction to 1990	- 79.0%	CO_2-reduction to 1990	- 85.1%

CATEGORY / DESCRIPTION	
●	**Heat** - Utilisation of residual heat
●	**H2 as fuel** - Replacing natural and refinery gases with (blue) hydrogen to heat furnaces
●	**Electrification**- Electrification of drives (e-boilers, e-furnaces etc.)
●	**CCS** (blue H2) - CCS on steam methane reformer (SMR) for blue hydrogen production
●	**CCS** (refining processes) - CCS on refinery processes
●	**Energy efficiency** - Energy efficiency measures
●	**Upgrading projects** - Upgrading processes to meet tightened requirements (e.g. for cleaner fuels)

ENERGY PROFILES OF SIMPLE & COMPLEX REFINERIES
(size 55 Mn barrels per year, energy in PJ, emissions in Kt)

Simple refineries

Different scenarios	Gas	Electricity	Electricity	CO_2 em.
Current	9.4	0.5	4.1	439
2040 H_2 +CCS	5.4 -43%	1.1 +134%	10.9 +168%	96 -78%
2040 CCS	9.4	1.4 +183%	4.1	135 -69%

Complex refineries

Different scenarios	Gas	Electricity	Hydrogen	CO_2 em.
Current	17.0	1.4	7.6	1577
2040 H_2 +CCS	9.7 -43%	3.3 +134%	20.3 +168%	345 -78%
2040 CCS	17.0	4.0 +183%	7.6	485 -69%

Source: DNV-GL (2018) ‘CO_2 Reductie Roadmap van de Nederlandse raffinaderijen’ NOTE: Route three ‘Electrification’ is excluded from this study due to relatively lower CO_2-reduction potential by 2050;
1) Since the ‘Simple refinery’ arcetype does not have an SMR, we assume that the same reduction is achieved with post-combusion CCS

Source: PwC Strategy& (2025)

For e-SAF production, two potential routes are investigated. The first route involves the direct production of e-SAF from hydrogen and carbon dioxide, while the second route involves indirect production by synthesizing methanol from hydrogen and carbon dioxide and then converting it into e-SAF. The direct method requires about 50 GJ per ton of e-SAF, mainly in hydrogen. The indirect method requires around 70 GJ per ton of e-SAF; 67 GJ for electric methanol production and 3 GJ for converting methanol to e-SAF. The benefit of the indirect method is that production can be split across regions, allowing the energy-intensive methanol to be produced in renewable energy abundant regions and the second step to be done in NW Europe. This setup is also planned by Power2X and Advario, who are developing an e-SAF production facility with a capacity of 250 kton per year.[53]

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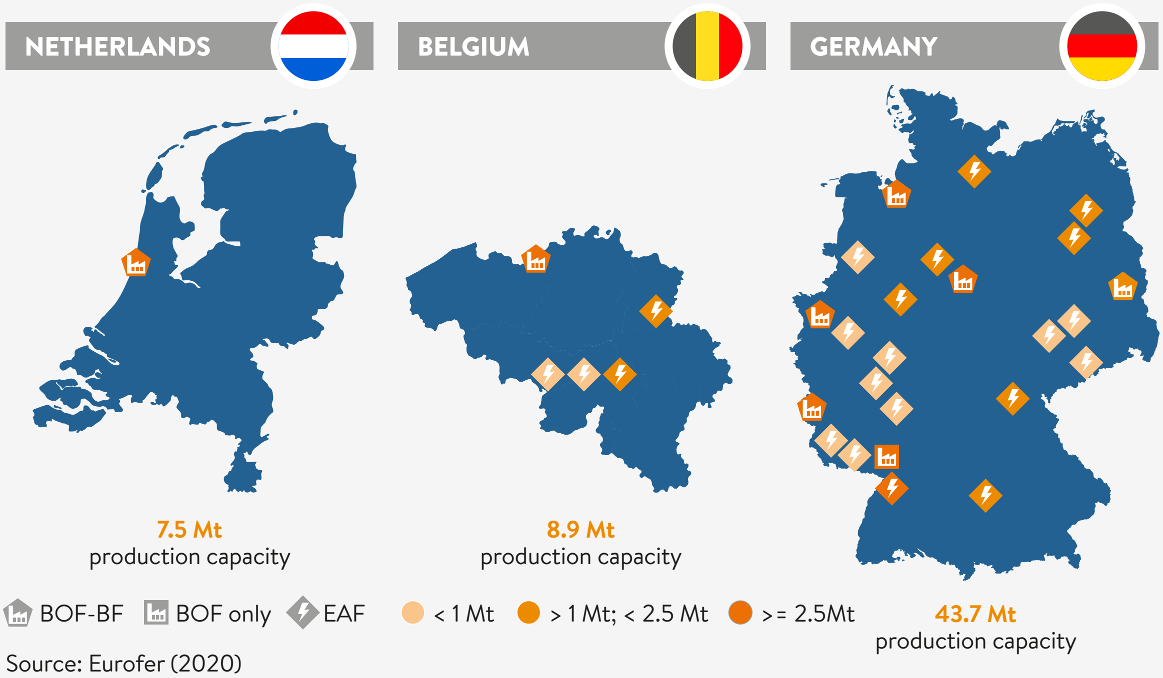
[53] Power2X (2024), Power2X and Advario to develop world-scale e-SAF hub in the Port of Rotterdam (link)

A4. STEEL

Current landscape

Northwestern Europe hosts a total annual steel production capacity of ~60 Mt.[54] Roughly 75% (44 Mt) is in Germany, while Belgium has a production capacity of 9 Mt and the Netherlands 8 Mt. Germany has 24 production plants, Belgium has 5 plants and the Netherlands has one production plant, namely Tata Steel in IJmuiden. Most of the Belgian and German plants constitute secondary steel production plants that use an Electric Arc Furnace (EAF) to primarily recycle scrap steel. In Germany, the largest primary steel producers (using a blast furnace and basic oxygen furnace, or BF-BOF) are ThyssenKrupp in Duisburg, Salzgitter AG in Salzgitter, and ArcelorMittal in Bremen with a production capacity of 12 Mt, 5 Mt and 4 Mt, respectively. In Belgium, the largest primary steel producer is ArcelorMittal, based in Ghent, with a production capacity of 5 Mt.

Figure 15. Steel production plants per country in 2023



Source: Eurofer (2020)

In 2023, Northwestern Europe produced 46 Mt of steel, accounting for approximately 36% of total European steel production.[55] However, the region's steel production has been decreasing over the past five years by 3 to 8 percent per year, with total output declining from 54 Mt in 2019. This decline has been driven by decreasing demand, higher energy prices and global overcapacity.

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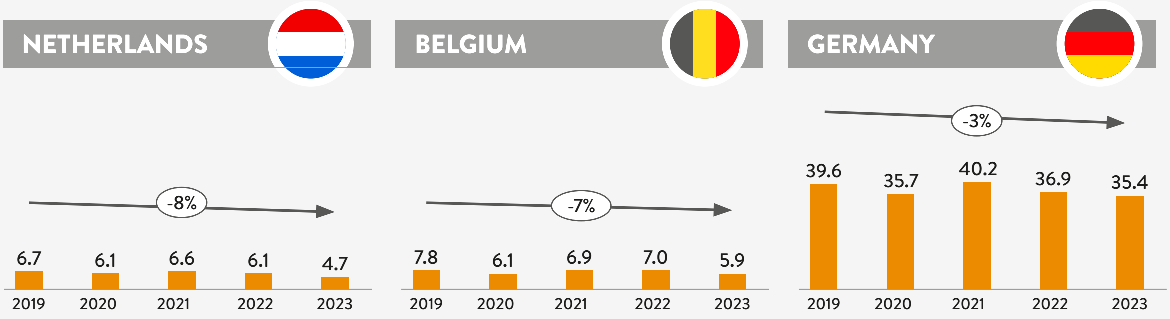
[54] Eurofer (2020), Map of EU steel production sites (link)

[55] Eurofer (2024), European Steel in Figures (link)

Figure 16. Actual steel production per country in 2023



Source: Eurofer (2024)

Northwestern Europe's steel production capacity exceeds its consumption.[56] From 2019 to 2023, the annual steel consumption of the Netherlands, Belgium, and Germany was 40.7 Mt. The Netherlands' average annual consumption from 2019 until 2023 is 4.6 Mt (76% of production), Belgium used 3.7 Mt (55% of production), and Germany needed 32.5 Mt (86% of production). It is not conclusive that Northwestern Europe is self-reliant in steel consumption due to significant specialization in the industry. For example, the share of demand for basic metals that is serviced by domestic production in the Netherlands is 41%, and an additional 26% is supplied by Belgium and Germany.[57] For Belgium and Germany, the shares of demand that is serviced by NWE is 71% and 60%, respectively. Note that the definition of basic metals is broader than only steel and only includes e.g. zinc and aluminium.

Overview of the process

Currently, there are two major production methods for producing steel. The first method consists of two steps where a blast furnace is used to extract iron from iron ore after which the iron is refined via a basic oxygen furnace. The first method, the BF-BOF route, is particularly energy-intensive as it relies on fossil fuels, primarily coal. Per ton of steel, 19 GJ of energy is required and 1.9 tons of CO_2 is emitted.[58]

The second production method is the production of steel with an EAF. However, this method is incompatible with iron derived from the blast furnace due to the high carbon content present in the iron. Consequently, EAFs are primarily utilized for recycling scrap metal into crude steel. This process converts 1.1 tons of scrap into 1 ton steel, consuming 2 GJ of energy and producing between 0 to 1 ton of CO_2, depending on the method of electricity generation.[59]

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[56] World Steel Association (2024), World steel in figures (link)

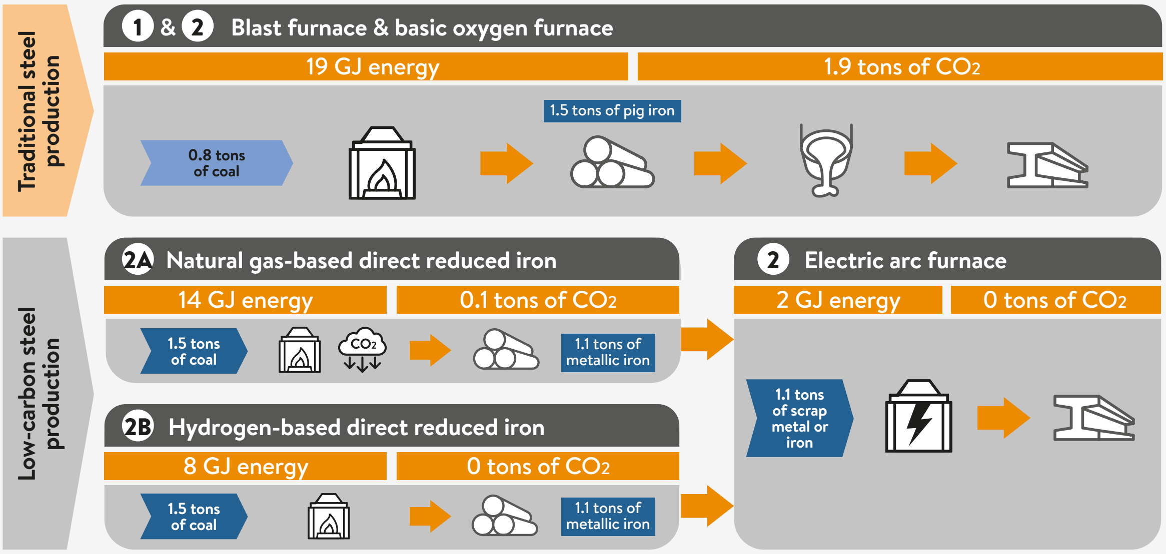
[57] PwC Strategy& (2025), De sociaaleconomische bijdrage van 6 sectoren in de basisindustrie (link)

[58] IEA (2020), Iron and steel technology roadmap (link)

[59] Toulouevski & Zinurov (2017), EAF in global steel production; energy and productivity problems (link)

Figure 17: Steel production process

Energy and emission overview per ton of steel



Source: IEA steel report (2020), Toulouevski & Zinurov (2017)

New methods

A sustainable production method for steel is the DRI-EAF route. First, iron ore reacts with natural gas or hydrogen to form direct reduced iron (DRI). Since this iron has a lower carbon content than traditional pig iron, an EAF can be used to convert this iron into primary steel. Because the ore does not need to be melted and both natural gas and hydrogen are cleaner energy carriers than coal, the energy consumption and CO_2 emissions drop significantly. The full production route of natural gas-powered DRI-EAF requires 14 GJ and emits 0.7 tons of carbon dioxide. When paired with a CCS system, the energy required jumps to 16 GJ while carbon emissions drop to 0.1 tons. Following the hydrogen-based DRI to EAF route requires 10 GJ and theoretically emits zero carbon dioxide.

APPENDIX B – SCENARIO OPERATIONALIZATION

BASED ON THE OUTCOMES DESCRIBED IN APPENDIX A, THE FOUR SCENARIOS (RETAINING GREEN, RETAINING BLUE, PARTIAL RETAINING AND FULL RELOCATION) ARE OPERATIONALIZED FOR THE FOUR ENERGY-INTENSIVE PROCESSES.

Chemicals – Synthetic fertilizer

Synthetic fertilizer can be decarbonised by introducing green or blue hydrogen. Moreover, splitting the production process according to energy-intensity seems feasible. Based on this, the figure below shows the operationalization of the four scenarios for synthetic fertilizer.

Figure 18. Scenario operationalization for synthetic fertilizer

In-scope industry		Retaining green scenario		Retaining blue scenario		Partial relocation scenario		Relocation
Fertilizer	Ammonia	✓	Complete production process is decarbonised (green H2)	✓	Most of emissions have been reduced with a CSS system	✗	Only second steps (Production of urea, ammonium nitrate and beyond are kept in the NL	✗
	Urea	✓		✓		✓		✗

The figures below in turn show energy consumption and CO$_2$ emissions per scenario.

Figure 19. Total energy consumption for synthetic fertilizer production per country for different scenarios (in PJ)

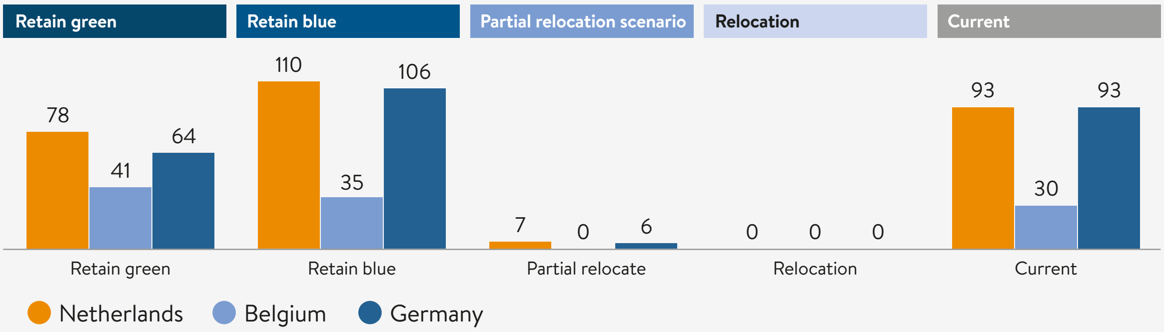
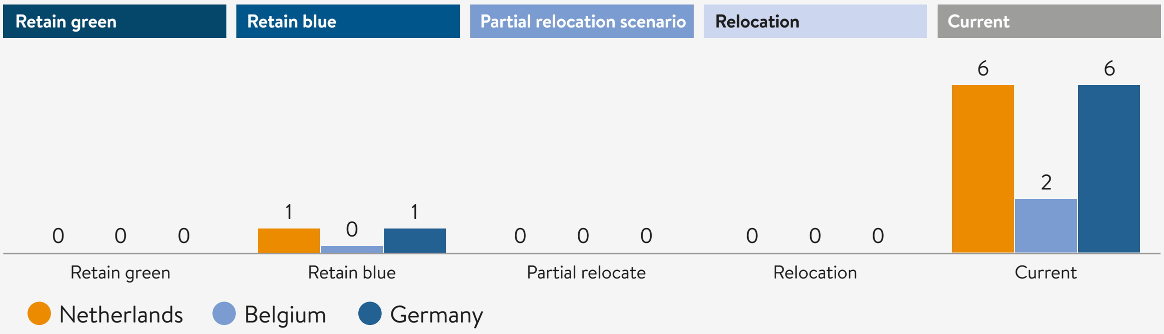


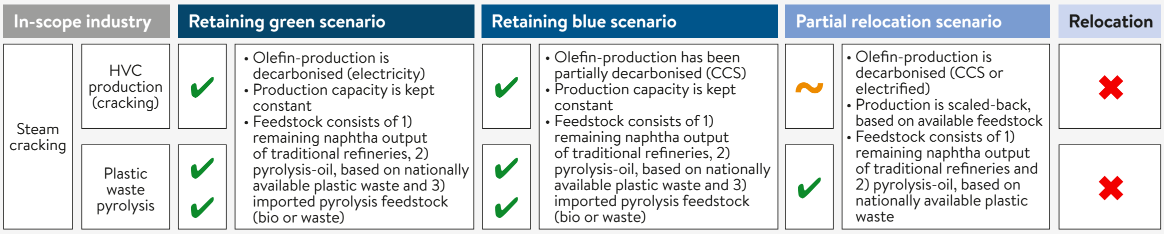
Figure 20. Total CO$_2$ emissions for synthetic fertilizer production per country for the different scenarios (Mt)



Chemicals – Steam cracking

Steam crackers currently rely primarily on fossil-based naphtha. For all future scenarios, this study has examined reduced levels of feedstock in proportion to the anticipated demand decline in the refinery sector (see section 3.3). Consequently, for olefin production to stay constant, a substitute for the feedstock will be necessary to address the shortfall. One potential method is using pyrolysis oil, which is recycled from plastic waste or biobased products and can serve as an alternative to naphtha.[60] In this study, only plastic waste is examined for domestic pyrolysis oil production. The Netherlands produces approximately 1 Mt of plastic waste.[61] The plastic waste for Belgium and Germany is estimated at 0.7 Mt and 4.6 Mt. As this is not sufficient to sustain current production levels, import of pyrolysis oil to bridge the gap entirely is incorporated in the full retain scenarios. In the middle scenario, the production level is adjusted and only includes domestic plastic waste.

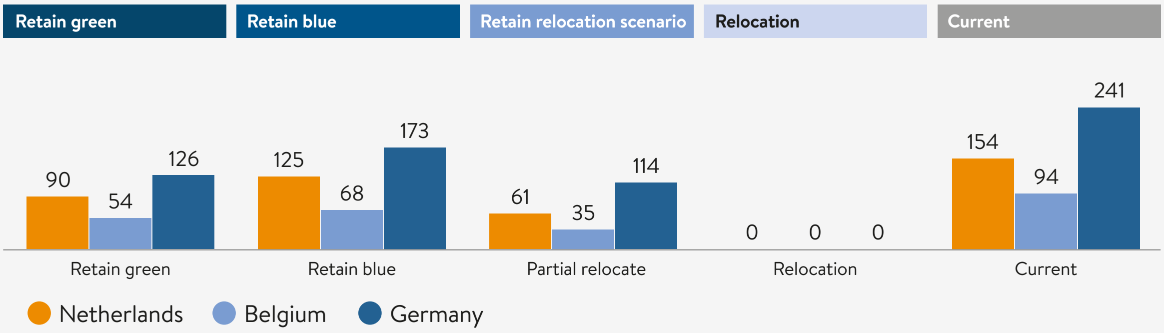
Figure 21. Scenario operationalization for steam cracking



In-scope industry		Retaining green scenario		Retaining blue scenario		Partial relocation scenario		Relocation
Steam cracking	HVC production (cracking)	✓	• Olefin-production is decarbonised (electricity) • Production capacity is kept constant • Feedstock consists of 1) remaining naphtha output of traditional refineries, 2) pyrolysis-oil, based on nationally available plastic waste and 3) imported pyrolysis feedstock (bio or waste)	✓	• Olefin-production has been partially decarbonised (CCS) • Production capacity is kept constant • Feedstock consists of 1) remaining naphtha output of traditional refineries, 2) pyrolysis-oil, based on nationally available plastic waste and 3) imported pyrolysis feedstock (bio or waste)	~	• Olefin-production is decarbonised (CCS or electrified) • Production is scaled-back, based on available feedstock • Feedstock consists of 1) remaining naphtha output of traditional refineries and 2) pyrolysis-oil, based on nationally available plastic waste	✗
	Plastic waste pyrolysis	✓ ✓		✓ ✓		✓		✗

The figures below in turn show energy consumption and CO_2 emissions per scenario:

Figure 22. Total energy consumption for olefin production per country for the different scenarios (in PJ)



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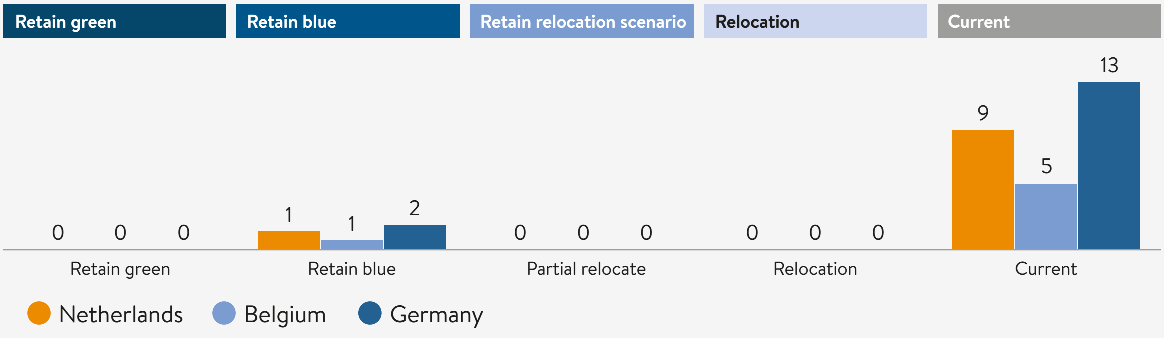
[60] Ohno et al. (2024), Feedstock recycling of waste plastics in an oil refinery: Scenario development based on sorting and pyrolysis experiments (link)

[61] Plastics Europe (2020), Circular economy for plastics (link)

Figure 23. Total CO_2-emissions for olefin production per country for the different scenarios (Mt)



Refining

Similar to steam cracking, this study accounts for the declining demand for fossil-based fuels in the operationalization of the scenarios for the refining sector. Meanwhile, European demand for e-SAF is expected to grow to ~6 Mn barrels annually and for the (partial) retaining scenario, it is assumed that NW European will continue to supply the same proportion of e-SAF as it currently does for fossil-based jet fuel.

In the retain green scenario, the green hydrogen route is used to decarbonise traditional refineries and in the retain blue scenario, the CCS route is used. Additionally, the production of e-SAF is included to address the anticipated increase in demand for sustainable jet fuel. A partial relocation within the conventional refinery industry has not been investigated, as traditional refining is a highly integrated process, which is difficult to split. As it does seem feasible to divide e-SAF production, based on energy-intensity, the partial relocation scenario examines the energy and emission profile associated with relocating the initial step, methanol production, abroad, while retaining the synthesis of e-SAF domestically. A noteworthy case study exemplifying this alternative method of producing e-SAF is the Power2X initiative at the port of Rotterdam, Netherlands.

Figure 24. Scenario operationalization for refining

In-scope industry		Retaining green scenario		Retaining blue scenario		Partial relocation scenario		Relocation
Refining	Traditional	✓	• Traditional refining is decarbonised (green H2) • e-SAF production is scaled-up based on produced green hydrogen	✓	• Most emissions have been reduced (CCS) • E-SAF is not applicable if refinery are still powered by fossil fuels	✓	• Refining is decarbonised (CCS or green H2) • e-SAF production is scaled-up (based on imported methanol)	✗
	e-SAF production	✓		✗		~		✗

The figures below in turn show energy consumption and CO_2 emissions per scenario:

Figure 25. Total energy consumption for refining per country for different scenarios (in PJ)

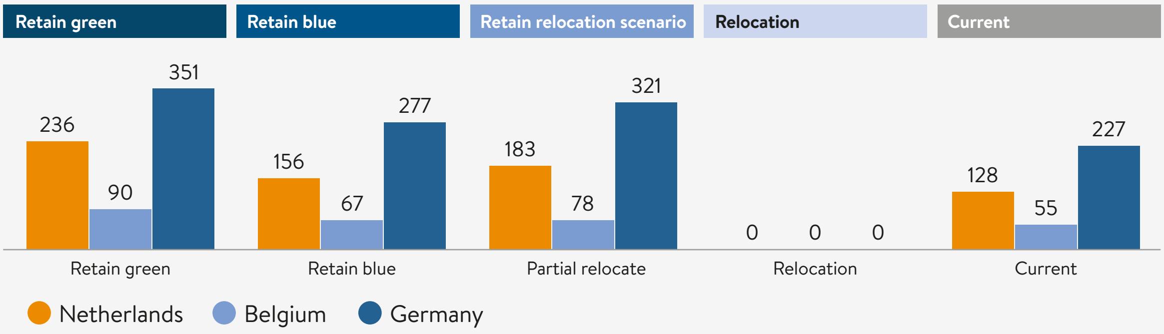
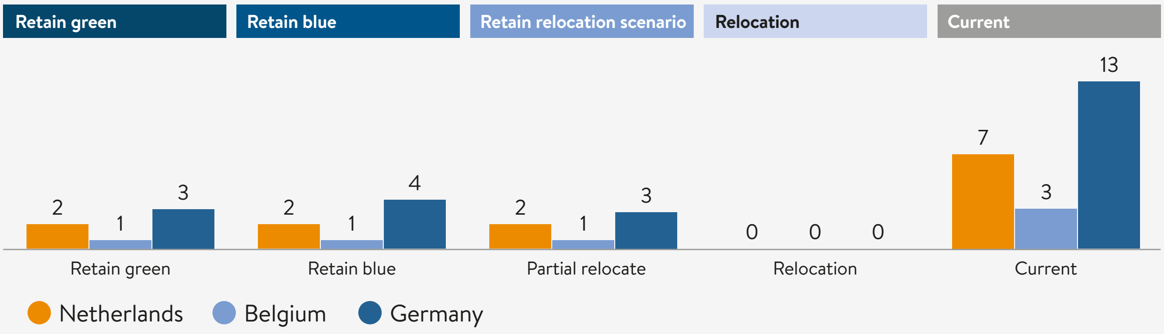


Figure 26. Total CO_2-emissions for refining per country for the different scenarios (Mt)



Steel

In the Retain green and Retain blue scenarios, domestic steel production is continued via the DRI-EAF route. Both scenarios assume that the electricity required for the EAF stage is derived from renewable energy sources. The difference between these scenarios lies in the energy carrier for the DRI process. In the Retain green scenario, hydrogen sourced from renewable energy powers the process, thereby eliminating carbon emissions entirely. In the Retain blue scenario, natural gas is utilized as the energy carrier, with an added CCS system to reduce carbon dioxide emissions.

In the partial relocation scenario, the first stage of steel production, DRI, is conducted internationally and the second stage, EAF, is done domestically. The rationale is that the EAF stage is much less energy intensive and does not emit any CO_2, and thus, meeting the future industry's energy demand is less strenuous on renewable energy infrastructure development. Additionally, the process of steel production through DRI-EAF seems to lend itself to be split into two, although there may be practical issues (e.g. energy-inefficiencies).

Figure 27. Scenario operationalization for steel

In-scope industry		Retaining green scenario		Retaining blue scenario		Partial relocation scenario		Relocation
Steel	DRI	✓	Complete production process is decarbonised (based on hydrogen-DRI)	✓	Most of emissions have been reduced (based on natural gas-DRI and CCS)	✖	Only second step (EAF) is kept in the NL	✖
	EAF	✓		✓		✓		✖

The figures below in turn show energy consumption and CO_2 emissions per scenario.

Figure 28. Total energy consumption for steel production per country for different scenarios (in PJ)

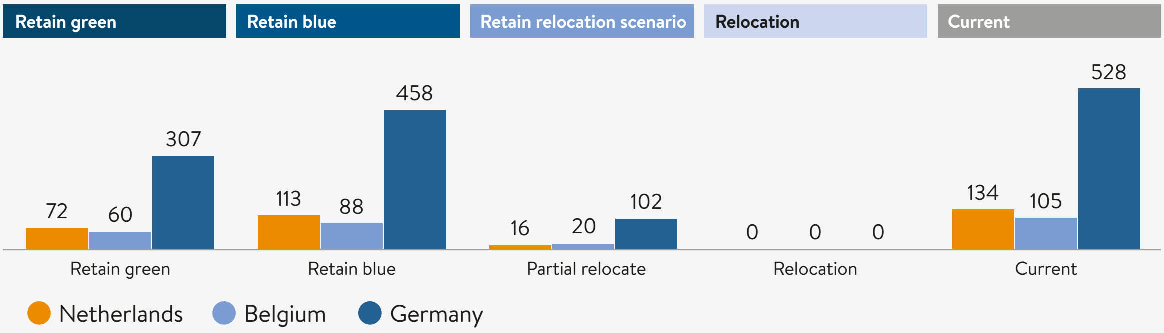
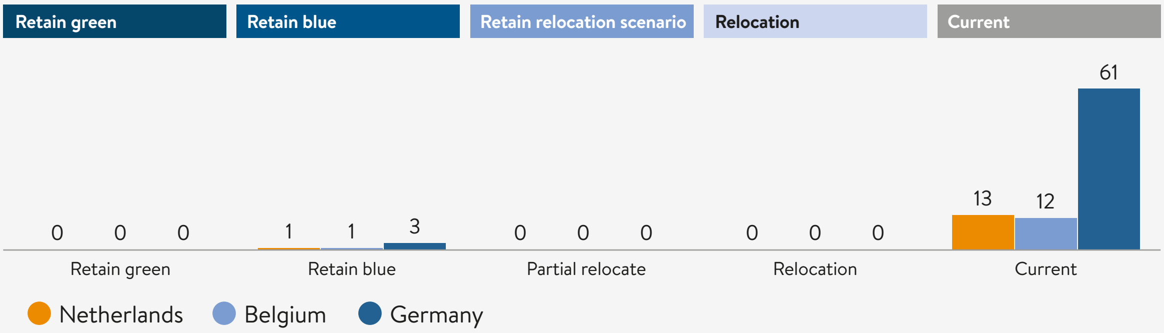


Figure 29. Total CO_2-emissions for steel production per country for the different scenarios (Mt)



APPENDIX C - DEEP-DIVE ON INFRASTRUCTURAL IMPACT OF DIFFERENT SCENARIOS

The required investments until 2040 in the Dutch energy grids (electricity, natural gas, heat and hydrogen) have recently been estimated at ~€219 bln, of which ~€197 bln relates to the electricity grid.[62] Moreover, a recent study shows that if total industrial energy demand drops by ~1/3 or ~2/3, the required investments in the electricity grid would drop by 10% and 25%, respectively. This is mainly driven by a decrease in required offshore wind.[63] This study adds to this by estimating the impact of different decarbonisation routes (green and blue), by isolating the energy-extensive parts of the energy-intensive industry in the partial retain scenario and by explicitly taking into account the second order effect of relocation decisions of the German and Belgian EII.

Methodology
First the total energy demand of the four energy-intensive sectors in the various scenarios (Retaining Green, Retaining Blue, Partial Relocation, Full Relocation) is compared with the demand assumptions within the ii3050 scenarios. Second, the impact on demand is analyzed for each individual energy carrier (electricity, hydrogen, natural gas). This leads to insights on how the expected energy demand in the Netherlands for 2040 is affected by the various industry scenarios.

Third, again based on ii3050 scenarios, changes in the required energy mix are established. This is done by pro-rata reducing the supply mix from the ii3050 scenarios until supply is again in line with demand. This leads to insights on how the supply mix could differ under the various industry scenarios.

Fourth, the impact on the whole energy system is analyzed. This is done because the energy system not only requires an equilibrium between yearly supply and demand, but also matching of demand and supply profiles. This leads to insights on how flexibility options are affected by the various industry scenarios.

Finally, the potential implications of the scenarios on the existing Dutch energy and infrastructure plans are estimated.

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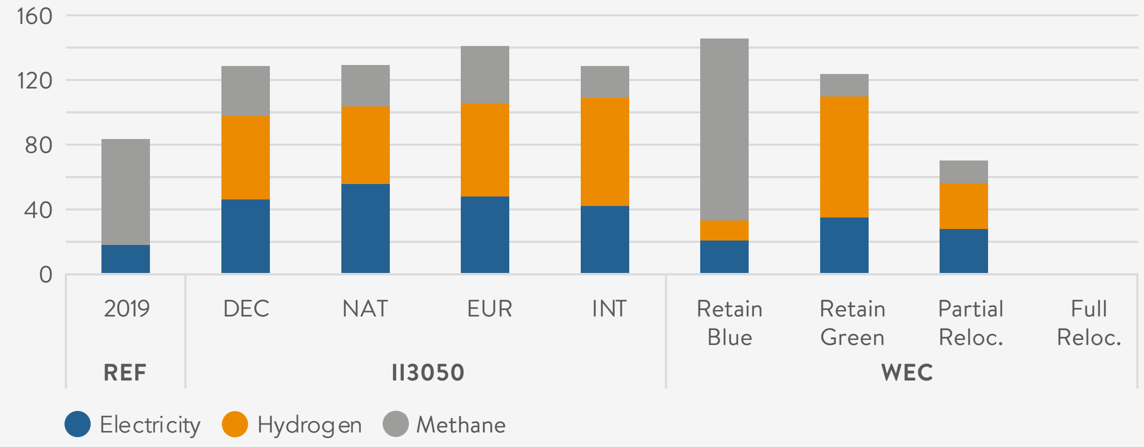
[62] Netbeheer Nederland, Financiële Impact Energietransitie voor Netbeheerders (16 December 2024)
[63] Kalavasta, Effecten van systeemkeuzesop investeringen elektriciteitsinfrastructuur (10 January 2025)

C1. ENERGY DEMAND OF THE 4 ENERGY-INTENSIVE SECTORS COMBINED

Total energy demand in 2040
In Appendix B the electricity, hydrogen and natural gas demand for the 4 energy-intensive sectors were presented. To put these numbers in perspective, the calculated total demand is compared with the ii3050 energy demand estimations for these sectors in 2040.[64]

As shown in figure 30, although the underlying energy mix vastly differs, the total energy demand estimations of the Retaining Green and Blue scenarios are in the same order of magnitude as the ii3050 estimations for the sectors in 2040.[65] Furthermore, the Partially Retain scenario reduces the energy demand of the 4 sectors with ~44-52%. Finally, full relocation of industry will result in a 100% reduction (meaning zero energy demand).

Figure 30. Total demand of the four energy-intensive industries sectors in 2040 (TWh)



The remainder of this section dives more specific into the impact of (partial) relocation of the energy-intensive industry on the Dutch hydrogen, electricity and natural gas demand in 2040.

i. Impact on the hydrogen demand in 2040
According to ii3050, the total expected yearly hydrogen demand in the Netherlands is 151-253 TWh by 2040.[66] Relocation of the energy-intensive industry has a big impact on the total hydrogen demand, as the calculated demand from these industries accounts for ~38-62% of the total hydrogen demand in the Netherlands as per 2040. The partial relocation scenario will lead to ~24-38% in reduction in total hydrogen demand compared to the Retaining Green scenario. Note that these reductions accounts for reduction in direct demand in NL as well as for reduction in transit requirements to Belgium and Germany.[67] Remaining demand is, according to ii3050, expected from other industry sectors, heavy mobility and hydrogen power plants to balance the electricity system. Remaining demand is assumed constant in this study.[68]

[64] Netbeheer Nederland, integrale infrastructuurverkenning 2030-2050 (30 June 2023), in this study 4 scenarios are defined: 'Decentrale initiatieven' (DEF), 'Natiaal Leiderschap' (NAT), 'Europese Integratie' (EUR), 'Internationale Handel' (NAT)

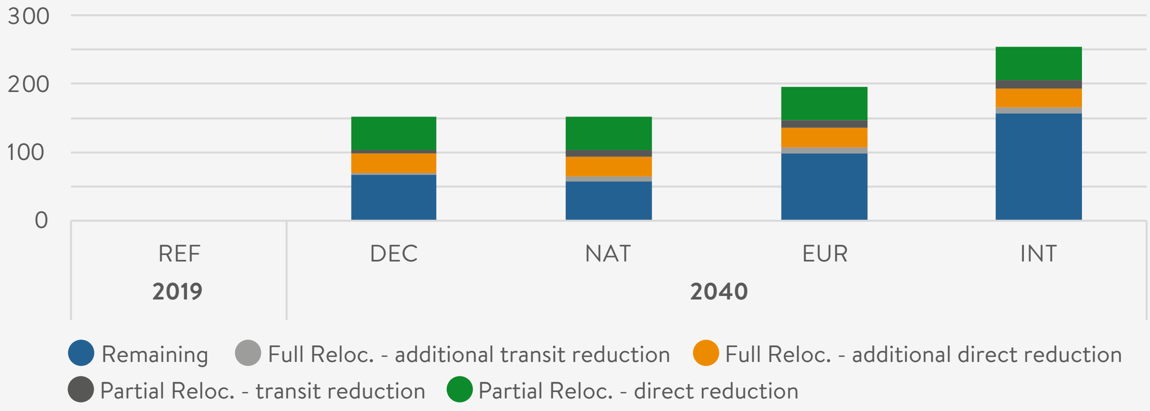
[65] The total energy demand related to the industries considered is in the Remaining Green scenario slightly below the lowest ii3050 scenario ('Internationaal Leiderschap'), whereas the Remaining Blue scenario is slightly above the highest ii3050 scenario ('Europese Integratie'). This is caused by the relatively large share of hydrogen in the energy mix in the Remaining Green scenario and the relatively high share of (less energy efficient) natural gas in the retaining Blue scenario.

[66] Including transit flows to neighboring countries

[67] Reduction in demand from Belgium and Germany was split pro-rata over the different supply sources (which besides transit from NL also includes transit from other countries and local production via electrolysers and SMRs).

[68] Note that one might argue that a (partial) relocation will also impact remaining demand, as it has a significant impact on the wider value chain

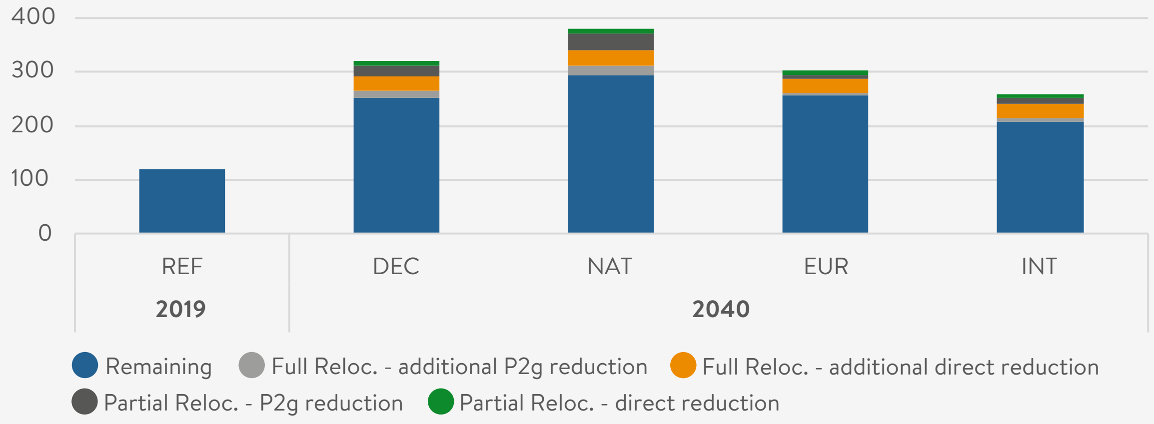
Figure 31. Impact of industry outsourcing on hydrogen demand in the Netherlands (TWh)



ii. Impact on electricity demand in 2040

According to ii3050, the expected yearly electricity demand in the Netherlands is 260-380 TWh by 2040. This demand includes direct electricity demand as well as for Power-to-gas (P2g) demand for hydrogen production.[69] Full relocation of the energy-intensive industry would lead to ~16-23% reduction of the total electricity demand in the Netherlands.[70,71] Partial relocation will lead to ~5-10% reduction.

Figure 32. Impact of industry outsourcing in the Netherlands (TWh)



iii. Impact on natural gas demand in 2040

In all but the Retaining Blue scenario, natural gas demand is drastically reduced (as was shown in Appendix B). Only the Retaining Blue scenario leads to a large natural gas demand by the four energy-intensive industries in 2040 (as shown in Figure 30). The natural gas demand of the four industries in the Retaining Blue scenario is roughly equivalent to 1/3 of the total current natural gas demand in the Netherlands.

[69] Electricity demand for hydrogen production is matched with the expected electrolyser capacity in various scenarios (see also next section).

[70] Note that the electricity demand takes both direct demand and indirect electricity demand from electrolysers into account.

[71] Note that the impact of (partial) relocation differs per ii3050 scenario. This is mainly due to different underlying assumptions for hydrogen supply (electrolyser vs import), where the share of electrolysers is considered in determining the total impact.

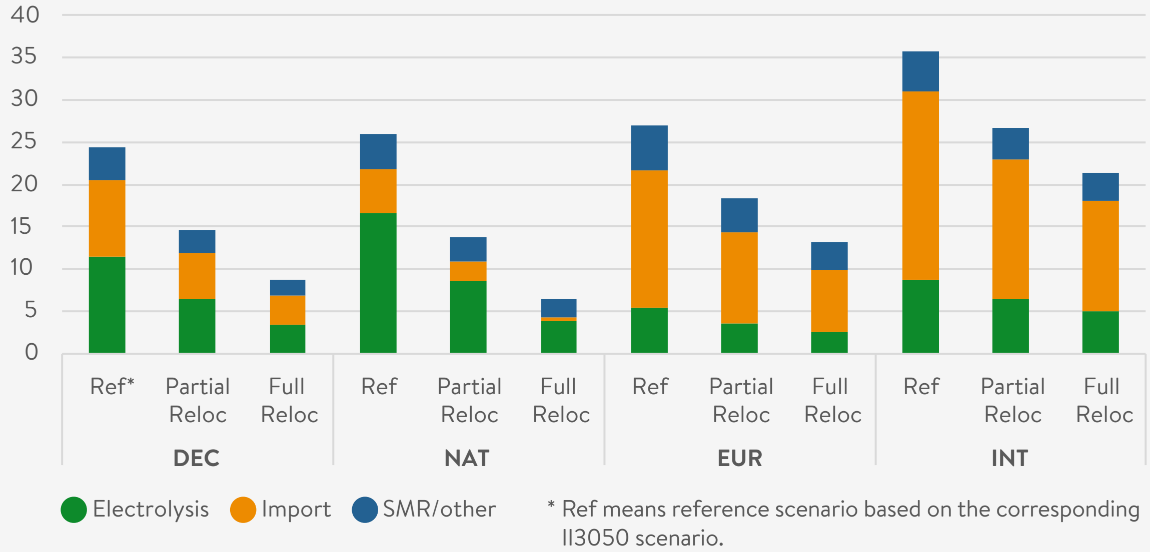
C2. REQUIRED ENERGY SUPPLY CAPACITY TO FULFIL THE YEARLY ENERGY DEMAND

In this section the effects of the various industry demand scenarios (as explained in the previous section) on the required energy mix are identified. This is done by scaling the ii3050 supply scenarios to meet the required supply per energy carrier for the various industry scenarios.

i. Impact on required hydrogen supply in 2040

The ii3050 scenarios each contain a different ratio of hydrogen supply sources (electrolysers, import and SMR/other). The figure below shows the indicative impact of (partial) relocation of the various industry scenarios on the required total supply capacities. In this study it is assumed that every supply source within ii3050 is reduced pro-rata.[72] Note that the combined supply capacity for each of the scenarios is based on different full load hours of the underlying sources (i.e. 3000 hours for electrolysers and 8000 hours for both import and SMR).

Figure 33. Impact on hydrogen supply capacities (GW)



* Ref means reference scenario based on the corresponding II3050 scenario.

The total hydrogen demand in the Retaining Green scenario requires in total approximately 24-36 GW hydrogen supply capacity, of which 5-17 GW electrolyser supply (expressed in hydrogen output) capacity. To put this in perspective, according to NPE, the Netherlands aims to have 15-20GW electrolyser (expressed in electrical input) capacity by 2040.[73,74] This means that required electrolyser capacity in the Retaining Green scenario is in line with the current electrolyser plans. Note however that, besides these electrolysers, also significant additional capacity is required from both Import and SMR/other.

Based on a pro-rata reduction of supply sources, partial relocation of the energy-intensive industry will reduce the total hydrogen supply requirements to 14-27GW. In this case the required electrolyser output capacity drops to 4-9GW. Full relocation of industry will lead to an even lower electrolyser output capacity of only 3-5GW.

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[72] Note that some of the conclusions in this chapter follow from this pro-rata assumption. Other assumptions, e.g. first reducing all import to minimize import dependency, might lead to other conclusions.

[73] Nationaal Plan Energiesysteem, Ministerie van Klimaat en Groene Groei (2023)

[74] Note that NPE given range is stated as electrical input capacity. The 15-20 GW input capacity translates to ~10-14GW output capacity.

According to PBL 10GW of electrolyser (input) capacity can be installed onshore[75], which could imply that offshore electrolysers and an offshore hydrogen grid are not necessarily required in case of a full relocation scenario. Note however that this highly depends on the import strategy, as imports from e.g. Norway could also require an offshore hydrogen grid (versus imports via ships from e.g. Oman).

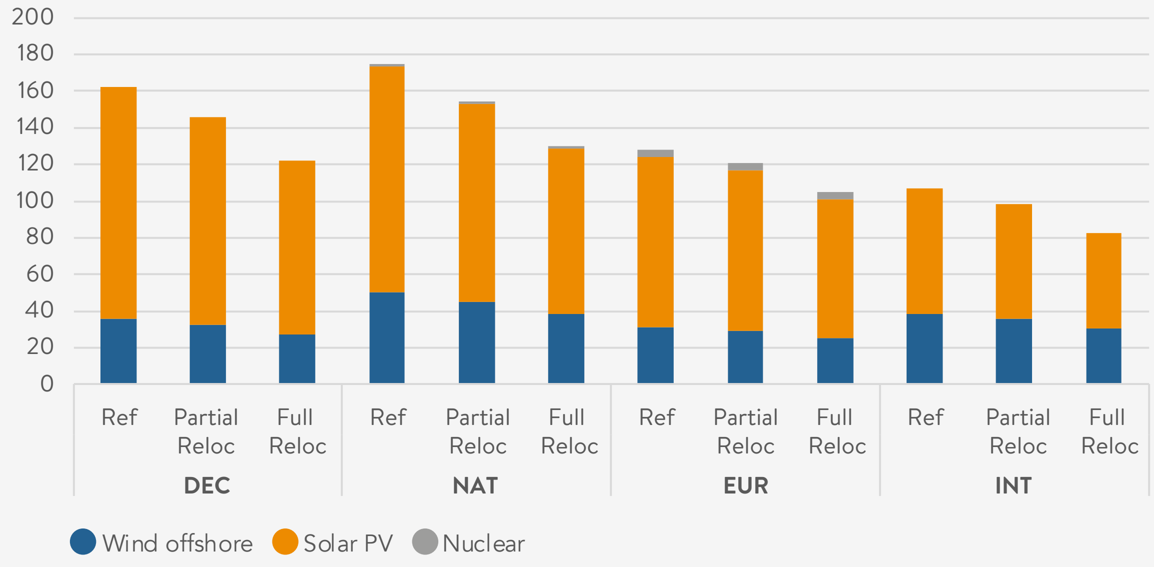
Alternatively, in case priority is given to energy independency, relatively more imports could be reduced in the relocation scenarios rather than pro-rata reducing supply sources. In that case offshore electrolysers and an offshore hydrogen network will also be required in the full relocation scenario to meet remaining hydrogen demand.

ii. Impact on electricity supply in 2040

The electricity supply capacity to meet industry demand is in theory equivalent to 10-19GW offshore wind capacity, 50-94 GW solar PV or 4-7 nuclear plants. In reality, a reduction in demand will likely lead to a reduction of various supply sources. Therefore, in this study it is analysed how the supply mixes of the various ii3050 scenarios could be impacted if they are reduced pro-rata.

The ii3050 scenarios each contain a different ratio of various electricity sources. The figure below shows how the offshore wind, solar PV and nuclear capacity could change under the various industry scenarios[76]. Note that the combined supply capacity for each of the scenarios are based on different full load hours of the underlying sources (i.e. 900 hours for solar, 4500 for offshore wind and 8000 for nuclear).

Figure 34. Impact on electricity supply capacities (GW)



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[75] PBL, Groene waterstof: *De practische uitdagingen tussen droom en werkelijkheid* (11 March 2025)

[76] It is assumed that changes in industry demand will mainly lead to changes in these 3 supply sources. Together they account for ~80% of the total electricity supply. Other supply sources are e.g. onshore wind, gas power plants and waste incinerators.

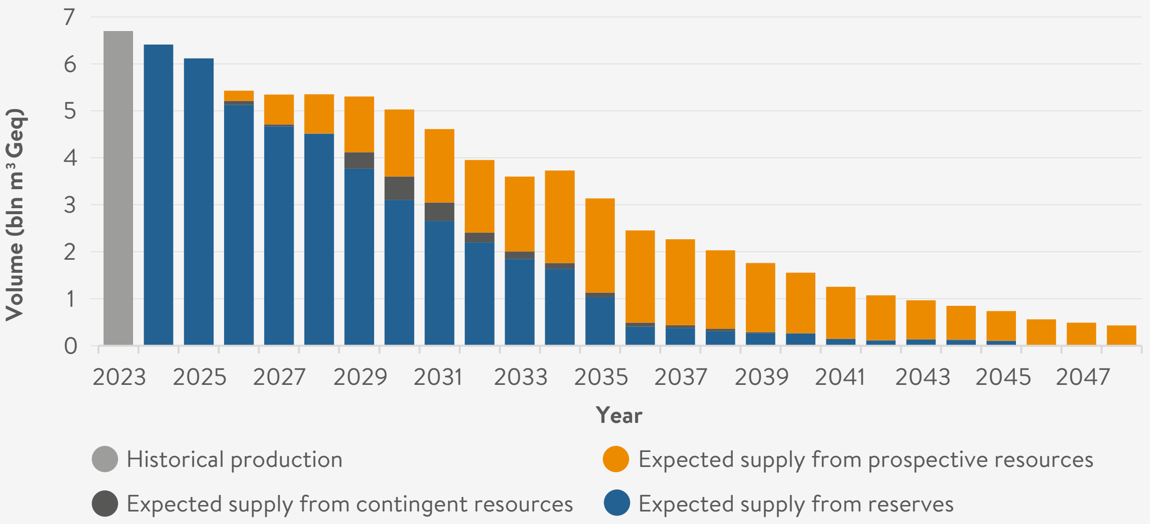
The total electricity demand in the Retaining Green scenario requires approximately 32-51GW offshore wind, 68-126GW solar PV and 0-4GW nuclear power in 2040. This means that required electricity capacity in the Retaining Green scenario is in line with the current NPE plans.[77]

However, relocation of industry has a big impact on the required electricity supply capacities. The partial relocation scenario only requires 30-45GW offshore wind, 63-113GW solar and 0-4GW nuclear. In the full relocation scenario the required supply is further reduced to 25-38GW offshore wind, 25-95GW solar and 0-3GW nuclear, together resulting in a reduction of 18-25% supply capacity.

iii. Impact on natural gas supply in 2040

Yearly natural gas production within the Dutch part of the North Sea is expected to decline from ~7 bln m^3 to zero between now and 2050.[78] By 2040, it is expected that ~1.5 bln m^3 gas will be retrieved on a yearly basis. This is roughly the equivalent of natural gas that is required for the energy-intensive sectors in in the Retaining Green or Partial Relocation scenario. However, in the Retaining Blue scenario this is less than a tenth of the demand of the 4 energy-intensive industries. This implies that the Retaining Blue scenario natural supply will mainly rely on imports to meet the natural gas demand (which is already common practice in the rest of Europe). However, import chains for natural gas (LNG) are already available with global and diversified supply chain.

Figure 35. Expected gas production from small fields at the Dutch part of the North Sea



Source: Ministry of Climate Policy and Green Growth, Natural Resources and Geothermal Energy in the Netherlands, Annual review 2023

C3. MATCHING DEMAND AND SUPPLY ON A SYSTEM LEVEL

To understand the impact on the whole energy system, it not only requires an equilibrium between yearly supply and demand, but also understanding the implications of demand and supply profiles. Energy-intensive industry will likely require a base load demand profile (high full load hours, i.e. 8000 hours), whereas supply of both locally produced green hydrogen and electricity will have a more volatile profile (with lower full load hours). This means that relocation of industry also means that less flexibility is required.

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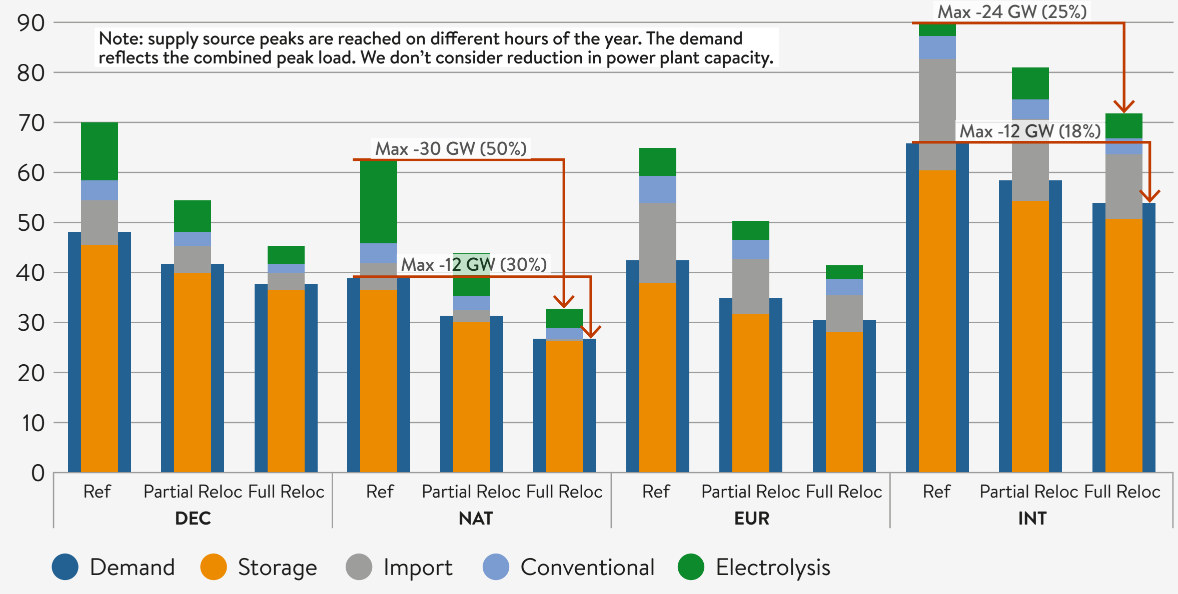
[77] According to NPE, the Netherlands aims to have 50GW of offshore wind, 117 GW of solar and 3.5GW of nuclear by 2040.

[78] Source: Ministry of Climate Policy and Green Growth, Natural Resources and Geothermal Energy in the Netherlands, Annual review 2023

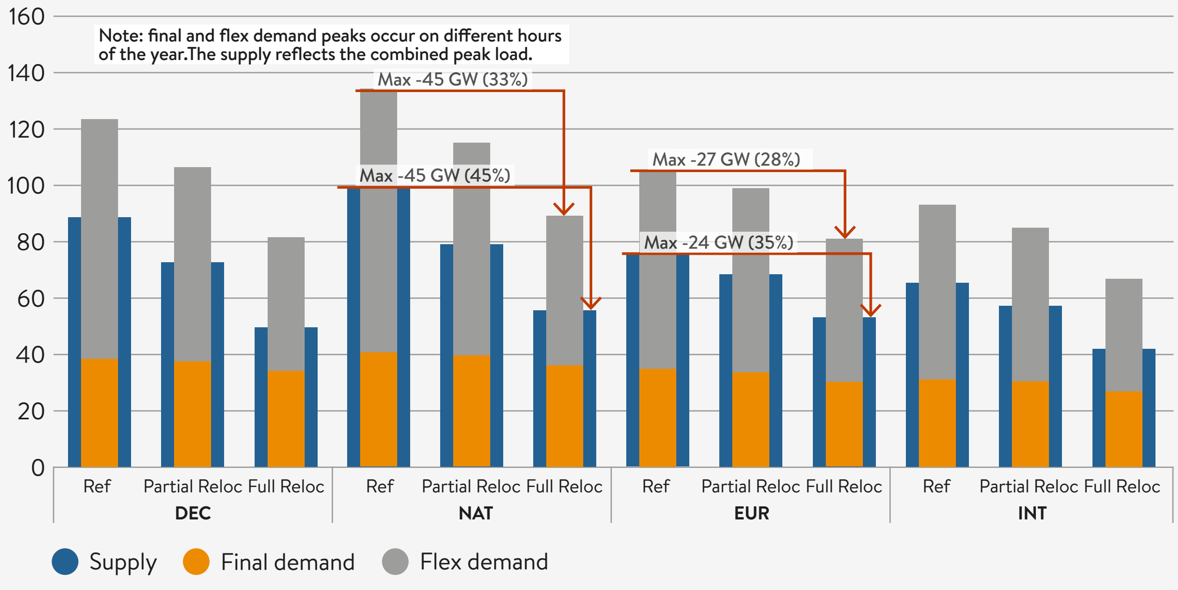
As shown in the figure below, the impact on the required hydrogen supply capacity is roughly twice the impact on the demand side (due to higher full load hours of industry).

Figure 36. Hydrogen supply and demand capacities in the Netherlands (GW)



Furthermore, relocation of industry has limited impact on final electricity peak demand, but will lead to substantial reduction in peak load of renewables and flexibility requirements.[79] Finally, (partial) relocation will require less base load demand, making it easier to meet the Dutch energy demand with an energy mix that includes more volatile energy sources (e.g. solar and wind).

Figure 37. Electricity peak capacity in the Netherlands (GW)



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[79] Flex demand consists of all flexibility options that are able to absorb supply when there is low demand (e.g. electrolysers, hybrid heating, demand side response, batteries etc)

C4. POTENTIAL IMPLICATIONS OF THE SCENARIOS ON THE EXISTING ENERGY & INFRASTRUCTURE PLANS

i. Impact on required hydrogen infrastructure in 2040

Based on the modelled scenarios, every scenario requires hydrogen to some extent. Therefore also an onshore hydrogen transport network, as developed in the actual Gasunie “Uitrolplan”, is required in every scenario. This onshore network will be used to connect hydrogen from electrolysers, SMRs and import to end users and storage locations.

As mentioned earlier in section C1.1. and C2.1., partial or full relocation of industry has a significant impact on the hydrogen demand and therefore could also have a significant impact on the required (offshore) electrolysers. According to PBL, 10GW of electrolyser (input) capacity can be installed onshore[80], which could imply that offshore electrolysers and an offshore hydrogen grid are not necessarily required in case of a full relocation scenario. This could lead to a reduction of ~€3 bln euros for the offshore hydrogen grid alone.[81] Note however that this also highly depends on the import strategy, as imports from e.g. Norway could also require an offshore hydrogen grid (versus imports via ships from e.g. Oman).

Alternatively, in case priority is given to energy independency, relatively more imports could be reduced in the relocation scenarios rather than pro-rata reducing supply sources. In that case offshore electrolysers and an offshore hydrogen network will also be required in the full relocation to meet remaining hydrogen demand.

ii. Impact on required electricity infrastructure in 2040

Earlier in section C1.2 it was shown that full relocation of the 4 energy-intensive industries will together result in a reduction of 18-25% supply capacity. Since final demand reduction is rather limited, the effects on the total onshore grid costs are assumed limited. However, as the total investment costs in the onshore grid expansions are ~€107 bln.[82], reductions of a few percent already could lead to reductions in the order of billions.

However, relocation of industry will likely have a significant impact on the offshore grid. Compared to the 50GW offshore wind ambition for 2040 in the NPE, the modelled offshore wind capacity in this study is 5-20GW lower in the partial relocation scenario. The full relocation scenario even leads to 12-25GW lower offshore wind. The investments for the offshore grid are estimated at approximately ~€2 bln euros per GW offshore wind[83]. This would imply that the full relocation scenario could lead to a reduction of ~€24-50 bln euros in offshore grid costs.

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[80] PBL, Groene waterstof: De practische uitdagingen tussen droom en werkelijkheid (11 March 2025)

[81] Based on expected investments on the offshore hydrogen grid until 2040, as was calculated by Netbeheer Nederland, Financiële Impact Energietransitie voor Netbeheerders (16 December 2024)

[82] Based on EUR 88 bln investments on the offshore grid from 2025 until 2040, as estimated in the report ‘schakelen naar de toekomst’, IBO bekostiging elektriciteitsinfrastructuur and the ambition for 2040 to have 50 GW offshore wind capacity operational as included in the underlying II3050 scenario’s.

[83] Porthos is expected to be operational by 2026. Aramis is currently still in the development phase.

iii. Impact on required CCS infrastructure in 2040

The required amount of infrastructure to capture, transport and use or store CO_2 will very heavily depend on the level of energy-intensive industry, as this is the predominant sector to make use of this infrastructure.

For the transport and storage of CO_2, the Porthos and Aramis projects are currently the main projects in The Netherlands. The Porthos project has an annual capacity of 2.5 million ton CO_2, whereas the maximum annual capacity of Aramis is estimated at 22 million ton CO_2.

CO_2 transport and storage are primarily relevant in the Retaining Blue scenario, where the 4 energy-intensive industries in the Netherlands alone would require 23 million ton of CO_2 storage per year. This is exactly the maximum storage capacity of Aramis. Potentially even more storage capacity is required for the energy-intensive industry in neighbouring countries (e.g. from Germany via the Delta Rhine Corridor). For the EII in Belgium, a total CCS requirement of 11 million ton is expected under the Retaining Blue scenario, and over 40 million ton for the EII in Germany.

Finally, significantly less CO_2 transport and storage infrastructure are required in case of the Retaining Green, or relocation scenarios. This would likely lead to reduced capacity for Aramis.

APPENDIX D – COMPARING COSTS OF PRODUCTION CHAINS IN DIFFERENT LOCATIONS

Properly comparing the costs of different locations of –parts of a- production chain is essential for the understanding of the economics of the scenarios in this report, but at the same time very complex. There are at least three reasons that make the cost comparisons complex.

- Firstly, as we demonstrated by the description of the four scenarios per sub-industry, the costs of the energy-intensive activities in the chains from raw materials to semi-finished products depend on the locational circumstances driving the costs of all the inputs needed.
- Secondly, the costs depend on the geographical location of the adjacent links in the production chain, upstream and downstream. Transportation costs and proximity to resources and end-user markets also play a part.
- And thirdly, what makes it complex are the estimates of future prices and market conditions, in the different regions, and for each of the cost drivers.

The 2024 PwC study for WEC NL explored the energy costs of producing highly energy-intensive products like steel, ammonia and refinery products. The study concluded that cost differences between global regions are significant, posing considerable competitiveness differences for industry in NW Europe and renewable energy-rich regions. Moreover, the study concluded that even in the longer run, after much of the energy transition investments have been put in place, an energy cost difference will likely remain, due to the mere fact that climatological solar and wind conditions in NW Europe are less favourable. The study also pointed out that locational choices do not only depend on energy costs alone, and if energy cost differences cannot be levelled, political focus should be on safeguarding the quality of those other locational attractors.[84]

TNO is currently conducting a study that compares the costs of producing several chemicals in NW Europe and Saudi Arabia. In this study, which is performed in cooperation with Nobian, TNO has made a model that simulates the logistical and chemical steps of the entire production, including the steps to produce the required energy carriers. The first two chains studied are the chloralkali chain and the chain producing synthetic oil products (syncrude, for instance for sustainable aviation fuels or SAF). Because of the historical developments, geographies, and geological and climatological differences, those chains take different forms, as economic pathways can be different.

The TNO study on both the chloralkali chain and the syncrude chain demonstrates that the cost comparisons are complex and driven by quite a few assumptions about parameters that are difficult to predict. Given that caveat, the study also seems to suggest that when the entire chain is assessed, the pure energy production prices may not be the ultimate determining factor of the true cost differences between NW Europe and Saudi Arabia. For example, although Saudi Arabia benefits from abundant solar resources, continuous processes like chloralkali production require round-the-clock electricity. In contrast, the aggregate load factor of wind and solar in NW Europe may better support 24/7 operations when accounting for storage needs. This underscores the importance of integrated system-level assessments, beyond marginal energy cost comparisons alone.[85]

This is also true for the case of steel.[86, 87] The exercise of quantifying these costs, however, goes beyond the scope and reach of this study, but a summary of (cost) implications and uncertainties to be considered with each of the scenarios is listed in the table underneath.

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[84] PwC, The Future of Energy-Intensive Industry in Northwestern Europe: A Balancing Act (April 2024)

[85] TNO, Exploration of the effects of partially replacing Dutch fertiliser and iron and steel production with imports (9 September 2024)

[86] Verpoort et al., Impact of global heterogeneity of renewable energy supply on heavy industrial production and green value chains. Nature Energy. (April 2024)

[87] Lopez et al., Transition towards a defossilised steel industry in Europe: Hydrogen direct reduction (H-DR) as a key method. Energy 273. (21 March 2023)

Figure 38. Key cost uncertainties and implications for future steel production costs

Retaining scenario	Partial relocation scenario	Relocation scenario
• **Electricity costs** are projected to remain higher in NW-Europe due to lower renewable potential compared to RE-rich regions. • **Hydrogen costs** are high compared to RE-rich regions due to limited renewable potential and higher electricity prices. • **Labour costs** are high compared to most RE-rich regions.	• **Exergetic losses** occur because HBI must be reheated after transport, resulting in increased energy input in decoupled processes. • **Yield losses** occur during HBI transport due to breakage and oxidation, reducing usable iron content. • **Productivity losses and quality risks** arise because cold, dense HBI melts more slowly and less uniformly than hot, fine DRI. • **High liquidity HBI market** does not yet exist; its emergence in the short and long term is uncertain, introducing supply and price volatility.	• **Low renewable load factors** in some RE-rich regions increase the need for large-scale storage, raising total energy system costs. • **Second-order economic effects:** large-scale relocation increases local demand for labour, energy, and infrastructure, which can drive up prices and reduce initial cost advantages. • **Greenfield development** requires high investment costs compared to the existing value of brownfield assets. • **Energy and logistics infrastructure** (e.g. electricity, transport, water) are often underdeveloped in RE-rich regions. • **Transport costs** are higher, especially when using scrap steel, which may need to be imported from developed regions, where exports restrictions could further increase cost. • **Operational expertise** and industrial workforce capacity often lack and must be built. • **Higher cost of capital** (WACC) in many RE-rich regions increases investment costs. • **Proximity to customers** will decrease, reducing supply chain responsiveness and increasing coordination costs. • **Future production expansion** is uncertain due to global overcapacity and competing demands for cheap renewable energy.

An economic consideration that is often overlooked in the debate whether it would be cheaper to relocate the EEI are the economic repercussions of increased demand for production capacity elsewhere. When large parts of NW Europe's steel production shift to regions like Brazil—attracted by hydro power and natural resource availability— one cannot assume that the additional demand for labour, energy, construction materials, and infrastructure will not have an effect on the respective prices, thereby reducing the favourable cost gap. Economists might argue that 'in the long run' additional capacity will be built, because the business case suggests that that is profitable, but in the meantime capacity constraints may restrict the relocation of the volumes we are talking about – not just physically but also economically.

A case in point is the Swedish green steel capacity. Though a major success in the decarbonisation of this important industry, fast growth turns out to be hit by physical and economic boundaries. From an electricity market perspective, the combined investments of LKAB, H2GS, and Fertiberia in Norrland cannot be realised profitably – neither in the short term until 2026 nor in the longer term until 2030 or later. Moreover, the currently cheap electricity in northern Norrland has attracted investments that are too large. If all investments are carried out according to plan, electricity prices will rise too much for the investments to be profitable, according to the Scandinavian Policy Institute.[88]

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[88] Skandinaviska Policyinstitutet, Till vilket elpris som helst: Impact on the Nordic electricity market of investments in fossil-free steel production in Norrland (2024)

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