Future production scenarios and resulting hydrogen demand 2030-2050

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Summary

Industrial emissions reduction is one of the major challenges in meeting 2030 and 2050 climate goals for northwest Europe. Many uncertainties in available options, their viability, boundary conditions and lack of regulations have delayed concrete action towards an industrial transition away from fossil fuels and towards low-carbon emissions production. In northwest Europe, hydrogen is seen as one of the key of options and drivers of changel. Different approaches are taken in efforts to estimate the hydrogen demand for 2050, but considerable uncertainty remains about where, when and most importantly to what extent hydrogen use in industry will begin to play a role in emissions reductions. Some of these questions have been highlighted in a recent study jointly published by Fraunhofer ISI and TNO through a site-specific analysis of potential hydrogen demand for 2030 and 2050.

The research involved different sub-sectors of energy-intensive manufacturing industry (chemicals, iron and steel, non-ferrous metals, non-metallic minerals) in three scenarios:
- Reference 1: Maximum hydrogen demand potential for high, medium and low temperature processes and feedstock use
- Reference 2: Maximum hydrogen demand potential for high temperature processes and feedstock use
- Reference 3: Hydrogen demand for high temperature processes and feedstock based on regular reinvestment cycles.

Hydrogen use for low- and medium temperature processes is often considered controversial as other decarbonization options, like electrification, are available – and future availability and cost of hydrogen produced from renewable electricity is uncertain. For this reason, sectors which require low temperature heat, such as food and beverage and pulp and paper production, are considered only in the maximum potential scenario (Reference 1), and not in the more realistic scenarios (Reference 2 & 3). Reference 2 includes only high-temperature heat and feedstock applications for hydrogen. Reference 3 takes into account years of start-up and expected operational life-time of individual plants to estimate the timing of large re-investment in equipment, assuming that hydrogen will be chosen. The specific focus for Reference 3 is on companies whose next reinvestment cycle is expected to occur by 2035. The original analysis defined scenarios based on constant output levels over time.

However, large-scale deployment of hydrogen in any scenario would require massive short term investment in new and renewable electricity generation, hydrogen production capacity and energy transport and distribution infrastructure. Uncertainties about levels of industrial output create risk for industrial stakeholders and policymakers. Based on results of the research conducted by Fraunhofer and TNO, this work aims to quantify the uncertainty in potential evolution of industrial output in large sectors in the future. The goal is to assess, based on existing literature and energy scenario analysis, the potential for production level change within Europe in the selected manufacturing sectors, and the impact of that change on future hydrogen demand in northwest Europe. As in the original scenario analysis, the focus of this work is on hydrogen demand for 2030, though 2050 outlooks are also included. Refineries are outside the scope of this work, but are certainly of importance to consider for future research.

Considering the range of published assumptions on industrial production outlooks in different sub-sectors, hydrogen demand for northwest Europe in 2030 is estimated to be in a range of 254 to 317 TWh/year for Reference 1, and 232 to 277 TWh/year for Reference 2. Production level change scenarios seem to affect German industrial hydrogen demand the most, with an estimated range of 140 to 171 TWh/year for Reference 1, and 122 to 148 for the Reference 2 scenario. Hydrogen demand for the Netherlands varies between 57 and 75 TWh/year for Reference 1 and 52 to 70 for Reference 2 scenario. Considering re-investment cycles and plants due for re-investment until 2030, production levels have a considerably smaller effect, with an estimated range opotential hyf drogen demand of 54 to 56 TWh/year in 2030.

Contents

1 Introduction

As a follow up to the previous work (Future hydrogen demands from industry transition towards 2030 - a site-specific bottom-up assessment for North-Western Europe, M. Neuwirth et al.) developed by Fraunhofer and TNO on potential hydrogen demand for industry in NW Europe, TNO has conducted an analysis of the impact of assumed industrial production levels on hydrogen demand. Production levels for key materials are a fundamental underlying assumption of the hydrogen demand scenarios, and can have a significant impact on the results.

Historically, global production of key industrially produced materials has grown steadily, and in recent years production growth of some materials has outpaced growth in global GDP and population. (IEA (2019), Material Efficiency in Clean Energy Transitions) The growth is not evenly distributed, but it points to a global challenge of realizing the energy transition in the face of rapid increases in consumption. Even as energy intensity in the industrial sector has fallen across every region of the world, globally by 2.3% from 2010 to 2019, industrial energy consumption and emissions have continued to grow in absolute terms, due to increasing demand and production. (IPCC (2022), Climate change 2022, Mitigation of climate change, Working group III contribution to the Sixth Assessment Report if the Intergovernmental Panel on Climate ChangeAR6 WGIII Full Report).

In northwest Europe, multiple trends will drive the evolution of industrial production levels. While general economic growth and increasing demand could push these levels up, changes in consumer behaviour or offshoring of energy-intensive industry could shift the trend downward. Policy measures such as the carbon border adjustment mechanism (CBAM) could keep industry in Europe, and strategic developments in low-carbon energy infrastructure could make Europe an attractive site for future production. On the other hand, policy measures encouraging circularity and material efficiency could drive down demand.

It is important to consider uncertainty in future production levels, as these are a key source of uncertainty in future energy demand – including hydrogen. This uncertainty can create risk for both policymakers and industrial stakeholders as decisions are made about investments in new assets and infrastructure. Historically, efficiency improvements have not kept pace with demand growth, leading to growth in industrial energy demand. In the worst case, this can lead to difficult choices between economic interests and environmental targets; in the best case, it could be an opportunity to explore innovative possibilities for the future of industrial production in Europe. This is particularly relevant for processes with hydrogen as a fuel or feedstock, because large upfront investments are required in the short term to scale up renewable hydrogen production, storage, transport and distribution infrastructure, in addition to end-use technologies.

2 Methodology

This work consisted of a literature review of industrial demand scenarios and output projections for key industrial materials for the European Union, northwest Europe, or a part of the target region in 2030 and 2050. Materials covered included crude steel, aluminium, cement, ethylene and ammonia. For many energy and economic scenarios and models, underlying assumptions about production are not published; the resulting dataset is therefore not comprehensive, and consists only of publicly accessible data from scenarios which use production levels as inputs. For sources which included only some milestone years, linear interpolation was used to determine production levels in intervening years. When only more geographically aggregated data were available, country-level data was calculated with the assumption of a constant share in the aggregated region from the most recently available statistics from PRODCOM (in most cases, 2020). The processed data was then mapped onto the years 2020 to 2050, and low, median and high production pathways calculated.

Building on the existing bottom-up calculation of site- and process-specific potentials for hydrogen use in the industrial sector in northwest Europe in 2030 presented in [Neuwirth et al., 2022], site-level production values for the five key products were updated to reflect the three new production scenarios: low, median and high. Because site-level data was not available for the reviewed production projections, these were extrapolated from the country- or region-level data, assuming the same share of national or regional production as in the base year. The same three potentials were calculated: maximum potential (Reference 1), maximum potential excluding low-to-medium temperature process heat (Reference 2) and a demand potential including only reinvestment cycles (Reference 3).

3 Results

A set of relevant industrial production scenarios was gathered for each sector considered in this analysis. In figure 3.1, the breakdown of scenarios by product and region is shown. The gathered scenarios are not an exhaustive list of all future production scenarios; it is limited to publicly available information within the geographical, temporal, and product scope of this analysis. This analysis can also be updated as more information becomes available. Note that production level assumptions for cement, steel, and ethylene were more readily available than other sectors, most likely because they are the largest energy-intensive sectors globally, as well as in Europe, and are responsible for a large share of the greenhouse gas emissions from industry. Ammonia as an energy carrier has been excluded, as the focus is on manufacturing of materials. Refineries and fuel production are also excluded for this reason, despite their potential for high hydrogen demand.

Large global or regional trade associations often perform analysis and make projections of production levels. Energy- and emissions-intensive sectors with relatively homogenous end products are also more likely to have extensive and accessible information, and more likely to be included in energy system models where such information is used and published. In general, European scenarios were more common than country-level analyses, particularly for northwest European countries.

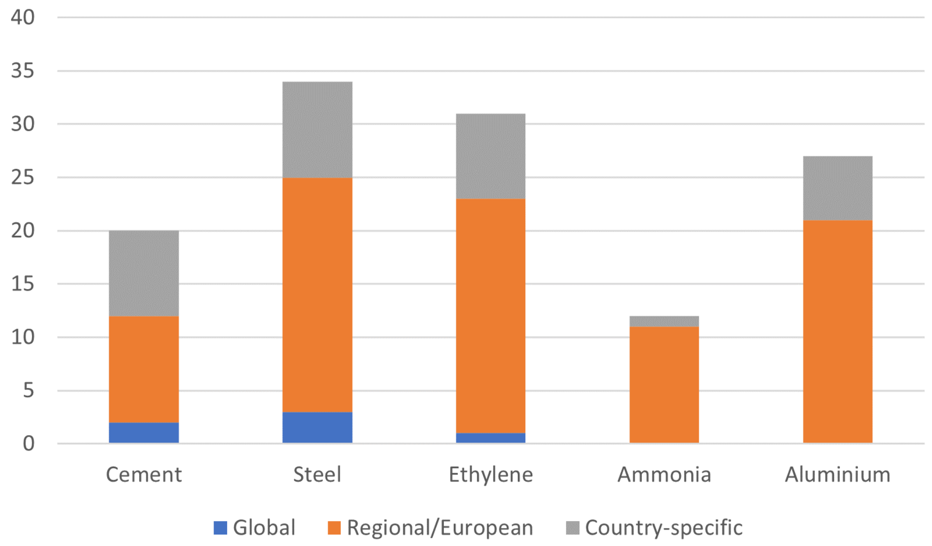

Figure 3.1: Number of scenarios considered for each product and region

When scenario data was given at global or regional level, the production was allocated to the target northwest European countries according to their shares of regional or global production in the most recently available historical statistics. This introduces additional uncertainty to the analysis, particularly for small countries with only a few producers present. The results should therefore be interpreted as only indicative, rather than as a prediction of absolute production levels.

3.1 Cement

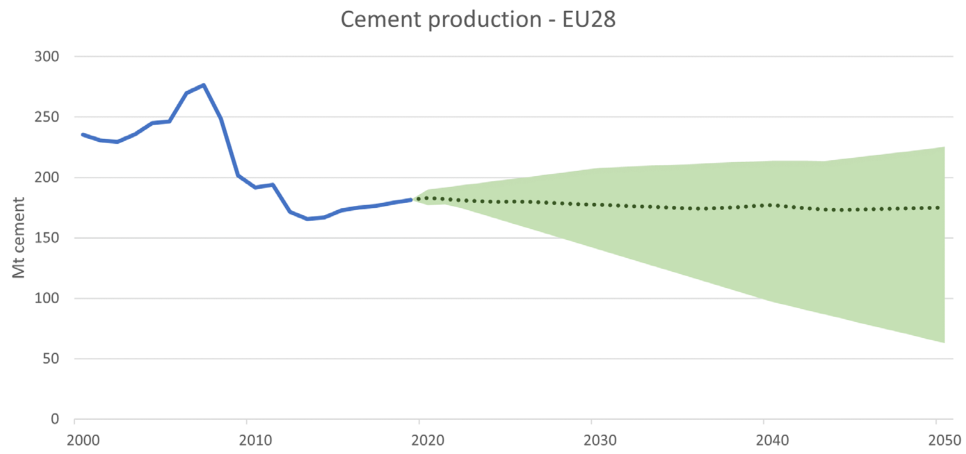

Figure 3.2: Historical: cement production and future production scenarios for the EU28 region

Several studies indicate that with material efficiency measures such as reduced cement content in concrete, reduced waste, and material efficient design, the demand for cement could be significantly reduced by 2050. Reducing clinker within safe limits might make a large difference in terms of emissions and energy demand. The range scenarios for cement production in the European Union in 2030 was about 140 to 210 Mt/y, while in 2050 this range is from around 60 to 225 Mt/y (see figure 3.3). Of the selected regions, north-west Germany and northern France are expected to remain the largest producers in northwest Europe.

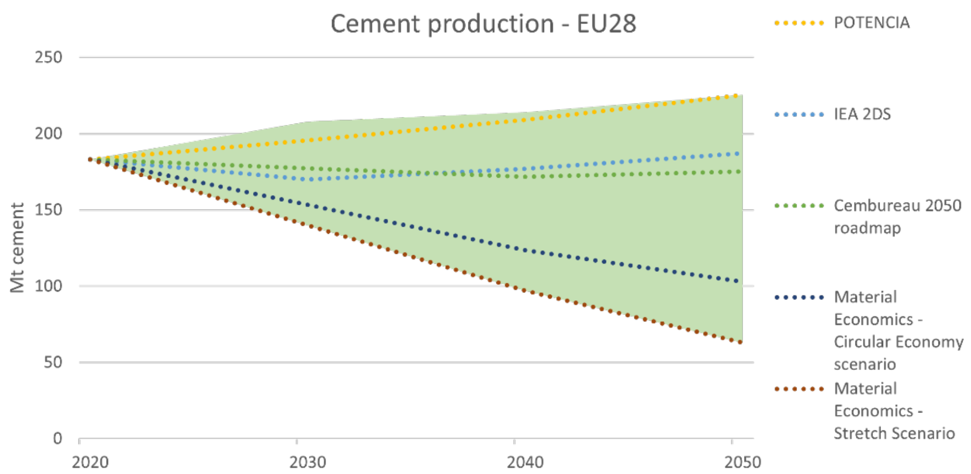

Figure 3.3: Range of cement production scenarios

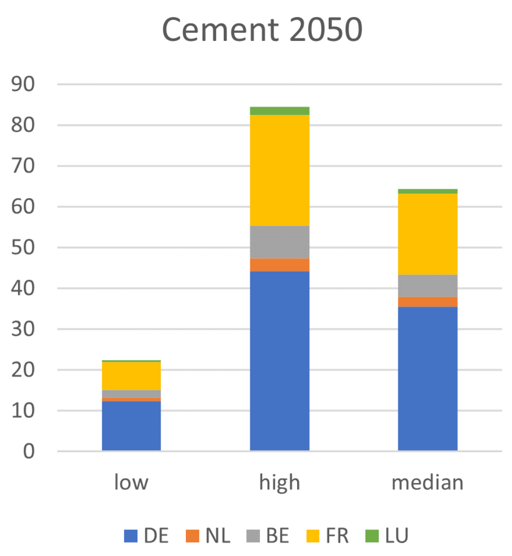

Figure 3.4: Distribution of cement production in 2050 in northwest Europe

3.2 Steel

Steel production, because of existing global overcapacity, is unlikely to grow quickly in Europe, but policy and technology developments still play a role in future capacity and hydrogen demand. The range of production scenarios for 2030 is rather narrow compared to other industries, but as one of the higher volume uses for H_2, the roughly 20 Mt range in 2030 could still mean a large difference in total hydrogen demand. Literature estimates put steel production in European Union in 2030 in the range of about 140 to 180 Mt/y, while in 2050 this range is from about 140 to 195 Mt/yr.

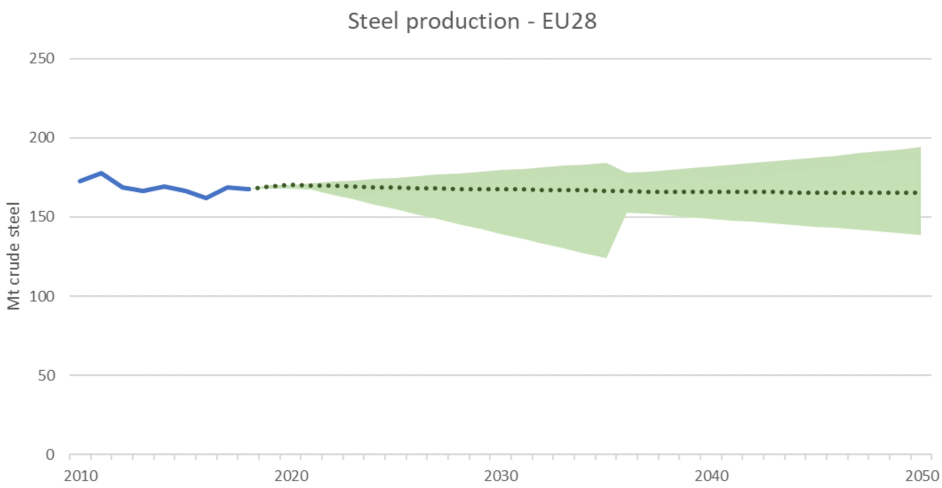

Figure 3.5: Historical steel production and future scenarios for the EU28

Steel output in northwest Europe in 2050 is estimated to be in the range from 60 to 90 Mt/y, as shown in figure 3.6. The highest steel production is expected in northwest Germany, followed by northern France and Belgium.

Figure 3.6: Distribution of steel production in 2050 in northwest Europe

3.3 Ethylene

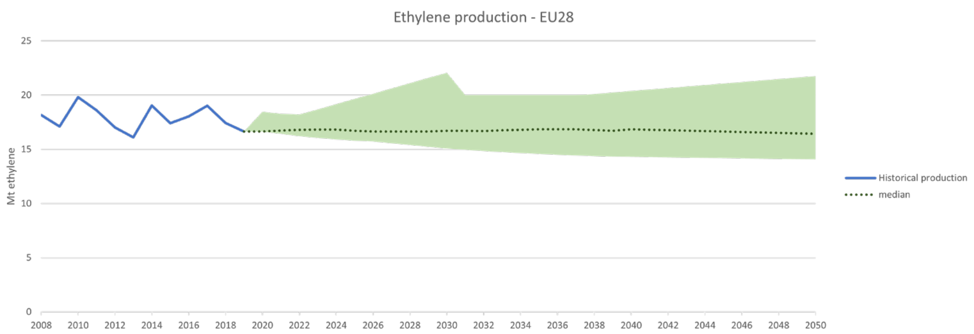

Figure: 3.7 Historical ethylene production and future scenarios for the EU28

Public information about ethylene output levels is very limited, even in often-cited scenarios. Nonetheless, assumptions about production of ethylene (and other high value chemicals) are critical to the overall outlook for energy in northwest Europe. Growth in production has historically been high, and many competing alternative pathways are under development based on different feedstocks and fuels. Large trade volumes in northwest Europe, as well as links to refining and transport sectors, make it a crucial piece of the energy transition puzzle.

The limited range of production levels in the above figure should be interpreted not as a measure of certainty, but rather a lack of extensive publicly available information. Production level scenarios that remain close to flat seem here to reflect uncertainty (and the need for simple, explainable assumptions) about the future of the sector.

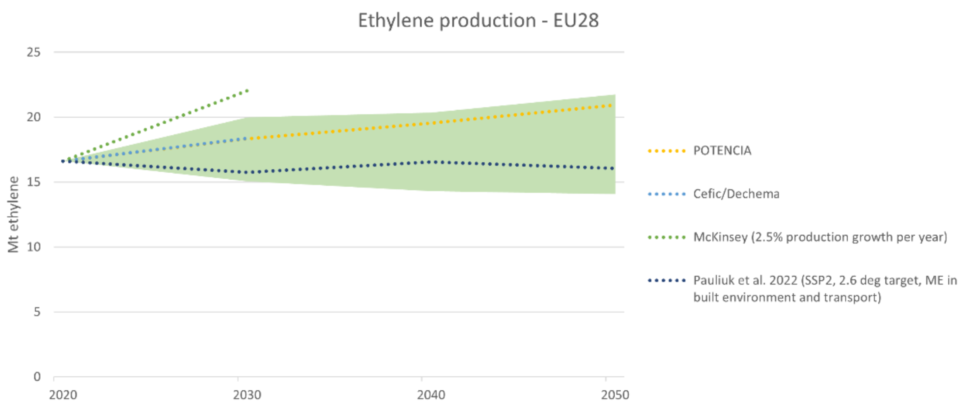

Figure 3.8: Range of ethylene production scenarios for 2030 and 2050

Ethylene production in northwest Europe in 2050 is estimated to be in the range of 9 to 15 Mt/y, as shown in Figure 3.9. The highest ethylene production is expected in northwest Germany and the Netherlands, where current production levels are already the highest in northwest Europe.

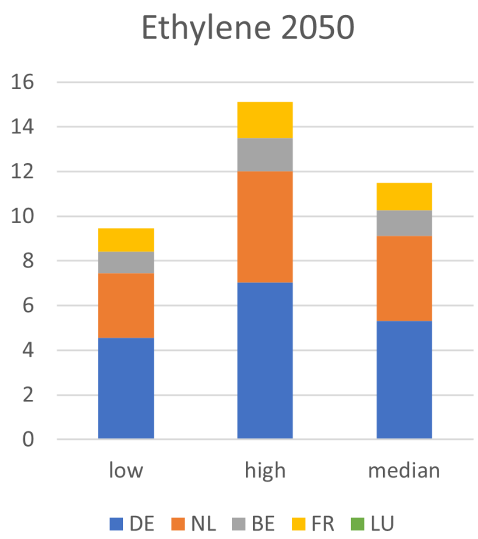

Figure 3.9: Distribution of ethylene production in 2050 in northwest Europe

3.4 Ammonia

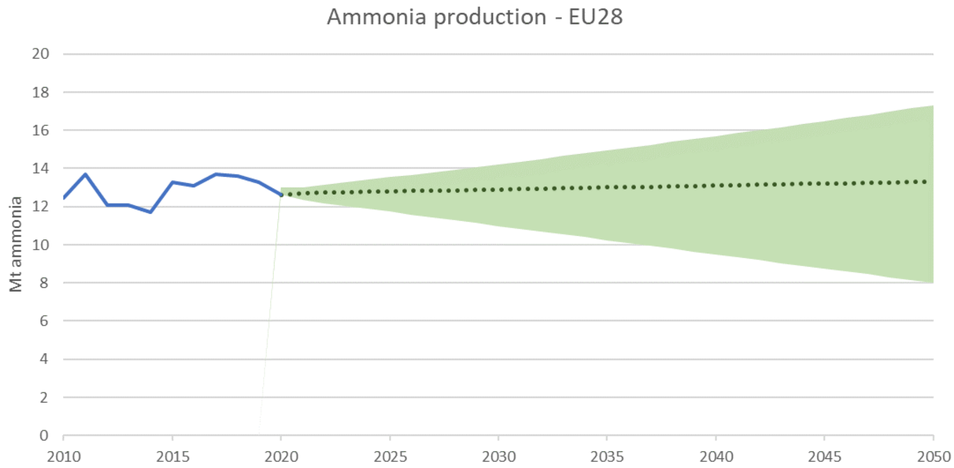

Figure 3.10: Historical ammonia production and future scenarios in the EU28

Ammonia is today primarily used as an input to fertiliser production. The scenarios considered in this work include only ammonia for material use; potential future energy applications are excluded for clarity. Literature on future production levels is mixed on whether energy use is included or excluded. Potential ammonia imports could put downward pressure on production of ammonia in Europe, especially given high natural gas prices in the short term, which have already had an impact on output. However, uncertainty in terms of demand for fertilisers and potential shifts to alternative fertilisers or farming methods, especially in combination with policy measures such as the Carbon Border Adjustment Mechanism (CBAM), could push demand in either direction.

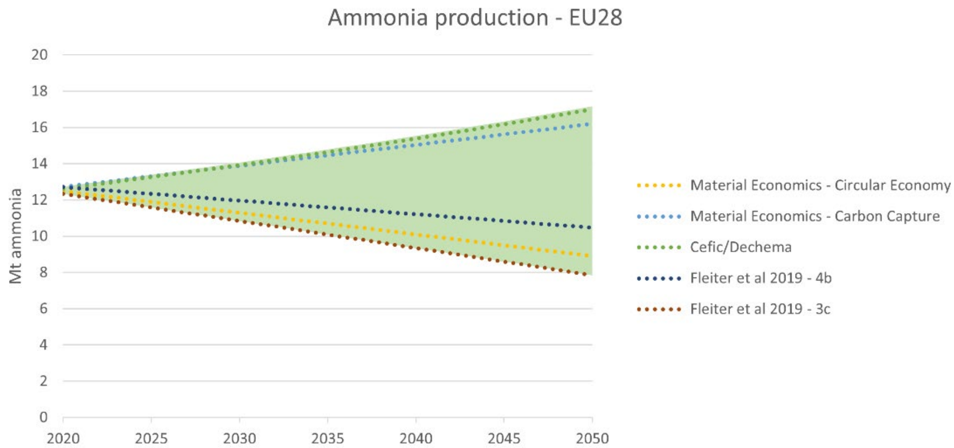

Figure 3.11: Range of ammonia production scenarios

Ammonia production in northwest Europe in 2050 is estimated to be in the range of 4 to 8 Mt/y, which is shown in Figure 3.12. The highest ammonia production is expected in the Netherlands, followed by northwest Germany. However, this is highly uncertain, as in some references, outsourcing ammonia production to regions with abundant low-cost renewable energy is a key lever for emissions reduction.

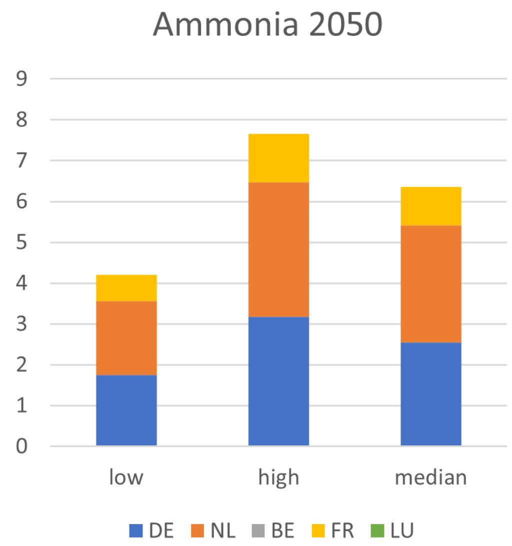

Figure 3.12: Distribution of ammonia production in 2050 in northwest Europe

3.5 Aluminium

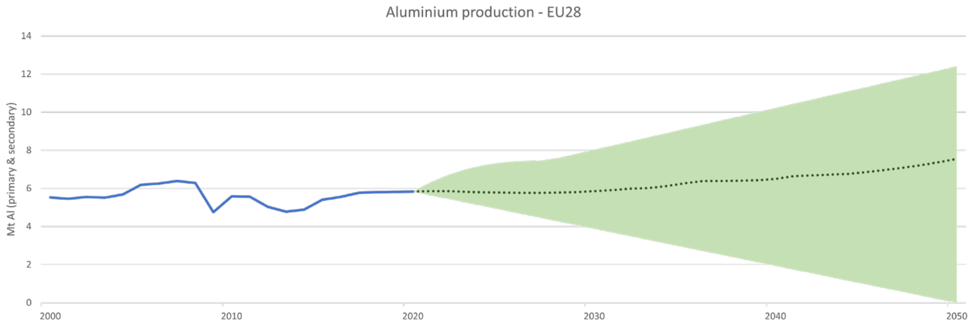

Figure 3.13: Historical: aluminium production and future scenarios for the EU28

Competitiveness of primary aluminium production is highly dependent on electricity prices, and secondary production on available aluminium scrap. Scenarios for European aluminium output range widely, from an end to production in Europe by 2050, to a doubling from 2020 levels, depending on assumptions about imports and recycling.

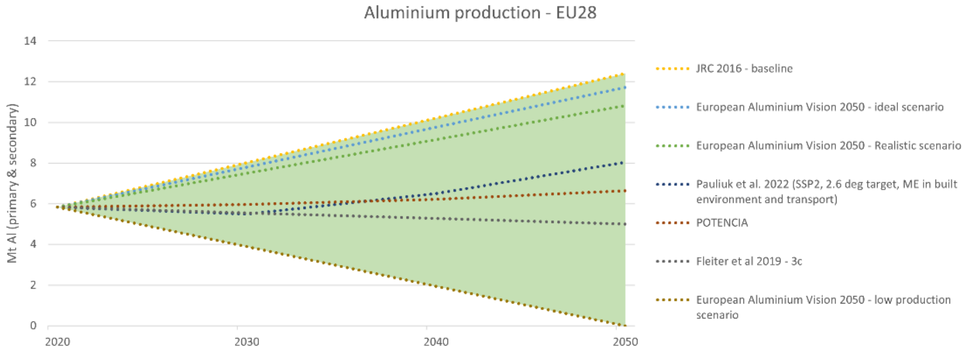

Figure 3.14: Range of aluminium production scenarios

Aluminium production in 2050 in northwest Europe is estimated at a maximum of about 4 Mt/y, which is shown in figure 3.15. The highest aluminium production is expected in northwest Germany, with about 2.5 Mt, followed by France, with about 1.5 Mt. However, the future competitiveness of primary aluminium production in Europe is seen as highly uncertain; in some scenarios, it is assumed to entirely shut down by 2050.

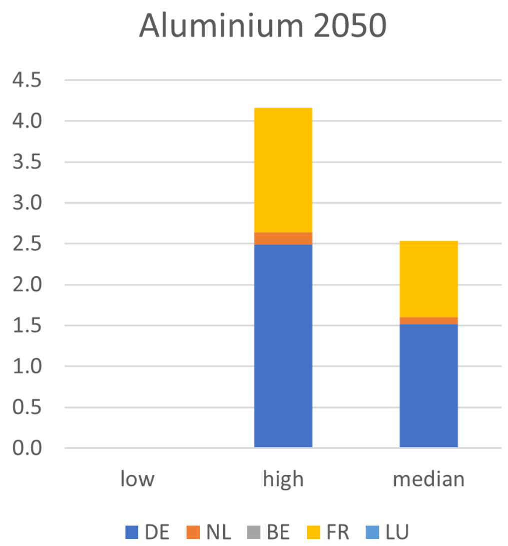

Figure 3.15: Distribution of aluminium production in 2050 in northwest Europe

3.6 Resulting hydrogen demand

Hydrogen demand estimation is performed based on scenarios previously defined by the joint research conducted by Fraunhofer ISI and TNO. The first scenario (Reference 1) considers hydrogen used for feedstock applications as well as for high, medium and low temperature heat production. If the supply of green hydrogen in northwest Europe is limited, it is less likely that valuable hydrogen resources would be used for low and medium temperature heat production, where other low-carbon options are available. This is reflected in the second scenario (Reference 2), which considers more realistic hydrogen demand for feedstock and high temperature heat applications only. The third scenario focuses on potential hydrogen demand application based on reinvestment cycles for 2030.

Reinvestment cycles consider a start-up year and technical lifetime and/or last retrofitting year of the plant to estimate when the next big investment will take place, with a focus on 2030. Retrofitting consists of the renovation or optimization of a technology, industrial process or its segments for which an investment has to take place. Reinvestment cycles are considering hydrogen demand for feedstock and high temperature heat production for plants which make the required retrofits during regular cycles of equipment maintenance. A summary of the defined scenarios is shown in figure 3.16. No additional assumptions are included regarding scale-up of other emissions reduction technologies, such as carbon capture or biomass use.

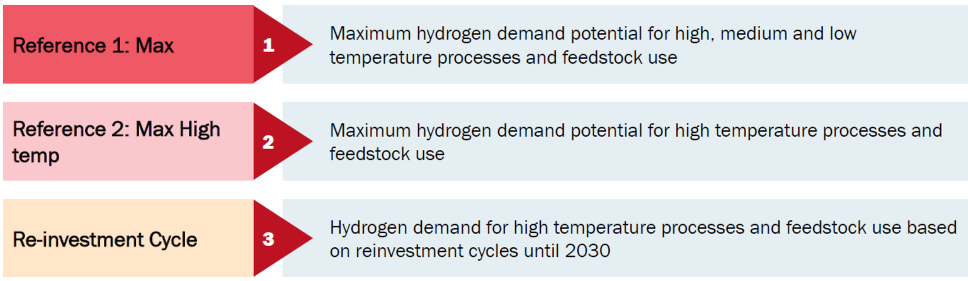

Figure 3.16: Overview of hydrogen demand scenarios for northwest Europe

In the original analysis, production levels were assumed to remain constant through 2030. When varying production levels are also included, the effects of the different scenarios are magnified. The impact of production level change on estimated hydrogen demand **per country** for Reference 1 is given in figure 3.17. Considering production level uncertainty in different sub-sectors, total hydrogen demand for northwest Europe is estimated to be in the range of about 250 to 320 TWh/y for Reference 1. The biggest impact is on German hydrogen demand, with a range from 140 to 170 TWh/y. Hydrogen demand for the Netherlands varies between about 55 and 75 TWh/y for the Reference 1 scenario.

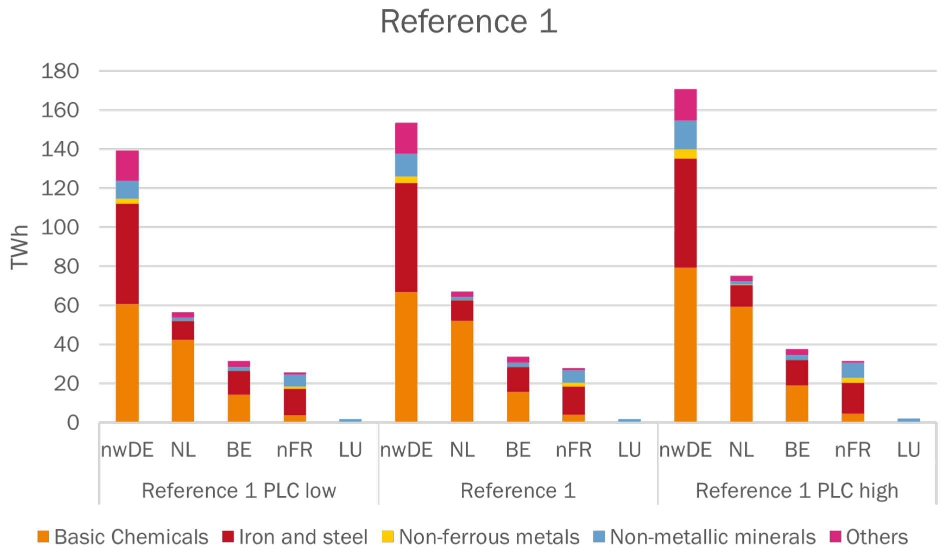

Figure 3.17: Estimated hydrogen demand per country for northwest Europe for maximum hydrogen demand scenario including a range for low and high production level change

Following the Reference 2 scenario presented in Figure 3.18, hydrogen demand for northwest Europe is estimated to be in the range of about 230 to 280 TWh/y for Reference

2. German hydrogen demand is highest, estimated to be between about 120 to 150 TWh/y for the Reference 2 scenario, followed with the Netherlands with between 50 and 70 TWh/y.

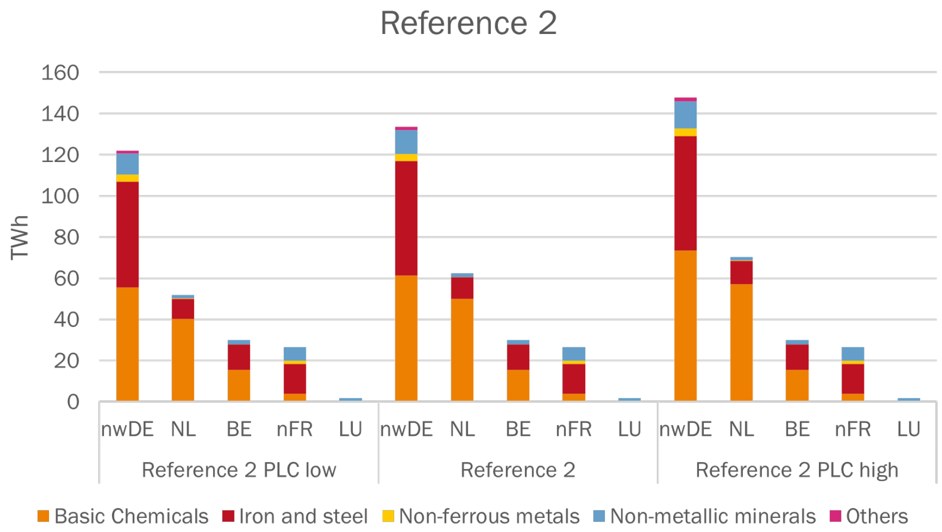

Figure 3.18: Estimated hydrogen demand per sub-sector for maximum hydrogen demand scenario including a range for low and high production level change

Hydrogen demand potential for Reference 3 is presented in Figure 3.20. The biggest investments until 2035 are expect to take place in Belgium, followed by northwest Germany, with total hydrogen demand around 55 TWh/y.

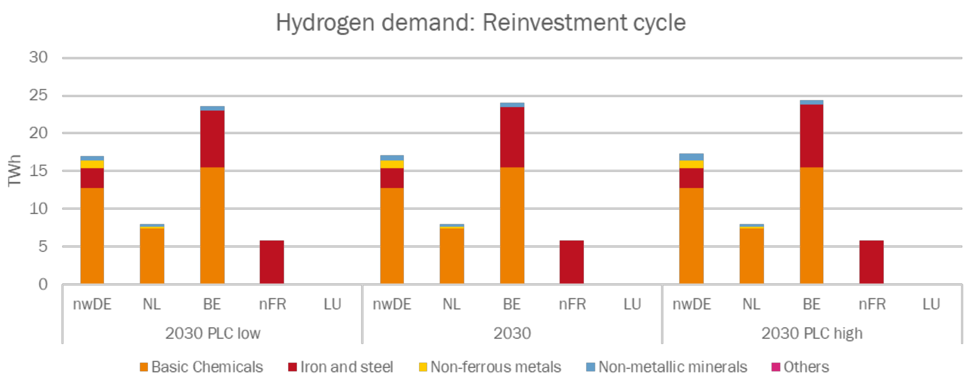

Figure 3.19: Re-investment cycle transition per country

Looking from the sub-sector perspective, production level change has the biggest impact on basic chemicals sub-sector: -18 to +23 TWh (Reference 1) and -16 to +19 TWh (Reference 2) in comparison with base case scenarios, while it has no impact on re-investment cycle scenario. For the iron and steel sub-sector, the impact is estimated to be in range from -6 to +2.5 TWh (Reference 1), -5 to +1 TWh (Reference 2) and -0.5 to +0.3 TWh in comparison with the base case for reinvestment cycle scenario. For non-ferrous metals, impact is estimated to be -1.7 to +2.2 TWh (Reference 1), -0.3 to +0.3 TWh (Reference 2), while there is no impact of the production level change on the hydrogen demand for the base case reinvestment cycle scenario. For non-metallic minerals, impact of production level change on hydrogen demand is estimated to be from –3.4 to +5 TWh ((Reference 1), -1.2 to +1.6 TWh (Reference 2) and -0.14 to +0.2 TWh in the reinvestment cycle scenario. This can be observed in Figure 3.20 a-c.

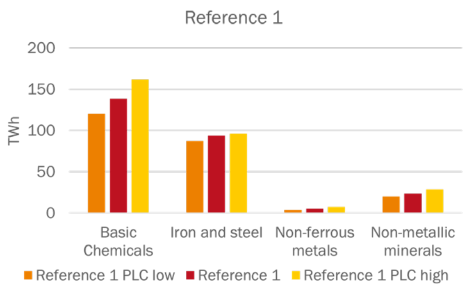

Figure 3.20a

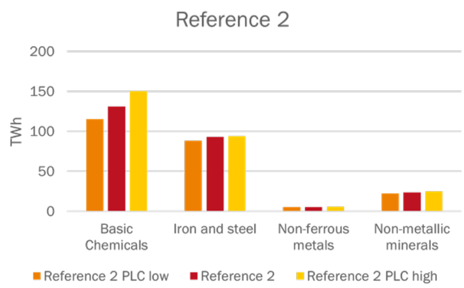

Figure 3.20b

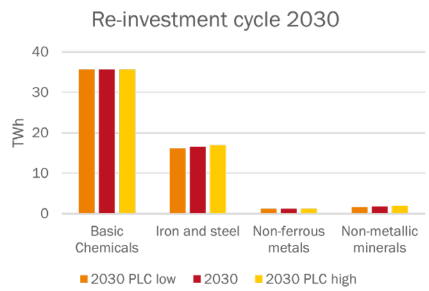

Figure 3.20c

Figure 3.20: Estimated hydrogen demand per country for northwest Europe for maximum hydrogen demand scenario including a range for low and high production level change

The impact of the production level change on total hydrogen demand for northwest Europe is summarized in Figure 3.21. In comparison with base case scenarios, the impact of production level change on hydrogen demand in four main subsectors is estimated to be in a range of -30 to +33 TWh for Reference 1 scenario, -22 to +22 TWh for Reference 2 scenario and -0.6 to +0.5 TWh for Reference 3.

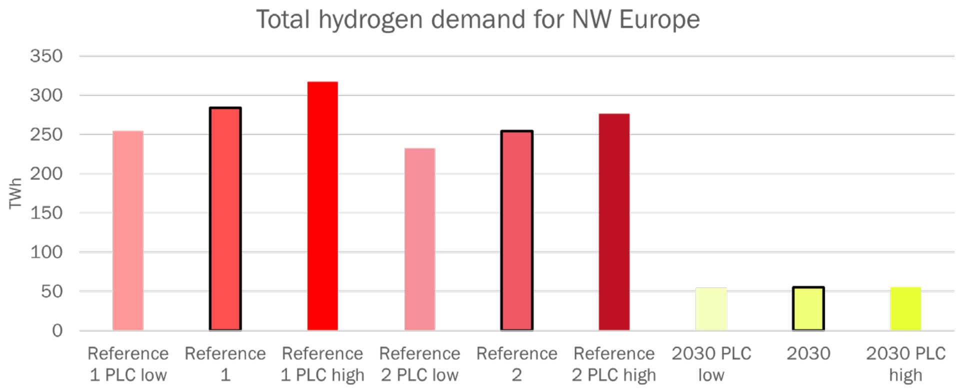

Figure 3.21: Impact of production level change on total hydrogen demand for northwest Europe

4 Conclusions

Today's energy- and emissions-intensive industrial sectors could potentially become large future consumers of hydrogen. There is considerable uncertainty in the hydrogen demand from these sectors, in addition to other end-uses like refineries, fuel production, and transport. This analysis of existing assumptions about output from large industrial sectors aims to give some insight into the implications of the range of possible future scenarios. The results of the analysis clearly indicate that production outlooks for manufactured materials are critical assumptions in any forward looking energy scenario, with a major impact on future hydrogen demand.

While it is impossible to pinpoint future energy demand with accuracy, scenarios can give some insight into interactions between sectors and technologies in the energy system. For example, other things being equal, a 5% increase in production levels through 2050 (0.6% CAGR) across the selected sectors would lead to an increase of about 12 TWh (42 PJ) in annual hydrogen demand in the Reference 2 scenario. Providing this additional hydrogen would be significant challenge for the energy system. This demand is equivalent to roughly the output of two GW-scale electrolysers running at 100% capacity for a year, or about 270 times the annual output of the largest existing PEM electrolyser in Europe, which producers 1300 tH_2/year, or 16 times the production capacity of the newly announced Shell electrolyser, Holland I (Shell, 2021).

However, despite the importance of these industrial output assumptions, information is limited, even on past production levels. Production outlooks are often politically sensitive, as they deal with strategic national economic priorities. Developing production level assumptions is also often outside the area of expertise or focus of energy researchers, and simple assumptions (such as constant production, or constant growth) are easily understood and communicated, and can limit "noise" in scenario results. For these reasons, it can be difficult for researchers and energy analysts to develop production level assumptions, or to understand the implications of those choices. Nonetheless, researchers make widely varying assumptions in future energy scenarios, often without explicitly discussing their sources or impacts on the scenario results.

More research is needed in this area, in order to improve the inputs to energy scenarios and thus energy policy and investment decision-making. A more comprehensive and systematic review of scenarios, particularly of those published at national level in other European countries or in languages other than English, would improve the quality of the analysis, and further investigation of the impacts of these assumptions on scenario results from other models and analyses would also be valuable. Inclusion of fuel production and refining would also be valuable, as a large share of hydrogen demand is likely to occur in these sectors.

Collaboration with economists and industrial stakeholders on input data could likely improve the quality of the results of such scenarios. Separation of different elements contributing to the output of materials could be investigated in detail, from consumption trends, to circularity and waste disposal, to competitiveness and trade. This analysis made use of data from the MIDDEN database, which is the result of extensive research into the Dutch industrial sector, with input from the companies themselves. Including other such initiatives with broader geographical scope would provide valuable information for researchers. Finally, greater transparency about production level assumptions in published research and scenarios would help to improve the understanding of existing results and provoke a discussion about the importance of these inputs.

Based on the results of this analysis, it is clear that production level assumptions play an important role; the dependence on this highly uncertain input creates uncertainty in the results, and risk for anyone drawing conclusions from our analysis (or a similar scenario). Regardless of production levels, any meaningful level of hydrogen demand in industry would require massive short-term investment in new renewable electricity generation, hydrogen production capacity, and energy transport and distribution infrastructure. On the high end of production levels, this raises the question: What can be done to limit these investment requirements, in a highly constrained situation where resources are limited? Is it feasible to sustainably and/or locally produce sufficient hydrogen to meet this demand?

Generally, in a future where production levels continue to grow beyond the pace of energy efficiency improvements, there is risk of energy shortages, missed climate targets, and other unforeseen environmental and economic consequences. It is unlikely that the amount of hydrogen needed at the upper range of these possible scenarios could be sustainably produced within Europe or affordably imported. Higher production levels exacerbate this problem. Specific research is needed to determine realistic expected levels of production and imports of sustainable hydrogen in northwest Europe.

On the lower end, the energy transition in industry (and the broader energy system) could potentially be less painful, costly and complicated than initially expected, freeing up resources to be used to tackle other challenges. This is not to suggest that all industrial production levels in northwest Europe should be minimized; rather, costs of industrial production, particularly where large amounts of renewable hydrogen are required in order to reduce emissions, should be weighed against economic benefits.

Policymakers and industrial stakeholders will need to make difficult choices about how to design future policy, and where and how to source or produce key materials and goods. These are complex questions which get to the heart of the difficulty of the energy (and material) transition, about making effective and fair climate and energy policy, balancing economic and environmental goals, and transforming the way that society produces and consumes materials and energy. A simple analysis of production levels in energy scenarios does not answer these questions, but it will help make energy scenarios and projections more transparent and hopefully, begin a discussion on the important questions surrounding what we as a society should produce, and how and where we make it.

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