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Options for achieving a close-to climate-neutral EU industry and their implications

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Abstract

Industry is a critical sector for the achievement of European climate goals, in particular specific energy-intensive products/processes (e.g. steel, cement, ethylene, ammonia). A reduction target of over 90% for industry requires a wide variety of reduction options. While the EU Low-Carbon Roadmap 2011 for the industry sector was still limited to energy efficiency, biomass and CCS, the new long-term climate protection strategy includes further options such as electrification, renewable synthetic energy sources, ambitious recycling management, material efficiency along the value chain and innovative manufacturing processes. For many industries, this transition involves fundamental process changes. Against this background, the paper aims to take a closer look at the implications for the individual sectors. In addition, a more in-depth assessment of material efficiency, substitution and recycling measures in the building sector and the use of hydrogen in the chemical and steel sectors is provided. The paper served as a basis for an input to the event "Decarbonizing industry - Energy and CO2 Saving Potentials in the short and longer term" at the EUSEW 2020 (EUSEW 2020) and is based on previous similar works.

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1 Introduction

Industry accounts for about 25% of EU final energy demand and its dominant energy carriers are gas, electricity, coal, and oil. This means the sector is critical for the achievement of European climate goals. The high share in final energy demand mainly stems from energy-intensive industries such as the iron and steel, non-metallic mineral, or the chemical sector. Within these industries, specific energy-intensive products/processes (e.g. steel, cement, ethylene, ammonia) are particularly relevant for the future achievement of European climate targets. Even though some sectors already use a high share of electricity and biomass (e.g. paper industry) - industry, in general, still needs to make substantial further efforts to reduce the use of fossil fuels in the next decades and the transformation of the industrial sector towards CO2-neutral production is facing major challenges. In terms of end-uses, most industrial greenhouse (GHG) emissions are from high-temperature process heat, either in the form of steam or hot water, or from the direct firing of various types of furnaces. The high temperatures and the specific requirements of furnaces limit the use of renewable energies to biomass or secondary energy carriers. Process-related emissions account for about one fifth of all direct emissions. At present, it is technically difficult or even impossible to mitigate them with market ready technologies.

Consequently, a reduction target of over 90% for industry requires a wide variety of reduction options. While the EU Low-Carbon Roadmap 2011 (European Commission 2011) for the industry sector was still limited to energy efficiency, biomass and CCS, the new long-term climate protection strategy (EU COM 2018) includes further options such as electrification, renewable synthetic energy sources, ambitious recycling management, material efficiency along the value chain and innovative manufacturing processes. For many industries, this transition involves fundamental process changes. In the steel industry, for example, this could mean a switch to hydrogen-based direct reduction. In the cement industry, new products using innovative binders are being developed which are expected to result in significantly lower process emissions. The EU Commission's 2020 Environmental Services Action Plan makes environmental services an important element in industrial transformation.

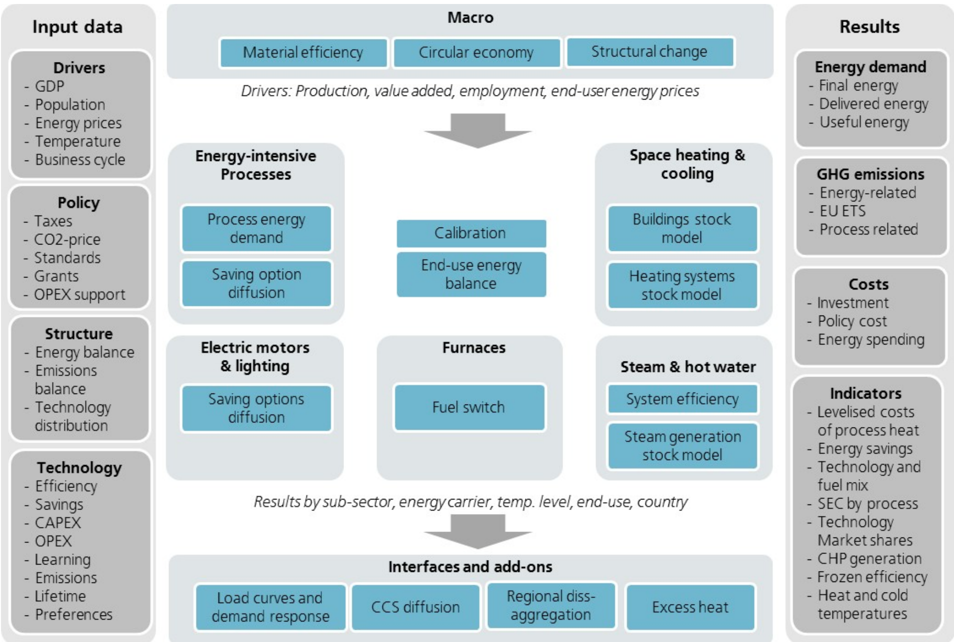
Against this background, the paper aims to take a closer look at the fields of action identified in the accompanying industry study (Fleiter et al. 2019) and their implications for the individual sectors. In addition, a more in-depth assessment of material efficiency, substitution and recycling measures in the building sector and the use of hydrogen in the chemical and steel sectors is to be provided for two particularly relevant focus topics. The paper served as a basis for an input to the event "Decarbonizing industry - Energy and CO2 Saving Potentials in the short and longer term" at the EUSEW 2020[1] and is based on previous works (Fleiter et al. 2019 and Ramboll, Fraunhofer ISI and Ecologic 2020).

1 https://euase.net/watch-webinar-decarbonising-eusew2020/

2 Approach

In the aforementioned study on pathways for deep decarbonisation in the industry sector (Fleiter et al. 2019) a scenario approach for the long-term development of energy demand and greenhouse gas emissions has been chosen, including a detailed modelling analysis of transition pathways for energy-intensive industry sectors towards 80% and 95% reduction targets by 2050 compared to 1990. The FORECAST model was developed by Fraunhofer ISI as a tool that can be used to support strategic decisions. The model considers a broad range of mitigation options combined with a high level of technological detail. Technology diffusion and stock turnover are explicitly considered to allow insights into transition pathways and speed. The model further aims to integrate policies and considers changes in the socio-economic framework (see Figure 1). FORECAST is designed to cover the entire industry sector including major energy-intensive processes with a high level of detail, but also many less energy-intensive sub-sectors and applications. The complete simulation is conducted on the level of individual sub-sectors like iron and steel. The scope of the model is defined by the energy balances and focuses on final energy, but also includes useful energy (for more details see Fleiter et al. 2018).

Figure 1: Forecast model structure



Source: Fraunhofer ISI

As mentioned before deep decarbonisation in 2050 requires a broad range of mitigation options. FORECAST considers the following mitigation options: energy efficiency, fuel switching, carbon capture and storage, and circular economy including recycling, material efficiency and substitution. These mitigation options are included with a varying level of detail in the individual sub-models. Energy efficiency improvements and fuel switching are modelled endogenously on a technology level in a number of individual sub-models. Mitigation options like material efficiency and recycling are considered via exogenous assumptions that need to be incorporated in the scenario definition.

3 Scenarios of future industrial energy demand and CO2-emissions[2]

3.1 Scenario definition and framework assumptions

Long-term quantitative scenarios always contain a huge uncertainty and may not be taken as forecasts. The main conclusions can, however, be drawn by comparing alternative scenarios, which requires a structured and well-defined scenario set-up. In the following, we show three scenarios:

- a reference case (Reference) which includes existing technologies and incremental energy efficiency (EE) improvement, price driven fuel switch to natural gas and biomass, limited progress in recycling based on historic trends;
- a best available technology case (BAT) which comprises the assumptions of the aforementioned reference scenario but additionally includes complete diffusion of today's best available technologies (BAT) with regard to EE where applicable as well as fast development of recycling;
- a high ambition mitigation scenario (Mix95[3]) comprising a balanced mix of mitigation options not only including BAT but also innovations with TRL >4 to achieve a reduction target of -95%.

The decarbonisation scenario represents a radical shift compared to today, which will also require substantial changes in the regulatory and economic framework, built up of infrastructure or public perception. However, this regulatory, economic, political as well as infrastructure related requirements have been outside the system boundary of the analysis (for details see Fleiter et al. 2019).

The macroeconomic framework data for the model-based analysis stem from the European Reference Scenario 2016 (European Commission 2016) and remain the same across all scenarios. The reason for this assumption is the better comparability of changes in policy parameters and assumptions between scenarios. The same applies to the assumptions on the wholesale price development of fossil fuels (coal, gas, oil), which are also based on the European Reference Scenario 2016 and are kept constant between the scenarios. A CO2 price is assumed for the ETS sector in line with the EU Reference Scenario 2016 for scenario 1 Ref. It is increased to 200 euros/t CO2 in the scenario 2 BAT by 2050. An even

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2 Fleiter et al. 2018, Fleiter et al. 2019

3 In der Originalarbeit wurde ein weiteres Mix-Szenario mit einer 80%-Minderung analysiert 4b-Mix95. Im Weiteren Mix95.

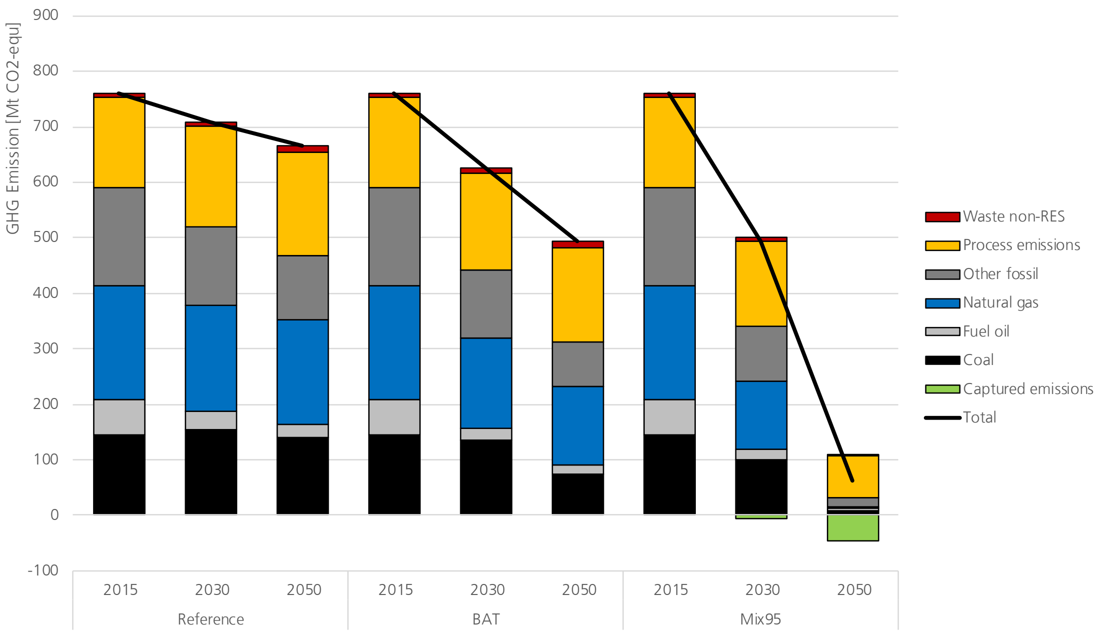
10 years earlier increase is assumed for scenario Mix95, which arrives at 200 euros/t CO2 in 2040 and then remain on that level. In addition to the EU ETS allowance price, the decarbonisation scenario assumes that the ETS price is also included for the industries in the non-ETS sector, which introduces incentives for fuel switching.

3.2 Overview scenario results

In the BAT scenario today's best available energy efficiency technologies are applied without considering innovations in the industry sector. Even though not taking into account radical process improvements and innovations a substantial decrease of GHG emissions by about 35% in 2050 compared to 2015 (59% compared to 1990) is achieved in this scenario (see Figure 2). This is mainly driven by energy efficiency improvements, price-driven fuel switch towards renewable energy and electricity as well as higher recycling rates particularly for steel. Biomass and ambient heat are assumed to gain importance while the use of coal and other fossil fuels fall substantially. The Mix95 results show a reduction of GHG emissions by 92% by 2050 compared to 2015, which equals about 95% compared to 1990 (see Figure 2). This is achieved by including ambitious changes in the entire industrial production system assuming a rapid speed of change which targets a nearly 100% transition by 2050. In some cases, this requires early replacement of technologies before they reach their ordinary end-of-life, which increases overall investment needs and costs (for a more detailed discussion see below).

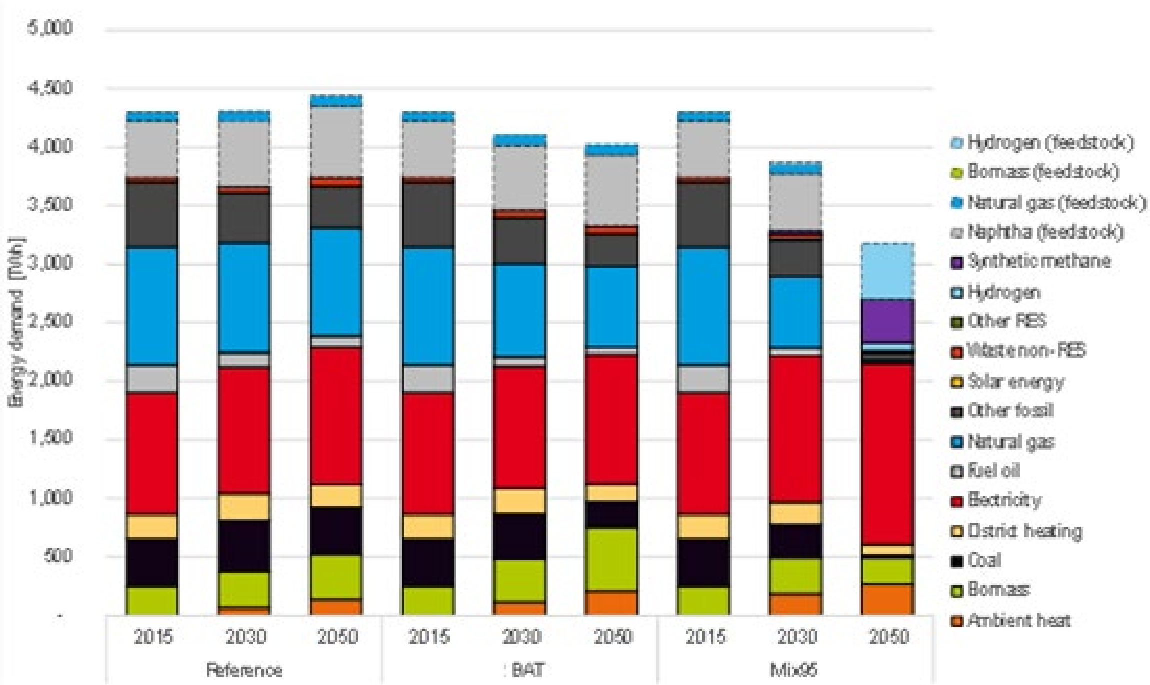
In the Mix95 scenario, electricity is the most important energy carrier in 2050 followed by hydrogen (mainly for feedstock use), synthetic methane, biomass and ambient heat. District heating falls substantiallyb (see Figure 3). However, from a systems perspective it might be more cost-efficient to use heat grids. Only minor shares of fossil fuels remain in 2050. In total, electricity demand increases from 1,041 TWh in 2015 to 2,946 TWh in 2050 of which 1,539 TWh are directly used and 1,407 TWh are needed for the production of hydrogen and synthetic methane via electrolysis.

Figure 2: EU28 Industrial CO2 emissions by source[4]



Source: Fleiter et al. 2019

Figure 3: EU28 Final energy demand plus feedstock demand by source



Source: Fleiter et al. 2019

4 The Reference scenario reflects the effects of current policies on the future energy system and serves as a benchmark to compare the other scenarios.

In the following you find a discussion on the different mitigation options (i.e. fuel switch, process switch and CCU) based on Fleiter et al. 2019 and Fleiter et al. 2020.

Energy efficiency

Both scenarios assume progress in energy efficiency. This includes the use of best available technology (BAT) for process technologies as well as for cross-cutting technologies such as engines, compressed air or steam generation in the BAT scenario. The processes currently used to produce energy-intensive basic material products have been optimised over many decades. Consequently, the remaining energy efficiency potentials due to applying the best available technology (BAT) are limited. In the Mix95 scenario the progress goes further than this by using innovative efficiency technologies that are not yet market ready. Despite increasing value added in the industrial sector - the combination of energy efficiency with measures of material efficiency and recycling leads to a significant reduction in final energy consumption (see Figure 3). Despite this ambitious improvement, energy efficiency can only make a certain contribution to decarbonisation - even if the available potential is largely exploited. In addition, the decarbonization of industry requires a fundamental change in many processes, which is often associated with the replacement of existing plants. In these cases, the (incremental) optimization of efficiency is not necessarily target-oriented in the long term. In the Mix95 scenario, the majority of the reduction effort is achieved by switching to CO_2-neutral energy sources.

Fuel switch to biomass and electricity

Switching to CO_2-neutral or low-CO_2 energy sources for the generation of process heat is a central lever for reducing industrial CO_2 emissions. This includes the generation of process steam, but also heat generation by means of industrial furnaces. In basic materials industries temperatures of more than 1000°C are often necessary. Here, only biomass and biogas as well as the use of renewables via secondary energy sources such as electricity, hydrogen or synthetic gas come into question. The conversion of process heat generation to biomass or renewable electricity is in many cases associated with fundamental conversions or the replacement of furnaces and steam generators. Besides economic considerations, the change of energy source in many processes depends on technical restrictions. For example, a minimum use of coke or coal is required in the blast furnace for steel production. In these areas, a comprehensive change of energy sources is only feasible if it is accompanied by a fundamental process change.

In the BAT scenario, biomass use increases substantially until 2050 from today's 251 TWh to about 550 TWh. This strong increase is mainly driven be the lack of innovative technologies for high temperature process heat and innovative low-carbon products in the scenario and low biomass prices. Electricity demand remains nearly on current levels (+6%). This indicates that electricity use in the scenario is not yet competitive compared to biomass and depends strongly on the regulatory framework. In the Mix95 scenario biomass use increases until 2030 (307 TWh) but falls again towards 2050 to todays level (229 TWh). Electricity demand shows very different patterns in the two scenarios. The scenario Mix95 experiences a sharp increase from about 1041 TWh to 1539 TWh in 2050. However, a larger share (57%) of this increase takes place after 2030. Given the decreasing overall final energy demand, the shares of both electricity and biomass are increasing substantially in the Mix95 scenario towards 2050.

Fuel switch to synthetic methane

The purely energetic use of synthetic gas to generate process heat in industrial furnaces and for steam generation is associated with low conversion costs on the demand side, because the equipment for firing natural gas can be used further. Starting from an established technological and economic basis for the use of natural gas in the existing energy system, PtG can maintain and expand in industrial furnaces and process steam generation. In doing so, it replaces (together with direct electricity use, biomass and ambient heat) coal and heating oil, as well as non-renewable waste and other fossil energy sources. In the Mix95 scenario the use of natural gas/PtG for process heat generation decreases from 1008 TWh (100% natural gas) in 2015 to 367 TWh synthethic methane and 19 TWh natural gas demand in 2050.

Fuel switch to hydrogen

Hydrogen use in the Mix95 scenario is summarized in the following. Steel production is switched to hydrogen-based processes. Specifically, two innovative processes for steel production are considered in the scenario. First, direct reduction with hydrogen, which is similar to the natural gas-based direct reduction process. Second, direct steel production in a hydrogen plasma process. This leads to a hydrogen demand in the sector of 73 TWh in 2050. The chemical industry uses H2 as feedstock for ethylene (Methanol-to-Olefines, MtO), methanol and ammonia production stemming from renewable-based electrolysis and is assumed to take place at a large scale (100% of ethylene, ammonia and methanol). This makes the supply of carbon necessary and offers a starting point for CCU concepts. Energetically, however, only the contribution of hydrogen is relevant. Hydrogen thus dominates the raw material supply of the chemical industry in the scenario (480 TWh in 2050).

Process switch to CO2-neutral industrial processes

In the Mix95 scenario, the transition to an almost CO_2-neutral industrial production requires fundamental transitions in the production of mass products in the basic industries such as ammonia, olefines, steel, glass and cement, which currently use fossil fuels and fossil feedstocks to a large extent. Until now, innovative low-carbon processes, some of which can potentially achieve CO_2 neutrality, are being developed (see Chan et al. 2019). These rely on direct or indirect electrification and thus on the actual and economic availability of renewable electricity. Other approaches pursue material substitution strategies, e.g. in the cement industry. Direct electrification includes the electrically heated glass smelter, which is already used on a comparatively small scale for the production of container glass. Indirect electrification includes the use of hydrogen produced by electrolysers as an energy carrier, reducing agent (steel: H_2-DRI, H_2-plasma) and raw material (chemistry: H_2-methanol, H_2-ammonia). Material substitution strategies include the market launch of new types of cement (low-CO_2 cement), which use smaller proportions of the raw material limestone and in some cases require less energy input.

Although all these processes show great potential for emission reduction, substantial economic uncertainties exist, that have so far prevented their widespread implementation (beyond pilot and demonstration plants). For this reason, technical questions of feasibility on an industrial scale have not always been answered yet. At the same time, there are currently several projects dedicated to the implementation of these technologies. In this study it is therefore assumed that the market introduction on an industrial scale is possible between 2025 and 2030. A complete reorganisation of production routes is then necessary by 2050 in order to bring the scenarios examined to a 93% GHG emission reduction relative to 1990.

CO_2 capture storage and use (CCU/S)

The scenario Mix95 does only assume CCS for remaining clinker and lime production as well as refineries, because other major emitters already mitigate emissions via other options. The total CO2 captured in 2050 is with about 46 Mt CO2/a rather low. This is explained by three main factors: first, alternative production technologies gain large market shares of mostly 100% in all energy-intensive sectors (e.g. low-carbon cement, H2-based chemicals and steel). Second, in glass and paper, CCS was not allowed as it is more unlikely in these sectors. Third, renewable electricity and clean gas reduce CO2 emissions drastically, which leaves little space for additional CCS. Consequently, a major application of CCS is the non-metallic minerals industry, where process emissions are difficult to mitigate. Here, it is mainly lime burning that applies CCS, because alternative mitigation options are not available. To conclude, the large-scale introduction of CCS might be related to substantial lock-ins and is a highly controversial subject regarding social acceptance and the distribution of costs (infrastructure, transport and storage), it might however play a small role in scenarios that aim for industrial CO2-neutrality.

CCU is not included in the Mix95 scenario. Mainly because short product lifetimes would not result in net long-term emission reductions or require additional carbon capture at the end of the product use chain (e.g. waste incineration). However, CCU might play a role in providing the needed carbon to produce synthetic methane from hydrogen or for the green hydrogen based basic chemicals industry. Process-related CO2 emissions, for example from the cement and lime industries, could be one potential CO2-source. Additional capture from other processes (e.g. waste incineration plants) or other technical solutions, such as direct air capture of CO2, are a possibility. However, long-term CO2 neutrality must be taken into account as an important condition, which may require the CO2 cycle to be closed at the end of the product's life.

4 Hydrogen use in industry[5]

Hydrogen based on renewable electricity could play a major role in the transition towards a CO2-neutral industrial production, since its use as energy carrier as well as a feedstock in various industrial process routes is promising (see section 3).

4.1 Hydrogen-based steelmaking[6]

The direct reduction of iron ore with hydrogen from renewable energy and the electric arc furnace offers a steel production process that could be close to carbon free, if the hydrogen is produced from renewable energy. Direct reduction of iron ore based on the consumption of natural gas is a commercially available process. To substitute coal based primary steelmaking with steelmaking based on the direct reduction of iron ore with hydrogen, the renewable hydrogen has to be available in the required quantities and at cost-competitive prices. Hydrogen based steelmaking is currently an intensively researched technology. E.g. the Swedish steelmaking company SSAB runs the HYBRIT-project in cooperation with the Swedish iron ore provider LKAB and the Swedish energy supplier Vattenfall or the German Salzgitter started the SALCOS project, that focusses on the step-by-step transition of a current coal-based primary steelmaking site to primary steelmaking based on hydrogen based direct reduction using currently available technologies Chan et al. 2019). If electricity is produced from renewable energy, the process can be close to CO2-neutral steel production. It is estimated that CO2-emissions can be reduced by 95% since carbon is still required for cathodes and since steel contains some carbon (less than 3%). The economic viability of hydrogen-based steelmaking largely depends on the price of electricity (or hydrogen), the price for CO2 and European and national policy developments (e.g. carbon contracts for difference, green hydrogen quotas, for details on policy options and their legal implications see Agora 2019).

5 Marius Neuwirth, Tobias Fleiter, Pia Manz and René Hofmann (to be published): The potential of hydrogen-based production technologies for energy-1 intensive industries - a site-specific approach applied to Germany. Forthcoming

6 Chan et al. 2019

4.2 Hydrogen use for process heat

In addition to the existing approaches, similar uses of hydrogen in other industries could also be conceivable. A report of the Hydrogen Council (2017) highlights the following potential industrial uses (HydrogenCouncil 2017):

- Chemical and petrochemical: use of by-product hydrogen to retrofit equipment (e.g. ethylene crackers)
- Aluminium recycling: retrofit of gas-fired furnaces for the use of hydrogen
- Cement: combination of hydrogen with waste-derived fuels
- Pulp and paper: use of hydrogen high-purity flames for quick drying of paper or for steam generation
- Cross-sectoral: use of hydrogen to complement electrification and heat pumps (<100-400°), use of hybrid boiler systems, hydrogen-based CHP plants

In general, it can be said that the use of hydrogen is conceivable both in steam generation and in industrial furnaces. However, the widespread implementation of H2 in the industrial sector still faces major challenges. Elvarasan (2018) identifies high flame speeds as the main challenge during the combustion of hydrogen as these make it difficult to control the flame, as high pressures are required. To stabilize combustion the hydrogen/air mixture has to be closely regulated. Another approach could be direct steam generation from hydrogen using a catalytic burner, which would allow to closely matching the combustion temperature to the desired temperature level (Neuwirth & Fleiter, T. (2020)).

To burn hydrogen in a furnace, burner technologies has to be developed and improved to meet the different characteristics of a hydrogen flame. Currently, various technology manufacturers are working intensively on hydrogen burner technologies (e.g. Toyota[7], E&M Combustion[8])

4.3 Hydrogen use as chemical feedstock[9]

One of the most important industries with great potential for hydrogen use is the chemical industry, in particular the production of basic chemicals like ammonia and methanol (and Methanol-to-Olefins) could have a key role in the transition towards a CO2-neutral industry (for details see Neuwirth et al. (to be published), Neuwirth et al. 2020, Chan et al. 2019).

7 https://global.toyota/en/newsroom/corporate/25260001.html

8 https://emcombustion.es/en/hydrogen-burner/

9 Neuwirth et al. 2020, Chan et al. 2019

Ammonia, one of the most important inorganic basic materials, is mainly used for the production of fertilizers and has a specific hydrogen demand of 0.178 tons per ton of ammonia, this corresponds to a hydrogen consumption of 516 kt and an energy consumption of about 27.5 TWh (Dechema 2017). The production of ammonia consists of two integrated process stages, the synthesis gas process and the ammonia synthesis according to the Haber-Bosch process (Dechema 2017; Smith et al. 2004). Sources for green hydrogen are water electrolysis using renewable energy (Power-to-Ammonia) and methane pyrolysis. No direct CO2 emissions are produced, and the coupling of hydrogen production by water electrolysis and the subsequent Haber-Bosch process makes it possible to avoid the use of fossil fuels (Ikäheimo et al. 2018). Due to the higher electrical efficiency of high-temperature electrolysis and the possibility of heat integration with ammonia synthesis for better heat utilization, high-temperature electrolysis may have the best potential for coupling with ammonia synthesis in the future (Cinti et al. 2017). The main difference between the alternative and conventional ammonia production is only the provision of the hydrogen required for the ammonia synthesis.

Methanol is widely used in the chemical industry as an intermediate for a variety of industrial chemicals, with a specific hydrogen demand of 0.189 tons of hydrogen per ton of methanol. Methanol production can basically be divided into three steps: Synthesis gas production, raw methanol production and methanol processing. The production of methanol via alternative routes differs from ammonia production only in the appropriation of the synthesis gas for methanol synthesis. CO_2 sources for mixing with hydrogen to produce synthesis gas can be the flue gases from power plants or factories that produce steel, cement and other large CO_2-intensive products. The required hydrogen can be provided by water electrolysis (power-to-methanol) or methane pyrolysis.

Ethylene is produced in the petrochemical industry by thermal cracking of long-chain hydrocarbons (usually naphtha) in a so-called steam cracker as a partial product of the process. Ethylene is conventionally produced by fossil heat generation for thermal cracking in steam cracker. (Dechema 2019). Compared to ammonia and methanol, the possibility of transforming ethylene production via hydrogen is much more complex, since no hydrogen is used in conventional ethylene production. In addition to the substitution of fossil-fired steam cracker by electrically heated boilers for steam generation, ethylene production via methanol (methanol-to-olefins) as an intermediate product represents a further variation for decarbonisation. The specific total energy requirement of hydrogen-based ethylene production via methanol-to-olefins (MtO) is, about factor 5 higher than the conventional route when based on electrolysis.

In order to avoid CO_2-emission by replacing conventional technologies with the above mentioned processes it is essential to provide the necessary electricity based on renewable energy sources, leading inevitably to the need of a faster transformation of the electricity sector in combination with infrastructure that allows either central or decentralized generation and/or distribution of hydrogen/electricity. Furthermore, transport of CO_2, which is needed for methanol production and the MtO route, has to be taken into account. Neuwirth et al. (2020) showed that based on the age structure of chemical plants in Germany, the conversion to alternative production routes could be faster than assumed (if supported by appropriate regulatory/policy framework).

5 Circularity to support decarbonisation[10]

To achieve the target of an almost climate-neutral industrial sector a bundle of technologies and measures will be needed that go beyond energy efficiency and fuel switching. In this context, circular economy is an important pillar in reducing the demand for energy-intensive raw materials and gains momentum in the political debate. In December 2019, the European Commission published its communication on the "The European Green Deal" highlighting to mobilise industry for a clean circular economy to transform the European Union into a CO_2-neutral system in which growth is decoupled from resource use (EU COM (2019)). To support this, the European Commission published in March 2020 a "New Circular Economy Action Plan". The main pillars of this action plan include (EU COM (2020)): making products sustainable (reuse, repair, recycling), empowering consumers, and ensuring less waste (avoidance, high-quality secondary uses).

Ramboll, Fraunhofer ISI and Ecologic (2020) – in a study carried out for the EEA – and Rehfeldt et al. (2020) analyzed decarbonisation benefits of sectoral circular economy actions for the construction sector, thereby mainly focussing on the implications on the demand of the energy-intensive basic material cement. The constructions sector is of major importance as it includes the use of vast amounts of energy- and CO_2-intensive products. The single most important product is concrete (and its precursor products cement and clinker), which is normally regionally produced within the EU. Consequently, circularity measures in the construction industry could make a significant contribution to reduce CO_2-emissions in the European cement industry. The analysis has been based on a bottom-up material flow modelling approach. The assessed measures include actions along the whole value chain. Some examples are the reduction of ~~over~~ specification, material substitution (e.g. new binders, wood use), extending buildings' lifetime, design for disassembly, etc. (see Figure 4).

10 Rehfeldt et al. 2020, Ramboll, Fraunhofer ISI and Ecologic 2020

Figure 4: Selected measures for quantification of benefits of circularity measure in the building sector

Lifecycle stage	Action	Related materials and products
Product Design	• Reduce the use of material at design stage (reducing overspecification)	• Steel use in all buildings • Concrete use in all buildings
	• Reuse building materials/components	• Structural steel • Structural (pre-cast) concrete use in non-residential buildings
	• Extend buildings' lifetime by renovating rather than demolishing and rebuilding	• Concrete use in residential buildings
	• Design buildings for disassembly	• Concrete use in all new buildings
	• Use timber as the structural material in buildings instead of mineral materials	• Residential buildings • Non-residential buildings
Production Processes	• Use other types of cement as a substitute for ordinary cement	• Cement use in all buildings
Consumption Models	• Optimise the use of space in buildings (intensifying building use, in number of users per square metre)	• Concrete use in non-residential buildings • Concrete use in residential buildings
Waste management	• Recycle building materials	• Cement collected from demolition of all buildings

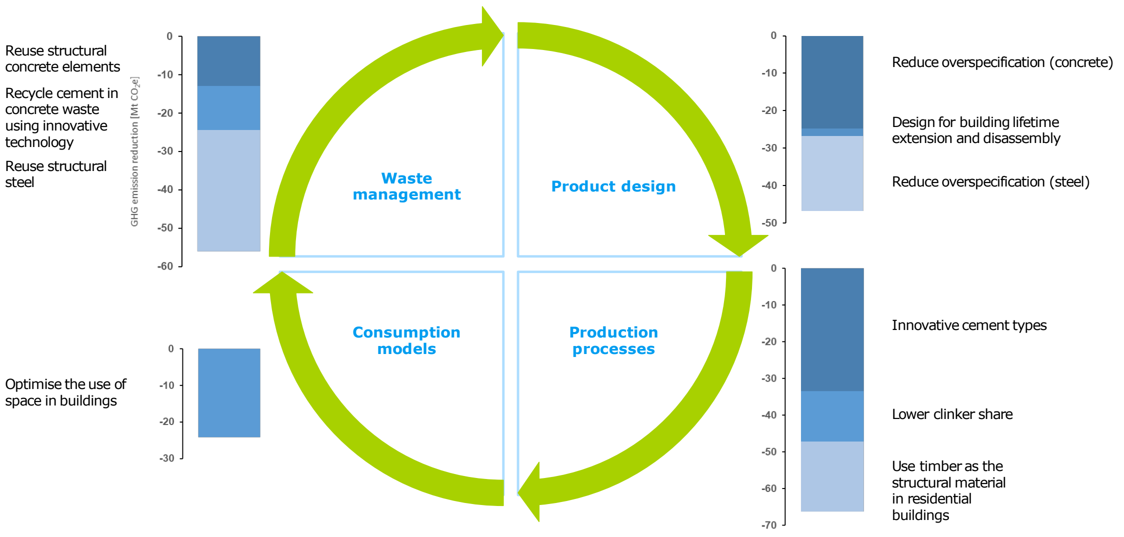
Source: Ramboll, Fraunhofer ISI and Ecologic 2020

The application of selected actions of material efficiency, circular economy and sufficiency in a high ambition scenario showed that the considered actions may contribute substantially to the decarbonisation of the construction sector, yielding CO_2-emission reductions of 91 Mt (58%). The manufacturing stage (i.e. clinker burning) accounts for the highest share both in absolute emissions and saving potentials. However, actions affecting the end use (e.g. optimized space use, re-use of concrete elements) indirectly affect the manufacturing stage by reducing material demand and thus also show relevant potentials. Therefore, while the manufacturing stage is the by far most emission intensive element in the life cycle of cement and concrete, circularity actions in all life cycle stages can be effective measures for CO_2-emission reduction.

However, a main challenge when determining circularity actions impact on greenhouse gas emission is the vast amount of data needed along the whole product life-cycle which is not yet readily available. Leading to assumptions and extrapolations from limited data sets. For example, while data on clinker and cement production can be considered to be highly reliable, the respective cement's end use (residential and non-residential buildings, infrastructure) is not regularly reported. Shifts in the end use shares may have substantial effect on the actions' effects, as these target specific end uses. Second, data on the actions specific saving potential are uncertain. While for model implementation, strict values were used, literature sources present ranges of saving potentials. Third, the material flow model includes only a limited representation of the end use, in particular the building stock. While for many investigated actions that affect the yearly production of cement (e.g. cement substitutes, clinker share variations), this perspective is sufficiently detailed, other actions would benefit from much more detailed representation of the building stock and its transformation in the framework of a 2050 carbon-neutral economy. Here further research and the structural gathering of data on EU-country level would be necessary to allow for more robust results.

Nevertheless, Ramboll, Fraunhofer ISI and Ecologic (2020) and Rehfeldt et al. (2020) show that measures along the entire value chain are relevant. Although innovative cement products using new binders have the highest potential for CO_2 avoidance in absolute terms in the individual analysis in the scenario, the differences to other measures such as the optimisation of space utilisation in buildings or the use of timber are not very strong. If the current market maturity of the innovative technologies is taken into account, the measures in the other life cycle phases receive even more weight.

Figure 5: Representation of the individual contribution of CE actions for both steel and cement to CO_2 emission reduction (in $MtCO_2$) building lifecycle (100% diffusion)



Source: Ramboll, Fraunhofer ISI and Ecologic 2020

Overall, however, there is still a need for further research and modelling in order to robustly assess the potential of CE actions in all sectors for CO_2 avoidance and to develop (policy) framework conditions for their widespread implementation.

Summary

The transformation of the industrial sector still faces very significant challenges at this point in time. Responsible for about 25% of GHG emissions in Europe, the industrial sector is of crucial importance for the achievement of European climate targets. A high dependency on fossil fuels in combination with high temperature requirements, technical restrictions, and process-related emissions from chemical reactions in the production process require significant changes in energy-intensive industrial sectors but also extensive support for renewable energies and efficiency.

The Mix95 scenario shows a pathway to nearly CO2-neutral industrial production by 2050. It includes ambitious changes to the entire industrial production system and assume a profound transformation in many sectors and value chains. The most important abatement levers are energy and material efficiency or circular economy, process change to secondary production routes and innovative CO2-neutral processes, as well as extensive use of CO2-neutral secondary energy carriers such as electricity and hydrogen.

In order for the transition to CO2-neutral industrial production by 2050 to succeed, the time horizon until 2030 is crucial. By then, it must be possible to scale up CO2-neutral processes from pilot and demonstration scale to industrial level and make them economically viable. Without a substantial use of new low CO2-neutral production processes such as the production of steel via direct reduction or green hydrogen based basic chemicals, the transformation cannot be achieved. Accordingly, the regulatory framework must provide a clear perspective for CO2-neutral production. This particularly concerns the availability and role of CO2-neutral hydrogen, gas and electricity. Green lead markets can also accelerate the transformation. Beyond the basic industry, CO2 price signals down to the consumption sectors are crucial to align value chains with the goal of CO2 neutrality and support the transformation towards a circular economy.

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