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Transitioning to climate neutrality by 2050: a major challenge for German industry

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With Germany and Europe aiming for climate neutrality, German industry needs to undergo a structural transformation to become climate-neutral by 2050. Climate action scenarios demonstrate that the transformation is technically possible. Key building blocks include improved energy efficiency, developing the circular economy, electrification on the basis of renewable energy, the use of biomass and green hydrogen, as well as carbon capture, storage and utilisation. But the challenges on the road to achieving climate neutrality are significant. Basic materials industries such as steel and chemicals in particular need fundamental changes to production processes which require high investment. Many key decarbonisation technologies have to be scaled to industrial levels first. Besides, the green transformation of industry needs large additional quantities of electricity from renewables as well as climate-neutral hydrogen. The necessary infrastructure needs to be created at an early stage.

High sums need to be reinvested in greenhouse gas-intensive basic industries by 2030. It is important to take advantage of this window of opportunity to advance the necessary structural transition to climate neutrality. As many key technologies for the decarbonisation of industry currently incur significant cost disadvantages compared with conventional fossil technologies, a political framework and economic incentives need to be set for their market penetration. In addition to continuous promotion of innovation and investment, a reliable and predictably rising CO_2 price signal is essential. Effective protection from carbon leakage, particularly for energy-intensive businesses competing internationally, is vital to ensure acceptance of the transformation.

At the same time, the environmentally sound transformation of the economy provides considerable opportunities for future value creation and employment. This applies particularly to the export of climate-friendly technologies, as increasingly more industrialised countries are joining Europe in committing to climate neutrality. As the world's second largest exporter of climate-smart goods after China, Germany is in a good starting position.

Industry is second largest greenhouse gas emitter in Germany

Climate change is one of the most pressing challenges of our times. Businesses are increasingly being affected by rising energy needs to cool down equipment and buildings during periods of heat and by damage from extreme weather events, for example. In order to make an effective contribution to the fight against global climate change, Germany and the European Union have committed to pursuing climate neutrality as a long-term goal by 2050. The aim is to reduce new 'net' greenhouse gas (GHG) emissions to zero by then. Under the German Climate Protection Act, by the year 2030 Germany's GHG emissions are to be reduced by at least 55% against the 1990 baseline (reduction in 2020: -42%[1]). Reaching climate neutrality in the long term will require considerable efforts from all economic sectors. Industry also has a responsibility to contribute to this goal. With a share of 23%, it is the second largest emitter of greenhouse gases in Germany – after the energy sector with 32% and before transport and buildings, which account for 20 and 15% (as at 2019).[2] The largest industrial GHG emitters include steel, chemicals, cement, non-iron metals, the lime, glass and paper industries, as well as self-generated electricity supply.[3]

Industrial sector to become greenhouse gas neutral by 2050

Industrial firms have already reduced their GHG emissions significantly in the past 30 years. Annual emissions fell by 34% between 1990 and 2019 (Figure 1). And even so, they generated approx. 40% more value during the same period (on a price-adjusted basis).[4] These savings were primarily the result of more energy and material-efficient manufacturing processes and products. In addition, producers increasingly switched to electricity-based manufacturing processes.[5] Much of the greenhouse gas reductions was achieved in the 1990s, partly as a result of the economic upheaval in Germany's eastern states and the general structural transition towards less energy-intensive sectors.[6] Since 2010, however, emissions in the industrial sector have largely stagnated (Figure 1). Most of the further GHG reductions from energy efficiency measures and the use of lower-carbon fuels were largely offset by increased energy consumption resulting from economic growth. To be sure, GHG emissions are likely to have dropped substantially in 2020 as a result of the coronavirus pandemic. But this decrease is probably only temporary. The experience of the global financial crisis of 2009 has shown that as the economy recovers, emissions also rise again quickly.

In 2016, the German Federal Government for the first time also set sector-specific greenhouse gas reduction targets for the year 2030 with its Climate Action Plan 2050. These were made into law with the passage of the Federal Climate Protection Act of the year 2019. The act requires the industrial sector to cut its GHG emissions in half by 2030 against the 1990 baseline (49 to 51%). In order to meet this target, annual GHG emissions have to be reduced by another approximately one quarter compared with 2019 (Figure 1). Thus, measured against the stagnating emissions of the past ten years, the pace of reduction will have to be accelerated significantly over the remainder of this decade. Moreover, a further increase in the aspiration level of the national sector targets for 2030 cannot be ruled out after the European Union in December 2020 agreed to strengthen its emissions reduction target for 2030 from -40% to at least -55% against the 1990 baseline. Over the long-term horizon to 2050, industrial emissions will have to be reduced by 95% or more. This is confirmed by a meta-analysis of relevant studies and climate action scenarios which model an almost greenhouse gas neutral Germany by 2050.[7]

On the path towards climate neutrality, the industrial sector faces the challenges of an enormous transformation. It will have to cut all its energy-related GHG emissions, which currently account for some two thirds of industrial emissions (Figure 2), to almost zero by 2050.[8] These include emissions from the burning of fossil fuels in the generation of process heat and electricity in industrial power plants, for example. In addition, process-related GHG emissions are directly released from chemical reactions in certain industrial production processes or from the non-energetic use of fossil energy resources. They currently account for around one third of industrial GHG emissions and must be reduced at least comprehensively by 2050.[9] Examples of process-related emission sources include cement production, which releases carbon dioxide bound in limestone, and steel production using coking coal as a reduction agent in blast furnaces (to remove the oxygen content from the iron ore). The largest emitters of process-related GHG emissions are found in the metal, chemical and construction materials industry. Reducing process-related emissions often requires new production processes and in some cases emissions cannot be completely avoided. Unavoidable industrial GHG emissions will have to be offset through natural or artificial sinks (e.g. afforestation or carbon capture and storage) in order to achieve greenhouse gas neutrality by 2050.

Fields of action for greenhouse gas reduction are largely known

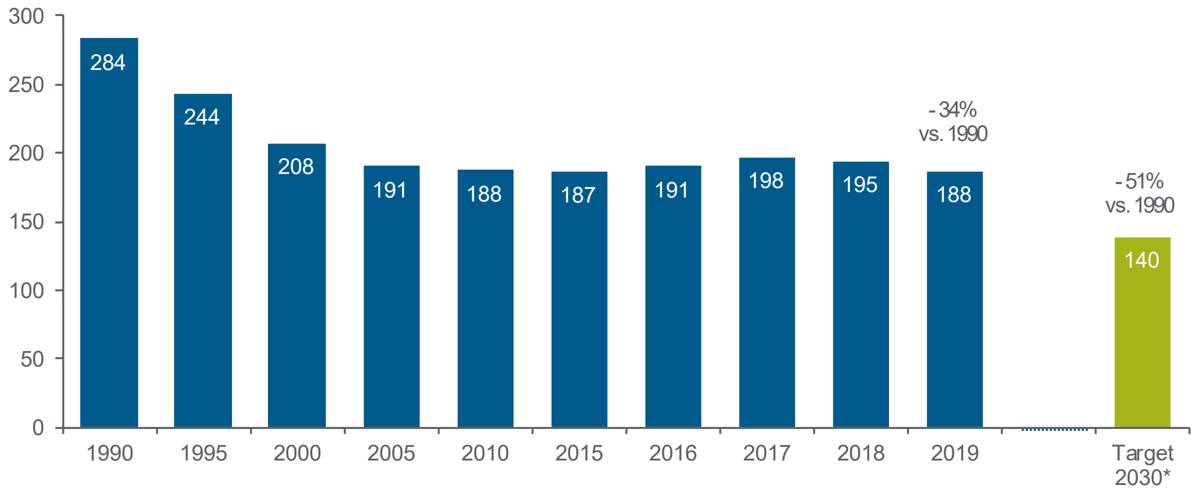
How can climate-neutral production be achieved by 2050? The technological solutions for decarbonising the industrial sector are largely known and can be derived from the studies already published, which identify the technological routes for a greenhouse gas neutral Germany:[10]

- **Improving energy efficiency**: Just under 90% of industrial final energy consumption is currently fossil-fuel based.[11] Further measures designed to improve energy efficiency would directly reduce the use of GHG-intensive fossil fuels and thus reduce the need to expand the use of climate-neutral energy sources. In particular, using process heat more efficiently in manufacturing offers even greater potential for reducing industrial energy consumption. Process heat is by far the most energy-intensive field of use, with a share of roughly two thirds of final energy consumption in the industrial sector.[12] Process heat is required in a wide range of production processes, for example to generate steam and hot water, and to operate furnaces and drying facilities. Unnecessary energy consumption can be avoided here, for example through improved insulation of plant components, needs-based plant dimensioning and control, as well as consistent use of waste heat. Across all sectors, the systematic optimisation of cross-cutting electricity consuming technologies such as electric motors, pressurised air, pumps and lighting provides further savings potential.[13]

- **Expanding the circular economy / improving material efficiency**: Improving resource efficiency also provides great energy savings and, therefore, GHG reduction potentials. An economical and efficient use of materials as well as more recycling can reduce the consumption of primary

Figure 1: Development of industrial greenhouse gas emissions

CO_2 equivalents in millions of tons



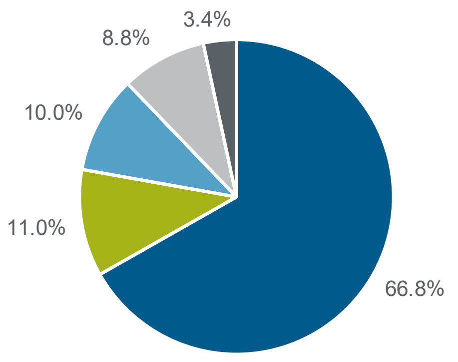
*Sector target according to Climate Action Plan 2050

Source: German Federal Environment Agency (2020), KfW Research.

natural resources whose extraction and processing is often very energy intensive. The use of secondary aluminium, for example, requires a mere 5% of the energy consumed in extracting aluminium metal from bauxite, the primary ore. Recycling scrap steel consumes 73% less energy than the production of crude steel from iron ore.[14] Various existing climate action scenarios for Germany therefore provide for a significant increase in the share of secondary materials in industrial production by 2050, most notably in the steel and non-iron metal industry, as well as in the chemical industry through the chemical recycling of plastic waste.[15] In order to be able to make cycles as closed as possible and increase the acceptance of the use of secondary materials on the buyer side, however, a greater focus will have to be placed on improving the quality of recyclates. Approaches include a more recycling-friendly product design that uses less material and improved recycling logistics[16].

Figure 2: Industrial GHG emission sources

In per cent



Source: Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2020).

- **Direct electrification based on renewable energy**: Almost all the remaining energy requirements in industry will have to be met using climate-neutral energy sources by 2050. For the supply of industrial process heat, which is currently generated almost exclusively from fossil fuels, electrification is a possible approach to the emission-free generation of low to high temperature heat. This can be done on the condition that the electricity comes from renewable energy. Applications referred to as power-to-heat convert electrical energy to heat. This can involve the use of electrode boilers, induction heaters or high-temperature heat pumps.[17]

- **Use of biomass**: Some climate action scenarios involve concentrating the country's available biomass (particularly residual timber or fast-growing species from short rotation plantations) in the industrial sector. For one thing, it can contribute to climate-friendly generation of process heat through combustion. For another, the carbon released in the combustion of biomass can be captured and used as renewable carbon feedstock in the chemical industry in the future. However, it must be taken into account that Germany's sustainable biomass potential is limited and that biomass is regarded as a means for achieving climate neutrality in other sectors as well, for example in aviation.

- **Use of green hydrogen (indirect electrification)**: Green hydrogen is also expected to play an important role in the decarbonisation of the industrial sector.[18] It is produced through the electrolysis of water using only electricity from renewable energy. The hydrogen (H_2) thus obtained can be further processed into synthetic fuels or chemical feedstock by adding a carbon source or nitrogen.[19] Electricity-based fuels and feedstocks enable the decarbonisation of industrial applications that are difficult or impossible to supply directly with renewable energy or with direct electricity generated from renewables. Examples include sub-segments of high-temperature heat generation in energy-intensive sectors. From a present perspective, the use of green hydrogen will also likely be indispensable for achieving a significant reduction of process-induced GHG emissions, especially in the steel and chemical industry. Primary steel production, for example, could become largely carbon-free if the currently prevailing coal-based blast furnace process were replaced by the technology of hydrogen-fuelled iron ore direct reduction.[20] Large quantities of fossil fuels – especially natural gas and oil – are currently being used as feedstock in non-energetic form in the chemical industry to produce important chemical feedstock such as ammonia, methanol and ethylene. Using green hydrogen as feedstock in the chemical industry enables these fossil energy sources to be substituted and GHG emissions to be significantly reduced.[21] The hydrogen-based production of chemical feedstocks and fuels often requires an additional carbon source which likewise has to meet sustainability criteria in the long term to achieve the goal of greenhouse gas neutrality. Methods being debated in this context include the direct capture of carbon from the ambient air (direct air capture – DAC) and the extraction of carbon from biogenic sources and waste (for example through chemical recycling of plastic waste).

- **Carbon capture und storage (CCS)**: CCS is a typical end-of-pipe technology in which carbon emissions are captured at power plants or industrial plants and then stored permanently in deep geological formations on land or beneath the ocean floor (e.g. in exploited gas fields or deep geological formations below the North Sea). The aim of storing carbon underground is to remove it from the atmosphere. The available climate action scenarios provide starkly diverging ideas on the possible role of CCS technology in decarbonising the industrial sector. In some scenarios, the use of CCS is a key climate action strategy[22] for adhering to tried and tested industrial production processes as much as possible in order to reduce costs. Other studies rather propose minimising[23] or even advise against[24] the use of this technology. A more restrictive CCS approach is motivated by the fact that environmental and health hazards from the release of CO_2 as a result of accidents or leakages cannot be ruled out and by strong misgivings about this technology in the community.[25] Still, most of the available scenarios assume that with the technology currently available, not all process-induced carbon emissions produced by the industrial sector can be avoided in the long term and a limited use of CCS will be necessary to meet the goal of greenhouse gas neutrality. An often cited, prominent example is the production of cement. It must be noted, however, that it is currently de facto not possible to add carbon storage reservoirs in Germany. Policies banning or heavily restricting underground carbon storage are in place in all federal states that have the geological conditions to serve as possible locations. Some scenarios refer to the potential storage of carbon in European reservoirs as an alternative. Countries often mentioned in this context are the Netherlands and Norway, which currently support projects aimed at storing carbon in exploited natural gas and oil fields below the North Sea and the Norwegian Sea.[26]

– **Carbon capture and utilisation (CCU)**: Unlike CCS, which refers to the permanent storage of carbon in geological formations, CCU involves re-utilising the carbon captured as feedstock in manufacturing. The captured carbon could thus be used in the chemical industry as an alternative carbon source (e.g. in the production of plastics). As concrete absorbs carbon dioxide (mineral carbonation), in future carbon could also be used in construction material production, which provides the benefit of chemically binding carbon dioxide in durable products. But in order to permanently remove carbon dioxide from the atmosphere, it is crucial that the recirculation of the bound carbon dioxide can be ensured after the lifetime of the relevant CCU products (e.g. through chemical recycling of plastic wastes).[27] As CCU does not involve final storage of captured carbon dioxide it can be presumed to meet with higher social acceptance than CCS. Many CCU technologies, however, are still in an early stage of development and are themselves very energy intensive.

For three selected climate action scenarios that model a far-reaching greenhouse gas reduction in Germany's industrial sector by 2050, Table 1 provides an overview of the relevance of the technical solutions described in their models. The comparison was based on the study entitled 'Klimapfade für Deutschland' (*'Climate pathways for Germany'*) (95% climate pathway) prepared by the Federation of German Industries (BDI), the dena study entitled 'Integrierte Energiewende' (*'Integrated energy transition'*) (technology mix scenario with 95% climate target), both of which were published in 2018, and the study 'Klimaneutrales Deutschland' (*'Climate-Neutral Germany'*) (KN 2050) published by Agora Energiewende et al. in 2020. The comparison shows that the scenarios examined for the industrial sector provide for various combinations of technical solutions and various intensities of deployment of individual technologies. This allows the conclusion that different pathways can lead to a far-reaching emissions reduction in the industrial sector, allowing some planning scope. A look at the Agora study, however, which for the first time points to technological pathways for a climate-neutral Germany and not just for a 95% greenhouse gas mitigation target[28], suggests that contributions from all the above fields of action will be necessary in the industrial sector over the long term. To what extent the relevant technological options will actually be deployed by 2050 is likely to depend primarily on the political frameworks, the costs and the population's acceptance of the relevant technologies.

Table 1: Technical solutions for minimising industrial GHG emissions for selected scenarios

Scenario	Industrial GHG reduction by 2050 against the 1990 baseline	Energy efficiency	Circular economy	Direct electrification	Biomass	Hydrogen	Carbon capture
dena 2018 (TM95)	-91%	+++	+	0	0	+++	+
Federation of German Industries 2018 (95% route)	-95%	+++	+	0	+++	0	+++
Agora 2020 (KN2050)	-111%	+++	+	+++	+++	+++	++

0 = technical solution not pursued or only marginally
+/++/+++ = technical solution pursued moderately / strongly/ very strongly

Source: KfW Research, in line with the Wuppertal Institute for Climate, Environment and Energy (2020): Vergleich der Strategien für weit gehenden Klimaschutz in der Industrie in deutschen, europäischen und globalen Szenarien (*'Comparison of strategies for far-reaching climate action in industry in German, European and global scenarios'* – our title translation, in German only), in: Energiewirtschaftliche Tagesfragen, issue 10/2020.

One special aspect of the Agora study that also deserves to be emphasised is that its climate action scenario for the industrial sector predicts not just climate neutrality but even total negative emissions of nearly 30 million tonnes of CO_2 equivalent by 2050. Negative industrial emissions are to help offset unavoidable residual emissions from agriculture. This is to be made possible by combining bioenergy with carbon capture and storage (BECCS) in industry. Plants remove CO_2 from the atmosphere during their initial growth phase. If this CO_2 is not released again from the use of biomass for energy but captured and permanently stored in deep geological formations, this may generate negative emissions. According to the Agora study, chemical and steel industry sites would be particularly suited for the use of this technology because of their high local demand for energy to generate steam and high temperature heat.

The steel, chemical and cement industry account for around 60% of industrial greenhouse gas emissions in Germany.[29] These sectors therefore must achieve the highest GHG reductions by the year 2050. In line with the Agora climate action scenario, Table 2 provides an overview of the key technologies that will be particularly relevant for the reduction of GHG emissions in the respective sectors.

Table 2: Overview of important key technologies by sector

Sector	Key technologies
Iron and steel	Increased share of secondary steel, direct reduction plants with hydrogen, use of biomass, biomass CCS
Chemicals	Hydrogen as feedstock and energy source, energy efficiency, electrification, chemical recycling of plastic waste, use of biomass, biomass CCS
Cement	Material efficiency, new cement types, use of biomass, CCS, biomass CCS
Other industry	Energy efficiency, electrification, biomass and hydrogen as an energy carrier, CCS

Source: KfW Research, based on Agora Energiewende et al. (2020): Towards a Climate-Neutral Germany (KN2050).

Making manufacturing climate neutral presents great challenges for Germany

The available climate action scenarios basically show that making Germany's industrial sector climate neutral by 2050 is technically feasible. However, enormous challenges must be overcome along the way:

Climate neutrality requires extensive investment

Gradual greenhouse gas reductions through energy efficiency measures – as observed in the industrial sector in the recent past – will no longer be sufficient to achieve the goal of greenhouse gas neutrality by 2050. Rather, manufacturing processes will have to undergo fundamental changes, particularly in greenhouse gas-intensive sectors. Many of the key technologies required to do this still have to be upscaled to industrial levels (e.g. electrification of steam crackers[30] in the chemical industry, hydrogen-based steel production processes, carbon capture in the cement industry). Possible financial and technical risks in the industrial-scale implementation of new technologies may pose a barrier to investment and should therefore be addressed by policymakers early.[31] The necessary structural transition to climate neutrality requires extensive investment. The study by the Federation of German Industries (BDI) entitled 'Klimapfade für Deutschland' (*'Climate pathways for Germany'*) estimates that its 95% greenhouse gas reduction pathway will require around EUR 230 billion in additional investment in the manufacturing sector (compared with business as usual) by 2050. No scientific estimate is available as yet for the more ambitious goal of climate neutrality. The additional investment requirements are likely to be significantly higher here, however, especially since there now appears to be a need for hydrogen-based manufacturing processes and the use of green hydrogen as feedstock in the chemical industry, which the BDI 95% reduction pathway has largely omitted.

High need for reinvestment in the basic industry should be used as a window of opportunity for transformation

In the transformation it is important to bear in mind that the emissions-intensive basic industry such as steel, cement and chemical production uses capital-intensive industrial plants that usually have a technical lifetime of several decades. According to the Wuppertal Institute, more than half of the energy-intensive production plants in the steel industry (blast furnaces) and the chemical industry (steam crackers) and more than half of the kilns in the cement industry have to be renewed between 2020 and 2030. This major reinvestment phase opens up a window of opportunity for the necessary structural transition to climate neutrality. At the same time, however, there is a risk that renewed investment in conventional technologies will cement fossil fuel use for many decades (carbon lock-in effect).[32] Against this background, policy decisions now need to be adopted which ensure that upcoming reinvestments that bind capital for a long time are compatible with the goal of reaching climate neutrality by 2050. This will at once create investment certainty and protect investors from the risk of stranded investments.[33]

Pushing ahead with the expansion of renewable capacity and hydrogen infrastructure

Sufficient availability of electricity from renewables and climate-neutral hydrogen is a major prerequisite for the decarbonisation of industry. The Agora climate action scenario predicts an increase in annual industrial gross electricity consumption from 226 TWh to 304 TWh between 2018 and 2050, mainly driven by the electrification of process heat.[34] Additional demand for electricity would come from domestically generated and industrially used green hydrogen. In order to be able to fully meet the growing electricity demand from all sectors (that is, including transport, private households, industry, trade and services) with zero impact on the climate in 2050, the Agora scenario estimates that current domestic renewable electricity generation will have to grow 3.5-fold by 2050. These figures underscore the need to accelerate the pace of renewables expansion in Germany and further advance the associated electricity grid expansion.

Most hydrogen is currently produced from fossil fuels for cost reasons – usually from natural gas through steam reforming (also referred to as grey hydrogen) – and primarily used as feedstock in the chemical industry. Germany's national hydrogen consumption is currently around 55 TWh.[35] So far, carbon-free hydrogen is being produced in very small quantities in Germany and elsewhere, primarily in pilot and demonstration plants. In order to reduce the currently very high costs of producing green hydrogen and its derivatives, and to make available the quantities required by industry in due time, production capacities in Germany and abroad have to be increased to industrial scale early. In addition to installing electrolysis capacities, this includes building a pipeline infrastructure to transport and distribute hydrogen to future industrial consumption hubs. With the National Hydrogen Strategy adopted in June 2020, the German Federal Government intends to support the national and international market ramp-up of hydrogen technologies. The strategy aims to make climate-neutral hydrogen competitive, enable the development of a domestic market, pave the way for imports and initiate necessary investment and innovation. In this context, the Federal Government's economic stimulus package of June 2020 includes EUR 9 billion in additional federal funds to promote the production, transport and use of green hydrogen and its derivatives.

The Federal Government expects that around 90 to 110 TWh hydrogen will be needed each year by 2030, primarily in the industrial and transport sector. At least 13 to 16% of this demand is to be generated from sustainable sources through the establishment of a green hydrogen production industry in Germany with an electrolysis capacity of up to 5 GW. A further 5 GW is to be installed by 2035 or 2040 at the latest.[36] Significant additional renewable electricity generation capacity will be required for the production of green hydrogen. Given the limited land area available for expanding renewables in Germany and other countries' more favourable local conditions and thus cost advantages, most analyses predict that Germany will have to rely on significant imports of green hydrogen in the long term, for example from northern and southern Europe and North Africa.[37] The Agora study entitled 'Towards a Climate Neutral Germany' estimates that the country will import around 70% of carbon-free hydrogen in the year 2050. Import structures with the related electrolysis and renewable electricity generation capacities must still be established in the supplier countries, a time-consuming and capital-intensive process. The Federal Government therefore intends to intensify cooperation with other EU member states and international partners to advance the development of global supply chains for green hydrogen including the necessary transport infrastructure. The EU is planning to push offshore wind energy generation for hydrogen production in the North Sea and the Baltic Sea in particular. Pilot projects for trialling technologies are to be initiated in the context of German development cooperation.

A controversial debate is going on among policymakers and researchers as to whether 'blue' hydrogen should play a certain role in the decarbonisation of industry over a transitional period. Like grey hydrogen, blue hydrogen is produced through steam reforming from natural gas. The CO_2 produced in the process, however, is not released into the atmosphere. It is to be captured and permanently stored underground (CCS = carbon capture and storage). Proponents of this technology argue that so long as not enough green hydrogen from electrolysers is available at competitive prices, the use of blue hydrogen could be an option to push the market ramp-up of hydrogen-based production processes early (e.g. in the steel industry). This presupposes that the necessary capacities for the production of blue hydrogen can be established faster than for green hydrogen. Critics warn of the risk of carbon lock-in effects that may result from creating fossil infrastructures for the production of blue hydrogen. Besides, blue hydrogen is not entirely climate neutral compared with green hydrogen. For one thing, carbon capture always leaves residual emissions and for another, the extraction, processing and transport of natural gas releases climate-impacting upstream emissions.[38]

Creating acceptance of infrastructure development in the population

As we can see from the above, many technologies needed to decarbonise industry require extensive infrastructure investment. This includes expanding renewable energy capacity, electricity networks, hydrogen pipelines and underground carbon dioxide pipelines and reservoirs for the implementation of CCS technology. This investment will result in visible alterations to landscapes and / or interventions in the natural environment. Ensuring public acceptance will therefore play an important role for the viability of these infrastructure investments and will be a non-negligible political task on the road to climate neutrality.[39]

Ensuring international competitiveness

While measures aimed at improving energy and material efficiency usually lead to cost savings, most other GHG mitigation options currently involve significant additional costs compared with conventional technologies.[40] Estimates show, for example, that the cost of producing a ton of green steel (through direct reduction with hydrogen) will be 40 to 60% higher than for conventional steel from the coal-based blast furnace route.[41] Another prediction is that the specific costs of providing steam in the chemical industry will rise by 50 to 80% if steam generation is switched over from fossil combined heat and power technology to an electrode boiler that runs on renewable electricity.[42] These examples of additional costs illustrate that without a policy framework and financial incentives, the technologies will not achieve the broad market penetration needed in the long term to achieve the goal of climate neutrality in the industrial sector. What also needs to be considered is that parts of the industrial sector are exposed to intense international price competition. This applies above all to the commodities industry, whose products have a high degree of conformity. Until there is a globally harmonised CO_2 price – at least at G20 level – and so long as the levels of ambition for climate action outside the EU differ considerably, further instruments will be necessary for these enterprises to offset possible competitive disadvantages resulting from more ambitious climate action. This will be vital to ensure acceptance of the transformation. Shifting production and emissions to countries with considerably weaker climate regulations (carbon leakage) would not be in the interests of global climate action and Germany as an industrial location.

Policymakers need to create frameworks, set incentives and provide start-up finance

The commitments to reduce GHG emissions under the Paris Climate Agreement and within the European Union require Germany to make a structural transition towards a climate-neutral economy by 2050. Given the long reinvestment cycles in industry, policymakers must set the course for the transformation early. The tense economic situation caused by the coronavirus crisis and lower prices of fossil energy carriers currently pose new barriers to the mobilisation of necessary investment. The focus on overcoming the coronavirus crisis must not slow down climate action efforts because global temperatures are continuing to rise unabated. Rebuilding the economy and combating the climate crisis should therefore go hand-in-hand because an ambitious climate policy contributes to modernising the economy and makes it fit for the future.

For the transition to net zero emissions to succeed, investors need planning certainty. A reliable and projectably rising CO_2 price signal is an essential factor for success so that over the long term, climate-friendly technologies can be more cost-effective than fossil alternatives that damage the climate. Adjusting the National Fuel Emission Trading System and the EU Emission Trading System to the most recently lifted EU greenhouse gas reduction target for 2030 is therefore of great importance. In order to prevent carbon leakage, existing compensation mechanisms for energy-intensive enterprises that compete internationally must be continued (including the free allocation of emission allowances and electricity price compensation).

As there are no signs that over the next ten years the carbon price will rise at a rate that would be necessary for key technologies for decarbonising industry to achieve market breakthrough, additional innovation and investment promotion tools will be necessary.[43] The first priority will be to strengthen the market ramp-up of new technologies through the promotion of demonstration plants at industrial scale, thereby harnessing cost reduction potentials. The Federal Government has already launched programmes to finance investments in this area. In order to remove investment barriers, the Federal Government also plans to trial ‘Carbon Contracts for Difference’ in selected sectors (especially the steel and chemical industry) with the aim of offsetting higher operating costs and, hence, competitive disadvantages of low-carbon key technologies over conventional technologies.[44] It intends to provide project-specific contributions to operating costs to offset CO_2 avoidance costs, with the amount provided usually calculated as the difference between actual CO_2 avoidance costs and the current CO_2 price.

In order to create reliable sales markets for GHG-neutral products, mandatory quotas for the use of ‘green’ feedstocks in the following value chains are also being discussed in the political arena (e.g. use of green steel in car manufacturing, a quota for hydrogen-based synthetic kerosene in aviation). Public procurement systems could also help generate demand for products manufactured on a net zero emissions basis and thereby help incentivise such production in line with market economy principles. For example, public construction projects could be mandated to use green steel or climate-neutral cement.

Looking further ahead, European and international market conditions have to be further developed in such a way that industry investment in climate-neutral key technologies is competitive and cost-effective without public subsidies. It is obvious that the introduction of a global, uniform carbon price would be an efficient instrument for this.[45] International climate diplomacy gains in importance against this background. But international negotiations on the introduction of a global carbon price and its increase to a sufficiently high level are likely to be difficult and protracted. In the context of the recently raised EU climate target for 2030, there is concern at EU level that increasingly lower quantities of certificates and anticipated rises in certificate prices mean that the protection against carbon leakage currently afforded under the EU Emissions Trading Scheme may no longer be sufficient in the medium term. The EU Commission is therefore considering the introduction of a carbon border adjustment mechanism for selected sectors in order to reduce the risk of carbon leakage to non-EU countries. This basically involves putting a carbon price similar to that of the European Emissions Trading Scheme on imported goods from third countries that have not taken comparable climate action. The aim is to ensure that foreign companies pay the same price to protect the climate as their domestic competitors. The greatest challenge here is to ensure that the instrument conforms to WTO rules and to correctly determine the carbon footprint of the imported goods.

Conclusion

Transitioning to a climate-neutral industry in 2050 requires fundamental changes to production processes in greenhouse gas-intensive sectors as well as significant investment. Many key technologies have yet to be scaled up to industrial size. Large additional quantities of electricity from renewable energy as well as climate-neutral hydrogen are also required to transform the industrial sector. The necessary infrastructure needs to be created at an early stage.

High sums need to be reinvested in the energy-intensive basic industry by 2030. This window of opportunity must be grasped to advance the necessary structural transition to climate neutrality. As many key technologies for the decarbonisation of industry currently incur significant cost disadvantages over conventional technologies, a policy framework and economic incentives need to be set to promote their market penetration. Designing the policy instruments comes with the challenge of setting the framework in such a way that the domestic industrial sector becomes climate neutral by 2050 while maintaining its international competitiveness.

The transition to a climate-neutral economy is a major challenge, but it also provides considerable opportunities for future value creation and employment. This applies particularly to the export of climate-friendly technologies, as increasingly more large industrialised countries are joining Europe in committing to climate neutrality, and this will lead to growing demand for low-emission technologies worldwide. Germany has a good starting position in this field. In 2017 the country was the world's second largest exporter of climate technology after China, taking a share of 11% of global trade.[46]

[1] Preliminary estimate, cf. Agora Energiewende (2021): Die Energiewende im Corona-Jahr: Stand der Dinge 2020 (*The energy transition in the coronavirus year: situation in 2020* – our title translation, in German only).

[2] Cf. German Federal Environment Agency (2020): National trend tables for greenhouse gas emissions by sectors of the German Climate Protection Act 1990–2018. Under the sector definition of the Climate Protection Plan 2050, the industrial sector comprises all emissions from combustion processes and self-generated electricity supply of the manufacturing sector as well as emissions from industrial processes and the utilisation of fluorinated gases (direct emissions). Based on the principle of origin, emissions from the use of external electricity and district heating are captured in the energy sector (indirect emissions).

[3] Cf. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2020): Climate Action in Figures, 2020 edition.

[4] Cf. Federal Ministry of Economics and Technology (2020): Federal Ministry of Economics and Technology, Zahlen und Fakten: Energiedaten (Energy facts and figures – our title translation, in German only) (as at 5 February 2020)

[5] Cf. German Federal Environment Agency (2020): Indicator: Industrial greenhouse gas emissions, https://www.umweltbundesamt.de/indikator-treibhausgas-emissionen-der-industrie#die-wichtigsten-fakten (in German only, retrieved on 21 August 2020).

[6] Cf. Federal Ministry for the Environment, Nature Conservation and Nuclear Safety (2020): loc. cit.

[7] Cf. Navigant et al. (2019): Energiewende in der Industrie. Potenziale und Wechselwirkungen mit dem Energiesektor (*Energy transition in industry. Potentials and interactions with the energy sector* – our title translation, in German only), study commissioned by the Federal Ministry of Economics and Technology.

[8] Cf. ibid.

[9] Cf. ibid.

[10] See i. a. dena (2018): dena-Leitstudie Integrierte Energiewende (*dena study on an integrated energy transition* – our title translations, in German only); BDI (2018): Klimapfade für Deutschland (Federation of German Industries (2018): *Climate pathways for Germany* – our title translations, in German only); Agora Energiewende et al. (2020): Klimaneutrales Deutschland (*Climate-neutral Germany* – our title translation, in German).

[11] Cf. dena et al. (2019): Expertise bündeln, Politik gestalten – Energiewende jetzt! Essenz der drei Grundsatzstudien zur Machbarkeit der Energiewende bis 2050 (*Pooling expertise, shaping policies – energy transition now! Essence of the three policy studies on the viability of the energy transition by 2050* – our title translation, in German only).

[12] Cf. Federal Ministry of Economics and Technology (2020): Zahlen und Fakten: Energiedaten (*Facts and figures: Energy data* – in German only) (as at 9 September 2020).

[13] Cf. Brüggemann, A. (2015): Energieeffizienz in Industrie und Gewerbe: Wo liegen die größten Potenziale? (*Energy efficiency in industry and business: where is the greatest potential?* - in German only), Focus on Economics No. 96, KfW Research.

[14] Cf. BDE et al. (2020): Statusbericht der deutschen Kreislaufwirtschaft 2020 (*Status report of the German circular economy 2020* – our title translation, in German only).

[15] Chemical recycling (or feedstock recycling) involves breaking down plastic wastes into their basic chemical elements through thermochemical and chemical processes. The petrochemical feedstock thus obtained, such as oils or synthetic gases, can be used in the chemical industry to produce new plastics or for other uses and replace primary fossil resources as secondary carbon feedstock.

[16] Cf. Brüggemann, A. (2019): The circular economy – pivotal to sustainability and resource security, Focus on Economics No. 258, KfW Research.

[17] Cf. Agora Energiewende (2019): Klimaneutrale Industrie.

[18] Cf. ibid.

[19] Converting electricity from renewables into synthetic fuels or chemicals is also referred to as Power-to-X (PtX).

[20] Cf. Lechtenböhmer, S. et al. (2019): Grüner Wasserstoff, das dritte Standbein der Energiewende (*Green hydrogen, the third pillar of the energy transition* – our title translation, in German only), in: Energiewirtschaftliche Tagesfragen, Heft 10/2019. Supplementary note: The blast furnace route uses coking coal as a reduction agent to remove the oxygen content from the iron ore. At the same time, the iron ore is melted into pig iron with the aid of coke or coal used as a fuel. The molten pig iron is subsequently processed into steel by blowing oxygen over the pig iron inside a converter. In the direct reduction process, the iron ore is reduced to solid sponge iron with the aid of natural gas/hydrogen (DRI, direct reduced iron). It is subsequently molten in an electric arc furnace (EAF) and processed into crude steel. According to Salzgitter AG, this allows carbon emissions to be reduced by up to 95% compared with the blast furnace route, provided the DRI process uses green hydrogen and the electric arc furnace electricity from renewables.

[21] Cf. ibid.

[22] Cf. Federation of German Industries (2018): Klimapfade für Deutschland (*Climate pathways for Germany* – our title translation, in German only).

[23] Cf. dena (2018): dena-Leitstudie Integrierte Energiewende (*Study on an integrated energy transition)*.

[24] Cf. German Federal Environment Agency (2019): Wege in eine ressourcenschonende Treibhausgasneutralität (*Pathways towards resource-efficient greenhouse gas neutrality* – our title translation, in German only).

[25] Cf. German Federal Environment Agency (2018): Carbon Capture and Storage, https://www.umweltbundesamt.de/themen/wasser/gewaesser/grundwasser/nutzung-belastungen/carbon-capture-storage#grundlegende-informationen (retrieved on 16 December 2020).

[26] Cf. Agora Energiewende et al. (2020): Klimaneutrales Deutschland (*Climate-neutral Germany* – our title translation, in German only).

[27] Cf. Agora Energiewende (2019): Klimaneutrale Industrie.

[28] The Federal Climate Protection Act that was passed in October 2019 commits the Federal Republic of Germany for the first time to pursue greenhouse gas neutrality by 2050 as a long-term goal. The 2050 goal of the Federal Government was previously 80 to 95% GHG reduction (against the 1990 baseline).

[29] Cf. Agora Energiewende (2019): Klimaneutrale Industrie.

[30] Steam cracking or steam decomposition is a petrochemical process in which longer chains of hydrocarbons (such as naphtha, also known as raw petrol) are converted into short ones through thermal cracking in the presence of steam. The main end products are hydrogen, methane, ethene and propene. Steam crackers produce chemicals that are processed mainly into plastics, varnishes, solvents or plant protection agents.

[31] Cf. Agora Energiewende (2019): Klimaneutrale Industrie.

[32] Cf. Agora Energiewende, Wuppertal Institute (2019): press information 'Wie die Politik das Investitionsdilemma der energieintensiven Industrie lösen und industriellen Klimaschutz ermögli-chen kann' (*'How policies can solve the investment dilemma of energy-intensive industry and enable industrial climate action'* – our title translation, in German only).

[33] Stranded investments are defined in this context as investments whose earning power or market value drops dramatically as a result of the demands of a climate-based transformation to the point when they become almost or completely worthless (e.g. through new laws and regulations, changes in demand behaviour in the markets).

[34] The renewable energy and green hydrogen requirements predicted for the year 2050 vary considerably in the climate action scenarios examined and depend strongly on the selected technological options.

[35] Federal Ministry of Economics and Technology (2020): The National Hydrogen Strategy

[36] Cf. ibid.

[37] Cf. Öko-Institut e. V. (2019): Die Bedeutung strombasierter Stoffe für den Klimaschutz in Deutschland (*The importance of electricity-based substances for climate action in Germany* – our title translation, in German only).

[38] According to the Agora study 'Towards a Climate Neutral Germany', only 90% of carbon emissions can be captured in the production of blue hydrogen.

[39] Cf. Wuppertal Institute (2020): Integrierte Klima- und Industriepolitik als Kernstück des europäischen Green Deal (*Integrated climate and industrial policy as a key element of the European Green Deal* – our title translation, in German only), in: Wuppertaler Impulse zur Nachhaltigkeit (in brief), edition 09/2020.

[40] Cf. Federal Ministry of Economics and Technology (2020): Wie wird die Produktion klimaneutral? (*How will production become climate neutral?* – our title translation, in German only) in: Schlaglichter der Wirtschaftspolitik, monthly report 2020.

[41] Cf. Lösch et. al. (2020): Bewertung der Direktreduktionsroute zur Herstellung von Primärstahl mit grünem Wasserstoff (*Assessing the direct reduction route for the production of primary steel with green hydrogen* – our title translation, in German only), in: Energiewirtschaftliche Tagesfragen, edition 5/2020.

[42] Cf. Agora Energiewende (2019): Climate-Neutral Industry

[43] Cf. Agora Energiewende (2020): A Clean Industry Package for the EU.

[44] BMU (2021): Ausgewählte BMU-Vorhaben bis zum Ende der 19. Legislaturperiode (*Selected BMU projects up to the end of the 19th legislative period* – our title translation, in German only).

[45] Cf. Edenhofer, O. et al (2020): Das Klimaschutzprogramm der Bundesregierung: Eine Wende der deutschen Klimapolitik? (*The Climate action programme of the Federal Government: an inflection point of German climate policy?* – Our title translation, in German only) in: De Gruyter Perspektiven der Wirtschaftspolitik 2020 21(1).

[46] Cf. German Federal Environment Agency (2020): Die Umweltwirtschaft in Deutschland. Entwicklung, Struktur und internationale Wettbewerbsfähigkeit. (*Germany's environmental industry. Development, structure and international competitiveness* – our title translation, in German only)