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Allianz Research

05 April 2023

The green industrial revolution

Investment pathways to decarbonize the industrial sector in Europe

Executive Summary

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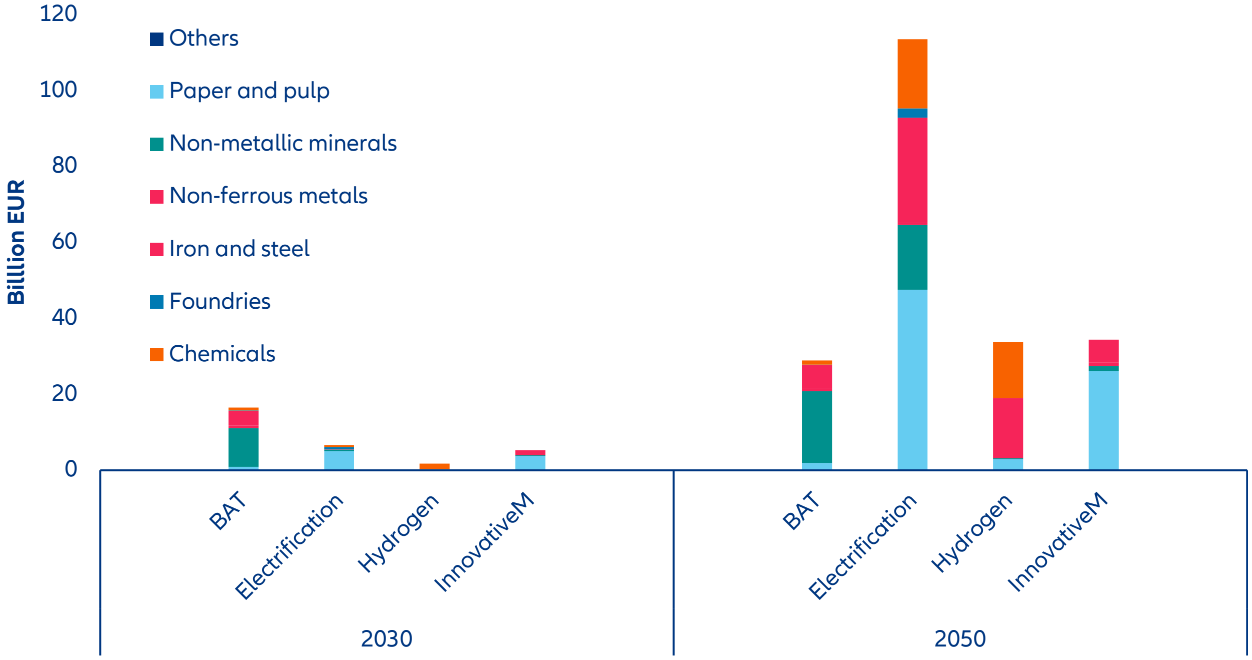
- **The industrial sector is responsible for roughly one quarter of global greenhouse-gas (GHG) emissions.** A mix of measures, including energy-efficiency improvements, using hydrogen and biomass as feedstock or fuel, producing heat through electric means and adopting carbon-capture technologies, can reduce the sector's carbon dioxide emissions to almost zero. To decarbonize the industry sector globally will require cumulative investments of EUR2.7trn until 2050. Of this, the EU needs 8% or EUR210bn, and half of this for electrification investments alone. The rest is almost equally split between hydrogen use, innovative production processes and new technologies. Additionally, at EUR330bn until 2050, the EU industry's total investment needs for carbon capture and storage (CCS) are almost 60% higher than the investments in all other industry decarbonization measures combined.

- **To meet these needs, the EU28 countries need to invest EUR3bn per year between 2020 and 2030, and EUR9bn annually from 2030 to 2050, when technologies will be ready for full-scale deployment.** The pulp & paper industry requires the largest overall investments – EUR 78.4bn until 2050 – followed by iron & steel (EUR55.4bn) and cement (EUR37.6bn). These investments would cut emissions by 265 MtCO2 (-92%), which yields an average abatement investment of EUR790 per tCO2.

- **In this context, governments should use the instruments at their disposal (e.g. subsidies, carbon taxes) to effectively align sector pathways with overarching net-zero transition goals.**

Figure 1: Investment needs in the industry sector to achieve net-zero emissions in the EU28

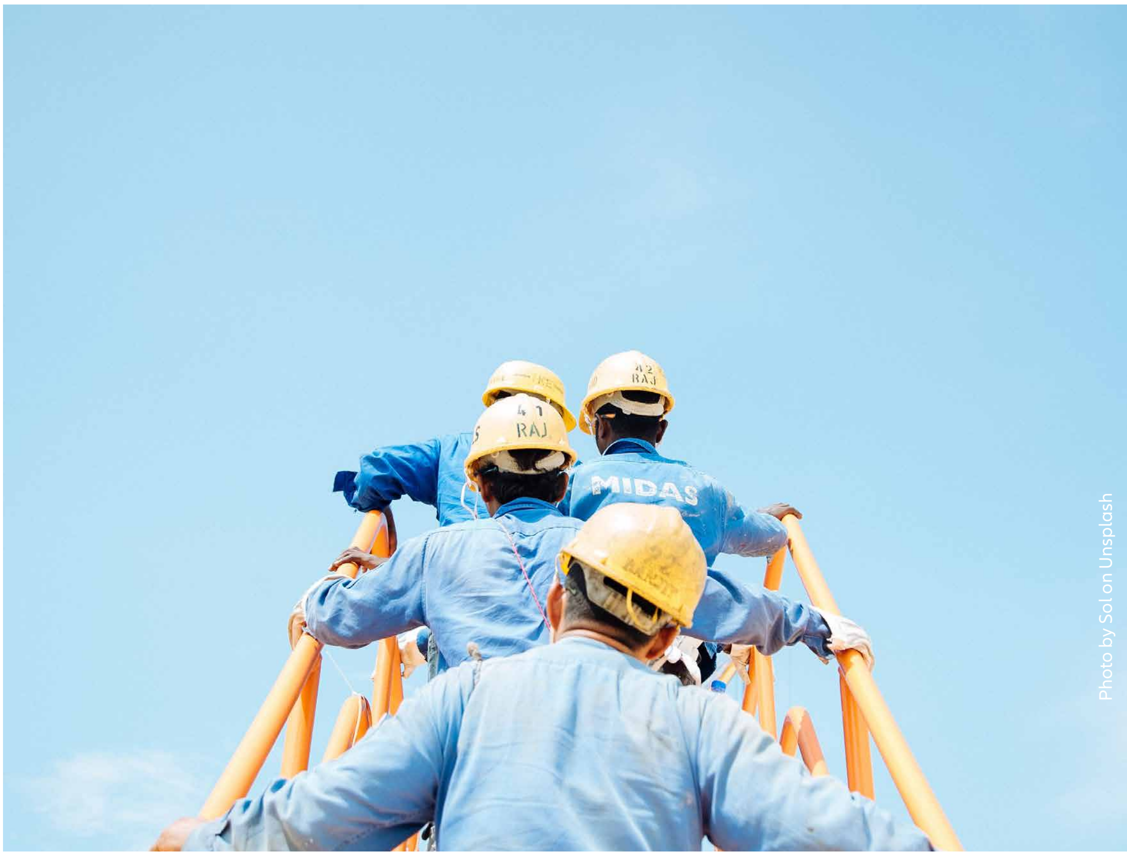


Sources: IndustryPLAN, Allianz Research. Note: BAT refers to best available technologies. Includes EU + UK. See Appendix for decomposition of investments by country.

What does it take to limit global warming to 1.5°C ?

Check out our five sector pathways already published:

The great green renovation: buildings sector transition pathway
A Carbon farming: A transition path for agriculture & forestry
The EU utility transition: A pathway powered by solar and wind
Jostle the colossal fossil: A path to the energy sector transition
Transport in a zero carbon EU: Pathways and opportunities



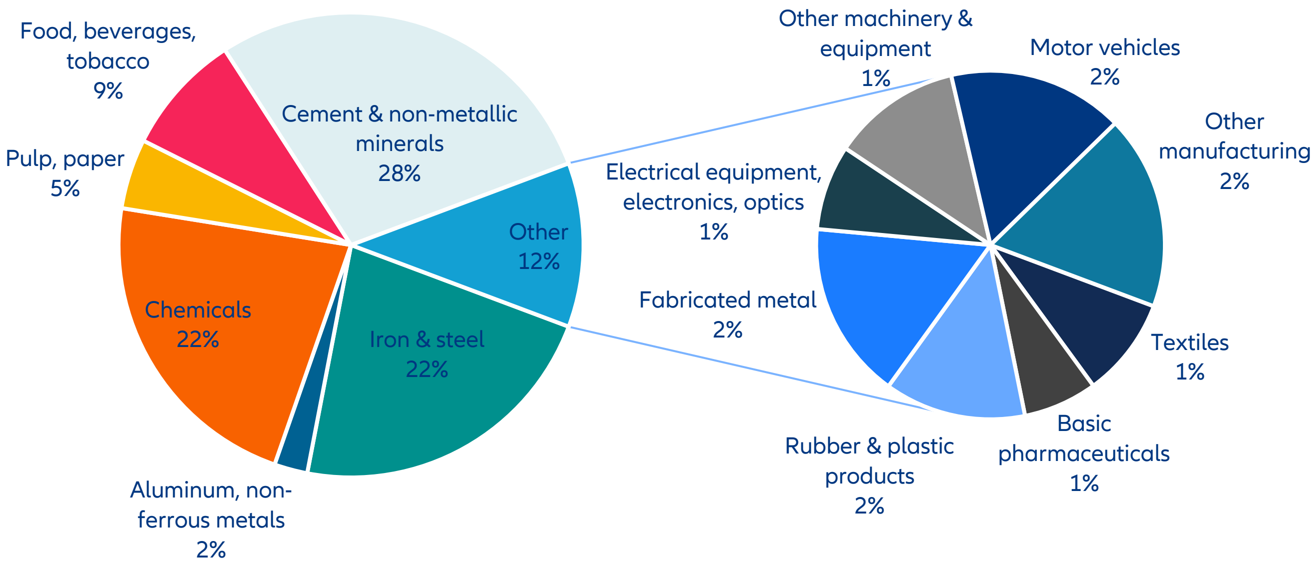
The starting point

Over the past few decades, the industry sector has made significant progress towards reducing its emissions and improving energy efficiency. By 2010, European industry alone had reduced its emissions by -29%, and by -39% by 2020 compared to 1990 levels.[1] Despite intense international competition, European industry has managed to adjust its business practices and models to align with the continent's climate and energy goals, all while maintaining a viable economic approach.

Nonetheless, the sector is still responsible for 650Mt of CO2 emissions – with CO2 accounting for over 90% of direct GHG emissions from industry in 2020. The cement, iron and steel and chemicals sectors (see Figure 2) are the largest contributors to CO2 emissions and industrial energy consumption: The three sectors generated three-quarters of industrial emissions in the EU-28 in 2020.

[1] EEA (2021). Data viewer on greenhouse gas emissions and removals

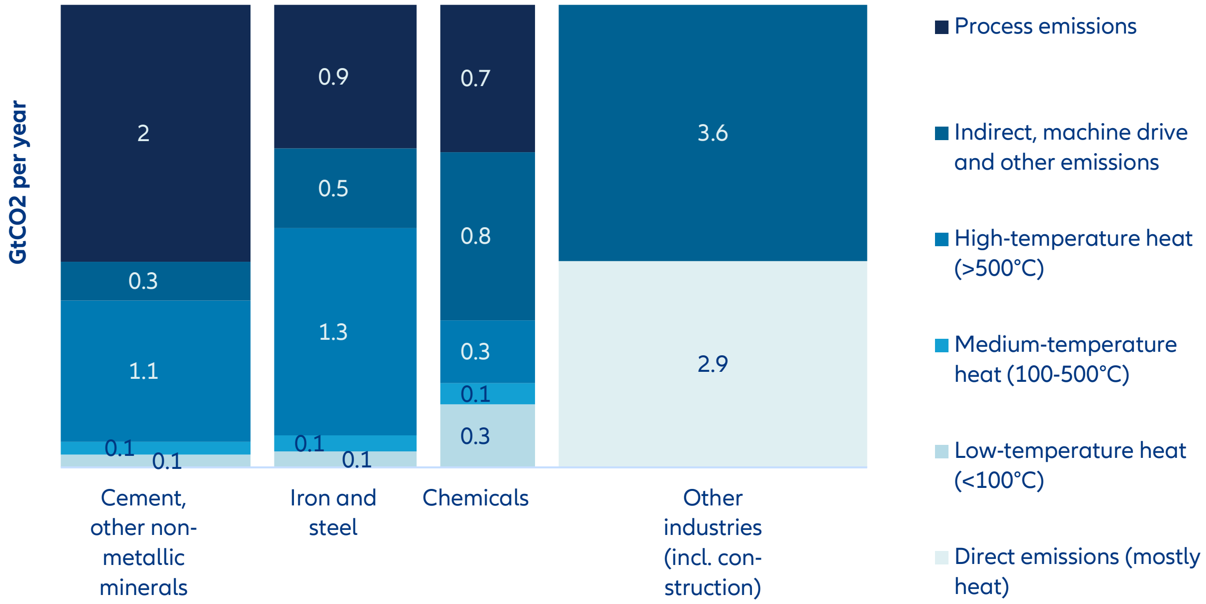
Figure 2: EU-28 industrial CO2 emissions in 2020



Sources: Eurostat, Allianz Research (excluding emissions from refineries).

To add to this, all three sectors also produce sizeable process emissions, ranging from 25% to 50% (see Figure 3). This matters because industrial process emissions are particularly hard to abate. As a consequence, even in the net-zero transition scenario, only three-quarters of these emissions are expected to be avoided in the EU. In contrast, other industrial sectors such as food and tobacco; paper, pulp, and print and nonferrous metals, generate mainly indirect and direct emissions (Figure 3), with the former resulting mostly from centrally produced electricity and the latter mostly from heat generation. These are more or less "automatically" reduced by decarbonizing energy and heat generation. For example, nearly 55% of CO2 emissions in these sectors result from the use of centrally produced electricity, primarily from natural gas and coal for low- and medium-temperature heat demand.

Figure 3: Global CO2 emissions in different industries by emission source (in GtCo2/yr)

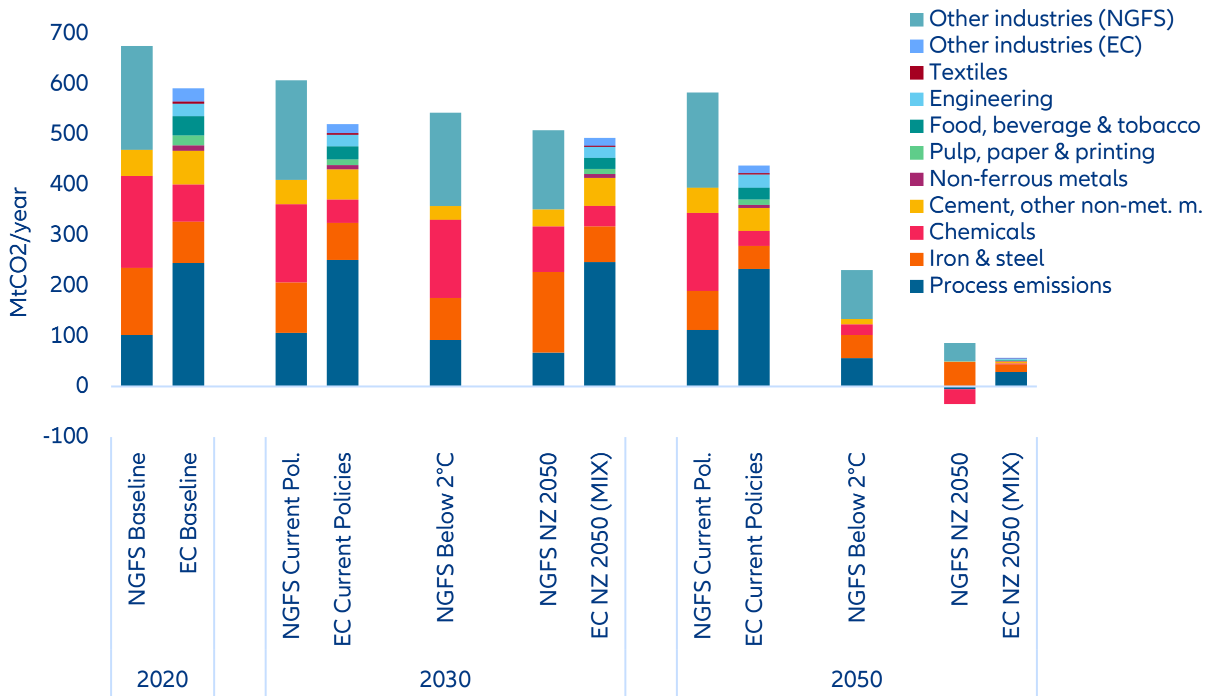


Sources: McKinsey (2018), Allianz Research.

Figure 4 illustrates the gargantuan task of bringing the industry in line with the net-zero path: By 2050, emissions must be reduced by 92%, with some sectors even generating negative emissions, i.e. capturing more CO2 emissions than they produce. The figure compares the Network for Greening the Financial System (NGFS) projections with the European Commission (EC) assessment for the EU Green Deal. The two sources use different definitions for the boundaries of the sectors shown, as well as for the allocation of process emissions and energy emissions. As a result, the sectoral emissions differ and the NGFS baseline is slightly higher since the Other Industries category is broader. The trend for following a 1.5°C path is similar in both assessments and net emissions in 2050 are comparable as well, though NGFS explicitly reports negative emissions.

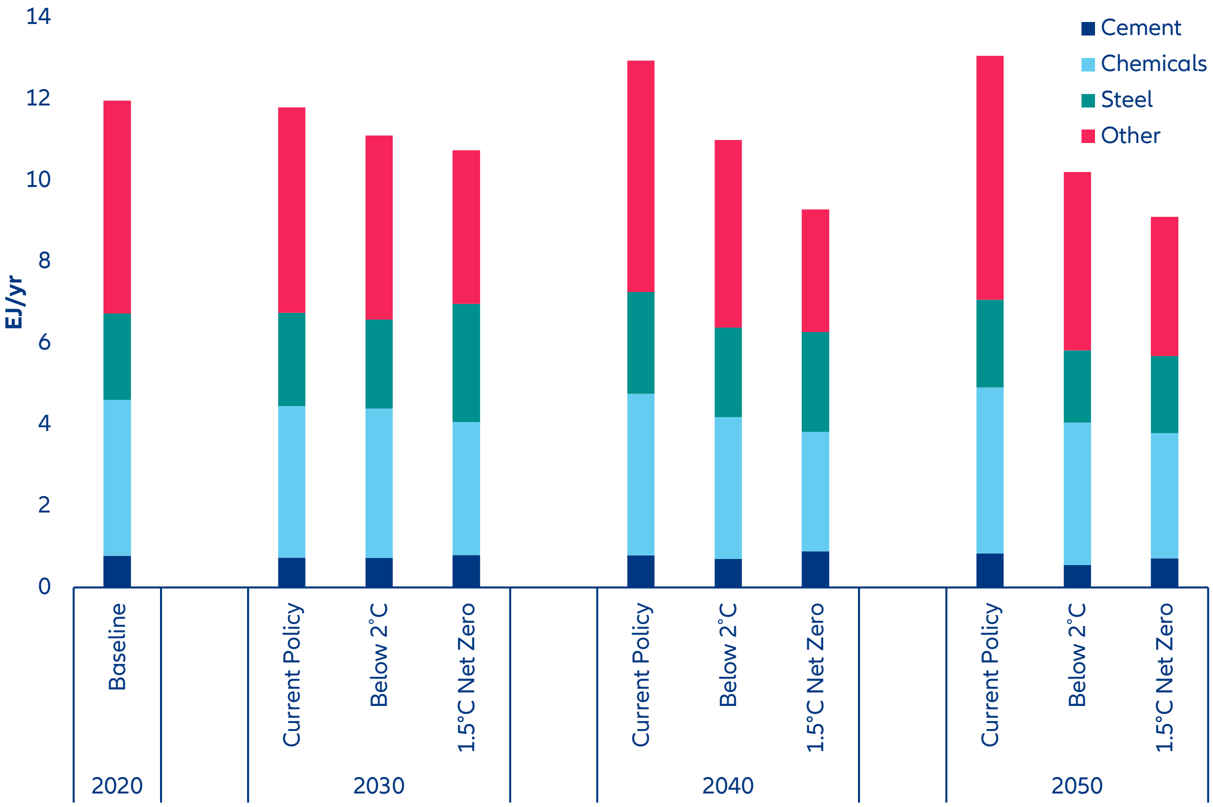
Figure 5 shows the development of the final energy use in the industrial sectors in different scenarios. While the relative composition between industries is not expected to change dramatically, cement, steel and chemicals are expected to have lower energy-saving potential than the other industries. By 2050, final energy demand in the Current Policies scenario is expected to increase by +14% relative to the 2020 baseline, while it is projected to decrease by -35% in the Net Zero 2050 scenario.

Figure 4: EU industrial CO2 emissions scenario comparison

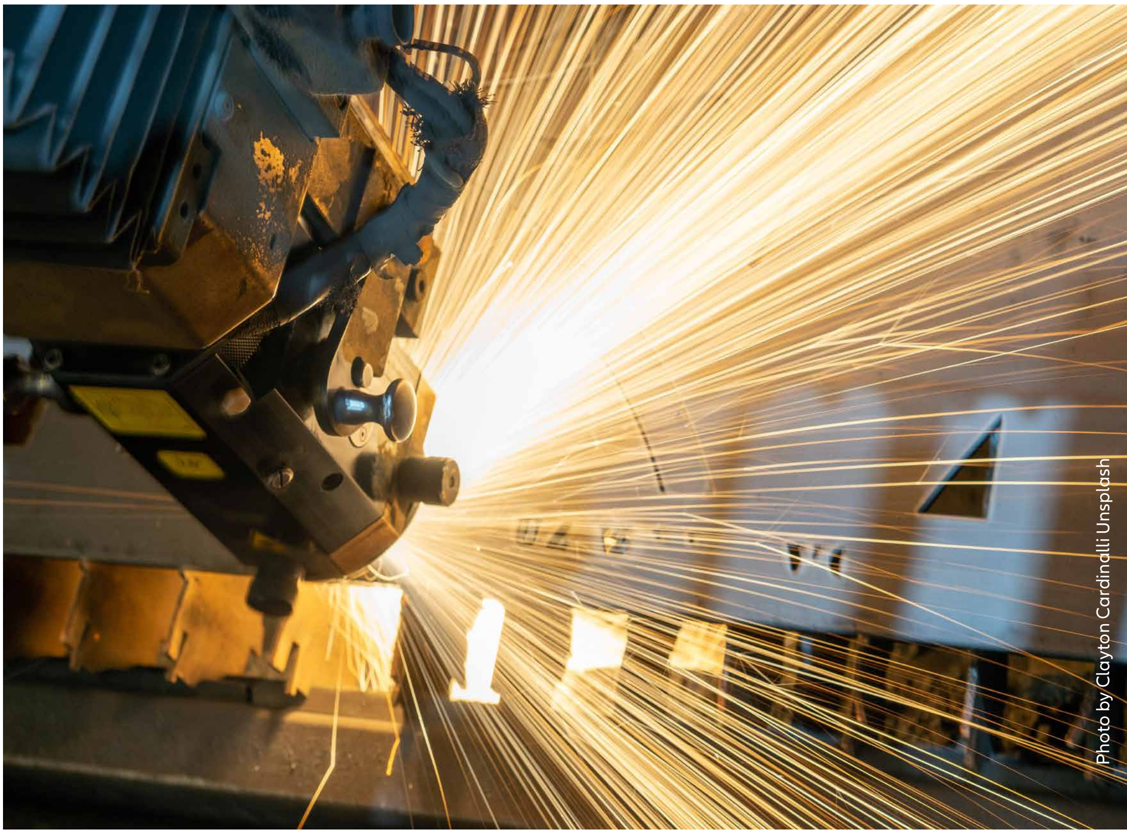


Sources: NGFS, European Commission, Allianz Research.

Figure 5: Final energy use by sector and scenario



Sources: NGFS, Allianz Research.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The options for the net-zero race

The different options for decarbonization can be broadly grouped together under energy efficiency, fossil-fuel substitution through sustainable fuels or electrification and CCS. However, energy efficiency and electrification often go hand-in-hand since they are the two sides of the same coin. Take heat pumps, for example, one of the main technologies for electrification, which increase the efficiency of energy use as well. Whenever cooling is needed, heat will be created as a by-product, and the opposite is true as well. Heat pumps make use of this relationship and reduce wasted energy in heating or cooling processes. While they are currently relatively common in residential settings, they are far less established for industrial purposes. Large industrial heat pumps (IHP) can run on renewable energy or source waste energy from buildings and processes. They can be installed in thermal processes, for example in the food, paper or chemical sectors.[2] For instance, in the dairy industry, milk must be cooled before transport and consumption, while heat is needed for the pasteurization process. The waste heat from the cooling process can be recovered and used as a heat source for pasteurization. However, a significant challenge in many industries is that steam is typically used to transfer heat across a site, resulting in high-temperature system designs. Switching to air or liquid water requires new pipes, pumps and process designs, which entail high investment costs and potential disruptions.[3]

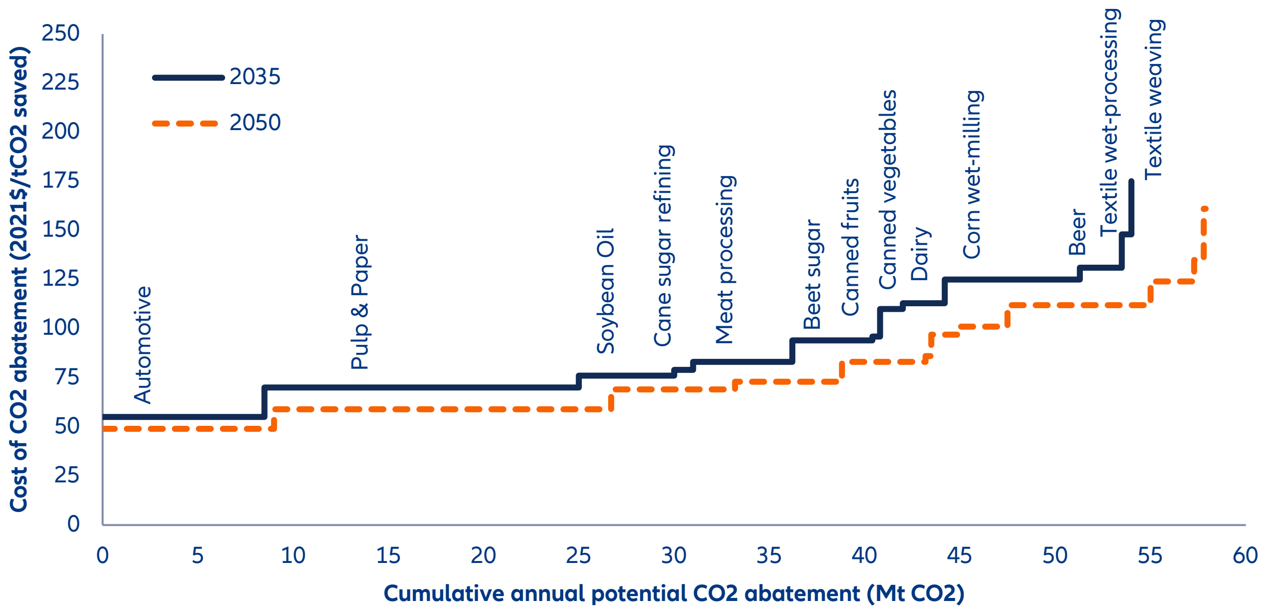
[2] IEA (2014). Application of Industrial Heat Pumps

[3] For examples of practical applications of heat pumps in industry, see U.S. Dept. of Energy (2003) Industrial Heat Pumps for Steam and Fuel Savings; IEA (2014); European Heat Pump Association (2020a). Large scale heat pumps in Europe; EHPA (2020b). Large scale heat pumps in Europe vol. 2
For the methodological approach to emission savings, see FfE (2019). Small-scale modeling of individual GHG abatement measures in the industry

Heat pumps leverage the positive effects of a greener energy mix. With every installed heat pump, overall energy efficiency is increased. However, the net effect of a heat pump depends on where its electricity comes from. Studies have shown that installing a heat pump that runs on electricity from fossil fuels instead of creating heat from gas has a negative net-carbon impact. Heat pumps are more carbon-efficient than electrical resistance heaters because of their higher efficiency. For example, a heat pump with a COP 3.5[4] emits less CO2 per kWhth compared to natural-gas-condensing boilers when the electricity grid factor is below 740gCO2/kWh, and oil-condensing boilers when the electricity grid factor is below 980gCO2/kWh.[5] At the same time, however, this means that installing many heat pumps leverages the positive net effects of green electricity. As renewable energy takes over the energy mix, more installing more heat pumps will push down carbon intensity faster across sectors.

The costs of reducing CO2 emissions through heat pumps vary widely across industries. A comprehensive study by Zuberi, Hasanbeigi and Morrow analyzes the abatement cost associated with the use of heat pumps in different industries.[6] The authors developed CO2 abatement cost curves and energy-conservation cost curves and estimated the potential reduction in CO2 emissions and energy savings from the application of IHPs. Their results indicate that electrifying hot water and steam-generation systems in 13 industrial processes could reduce annual CO2 emissions by approximately 17MtCO2 in the base year 2021, with a 100% adoption rate of IHP applications. However, with the continued decarbonization of electricity grids, the total CO2 abatement potential is expected to reach 54.5MtCO2 per year in 2035 and 57MtCO2 in 2050, equivalent to 5% of total greenhouse-gas emissions from US manufacturing today, as shown in Figure 6. Furthermore, the CO2 abatement costs are expected to range from USD55 to USD175 per tCO2 in 2035 (USD50 to USD155 in 2050), depending on the industrial process. Further details on the costs associated with energy savings can be found in Appendix: industrial heat pumps.

Figure 6: CO2 abatement potentials through heat pumps in US manufacturing



Sources: Lawrence Berkeley National Laboratory, Allianz Research.

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[4] COP (Coefficient of Performance) is defined as the relationship between the power (kW) that is drawn out of the heat pump as cooling or heat, and the power (kW) that is supplied to the compressor. A COP of 3.5 reflects the current state of technology.
[5] WBCSD (2020). Heat pump technologies
[6] Lawrence Berkeley National Laboratory (2022). Electrification of U.S. Manufacturing With Industrial Heat Pumps

Regardless of how large the efforts in electrification and other areas of the energy transition are, it is highly unlikely that cumulative carbon emissions between now and 2050 will be consistent with the levels of the Net-Zero 1.5°C scenario.[7] Sectors such as cement and steel have limited potential for emission-reduction since some level of CO2 production simply cannot be avoided. In other sectors, decarbonization efforts are technically possible but only at a prohibitively high cost. In such sectors, Carbon Capture and Utilization or Storage (CCUS) will play a vital role as an economically viable technology that can help sectors reach their net-zero goals.

Using today's technologies, CO2 capture rates of over 90% are technically feasible. Carbon capture and storage (CCS) is a process that involves capturing the CO2 from power generation or another industrial activity, transporting it and then storing it in rock formations deep underground. CCUS adds the potential commercial sale and use of the captured CO2. There is potential for carbon capturing whenever fossil- or biomass-based fuels are combusted or even before combustion, for instance for blue or turquoise hydrogen. It can also be applied in the ammonia, iron, steel or cement industries.

The implementation of CCUS has two major use-cases across all industries. The most straightforward application happens in the context of carbon removal. Here, technologies for Direct Air Carbon Capture and Storage (DACCS) and Bioenergy with Carbon Capture and Storage (BECCS) play a major role. Both technologies result in the removal of emissions, so-called "negative emissions", when the captured carbon is permanently stored.

Secondly, CCUS can be applied to capture emissions in industrial processes. The focus here will lie on those sectors where emissions cannot completely be removed from the industrial process and alternative non-CO2 emitting processes are not available, such as cement, steel or chemicals.

Figure 7a shows the average CCS investment and 7b the cumulative CCs investment, comparing two different sources. While ETC provides a decomposition by CCS technology by sector, as well as additional investment needs in renewable energy to supply power to DACC, the NGFS analysis shows details on the regional split of CCS investments. Around 17% of total investments occur in the EU. Notably, investment in Nature-Based Solutions (NBS) are not included but have been addressed in our previous Carbon Farming Report (see Allianz Research (2022). Carbon Farming: A transition path for agriculture & forestry). DACC technologies are, however, usually deployed at or in close vicinity to permanent storage sites. Investment in transportation (and storage) will thus be significantly lower for DACC.

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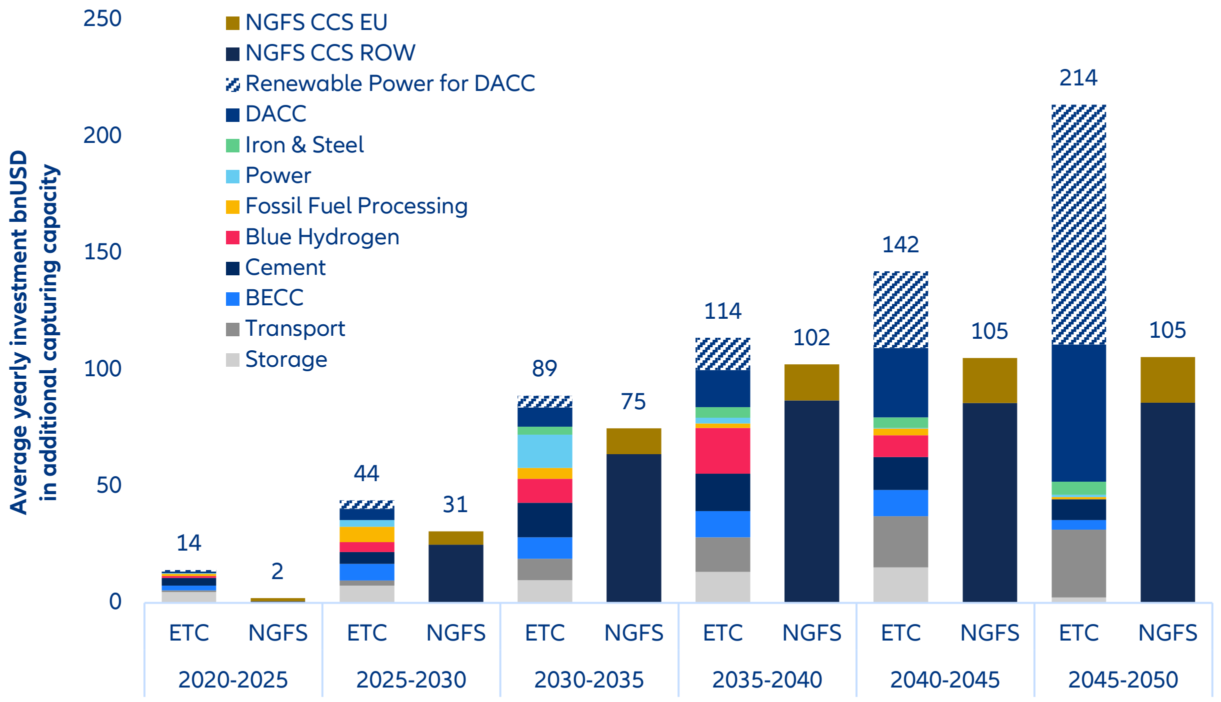
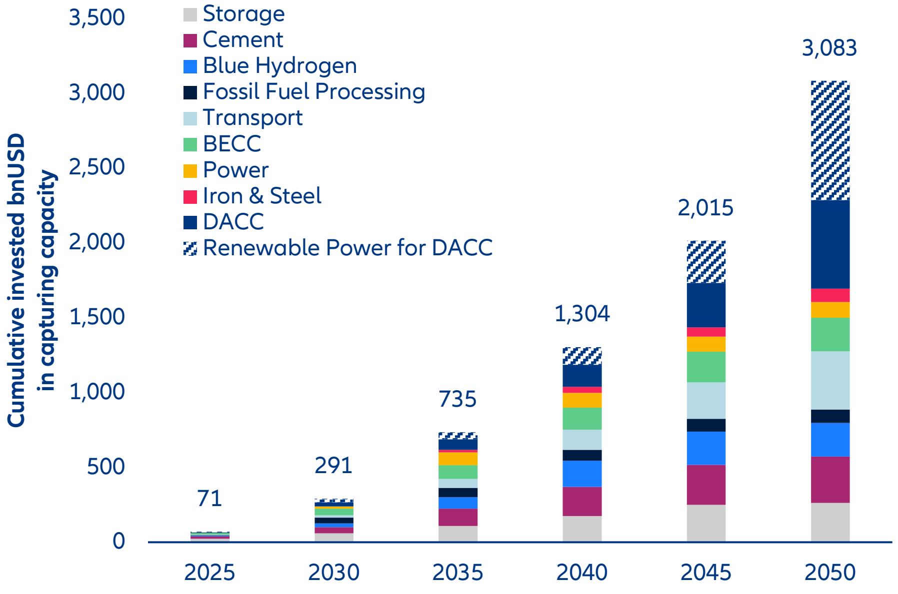
[7] ETC (2022). Carbon Capture, Utilisation and Storage in the Energy Transition: Vital but Limited

Figure 7a: CCS average global investments, USD bn per year



Sources: ETC base scenario, NGFS Net Zero 2050 scenario, Allianz Research.

Figure 7b: CCS cumulative global investments, USD bn



Sources: ETC, Allianz Research.

Cement industry and other non-metallic minerals

After water, concrete is the second most-consumed substance in the world[8], and accounts for 7% of global emissions. Without concrete, our infrastructure would crumble so on the road to a net-zero global economy, there is no way around making it clean. While the non-metallic minerals sector consists of a variety of different products such as glass, ceramics, bricks and gypsum, cement and lime production dominate emissions. This includes 1) the process emissions from the chemical reaction that turns limestone into cement; 2) the energy emissions from the energy used to create the high temperatures needed in cement production and 3) to a lower extent, emissions from cement transport.

Decarbonizing the cement sector is a challenging task mainly due to process emissions, which are difficult to avoid. Part of the solution lies in developing new cement chemistries. To meet the ambition of achieving net-zero emissions by 2050 in the cement sector, the clinker-to-cement ratio[9] needs to be reduced and innovative technologies deployed, such as carbon capture and storage and clinkers made from alternative raw materials.[10] The global average clinker-cement ratio is about 0.81, with the balance comprising gypsum and additives such as blast furnace slag, fly ash and natural pozzolana. As clinker production is the most energy-intensive and CO2-emitting step of the cement-making process, reductions in the clinker-cement ratio (through the use of clinker substitutes) would lower energy use and process CO2 emissions. Another possible way to reduce energy and process emissions in cement production is to blend cements with increased proportions of alternative (non-clinker) feedstocks, such as volcanic ash, granulated blast furnace slag from iron production or fly ash from coal-fired power generation. Governments can stimulate investment and innovation in these areas by funding R&D and demonstrations, creating demand for near-zero-emission cement and adopting mandatory CO2 emission-reduction policies. Reducing CO2 emissions while producing enough cement to meet demand will be challenging, especially as demand growth is expected to resume as the potential slowdown in Chinese activity is offset by expansion in other markets.[11]

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[8] Gagg 2014. Cement and concrete as an engineering material: An historic appraisal and case study analysis. Engineering Failure Analysis. https://doi.org/10.1016/j.engfailanal.2014.02.004

[9] Cement is a binding agent that sets and hardens to adhere to building units such as stones, bricks or tiles. Clinker is a nodular material which is used as the binder in cement products. The primary use of clinker is to manufacture cement.

[10] UN Climate Technology Centre & Network (2010). Clinker replacement

[11] IEA (2022). Tracking report - Cement

On the other hand, carbon emissions from heat used in cement production could be reduced through a switch from coal to gas, and eventually fully eliminated through heat electrification, and the use of biomass or hydrogen. However, each of these options will entail significant additional costs.

Last but not least, reducing carbon emissions from cement will also require better demand management. The use of timber as a substitute for building material is not without its challenges. Therefore, global cement production is expected to continue to grow worldwide: while it is projected to stagnate in Europe between 2030 and 2050, it will increase in India, other developing Asian countries and Africa. However, demand growth could be slowed down via greater material efficiency in building design, waste reduction, maximizing the life of buildings and infrastructure and some materials circularity.

Cement emissions are being addressed by the EU Emissions Trading System (ETS) and several other countries, including Canada, South Korea and China, have also introduced pricing schemes. Additionally, the EU is developing a carbon border adjustment mechanism for industries, including cement, which aims at limiting carbon leakage and incentivizing stronger emissions measures in foreign countries.[12] Many governments and organizations have also released roadmaps for decarbonizing the cement sector and reaching net zero by 2050[13].

For this, it is crucial to commercialize CCS by 2030. Therefore, governments must plan and construct infrastructure to transport and store captured CO2 as the lack of such infrastructure can cause significant delays in technological deployment. Transporting CO2 through pipelines is the most suitable way, and governments must gain public support for building these pipelines and CO2 storage facilities.

An extensive analysis of the required abatement costs associated with the implementation of the necessary measures from electrification to CCS can be conducted using the IndustryPLAN[14] model (Johannsen & Mathiesen 2023). Employing a bottom-up approach, the model defines specific measures for the sector with adjustable implementation rate parameters and yields results on energy savings and investments for the EU+UK. The aggregate and averaged investments per ton of CO2 abated for the non-metallic minerals sector (cement, ceramics and glass) shows a relatively stable relationship at various levels of emission intensity of energy use, with around EUR615/tCO2 (Figure 8a). In the other sectors analyzed, average investment needs will rise more strongly since marginal cost increases for the last measures to reach zero emissions are typically higher than for the "low-hanging fruits" implemented first. As seen in Figure 8a, implementing the suggested measures from the IndustryPLAN[15] model is estimated to result in a decrease of the emission intensity from 41.7tCO2/MJ in 2030 to 6.6tCO2/MJ by 2050.Analyzing the Material Economics (2019) results for the cement sector (Figure 8b) and aggregating the results yields an average global investment of around EUR250/tCO2 to reduce emissions.[16]

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[12] In the terminology of the European Commission, 'carbon leakage' does not only refer to emissions just being emitted in another country instead of the EU, which wouldn't help the global climate ambition. Rather 'carbon leakage' also refers to the value added and jobs that will be lost in the EU if production gets outsourced to a non-EU country.

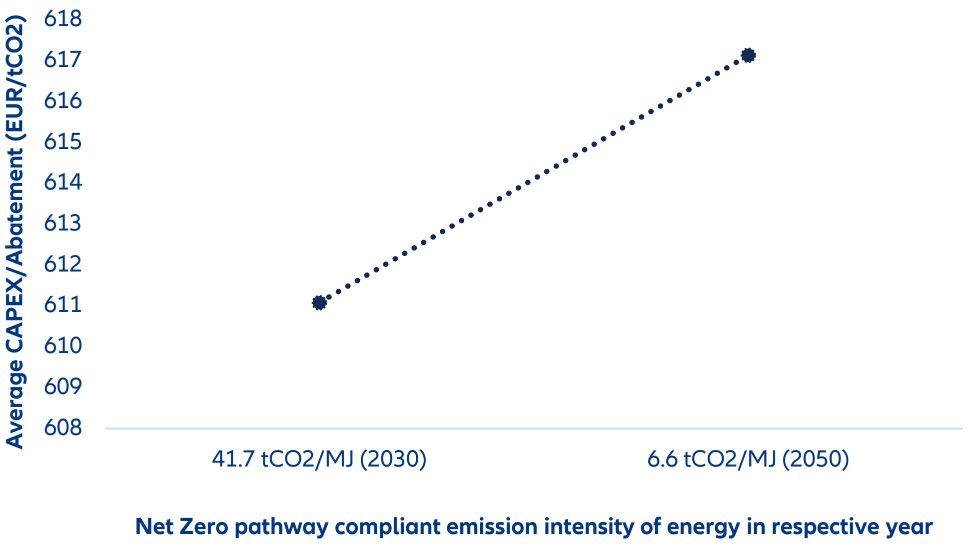
[13] In 2022, GCCA published the Concrete-Future-Roadmap which is summarized in the Appendix GCCA Roadmap. Another roadmap is the IEA Cement Technology Roadmap which builds on the long-standing collaboration of the IEA with the Cement Sustainability Initiative (CSI) of the World Business Council for Sustainable Development (WBCSD).

[14] IndustryPLAN chooses the decarbonization actions in a bottom-up approach from a merit-order of technology options.

[15] More on the background of the technologies and mitigation potentials can be found in Appendix: Industry emission reduction potentials.

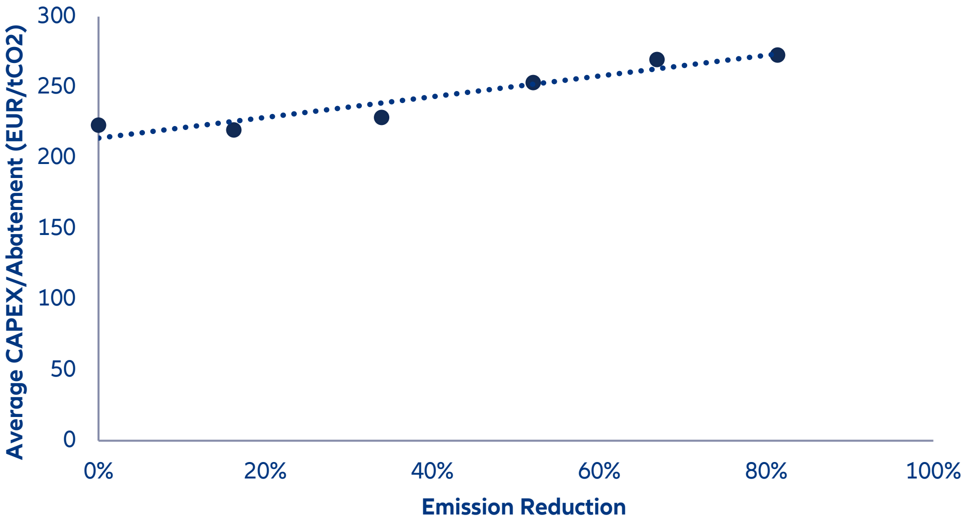
[16] Caution: The stated IndustryPLAN numbers refer to reducing the emission intensity of energy use (tCO2/MJ) while the Material Economics model numbers refer to reducing emissions (% CO2 total emission reduction). The dots in the Material economics graph show the actual calculated average abatement costs in the model at differing emission reduction levels, while the line shows the OLS estimate derived from the calculated values shown as dots.

Figure 8a: Average investment in the cement/non-metallic minerals metals sector (EUR/tCO2) needed to reach emission intensity targets on the path to net zero



Sources: IndustryPLAN, Allianz Research. Notes: Coverage EU + UK. Non-metallic minerals include cement, ceramics and glass.

Figure 8b: Average cement sector investment (in EUR/tCO2) relative to emission reduction target



Sources: Material Economics, Allianz Research. Notes: Coverage is EU.


Photo by Sonika Agarwal on Unsplash

Chemicals

The chemical sector plays a crucial role in the European economy, with chemicals being integral to major European value chains such as pharmaceuticals, electronics, batteries for electric vehicles and construction materials. The EU-27 is the second-largest chemicals producer globally, generating EUR499bn in sales in 2020 and accounting for around 7% of manufacturing output by turnover, which makes it the fourth-largest industry in the EU. The chemical industry employs highly skilled workers and boasts 67% greater labor productivity than the manufacturing sector average.

While chemical production in the EU-27 has jumped by +47%, GHG emissions have decreased by -54% compared to 1990 levels, and energy consumption has fallen by -21% over the same period. But the chemical industry still remains the third-largest emitter of CO2 emissions in the EU[17].

The use of natural gas and other fossil fuels, along with process-related emissions in ammonia production, dominate GHG emissions in the EU's chemical industry. The industry uses a significant portion of energy carriers as feedstocks for production of olefins, ammonia and methanol, with ethylene and other olefins dominating both energy consumption and feedstock use. A detailed study by DECHEMA[18] provides a net-zero transition overview for an even broader product range, including chlorine and the aromatics benzene, toluene and xylene.

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[17] The European Commission developed a transition pathway for the chemical industry in the form of a roadmap. It is based on eight building blocks (including competitiveness, funding, infrastructure, skills, the social aspect and more), which were used to sequence key topics against a timeline. The roadmap includes three components: 1) An action-oriented one that groups topics under three cross-cutting themes: collaboration for innovation, clean-energy supply and feedstock diversification. 2) A technology overview and roadmap, based on the SET action plan, its supportive actions and EU initiatives. 3) A regulatory overview, including major R&I initiatives influencing developments in the chemical industry.

[18] DECHEMA (2017). Low carbon energy and feedstock for the European chemical industry

Box 1: Ammonia

Ammonia production is responsible for around 1% of global emissions and approximately 33% of global chemical Scope 1 emissions, making it the largest carbon-emitting chemical process. The 183Mt of ammonia produced annually are primarily used for nitrogen-based fertilizer (70%) and chemical feedstock (30%) in various industries such as explosives, mining, construction, plastics, cleaning products and textiles. With the global population set to increase, an additional 44Mt (fertilizer) and 24Mt (feedstock) may be required by 2050[19]. Furthermore, around 50% of greenhouse-gas emissions from ammonia come from Scope 3 emissions, downstream in the application of fertilizers to soil and upstream in fossil-fuel extraction. To achieve net-zero ammonia, it is crucial to eliminate emissions in the hydrogen input. This can be achieved through the use of green hydrogen from renewable energy sources, blue hydrogen from various variants of steam methane reforming (SMR) or autothermal reforming (ATR) with carbon capture and storage (CCS), biomass-based hydrogen from gasification of biomass or biomethane reforming and methane pyrolysis powered by renewable energy. However, according to ETC, this transition requires significant investment.[20] Until 2025, the global annual investment required for transitional technologies ranges from USD4bn to USD12bn, while an average investment of USD25bn to USD52bn in zero-emission ammonia production plants is needed until 2030. By 2050, an average of USD59bn to USD109bn of investments will be necessary.

[19] The IndustryPLAN model shows an annual ammonia production of 16.6Mt for the EU in 2020 which is expected to increase only marginally to 17Mt in 2050. However, depending on the scenario ammonia production might increase substantially. In the MPP ammonia model (MPP 2022C) global ammonia production might increase from currently 185Mt to 800Mt. The reason for this is that green ammonia might play an important role as a "shipping fuel, as well as in power generation and as a hydrogen vector for long-distance transport for resource-scarce regions".
[20] MPP (2022). Making Net-Zero 1.5°C-Aligned Ammonia Possible

Investments required in the chemical industry have been obtained using the IndustryPLAN[21] model (Johannsen et. al 2023). When aggregating bottom-up over the measure-specific investment costs and emission savings, the analysis suggests that reducing emissions will imply average investments in the European chemicals industry of EUR200 per tCO2 abated by 2030 and EUR580 per tCO2 abated by 2050 at emission intensities of 28.3tCO2 per MJ and 1.4tCO2 per MJ, respectively (Figure 9a). Thus, marginal investment needs to abate an additional ton of CO2 increase as the energy use becomes cleaner. In the case of ammonia, applying the MPP ammonia model developed by the Mission Possible Partnership (MPP 2022C) and aggregating the results yields average global investment needs of over EUR700/tCO2 to reduce emissions[22]. According to the MPP findings, most investments go to green ammonia production (79%) using renewable electricity in hydrogen generation, nitrogen separation and ammonia synthesis (Figure 9b).

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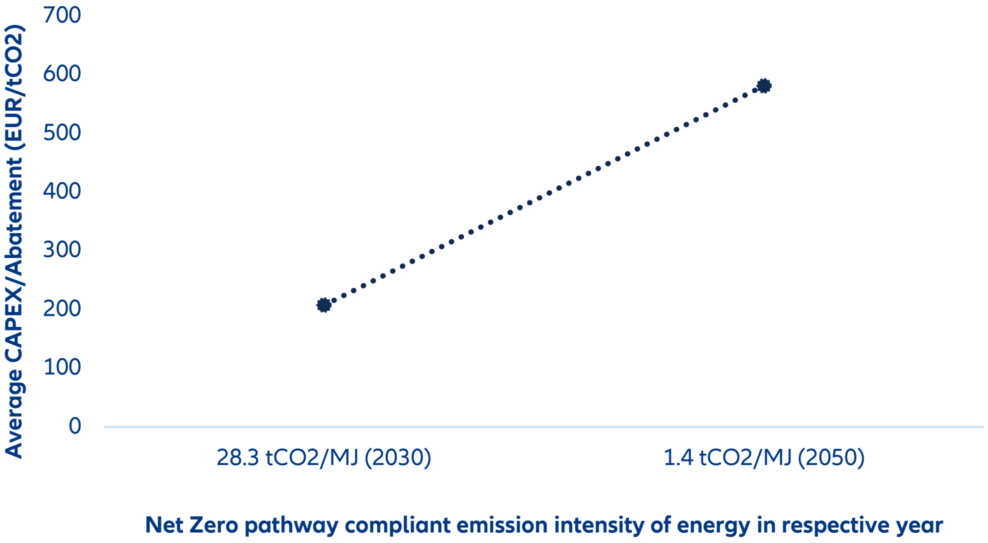
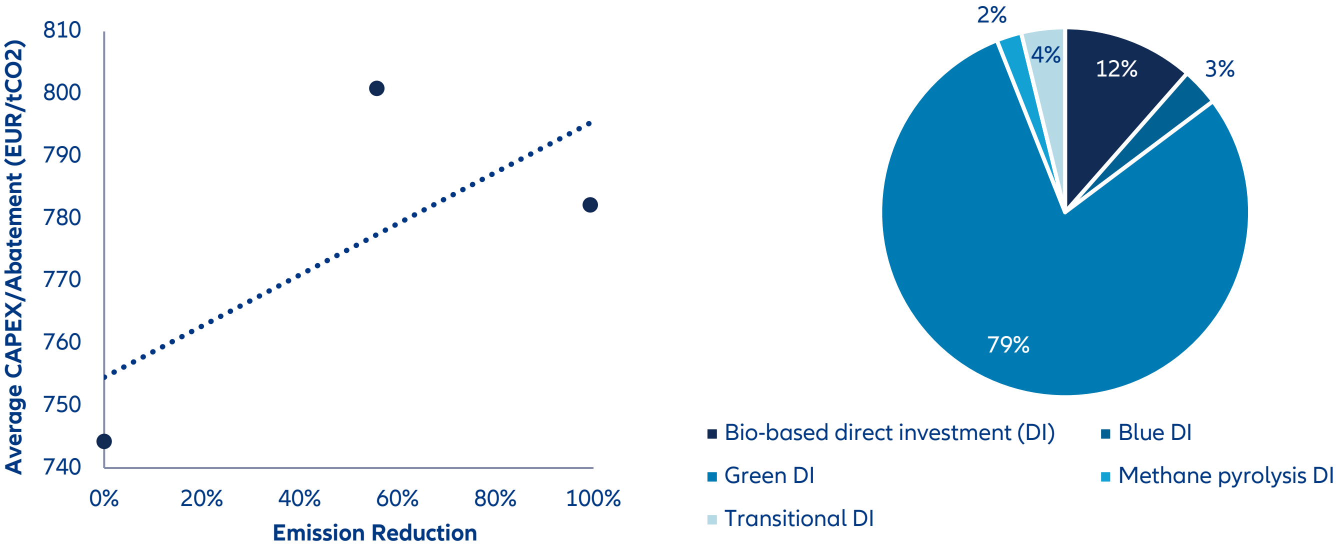
[21] IndustryPLAN chooses the decarbonization actions in a bottom-up approach from a merit-order of technology options. More on the background of the technologies and mitigation potentials can be found in Appendix: Industry emission reduction potentials.
[22] Caution: The stated IndustryPLAN numbers refer to reducing the emission intensity of energy use (tCO2/MJ) in Europe while the MPP numbers refer to reducing emissions (%CO2 total emission reduction) globally. The dots in the MMP graph show the actual calculated average abatement costs in the model at differing emission reduction levels and the line shows the OLS estimate derived from the calculated values shown as dots.

Figure 9a: Average investment in the chemicals sector (EUR/tCO2) needed to reach displayed emission intensity targets on the path to net zero



Sources: IndustryPLAN, Allianz Research. Notes: Coverage EU + UK.

Figure 9b: Average ammonia sector investment (in EUR/tCO2) relative to emission reduction target



Sources: MPP (2022C), Allianz Research. Notes: Coverage is global averages.

Photo by Greg Rosenke on Unsplash

Iron, steel and aluminium

The iron and steel industry is responsible for 2.3Gt of CO2 emissions, which accounts for 7% of global CO2 emissions. In a business-as-usual scenario, as global steel production is expected to increase by +30%, these emissions could surge to 3.3Gt/y by 2050.[23]

The production of steel starts with mining iron ore, an energy-intensive activity that generates substantial greenhouse-gas emissions. The ore is then transported to a steel mill, melted and combined with other materials to create steel. This process requires high temperatures that are typically achieved through the burning of fossil fuels. The steel produced is often transported long distances to its destination.

To tackle these emissions, several actions are possible. One is to reduce the total demand for steel. Another is to transition from ore-based (primary) steel to scrap-based (recycled) steel, which could reduce global annual carbon emissions from steel production by -37% by 2050 (and by -52% by 2100) relative to the business-as-usual scenario.[24] A radical process change that produces zero-carbon ore-based steel is also an option. The two main routes to achieve this are hydrogen-based reduction and carbon capture.

There are three major technologies involved in steel production: 1) BF-BOF furnaces (Blast Furnace-Basic Oxygen Furnace), with emissions of about 2.3t of CO2 per ton of steel. 2) DRI (Direct-Reduced Iron) with gas as the input, with emissions of 1.1t of CO2 per ton of steel. 3) EAF (Electric Arc Furnaces) processes based on scrap or direct-reduced iron with emissions of about 0.4t or less, depending on the electricity input (Figure 10). A shift away from the prevalent BF-BOF route towards EAF processes can lead to a significant reduction in the industry's CO2 emissions. Zero-carbon electricity can reduce nearly all emissions from steel production.

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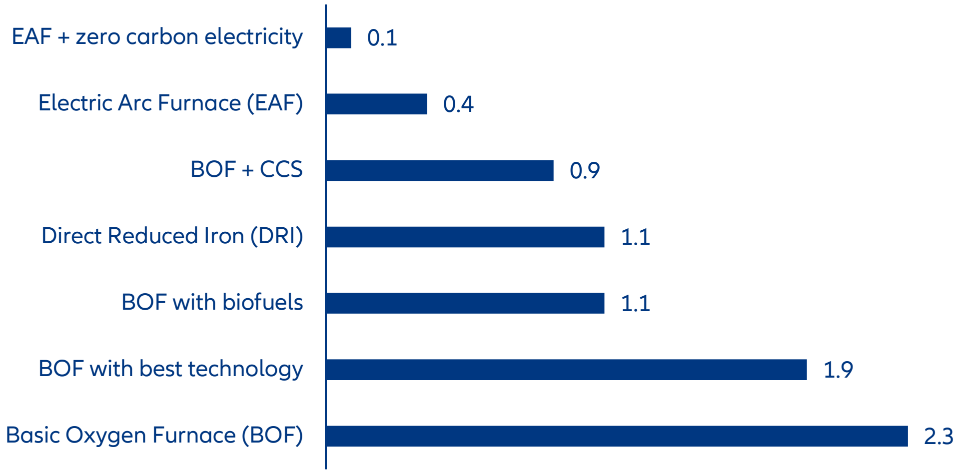
[23] ETC (2020). Reaching net-zero carbon emissions from steel

[24] Material Economics (2018) The Circular Economy: a powerful force for climate mitigation

Figure 10: CO2 intensity of steel production (in tCO2/t steel)



Source: ETC (2020), Allianz Research.

To assess the investment needs for implementing each of the measures described above for the iron & steel industry, we can use the aforementioned IndustryPLAN[25] model (Johannsen & Mathiesen 2023) and the steel model developed by the Mission Possible Partnership (MPP 2022A). Both use different bottom-up modeling approaches looking at measure-specific investments for the whole sector (IndustryPLAN) and plant-level technology switches (MPP), respectively. In terms of geographical scope, the IndustryPLAN covers European countries (EU+UK) while the MPP model observes expenditures at a global scale. The resulting investments are shown in Figure 11a and 11b. When looking at the investment efforts necessary for a net-zero transition in the iron & steel sector as a whole, Figure 11a shows aggregate investments relative to achievable abatements for the years 2030 and 2050. Up until 2030, the cost of abating one ton of CO2 in a net-zero scenario averages EUR117. This increases by 2050 to about EUR450/tCO2. At the same time, emission intensity per energy unit decreases from 58.8 tCO2/MJ to 4.4t CO2/MJ by 2050. For the steel sector in particular, modelling a global net-zero transition using the MPP steel model yields aggregate investment per abatement ranging from EUR250/tCO2 to EUR360/tCO2 (Figure 11b))[26]. Here, the model predicts that most investments (65%) will be used in switching production technologies to less energy- and emission-intensive alternatives such as "Direct-Reduced Iron – Electric Arc Furnaces" (DRI-EAF) or Direct-Reduced Iron – Basic Oxygen Furnaces (DRI-BOF) (Figure 11b).

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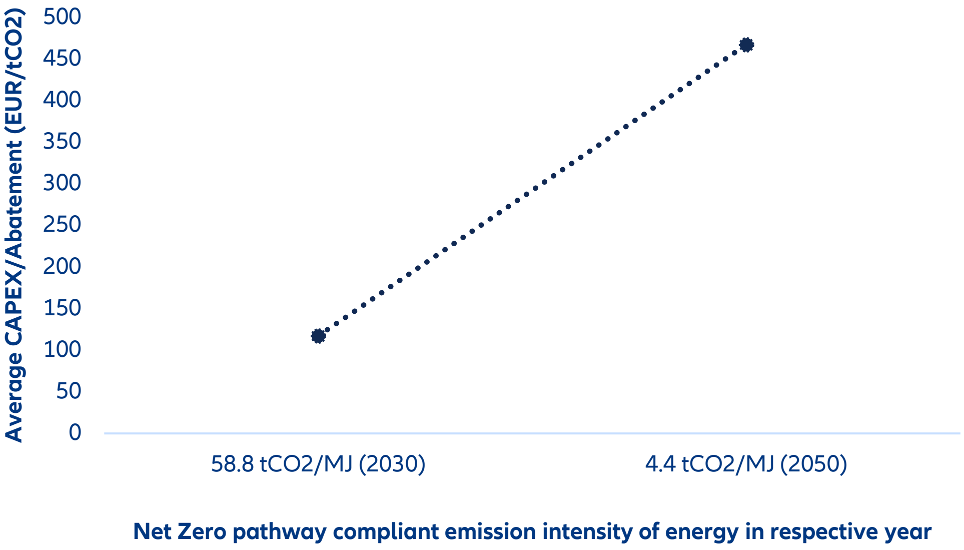
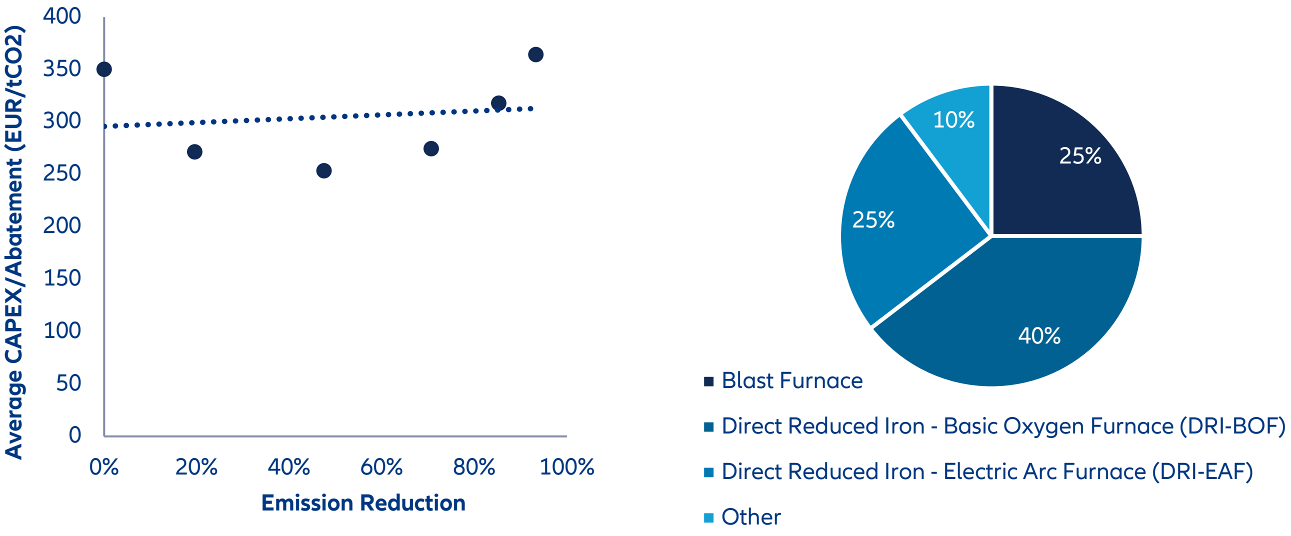
[25] IndustryPLAN chooses the decarbonization actions in a bottom-up approach from a merit-order of technology options. More on the background of the technologies and mitigation potentials can be found in Appendix: Industry emission reduction potentials.
[26] Caution: The stated IndustryPLAN numbers refer to reducing the emission intensity of energy use (tCO2/MJ) in Europe while the MPP numbers refer to reducing emissions (%CO2 total emission reduction) globally. The dots in the MMP graph show the actual calculated average abatement costs in the model at differing emission reduction levels and the line shows the OLS estimate derived from the calculated values shown as dots.

Figure11a: Average investment in the iron and steel sector (EUR/tCO2) needed to reach displayed emission intensity targets on the path to net zero



Sources: IndustryPLAN, Allianz Research. Notes: Coverage is EU + UK.

Figure11b: Average steel sector investment (in EUR/tCO2) relative to emission reduction target



Sources: MPP (2022A), Allianz Research. Notes: Coverage is global averages.

Photo by Teslariu Minhai on Unsplash

Aluminum industry and other non-ferrous metals

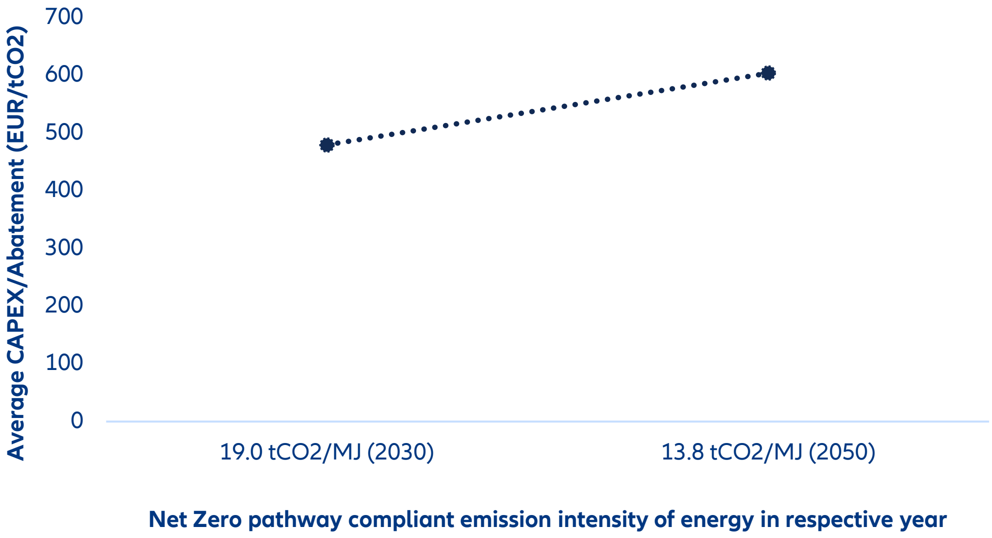
These industries are responsible for about 2.4% of industrial emissions in the EU, or 13 Mt CO2 annually. Without intervention, these emissions are expected to increase by +50% by 2050. China and Southeast Asia are expected to meet most of the global demand for aluminum, but current producers rely heavily on coal-powered electricity during the smelting process. About 77% of the industry's global CO2 emissions are generated during the smelting process, with more than half due to coal-powered electricity usage. Approximately one-third of the industry relies on power from the grid, while the remaining two-thirds use their own power sources.

Recycling aluminum offers a low-carbon alternative. Although recycled aluminum accounts for 30% of industry demand, it only creates 10% of the industry's emissions. Recycling aluminum requires only 5% of the energy needed for primary production. However, rising demand for aluminum will make additional primary aluminum production necessary. Therefore, the industry will need to transition to renewable energy sources and implementing CCS technologies to achieve net-zero emissions.

Transitioning from coal-fired power plants to renewable sources can be challenging for those production sites built in areas with limited or unreliable grid power alternatives. Energy-storage solutions are necessary to ensure that smelters have a constant power supply. Another complication is that plants have long lifespans (30-40 years), making the use of CCS technologies necessary. Process emissions, including direct emissions from carbon anodes and fuel combustion during unit processes, account for about 25-30% of the industry's emissions. To reduce these emissions, non-carbon alternatives for the anodes used in the smelting process must be found. Moreover, transitioning towards technologies that can provide heat and steam without the use of fossil fuels can also reduce emissions.

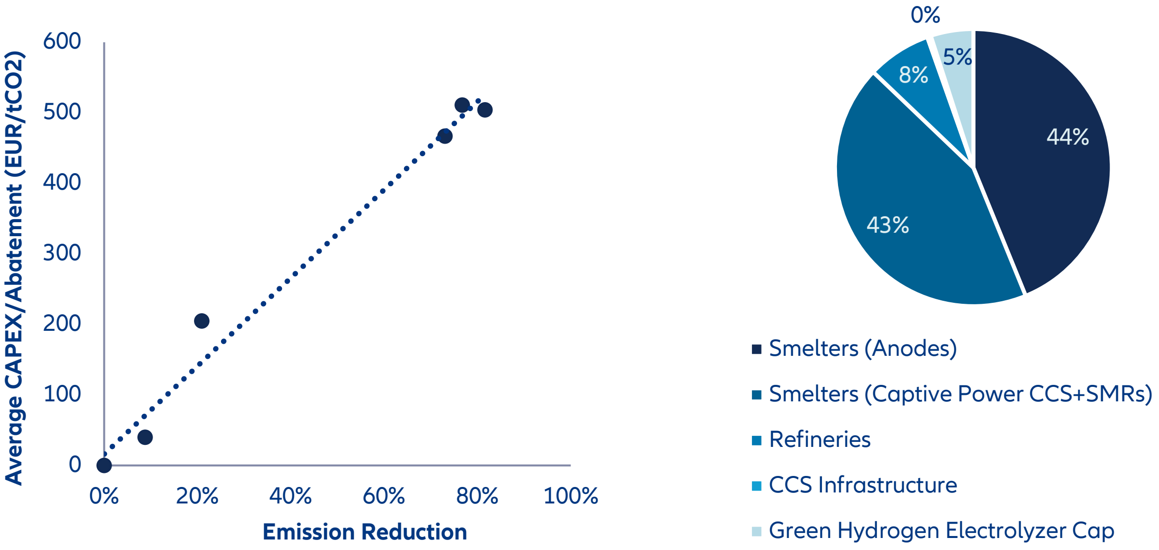
When analyzing the aggregated non-ferrous metals sector (such as aluminum, copper, lead, nickel and others) using the IndustryPLAN bottom-up model (Johannsen & Mathiesen 2023), the average investment needs lie in the range of EUR500-600/tCO2 (Figure 12a)) and increase slightly as the emission intensity of consumed energy declines. Notably, the emission intensity decreases but does not reach zero, indicating leftover emissions that are not abated directly but could be compensated for by using other means (e.g. CCS). Looking at net-zero-consistent investment strategies for the aluminum sector (Figure 12b)), the modeled results obtained from the Mission Possible Partnership aluminum model (MPP 2022B) suggest a comparatively wide range of CAPEX expenditures per unit of abatement, indicating that the "last stretch" of emission-reduction efforts can be substantially more expensive than in the steel industry. In the case of aluminum, the first 10% of emission reductions can be reached with an investment of only about EUR50/tCO2, while the reduction of 70-80% compared to 2020 levels will increase investment efforts to an average of almost EUR500 per tCO2 that is abated. For the main investment components, the MPP model finds that 87% of total expenditures are used for implementing new smelter technologies.

Figure12a: Average investment in the non-ferrous metals sector (EUR/tCO2) needed to reach displayed emission intensity targets on the path to net zero



Sources: IndustryPLAN, Allianz Research. Notes: Coverage Europe + UK. Notes: Non-ferrous metals comprise i.a. aluminium, copper, lead, tin, titanium and zinc, and alloys such as brass.

Figure12b: Average aluminum sector investment (in EUR/tCO2) relative to emission reduction target



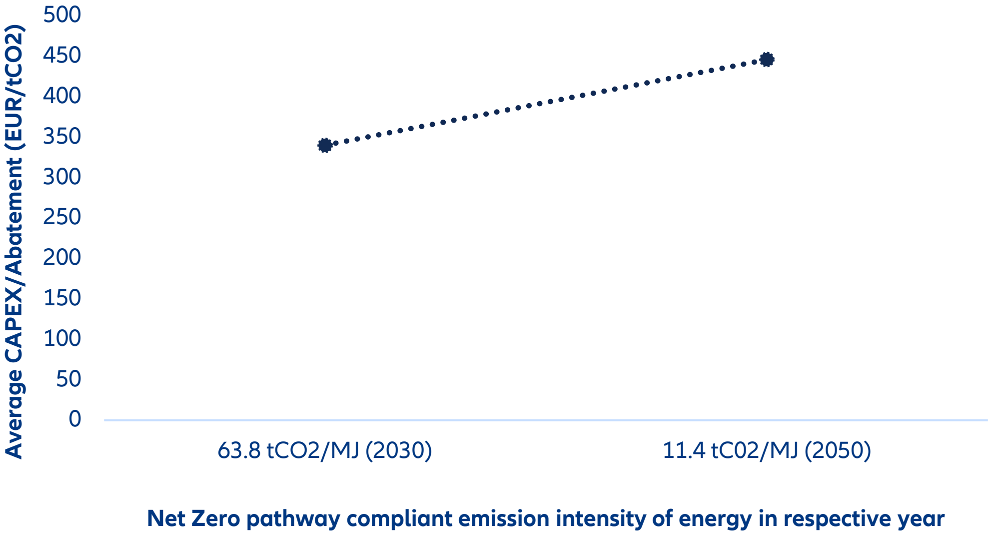
Sources: MPP (2022B), Allianz Research. Notes: Coverage Global.

Photo by Kayle Kaupanger on Unsplash

Foundries

Foundries contribute to emissions primarily through the energy-intensive process of casting and reforming metals for machinery and vehicle production. Thus, downstream processing also offers significant emission-reduction opportunities. In the case of metal casting in foundries, the annual emissions in the EU28 in 2015 amounted to 7.15 MtCo2 per year (Johannsen et.al 2023). Relative to the production emissions in the non-ferrous metal and iron-and-steel sector, the metal casting emissions are as high as 81% of the former or 5% latter. To abate the emissions associated with metal casting, the IndustryPLAN model assesses average investment requirements of EUR350/tCO2 for initial investments until 2030, increasing to almost EUR450/tCO2 by 2050 (Figure 13). Following this investment pathway, the achievable emission reductions are approximately 5.8 Mt, or 81% of initial emissions.

Figure 13: Average investment in foundries (EUR/tCO2) needed to reach displayed emission intensity targets on the path to net zero

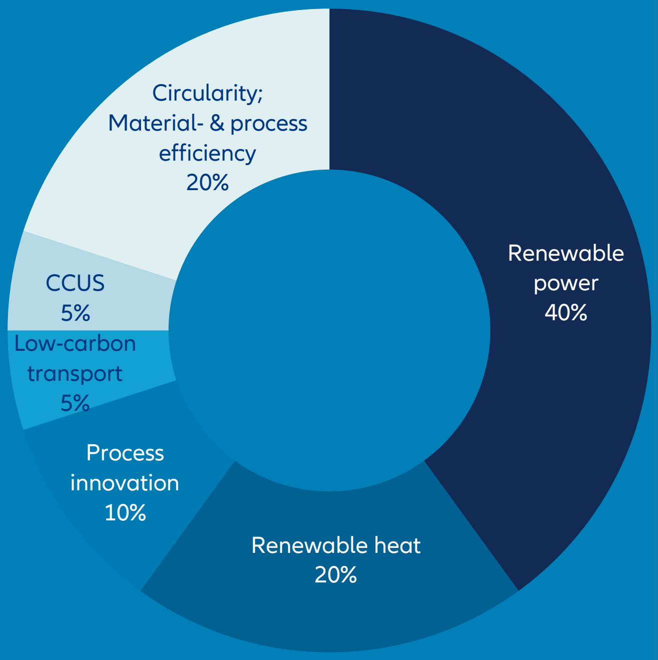


Sources: IndustryPLAN, Allianz Research. Notes: Coverage EU + UK.

Box 2: Automotive

The automotive sector and the motor vehicles sector as a whole only contribute 2% to direct industry emissions. Yet it receives much attention due to the CO2 emitted by internal-combustion engines during usage, which is not the focus of the analysis here and has been addressed in our previous report on the transportation sector (Allianz Research (2021). Transport in a zero carbon EU: Pathways and opportunities). One of the key solutions to reduce production emissions is the transition to renewable power, which can lead to emission savings of up to 40% (Figure 14)[27]. In addition, renewable heat can also be used in various manufacturing processes, such as drying in battery-cell production, which can result in a further -20% reduction in emissions. The transportation sector can address 5% of emissions through fuel switching, while the remaining 5% can be tackled using CCS technologies. Despite the necessary changes, rises in consumer costs in the automotive industry are expected to be limited. According to the World Economic Forum (WEF), in a net-zero 2050 scenario, the cost of a car would increase on average by less than +2%.

Figure 14: Emission reduction potentials in the automotive sector



Sources: WEF, Allianz Research.

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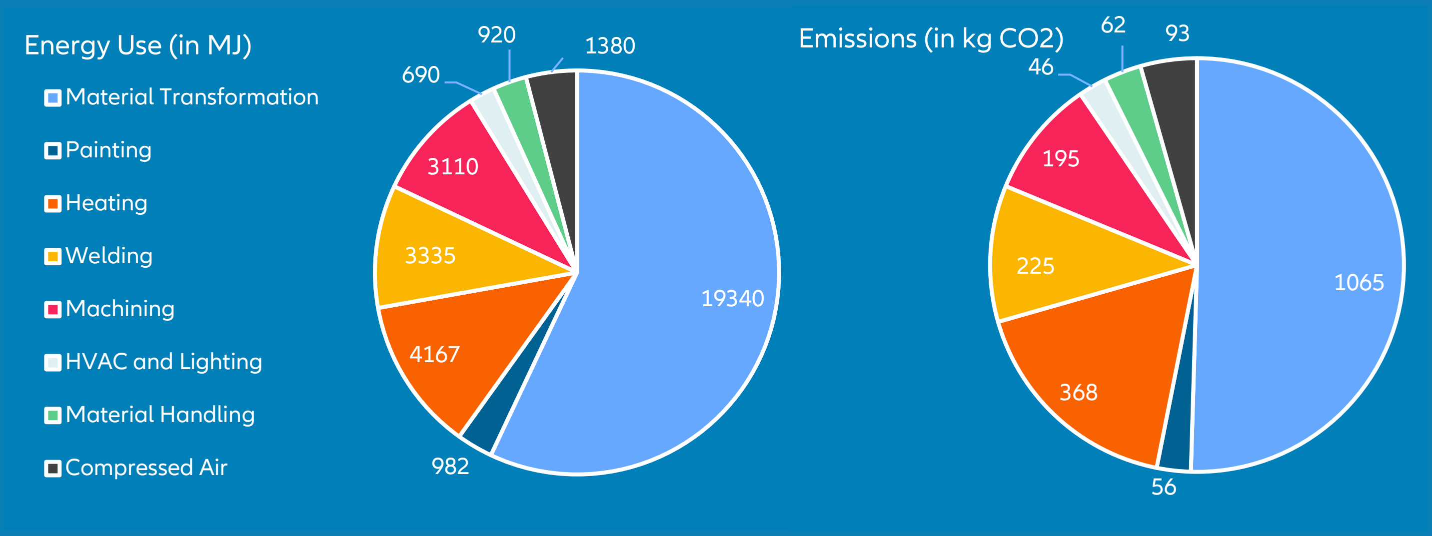
[27] WEF (2021) Net-Zero Challenge: The supply chain opportunity

Fuel and exhaust account for the majority (65-80%) of a car's emissions throughout its lifespan. But the production of the automobile itself accounts for only 4-8% of its life-cycle emissions.[28] Figure 15 decomposes the energy use and CO2 emissions associated with the production of a car. To decarbonize the automotive industry, critical processes and footprints must be addressed, including product development, buildings and facilities, manufacturing operations, end-of-life, and supply-chain management.

Power Purchase Agreements (PPAs) enable automobile manufacturers to ensure the use of renewable energy through agreements with their utilities, while the use of industrial internet of things (IIoT) technologies can help optimize operations to reduce energy consumption and waste. To address end-of-life issues, manufacturers are increasingly focusing on design for recycling and dismantling, creating the path for an automotive circular economy. This involves using low-carbon resources, materials and assembly; integrating with the energy grid to achieve net-zero carbon emissions across the entire vehicle lifecycle and disassembling end-of-life vehicles. It also involves recycling batteries and other materials to enable resource recovery and closed material loops, and adopting subscription-based ownership, reuse, and remanufacturing to increase the lifetime of vehicles and components, and ensure efficient vehicle use over time and occupancy. While these initiatives are making progress, there is a long way to go before end-of-life cars can be used as a source of valuable materials. This would make particular sense for aluminum, which is infinitely recyclable. Recycling aluminum consumes only 5% of the energy required to produce primary aluminum, making it a highly sustainable alternative. [29]

Figure 15: Manufacturing an automobile - energy use and CO2 emissions



Sources: Siemens[30] , Allianz Research.

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[28] McKinsey (2020). The zero-carbon car: Abating material emissions is next on the agenda.
[29] World Climate Foundation (2021). The zero-carbon car: How circular material helps the automotive industry reach their climate targets
[30] Siemens (2022). Decarbonizing practices in the global automotive industry

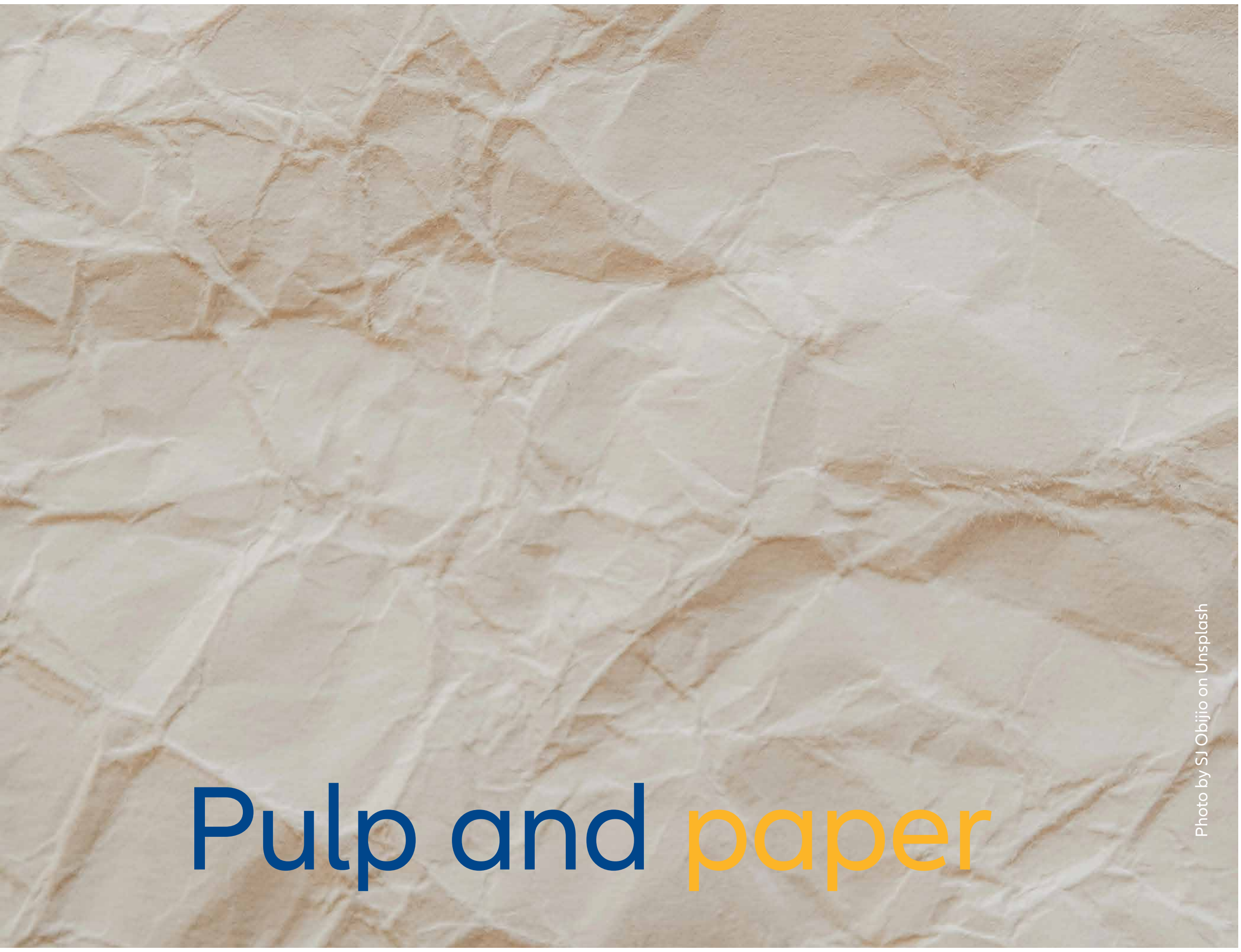


Photo by SJ Objio on Unsplash

Pulp and paper

The pulp-and-paper industry is one of the most energy-intensive sectors. It is the third-largest energy user in the European industry after chemicals and cement, with 31.8Mt of CO2 emissions in 2021 in the EU-27. The sector accounts for about 4% of EU industrial emissions of CO2, making it a major contributor to climate change. However, these emissions from energy use also create a big opportunity for emission-reduction efforts. Since 2018, the sector's energy efficiency has been flat. A move away from fossil fuels as an energy source and technological change in the industry's processes are long overdue and inevitable if the sector wants to achieve its climate goals. In a net-zero scenario, emissions intensity will have to fall by about -4% every year until 2030.

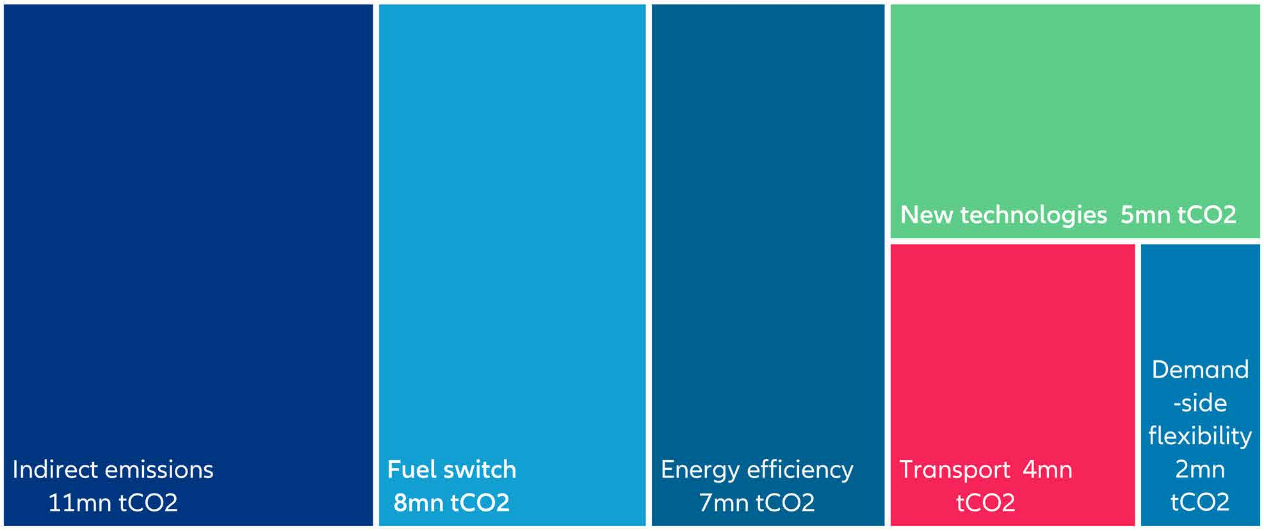
The production of paper is intensive in heat as water needs to be evaporated in the drying processes of pulp and paper. As a result, companies are searching for innovative technologies that allow them to reduce the input of energy and heat in their processes. Reducing emissions through recycling will not be an option for this industry. Primary paper production already heavily relies on the use of bioenergy sourced as a by-product from primary wood inputs. On the other hand, most of the recycled production has a much higher dependence on fossil fuels as there is no bioenergy to be recovered in the production cycle of recycled paper.[31]

[31] IEA (2022B). Pulp and paper.

Electricity accounts for a mere 7% of the sector's energy consumption within the EU; the overwhelming majority can be connected to heat energy. Within the industry, the emissions from manufacturing and processing differ widely. Fossil fuels are the source for about 30% of the sector's energy. The use of bioenergy, already very prevalent in the industry, needs to be increased from 43% in 2021 to 50% in 2030. There are pilot projects in Europe for superheated steam technology that would lead to massive energy savings through the recovery of thermal energy. The goal is to start introducing it by 2026.

By implementing a variety of strategies shown in Figure 16, the European forest fiber and paper industry is projected to achieve an 80% reduction in carbon emissions. Energy-efficiency measures, such as process improvements and Industry 4.0 adoption, along with investments in innovative production technologies, are expected to lower emissions by 7mn tons of CO2. Leveraging cogeneration assets and participating in the energy market could lead to an additional 2mn tons of emissions reductions through demand-side flexibility. The industry's existing use of biomass and gas-based boilers, along with its pioneering work in Combined Heat and Power (CHP) production, are estimated to achieve 8mn tons of CO2 emissions reduction through fuel switching. Further emission reductions of 5mn tons of CO2 could be realized through emerging and disruptive technologies, such as Deep Eutectic Solvents. Indirect emissions from purchased electricity are also projected to decrease by 11mn tons as European power production continues to decarbonize. Improvements in the transport and logistics chain, including fuel and transport efficiency, infrastructure enhancements, intermodality and the use of alternative fuels such as biogas, advanced biofuels, electricity, or fuel cells, could contribute to an additional 4mn tons tonnes of CO2 emissions reductions.

Figure 16: CEPI Decomposition of emission-reduction potential



Sources: CEPI[32], Allianz Research.

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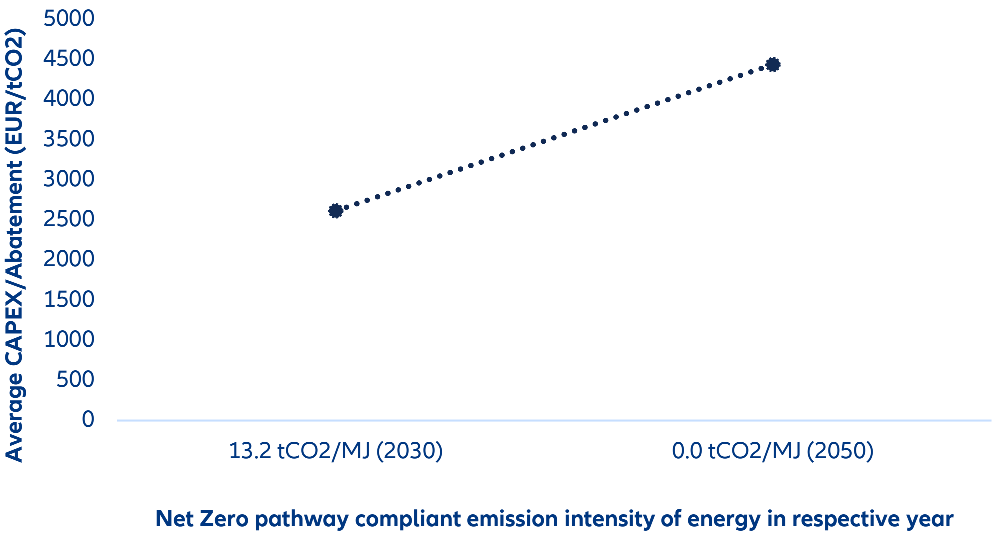
[32] Confederation of European Paper Industries (2017). Investing in Europe for Industry Transformation – 2050 Roadmap to a low-carbon bioeconomy

For the pulp and paper industry, the transition to net-zero leads to some further challenges. According to the FAO, the industry is the largest user of virgin wood, accounting for about 14% of total wood consumption.[33] When other industries (i.e. steel, cement, plastics or ammonia) transition their energy sourcing from fossil fuels to inputs such as low-carbon electricity and biomass, biomass as feedstock will become a highly sought-after commodity. Next to more common uses of biomass (i.e. biofuel) non-fossil carbon will be needed to produce petrochemicals and plastics or can also find use in the steel industry, where it could be employed as a reducing agent in steel production.[34]

Among the industries covered in the IndustryPLAN[35] project (Johannsen & Mathiesen 2023), the pulp and paper sector shows the highest average investment needs for CO2 abatement in a net-zero scenario with over EUR2500/tCO2 (Figure 17). Even though the emission intensity of energy in the sector is already initially lower than in other energy-intense industry sectors – making remaining emission reductions potentially more costly than in other sectors – this does not completely explain the substantial cost differences. When looking at the type of investments made (Figure 1), it is clear that most of the investment flows are expected to go into electrifying production processes and the adoption of new innovative production measures. In the electrification process, the major component adding to costs consists of using high temperature heat pumps in the production of different products such as mechanical pulp or graphic paper.

Figure 17: Average investment in the pulp and paper sector (EUR/tCO2) needed to reach displayed emission intensity targets on the path to net zero



Sources: IndustryPLAN, Allianz Research. Notes: Coverage EU + UK.

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[33] Del Rio, D. D. F. et al. (2022). Decarbonizing the pulp and paper industry: A critical and systematic review of sociotechnical developments and policy options. Renewable and Sustainable Energy Reviews, 167, 112706.
[34] Material Economics (2019). Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.
[35] IndustryPLAN chooses the decarbonization actions in a bottom-up approach from a merit-order of technology options. More on the background of the technologies and mitigation potentials can be found in Appendix: Industry emission reduction potentials.

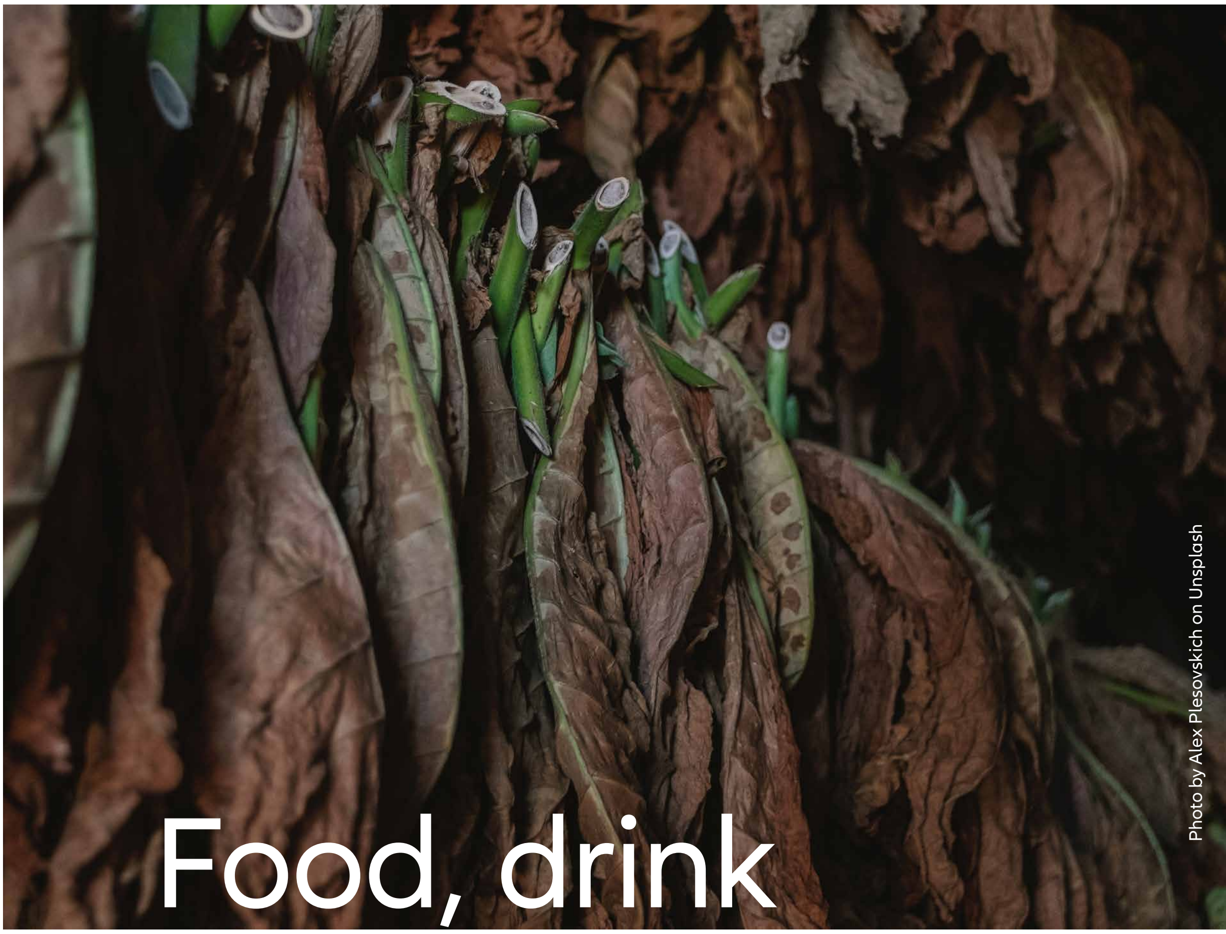

Photo by Alex Plesovskich on Unsplash

Food, drink and tobacco

Climate change discussions often center around major emissions sources such as power generation, transportation and factories but everyday activities like food and drink consumption receive less attention. In fact, the food value chain is estimated to account for 30% of total carbon emissions in the EU, including farming, manufacturing, production and transport. Within the EU, food and drink manufacturing contributes 11% of the total agrifood value chain emissions. Relative to the other industries, the food industry emits 9% of total industry CO2 emissions. The majority of emissions from this sector come from energy use, with 62% consumed as heat and 38% as power from the grid. This sector is distinguished by the fact that a significant amount of electricity is dedicated to cooling, higher than what is typically observed in other manufacturing industries. Despite this, decarbonizing the process of heat consumption at higher temperatures poses the most significant challenge for this sector.

The challenge lies in the complexity of the value chain involving numerous actors, especially for SMEs that depend on industries outside of their value chains for the majority of emissions. Nonetheless, a recently published industry roadmap aims to address these challenges and help the sector reach decarbonization goals[36]. The European food system should become a global standard for sustainability. The EU strategy is to reward farmers, fishers and other food chain operators who have already adopted sustainable practices, facilitate the transition for others and create more opportunities for their businesses.

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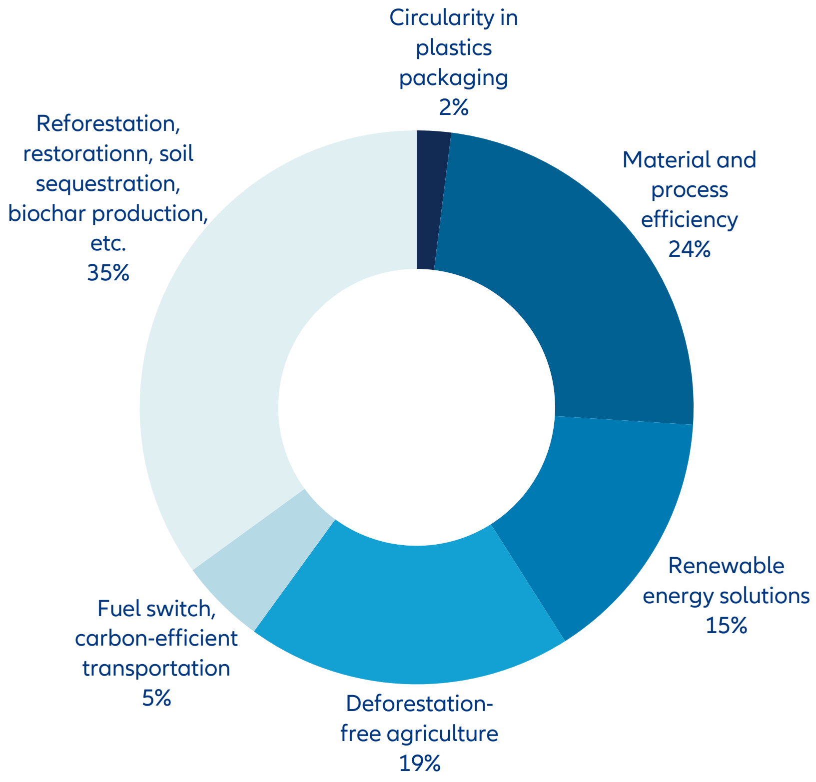
[36] FoodDrinkEurope (2021). Decarbonising the food and drink industry

In order to decarbonize the agrifood value chain, several measures can be taken according to WEF(2021)[37] (Figure 18). Circular plastics packaging can result in a reduction of about -2% of emissions. Material- and process-efficiency improvements can lead to a reduction of approximately -25%. Transitioning to renewable power sources can help to reduce emissions by -15%. Additionally, implementing deforestation-free agriculture practices can lead to a reduction of around -20%. Switching to more carbon-efficient transport fuels can contribute to a -5% reduction in emissions. However, it is important to note that approximately 35% of emissions in the food industry are inherent to agriculture and cannot be fully eliminated through these measures alone. Additional steps, such as reforestation, restoration of mangroves and peatland, soil sequestration and biochar production, will be necessary to fully address these emissions.

Figure 18: Emission-saving potential in the food industry



Sources: WEF[38], Allianz Research.

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[37] World Economic Forum (2021). Net-Zero Challenge: The supply chain opportunity
[38] World Economic Forum (2021). Net-Zero Challenge: The supply chain opportunity

Box 3: ICT sector

Unlike oil and gas, we cannot even imagine doing without today's information and communications technologies (ICT). Broadband access has now become a human right, the internet of things is fast becoming our planet's nervous system, cryptocurrencies keep speculators, central bankers and climate activists awake at night and artificial intelligence is growing by leaps and bounds, permeating ever more areas of daily life.

With electricity powering all these technologies, how this electricity is produced plays a pivotal role in the ICT-related carbon footprint, a footprint that is by no means negligible. Bitcoin and Ethereum cryptocurrencies alone consume up to 240 terawatt-hours annually, an amount that accounts for around 0.9% of annual global electricity usage and exceeds Australia's yearly electricity consumption.[39]

Add to this the world's cloud computing infrastructure, datacenters, transmission and broadcasting gear, the systems powering artificial intelligence outfits and the myriad devices in our pockets, wrists, ears and cars and appliances and we are talking about an estimated share of global GHG emissions ranging from 1.8 to 2.8% in 2020.[40] That is comparable to global aviation's GHG output.

Fortunately, the process that makes crypto assets so energy-intensive is undergoing a fundamental change. Ethereum, instead of demanding "proof-of-work" as cryptographic proof, has switched to "proof-of-stake" as a climate-friendlier alternative.[41] The new system, apart from being far more secure, requires 99.9% less energy to operate.

What about the rest of the ICT sector? The first step has been to set up some goals. The International Telecommunication Union (ITU), an agency of the UN, has defined a standard that aims at a -45% reduction by 2030 and net zero by 2050. However, given that the 1.5°C goal is presented as a recommendation, ICT industries are not bound to comply with this voluntary standard. In practice, this means that the trajectory will most likely lie between the business-as-usual and 1.5°C scenarios.

The definition of the ICT sector's carbon footprint has two components: embodied emissions and operational emissions. The first cover the emissions originating from manufacturing and installation of the equipment and appliances. Operational emissions, in turn, stem from the use of these networks and devices, primarily electricity consumption and related emissions from the global electricity mix. Embodied emissions account for roughly 30% of the total carbon footprint, while operational emissions account for the remaining 70%.[42]

Consumer behavior will most definitely not change drastically towards a reduction in the use of electronic devices in the future – rather the opposite, in fact. Thus, the way to reduce emissions is to increase the share of renewable electricity in the mix. The remaining emissions could be brought down by optimizing the product life cycle, such as by reassessing material selection, design choices, manufacturing and transportation.

[39] Until now, the right to update the blockchain databases that underlie such assets was earned by solving exceptionally difficult mathematical puzzles; the winners (called "miners") were rewarded with freshly minted cryptocurrency. This process, known as "proof-of-work", requires massive amounts of computing power, and therefore energy. So much so, in fact, that China banned cryptomining operations in its territory (which, incidentally, just drove the miners underground: China is still the No. 2 Bitcoin miner in the world after the US. See also: The White House (2022). Climate and Energy Implications of Crypto-Assets in the United States

[40] Freitag, C. et al. (2021). The real climate and transformative impact of ICT: A critique of estimates, trends, and regulations. Patterns, 2(9), 100340.

[41] Forkast (2022). China banned Bitcoin mining and became world's No.2 Bitcoin miner

[42] Malmodin, J. (2020). The ICT Sector's Carbon Footprint. Presentation at the techUK Conference in London Tech Week on 'Decarbonising Data'.

Appendix: Decomposition of investments by country

Table 1A: Cumulative investment per country for EU27 + UK until 2050 (in EUR mn)

Country\Industry	Chemicals	Foundries	Iron and steel	Non-ferrous metals	Non-metallic minerals	Paper and pulp
Austria	909.0	54.5	3685.2	19.4	1029.4	4525.0
Belgium	3077.9	14.3	2659.7	19.4	1298.6	1787.3
Bulgaria	402.4	7.6	26.0	19.4	571.5	316.4
Croatia	353.8	12.5	4.6	13.2	496.9	158.7
Cyprus	0.0	0.0	0.0	0.0	159.9	0.0
Czechia	239.8	77.6	2539.1	19.4	805.5	904.3
Denmark	0.0	3.8	1.3	8.8	403.3	84.9
Estonia	45.0	0.0	0.0	0.0	79.1	66.9
Finland	402.9	12.9	1442.4	19.4	159.5	11325.2
France	1635.9	323.8	5614.1	370.4	3323.5	7253.0
Germany	9513.5	1082.2	16715.0	640.3	8157.2	16254.1
Greece	153.0	0.0	26.2	158.5	1073.3	102.5
Hungary	768.8	38.8	771.8	19.4	439.7	310.6
Ireland	0.0	0.0	0.0	19.4	507.3	9.0
Italy	2022.3	387.0	3385.2	131.9	5996.9	4938.8
Latvia	0.0	0.0	1.5	9.9	223.2	18.9
Lithuania	1126.2	0.0	0.0	0.0	239.9	70.7
Luxembourg	0.0	0.0	84.3	13.2	187.4	0.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	5142.7	0.0	3411.8	38.8	458.6	1376.9
Poland	3787.1	203.2	2883.0	19.4	3741.9	3169.0
Portugal	324.9	10.5	59.6	11.0	1136.2	3863.2
Romania	813.5	0.0	1217.3	210.6	934.3	170.7
Slovakia	507.2	0.0	2219.9	162.4	703.3	1433.1
Slovenia	0.0	43.5	27.1	84.6	134.2	483.4
Spain	1682.0	144.2	2475.4	291.4	3195.7	3648.4
Sweden	485.1	71.8	1593.4	109.5	184.6	15084.7
UK	710.4	99.4	4596.7	58.5	1947.8	1091.2

Sources: IndustryPLAN, Allianz Research.

Table 2A: Cumulative investment per country for EU27 + UK until 2030 (in EUR mn)

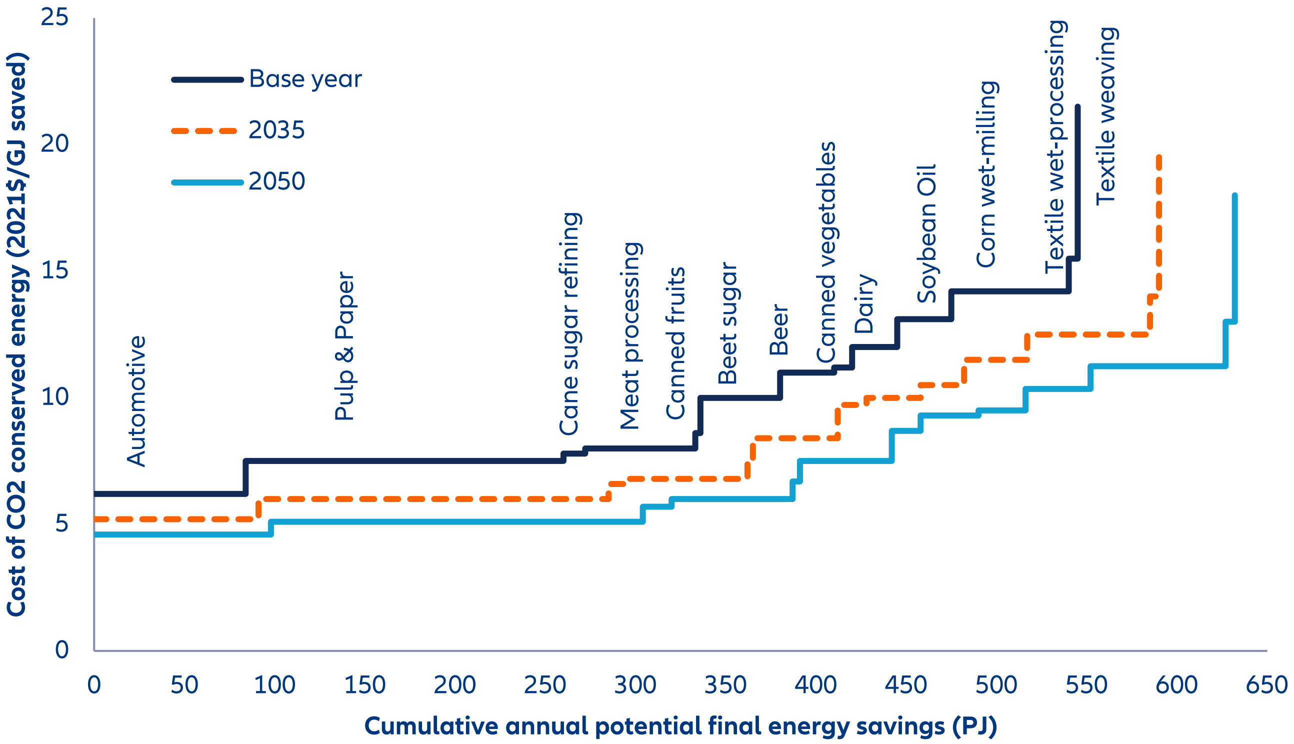
Country\Industry	Chemicals	Foundries	Iron and steel	Non-ferrous metals	Non-metallic minerals	Paper and pulp
Austria	72.4	13.4	257.3	4.3	297.6	516.6
Belgium	253.5	3.1	242.2	4.3	385.5	235.9
Bulgaria	27.2	1.6	12.7	4.3	151.4	34.9
Croatia	27.9	3.0	1.6	2.9	147.5	24.4
Cyprus	0.0	0.0	0.0	0.0	47.5	0.0
Czechia	21.0	18.1	185.8	4.3	239.1	96.3
Denmark	0.0	0.9	1.4	1.9	117.9	11.1
Estonia	3.0	0.0	0.0	0.0	23.5	7.1
Finland	35.7	2.9	128.6	4.3	82.2	1732.0
France	135.4	74.0	565.5	151.4	986.6	718.5
Germany	834.4	247.8	1551.5	231.2	2227.0	1831.9
Greece	10.3	0.0	10.0	64.6	318.6	12.3
Hungary	66.8	9.7	50.9	4.3	118.4	38.6
Ireland	0.0	0.0	0.0	4.3	150.6	2.0
Italy	178.3	94.1	518.3	29.2	1628.9	610.6
Latvia	0.0	0.0	1.4	2.2	66.3	2.3
Lithuania	76.0	0.0	0.0	0.0	66.9	8.5
Luxembourg	0.0	0.0	30.0	2.9	58.5	0.0
Malta	0.0	0.0	0.0	0.0	0.0	0.0
Netherlands	417.6	0.0	255.2	12.7	136.1	174.2
Poland	281.0	48.0	238.7	4.3	1025.0	369.4
Portugal	31.4	3.7	20.2	2.4	337.3	477.8
Romania	27.1	0.0	107.3	91.4	280.8	20.5
Slovakia	34.1	0.0	145.3	70.5	208.8	139.2
Slovenia	0.0	10.0	11.2	32.6	38.5	71.6
Spain	148.8	35.6	265.8	122.3	948.7	545.6
Sweden	24.5	16.1	148.1	43.4	84.9	2100.8
UK	87.0	23.0	354.0	20.7	578.2	219.4

Sources: IndustryPLAN, Allianz Research.

Appendix: Industrial heat pumps

Figure A.1 from Zuberi, Hasanbeigi and Morrow (2022), Lawrence Berkeley National Laboratory: Electrification through Industrial Heat Pump Applications in US Manufacturing, https://www.globalefficiencyintel.com/electrification-of-us-manufacturing-with-heat-pumps depicts the energy conservation cost curve, which displays the costs associated with energy savings resulting from the implementation of IHP applications, across various US industrial processes. The chart shows the process-wide energy saving potential (in PJ) on the x-axis and the specific costs on the y-axis. In 2021, the technical potential energy savings resulting from IHP applications are estimated to be 545PJ per year, equivalent to approximately 4% of the current total final energy demand in US manufacturing. However, the chart indicates that IHP applications lead to additional costs in each process, and none of the industrial processes studied have energy-conservation costs falling below the horizontal axis (which would have represented cost savings). This implies that overall costs are not economical and require additional investment in IHPs for energy shift across all industrial sectors.

Figure A.1 Energy saving potentials through heat pumps in US manufacturing



Sources: Lawrence Berkeley National Laboratory, Allianz Research.

Appendix: GCCA Roadmap:

Actions to achieve Net-Zero concrete/cement (from GCCA Concrete Future Roadmap to Net Zero)
GCCA-Concrete-Future-Roadmap-Document-AW-2022.pdf (gccassociation.org) (page 10)

Savings in process emissions

-> Carbon capture and utilization/storage at cement plants (36%; 1370 Mt CO2)

-> Efficiency in design and constructions (22%; 840 Mt CO2):
- Client brief to designers to enable optimization
- Design optimization
- Construction site efficiencies
- Re-use and lifetime extension

-> Efficiency in concrete production (11%, 430Mt CO2):
- Optimized mix design
- Optimization of constituents
- Continue to industrialize manufacturing
- Quality control

-> Savings in cement and binders (9%; 350 Mt CO2):
- 80% of concrete’s carbon footprint comes from cement
- Portland clinker cement substitution
- Alternatives to Portland clinker cements (use industrial byproducts such as iron slag and coal fly ash)

-> CO2 sink: recarbonation (6%; 240 Mt CO2):
- Natural uptake of CO2 in concrete = a carbon sink

Savings in energy emissions

-> Decarbonization of electricity (5%; 190Mt CO2):
- Decarbonization of electricity used at both cement plants and in concrete production

-> Savings in clinker production (11% 410 Mt CO2):
- Thermal efficiency
- Savings from waste fuels (“alternative fuels”)
- Use of decarbonated raw materials
- Use of hydrogen as fuel

Appendix: Industry emission-reduction potential

Fleiter et al. (2019) (EC & DG Climate Action (2020). Industrial Innovation: Pathways to deep decarbonisation of Industry) quantify the emission reduction potentials in the EU for various industries in differing decarbonization scenarios. A partial implementation and combination of these measures can achieve an efficient decarbonization. IndustryPLAN as a tool can analyze partial implementations and combinations of measures and evaluate them versus their emission reductions and costs.

Cement potential: A more ambitious switch to low-carbon fuels such as biomass and maximum improvements in energy efficiency result in a -16% reduction in emissions by 2050 compared to 2015. A large-scale implementation of CCS can achieve a reduction of -81%. The use of synthetic methane and low-carbon cement types that replace Portland cement allows for a reduction of about -50% by 2050, but significant process emissions remain due to the continued use of low-carbon cement types that emit CO2. A -62% reduction is possible by using biomass as the primary energy source and introducing material efficiency and recycling improvements in the construction industry, resulting in lower cement demand and production-related emissions. An ambitious switch to electricity combined with low-carbon cement types could result in a -45% reduction in emissions. A mix of measures that involves the use of electric furnaces for glass melting, low-carbon cements and material efficiency and recycling improvements, could result in a -56% reduction. If that mix is complemented by using synthetic methane in the gas grid and CCS for remaining conventional clinker and lime furnaces, this would result in an -86% reduction by 2050. Across all scenarios, the cement and lime production industries pose significant challenges to decarbonization, with low-carbon cement diffusion and material efficiency and recycling improvements in the construction industry being critical factors in reducing emissions.

Chemicals potential: The application of the best available technologies (BAT) in the chemical industry can achieve a -15% emission reduction by 2050 through energy efficiency improvements and increased biomass use. Employing innovative strategies can lower emissions further. The use of carbon capture and storage (CCS) in all major processes can achieve a -90% reduction in emissions, including the negative emissions from biomass. The large-scale use of synthetic methane and a switch to hydrogen-based processes in ethylene and methanol production can reduce emissions up to -77%. A comprehensive deployment of biomass and ambitious improvements in material efficiency and circular economy, resulting in lower demand for energy-intensive products and can reduced emissions by -63%. Emission cuts of about -70% can be achieved by using hydrogen-based processes in combination with switching to the direct use of electricity for process heat generation. The challenges for decarbonizing the chemical industry are feedstocks, process emissions and the high share of natural gas, but hydrogen may play a key role in the industry's decarbonization.

Iron and steel potential: Implementing the best available technologies in the iron and steel industry could already result in a -51% reduction in emissions. This reduction is primarily due to the shift from oxygen steel to electric steel, accounting for 67% of total crude steel production in 2050. Replacing 88% of the oxygen steel production route with direct reduction based on hydrogen (DR H2 + EAF) reduces emissions up to -88%. Replacing oxygen steel by electrolysis steel is assumed to be available after 2030. A reduction of -69% can then be achieved with increasing material efficiency and the innovative use of electric steel for high-quality products, increasing the share of electric steel to 77% in total crude steel production by 2050. Further replacing oxygen steel with alternative routes and additionally using synthetic methane to replace the remaining natural gas use achieves a reduction of -96%. Ultimately, the decarbonization of the iron and steel industry largely depends on the quick adoption of innovative CO2-free steel production routes that utilize either hydrogen or electricity. Furthermore, the implementation of scrap-based steel production, taking advantage of the expected future increase in scrap availability, has enormous potential for mitigation.

Pulp and paper potential: For the pulp and paper industry, the strict application of best available technology could achieve a -11% reduction by 2050 compared to 1990 by leveraging energy-efficiency improvements. By adopting carbon capture and storage (CCS) technology, the industry could achieve nearly -100% GHG emissions reduction, even if only about half of the paper mills combine bioenergy with CO2 capture installations (BECCS). This high rate of reduction is attributed to the capture of CO2 emissions from biomass results in negative emissions. Other measures include using electric steam boilers, replacing natural gas with synthetic methane, and phasing out coal-fired boilers and steam engines before their end-of-life after 2040. Given sufficient carbon prices, decarbonization through biomass and electricity usage could provide an additional business model for paper mills have access to carbon storage sites and are equipped with CCS: they have the potential to generate negative emissions through BECCS, which could compensate for process-related emissions in other industries.

References:

IEA (2022A). *Electrification*, IEA, Paris. Available at: https://www.iea.org/reports/electrification

IEA (2022B). *Pulp and Paper,* IEA, Paris. Available at: https://www.iea.org/reports/pulp-and-paper

IPCC (2022A). *IPCC Report, AR6 Working Group 3 Chapter 11 (2022).*https://www.ipcc.ch/report/ar6/wg3/downloads/report/IPCC_AR6_WGIII_Chapter11.pdf

MPP (2022A). *Steel*, MPP (September 2022). Explorer: https://dash-mpp.plotly.host/mpp-steel-net-zero-explorer/global_regional_lens. Model: https://github.com/missionpossiblepartnership/mpp-steel-model

MPP (2022B). *Aluminium*, MPP (September 2022). Explorer: https://dash-mpp.plotly.host/aluminium-net-zero-explorer/. Report: https://missionpossiblepartnership.org/wp-content/uploads/2022/10/Making-1.5-Aligned-Aluminium-possible.pdf. Model: https://github.com/missionpossiblepartnership/mpp-shared-code

MPP (2022C). *Ammonia*, MPP (September 2022). Explorer: https://dash-mpp.plotly.host/mpp-ammonia-net-zero-explorer/. Report: https://missionpossiblepartnership.org/wp-content/uploads/2022/09/Making-1.5-Aligned-Ammonia-possible.pdf

Johannsen, R. M. (Ophavsperson), Mathiesen, B. V. (Ophavsperson) (14 feb. 2023). *IndustryPLAN*. VBN. IndustryPLAN_V1(.xlsm). 10.5278/5fbe12d0-ab4b-4b13-8b33-5c82b527d294

Johannsen, R. M., Mathiesen, B. V., Kermeli, K., Crijns Graus, W., & Østergaard, P. A. (2023). Exploring pathways to 100% renewable energy in European industry. Energy, 268, [126687]. https://doi.org/10.1016/j.energy.2023.126687

Material Economics (2019). *Industrial Transformation 2050 - Pathways to Net-Zero Emissions from EU Heavy Industry.* https://materialeconomics.com/publications/industrial-transformation-2050

European Commission. *EU Reference Scenario 2020.* Available at: EU Reference Scenario 2020 (europa.eu)

IEA (2014). *Application of Industrial Heat Pumps.* Available at: annex-xiii-part-a.pdf (iea-industry.org)

ETC (2022). *Carbon Capture, Utilisation and Storage in the Energy Transition: Vital but Limited.* Available at: energy-transition.org

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