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WHITE PAPER

Industry in Transformation: Decarbonisation as a Strategic Imperative

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Industry in Transformation: Decarbonisation as a Strategic Imperative

Decarbonising industrial processes, essential for meeting the Paris Accord target of limiting global warming to 1.5°C, is arguably the most difficult source of emissions to bring to Net Zero.

Executive Summary

Industrial activities account for c. 25% of the world's GDP and contribute 25% to 30% of the global greenhouse gas (GHG) inventory (Rattle and Taylor, 2023). The reduction of these emissions has been painfully slow due to several factors, notably the high energy intensity of many industrial processes, making transitions non-trivial, and the wide variety of those processes, each requiring bespoke solutions. There is no 'one-size-fits-all' solution for industrial decarbonisation.

Progress in this area will require enhanced and stable policies, increased financial support, and the development of low-carbon alternatives to current carbon-intensive supply chains.

This report outlines various avenues to accelerate industrial decarbonisation. It explores technologies and processes with the potential to reduce GHG emissions in major industrial operations, whilst presenting financial and policy strategies for prioritising and pursuing these options. The paper concludes with recommendations for industrial participants to position themselves effectively in a Net Zero emissions world.

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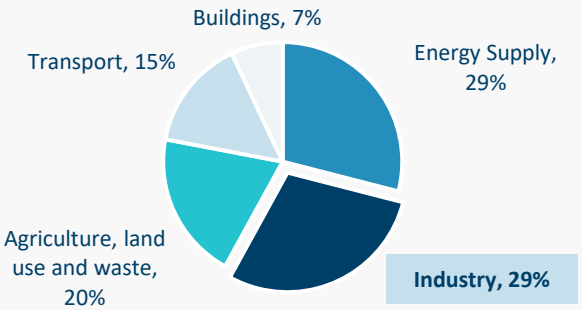
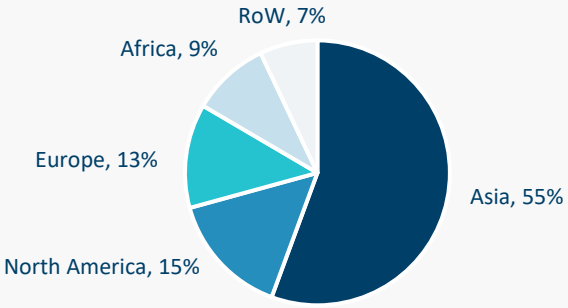
Industrial Emissions in Charts

Figure 1: Global GHG Emissions in 2021 per source



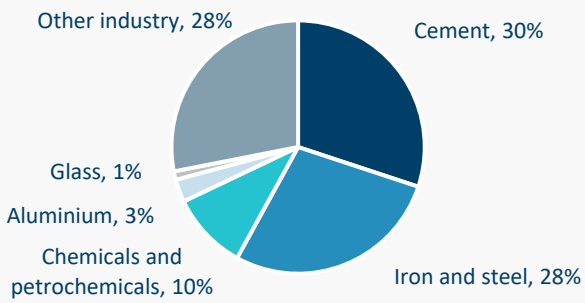
Source: Rhodium Group

Figure 2: Global GHG Emissions in 2020 per region



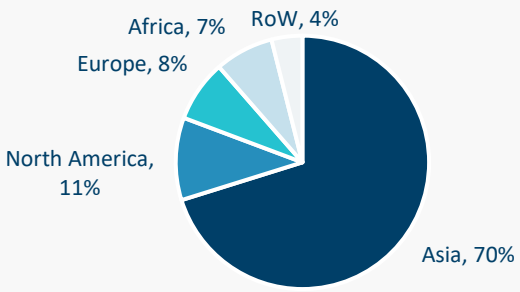
Source: Climate Watch

Figure 3: Industrial Emissions in 2021 per industry



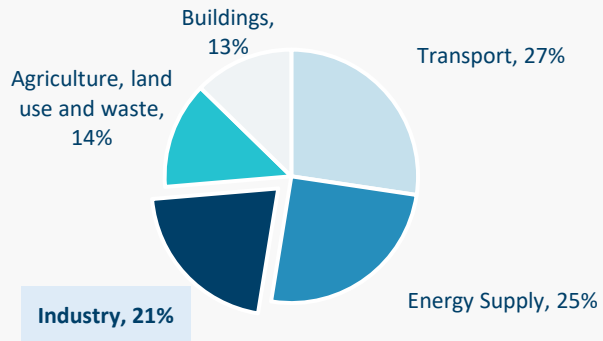
Source: IEA, McKinsey & Company, European Commission, Wired UK

Figure 4: Global Industrial Emissions in 2020 per region



Source: Climate Watch

Figure 5: EU GHG Emissions in 2021 per source



Source: European Environment Agency

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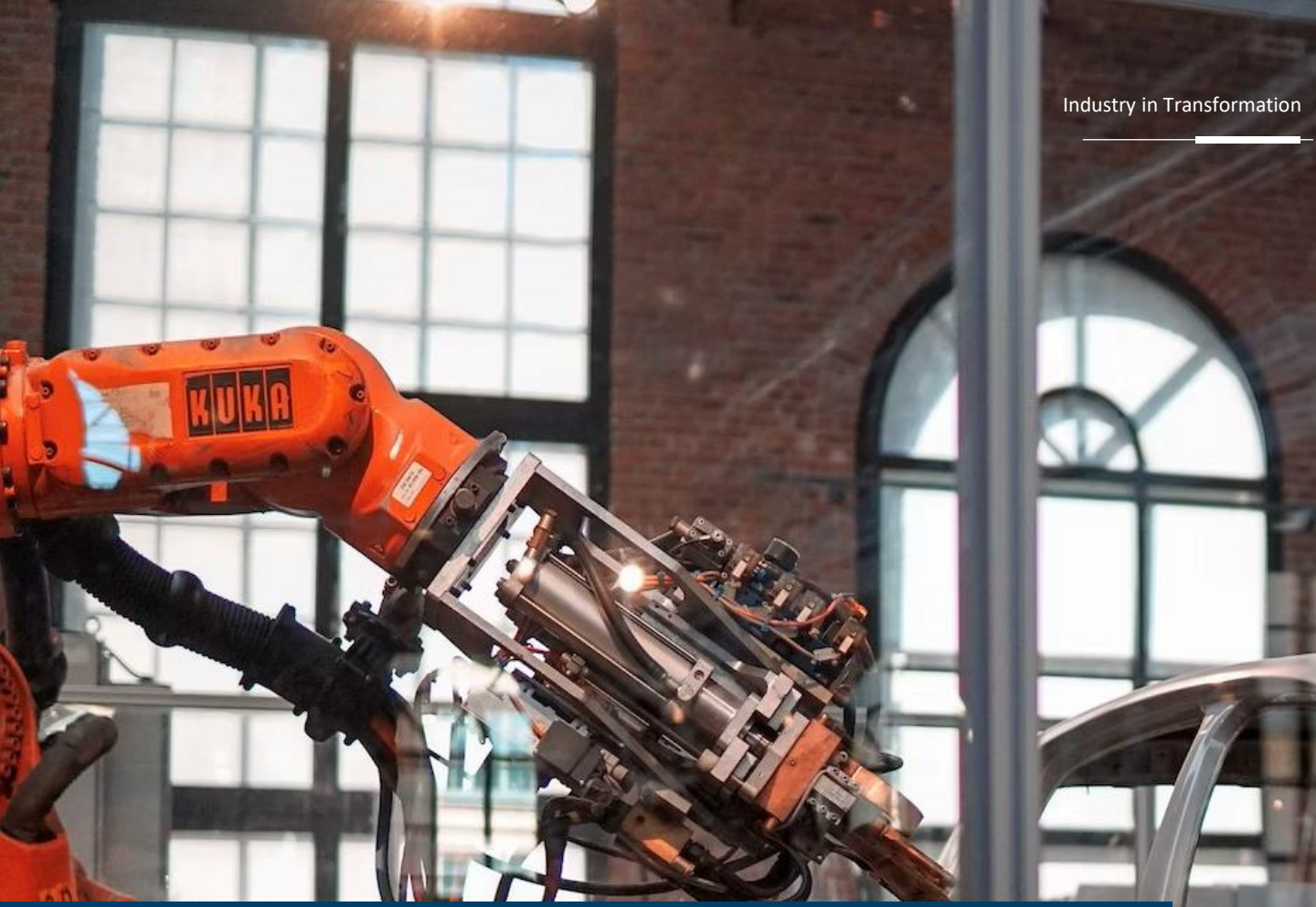

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2 Policymaking and Regulatory Interventions

3 Innovations for Industrial Decarbonisation

4 Financing Industrial Decarbonisation

5 Concluding Remarks

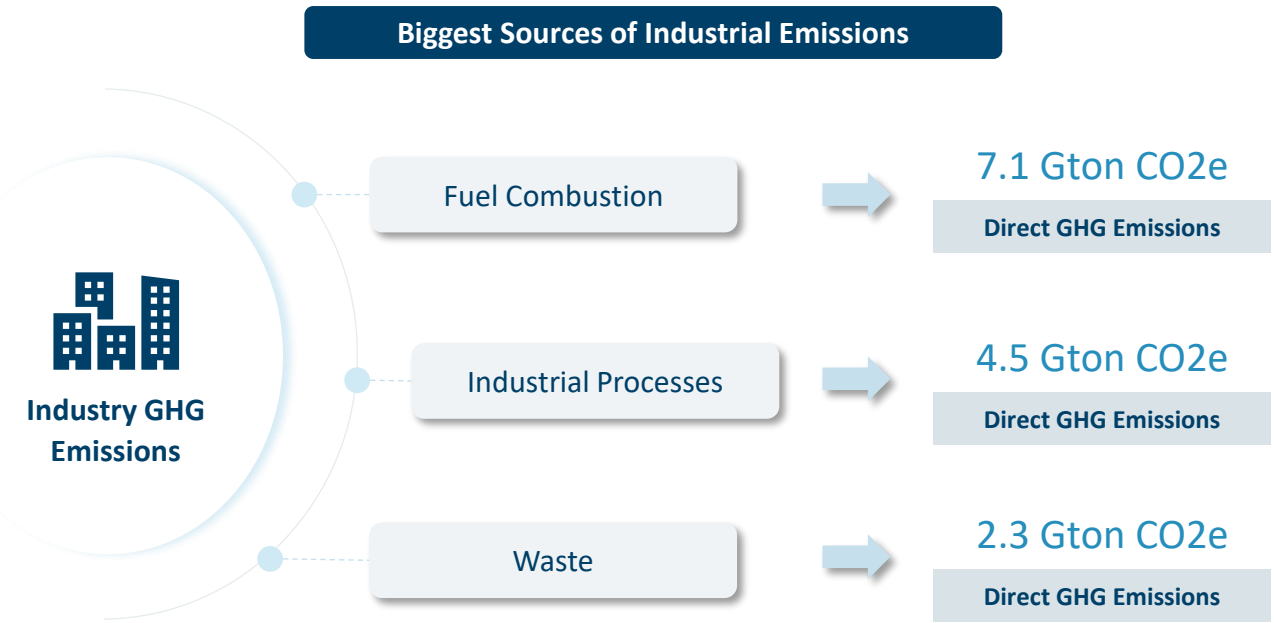
Source: Unsplash

CHAPTER 1

Industry’s Role in Climate Change

Source: Unsplash

Industry is the largest source of GHG emissions, alongside energy supply



Direct GHG emissions from the industrial sector amount to 14.1 Gigatons of CO2 equivalent (Gt CO2e) globally. This makes the industrial sector the largest contributor to total GHG emissions, alongside the energy sector, responsible for 25% to 30% of direct emissions.

When indirect emissions are included, the figure for industrial emissions rises to 20 Gt CO2e, increasing its share of total CO2e emissions to 34% (IPCC, 2023).

The GHG emissions attributed to the industrial sector primarily stem from industrial fuel combustion, which contributes 7.1 Gt CO2e directly and another 5.9 Gt CO2e indirectly (from electricity and heat generation). Additionally, industrial processes contribute 4.5 Gt CO2e, with products use adding an additional 0.2 Gt. Waste associated with industrial activities contributes an extra 2.3 Gt CO2e (IPCC, 2023).

Source: Unsplash

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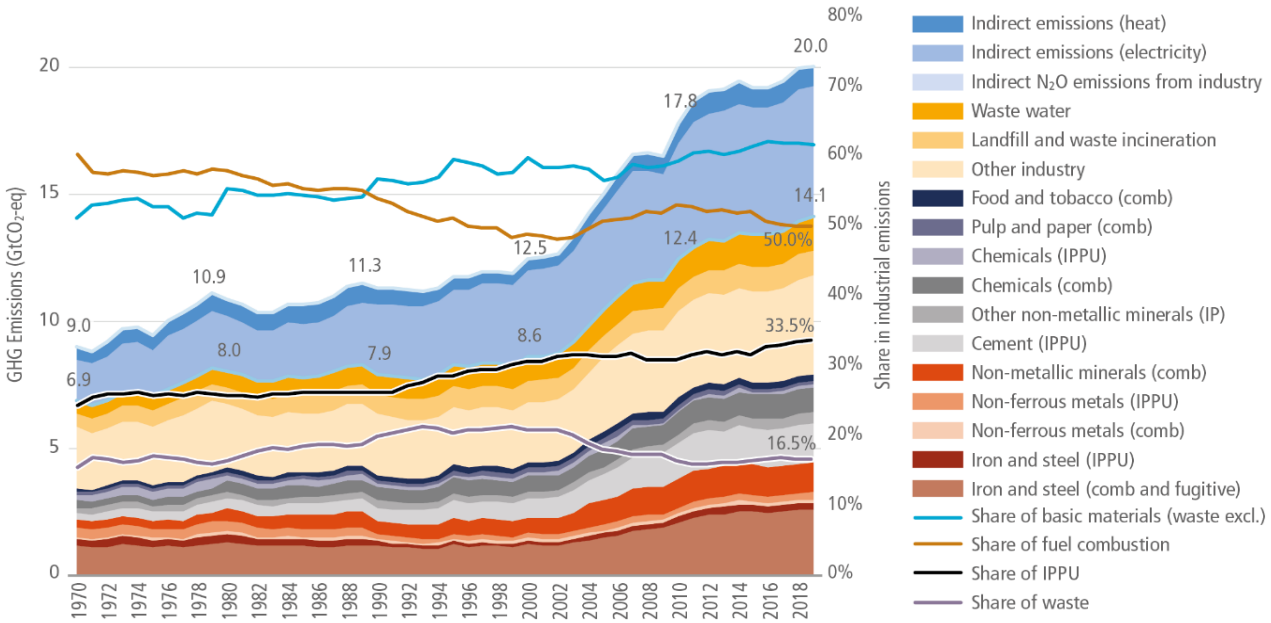
Figure 6 shows the evolution of industrial emissions by source since 1970. Up until 2000, Industrial emissions grew modestly, aided by the rise of electrification. However, starting from 2000, emissions surged significantly, driven by increased extraction and production of basic materials. Industries such as iron, steel, and cement saw their emissions reach record highs, reflecting the growing demand and production in these sectors (IPCC, 2023).

Figure 6: Industrial Emissions by Source (left scale) and Emissions Structure (right scale).

Comb – indicates direct emissions from fuel combustion. IPPU – indicates emissions from industrial processes and product use. Indirect emissions from electricity and heat generation are shown on the top. Shares on the right are shown for direct emissions.



Notes: Calculated based on emissions data from Crippa et al. (2021) and Minx et al. (2021). Indirect emissions were assessed using IEA (2021b). For (e): Cao et al. (2020); IEA (2020b, 2021a); GCCA (2021a); International Aluminium Institute (2021a); and Wang et al. (2021).

Source: IPCC

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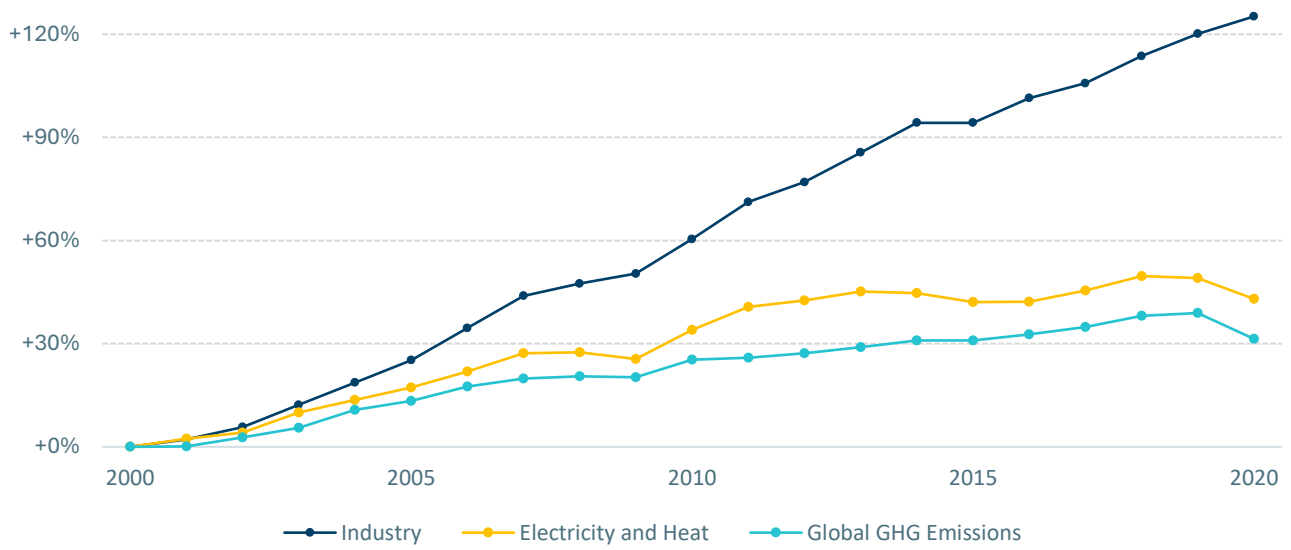
Industry is the fastest growing source of GHG emissions

Since 2000, GHG emissions in the industrial sector have increased faster than in any other sector (IPCC, 2023; Rattle and Taylor, 2023). As shown in Figure 7, industrial GHG emissions rose by 125% between 2000 and 2020. In contrast, emissions from sectors such as electricity and heat increased by 43% over the same period.

Figure 7: Change in GHG Emissions by Sector, 2000-2020



Source: World Bank, IEA

Source: Unsplash

This significant rise in industrial emissions is primarily driven by the growing demand for materials such as cement, aluminium, plastics, and steel. Over the past 25 years, the demand for these materials has surged by an estimated 2.5 to 3.5 times, propelled by global population growth and economic expansion.

As economies develop, urbanise and increase their consumption of goods and infrastructure, the per capita demand for building materials escalates correspondingly (IEA, 2019).

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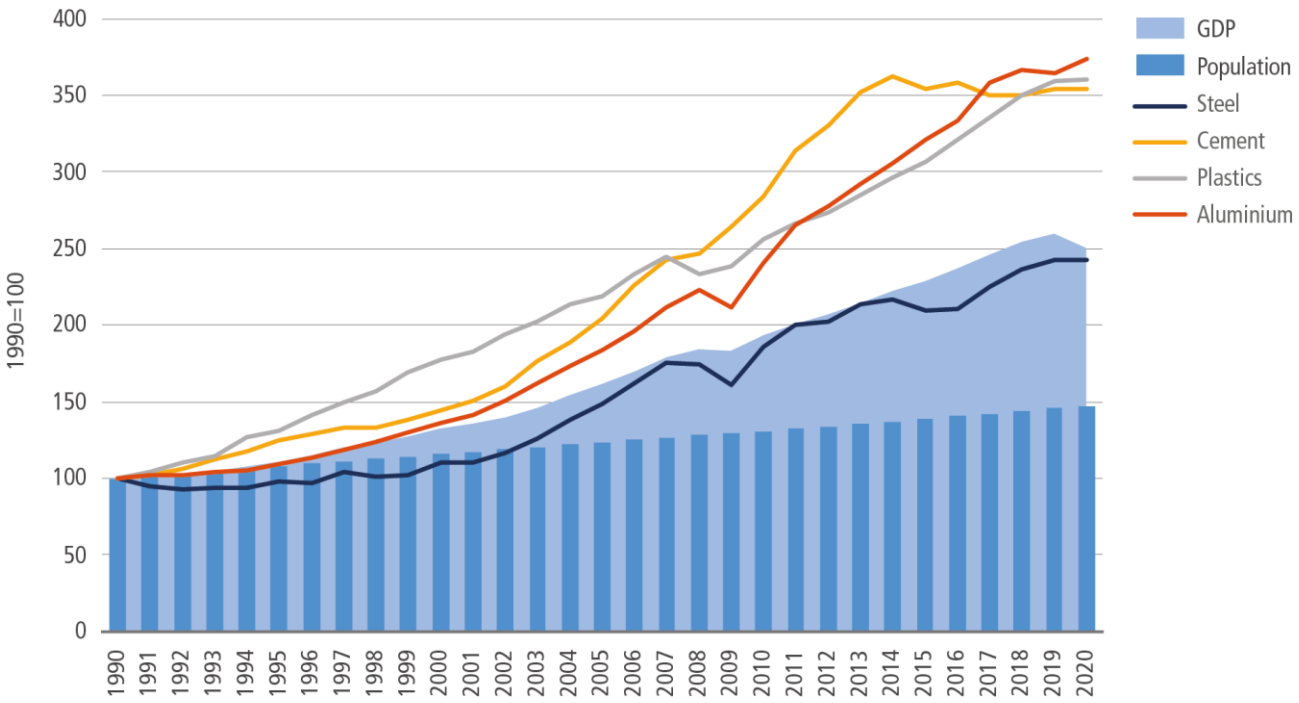
This trend underscores the challenges of decarbonising industries that are essential for modern infrastructure and economic development. Addressing this issue will require not only technological advancements but also systemic changes in material production and usage. This highlights the urgent need for effective strategies and policies to mitigate their impact.

Developing and implementing low-carbon technologies, enhancing energy efficiency, and promoting sustainable material use are crucial steps towards achieving significant emission reductions in the industrial sector.

Source: Unsplash

Figure 8: Growth in global demand for selected key materials and global population, 1990–2019.



Notes: Based on global values, shown indexed to 1990 levels (=100). Steel refers to crude steel production. Aluminium refers to primary aluminium production. Plastic refers to the production of a subset of key thermoplastic resins. Cement and concrete follow similar demand patterns. Sources: 1990–2018: IEA (2020b). 2019–2020: GCCA (2021a); International Aluminium Inst (2021a); Statista (2021b); U.S. Geological Survey (2021); World Bank (2021); World Steel Association (2021).

Source: IPCC

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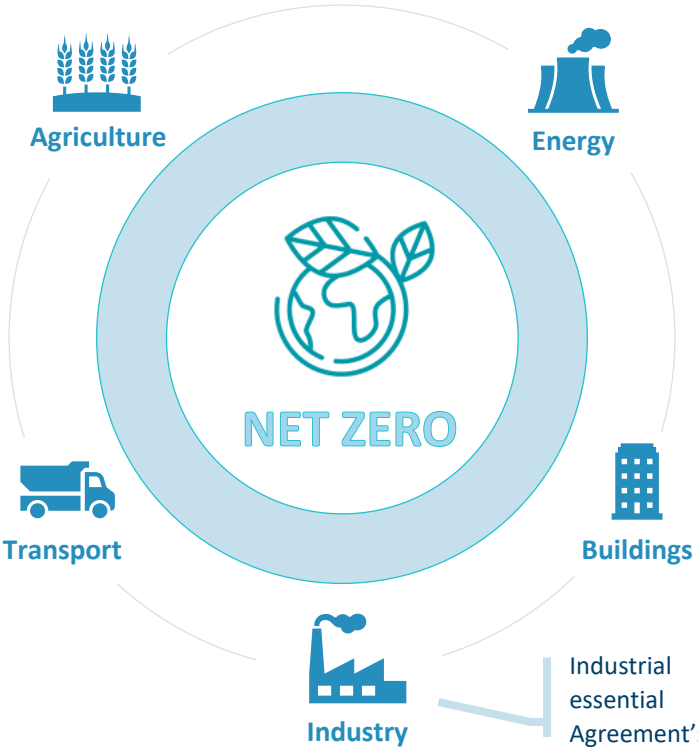
Industrial decarbonisation as a key component to reaching Net Zero goals



As industrial output, and correspondingly GHG emissions, is projected to grow until 2050, the sector could face challenges in meeting the emission reduction targets set by the Paris Agreement of 2015. This landmark agreement, embraced by 195 UN member states, endeavours to curb the average global temperature increase to well below 2°C above pre-industrial levels, with efforts to limit the increase to 1.5°C.

International scientific consensus indicates that to reach Net Zero by 2050, net human-caused CO2 emissions must decrease by an estimated 45 percent from 2010 levels by 2030 (Net Zero Climate, 2023). Despite various climate pledges, the world is still on track for a temperature rise of approximately 2.5-2.9°C by the end of the century, far above the Paris Agreement's targets (The Emissions Gap Report, 2023) and whilst recent evidence seems to suggest that global emissions will no longer rise post-2030, the 'bend' of the emission curve after 2030 is not rapid enough to meet those goals (UNFCCC, 2022).

To address this gap, prioritising industrial decarbonisation is essential given its significant share of global GHG emissions. Collaborative efforts, supported by robust policy frameworks, technological advancements, and dedicated financing solutions are needed to accelerate industrial decarbonisation and close the emissions gap (Bazilian *et al.,* 2023).

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Industry is the most complex and most costly area to decarbonise

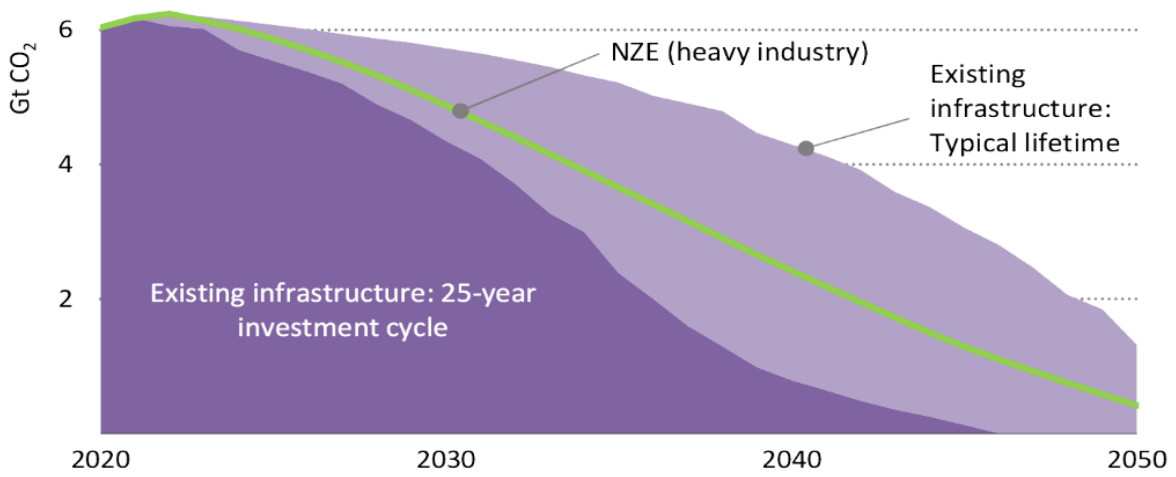
Industrial decarbonisation is a formidable conundrum (Griffin *et al.*, 2018). Change is made particularly complex by the heterogeneity of industrial processes. The fact that industrial assets are built to last, with lifetimes spanning several decades, compounds the decarbonisation challenge (Maghrabi *et al.*, 2023).

This means that the adoption of new processes will be gradual, decreasing the pace at which industrial emissions can be reduced. As the International Energy Agency (IEA) puts it, "for heavy industry, the year 2050 is just one investment cycle away".

> **"Unlike the power sector, where the path to decarbonisation is clear and cost competitive, there is no one-size-fits all solution for industry, or even within industrial sectors, making it a particular challenge to attain the Net Zero Scenario (NZE) by 2050.**

In Figure 9, the IEA has studied how emissions from heavy industries might decline between 2020 and 2050. If existing infrastructures are replaced at the end of their traditional lifetime i.e., up to 40 years for emissions-intensive assets (light purple area on the chart), the amount of CO2 emissions will remain above 1.5Gt by 2050. Even in the Energy Information Administration (EIA)'s Net Zero Scenario (green line), it is expected that heavy industries will not have fully eliminated their emissions by 2050.

Figure 9: CO2 Emissions from Existing Heavy Industrial Assets in the Net Zero Scenario by 2050



Source: International Energy Agency (2021), Net Zero by 2050, IEA, Paris

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Carbon efficient solutions are expected to cut cumulative emissions from heavy industries by approximately 40% until 2050.

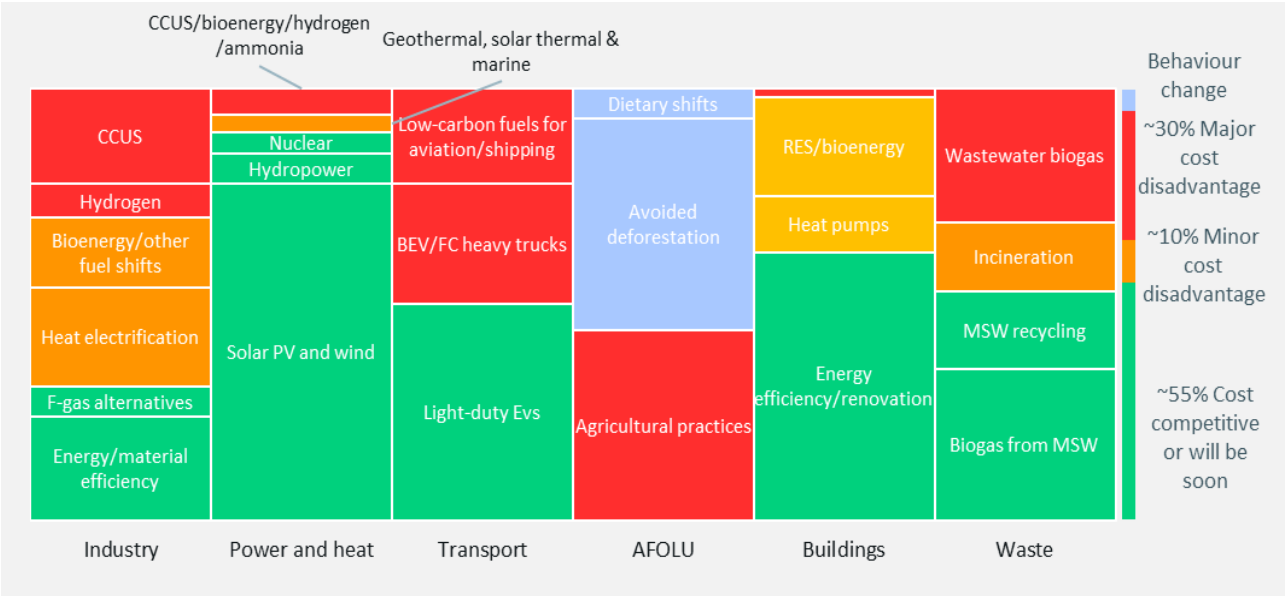
In essence, the coming decade will be critical for new technologies to reach maturity and be adopted by industrial players.

Finally, the pronounced disparities among regional energy mixes poses another great challenge to industrial decarbonisation. In Asia, coal accounts for over 50% of electricity generation. Given that Asia contributes approximately 70% to global industrial emissions, the structure of the energy mix constitutes a massive obstacle in industrial decarbonisation efforts at a global level (OurWorldinData, 2023) and points to targeted, regional focus until the energy mix in electricity production has decisively evolved.

> **"Achieving Net Zero with heavy industries would require reducing the lifetime of existing infrastructure to 25 years and replacing them with innovative, carbon efficient solutions, which are not yet ready today.**

As at today, the cost of carbon efficient technologies remains a significant hurdle for upgrading production processes. As Figure 10 shows, Industry (alongside Agriculture, Forestry and Land Use, or "AFOLU") is the space where carbon-friendly upgrades come at the highest cost disadvantage versus traditional technologies.

Figure 10: Sector and Technology Mitigation Pathways Toward 1.5°C by 2050



Notes: Cost-competitiveness is gauged in comparison to today's high greenhouse-gas reference, including capex and opex, and measured for the direct owner of the asset (as opposed to end-user price, for example); AFOLU = agriculture, forestry and land use; BEV/FC = battery electric vehicle/fuel cell; CCUS = carbon capture, utilisation and storage; EVs = electric vehicles; MSW = municipal solid waste (including industrial); PV = photovoltaic; RES = renewable energy sources;

Source: International Energy Agency; Intergovernmental Panel on Climate Change; Lena Höglund-Isaksson et al., "The Role of Anthropogenic Methane Emissions in Bridging the Emissions Gap", in Emissions Gap Report 2021: The Heat Is On, pp. 47–55; desk research; BCG analysis

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Industrial emissions stem mainly from the combustion of fossil fuels

The primary source of industrial emissions is the combustion of fossil fuels: oil, gas, and coal (Sameti & Syron, 2022). Approximately 80–90% of the total industrial fossil fuel consumption is used to generate the heat required in industrial production processes (Maghrabi *et al.*, 2023). The production of high-temperature heat (over 500 °C) contributes significantly to energy-related emissions.

High temperature heat is essential for certain industrial processes such as steam cracking for ethylene production (around 800 °C), the fusion of iron ore in steel manufacturing, along with the subsequent steel rolling process (approx. 1,200 °C), and the calcination of limestone, a distinctive mineral used in cement production (about 1,400 °C) (McMillan et al., 2016).

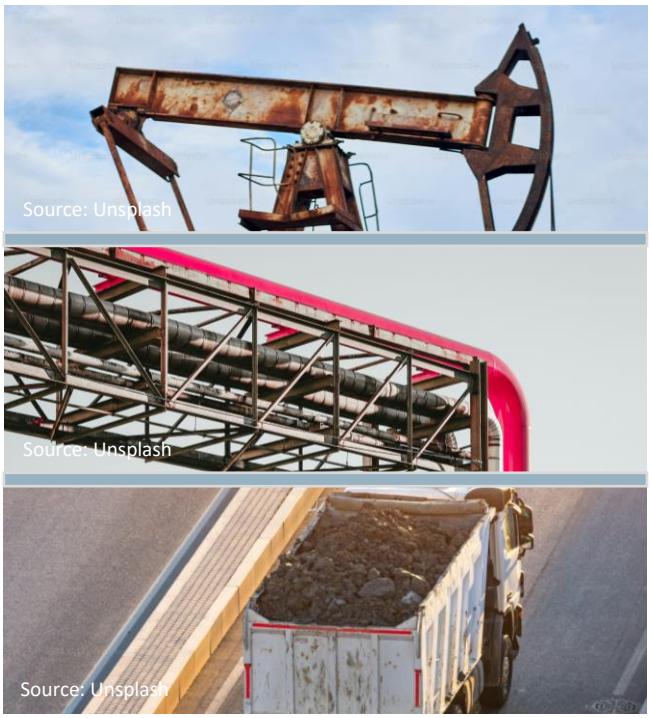
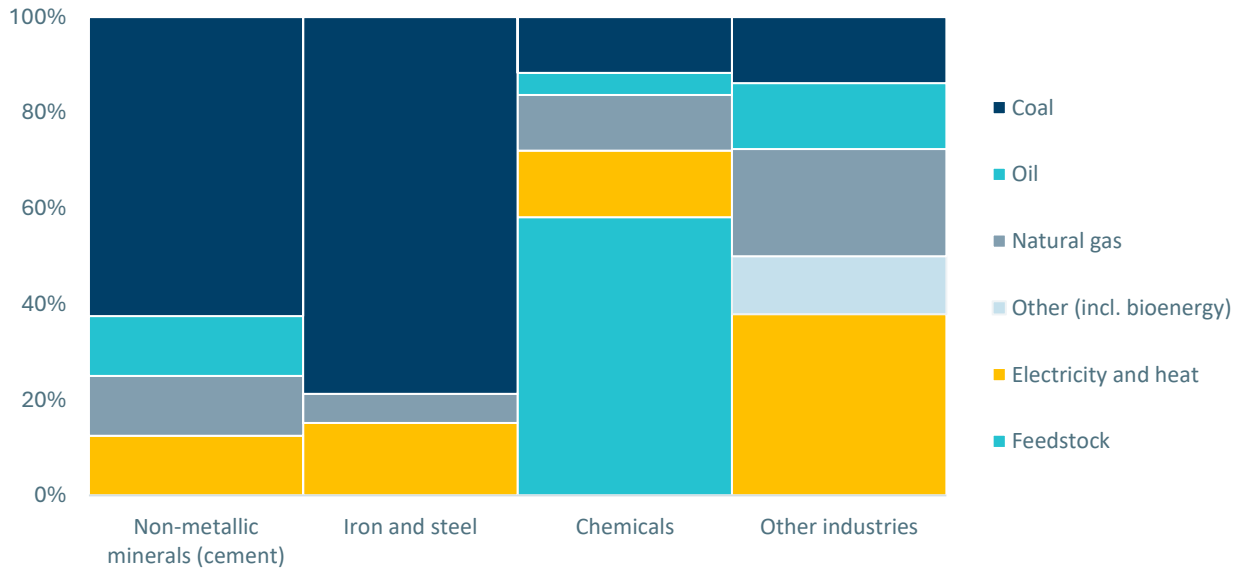


Figure 11: Energy Consumption in Energy-Intensive Industries (EJ/year, 2015)



Source: Chenavari, McKinsey & Company

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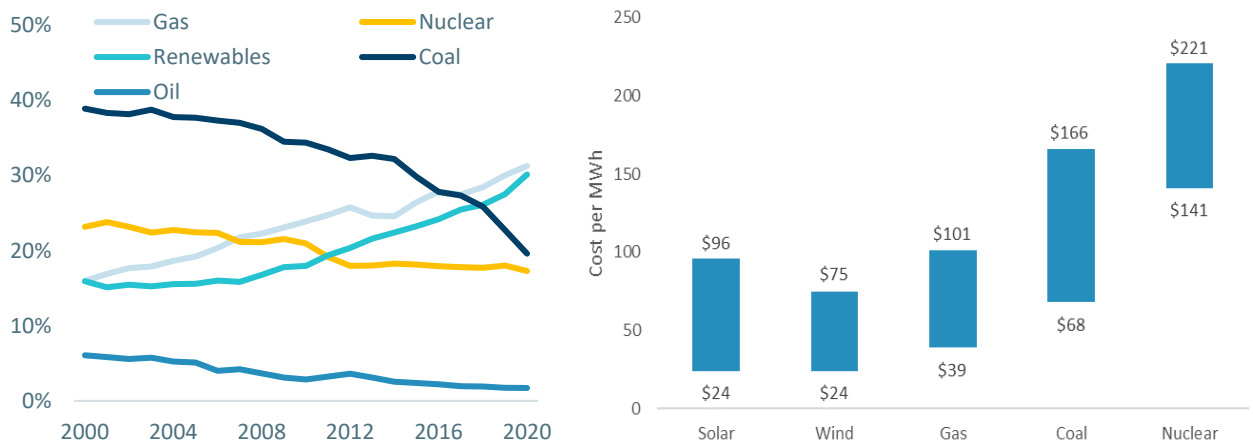
Clean energy as an initial step towards industrial decarbonisation

Achieving industrial decarbonisation demands heightened investments in industrial facilities, coupled with a concurrent expansion of zero-carbon electricity and power generation. Both must progress hand in hand to mitigate carbon emissions in the industrial sector.

Due to the immense significance of energy generation in the context of climate change, considerable public and private investments have been allocated to decarbonising power generation over the past decades – amounting to over USD 850 Billion in 2021 alone (Allen & Overy, 2023). This has played a pivotal role in driving the cost competitiveness of renewable energy, whose share of electricity generation has doubled between 2000 and 2020 (as shown on Figure 12).

Figure 12: Decarbonisation path of the energy sector

Global Electricity Generation by source (LHS), Levelized cost of electricity comparison (RHS)



Source: Lazard, IEA

> **Abundant renewable energy sources can potentially help in maximising electrification, which is widely accepted as the cheapest pathway to industrial decarbonisation before resorting to more expensive and often nascent technologies such as Carbon Capture and Storage (CCS) and green hydrogen.**

Utilising electricity directly or indirectly presents diverse options for emissions reduction within industrial processes (IPCC, 2022).

This shift towards clean energy not only helps industries to directly reduce their primary source of emissions in the form of fossil fuel combustion, but also lays the groundwork for further decarbonisation efforts throughout the industrial value chain, ultimately contributing to broader sustainability goals.

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Industrial decarbonisation – three main drivers from here:

Reducing industrial GHG emissions requires diverse approaches, each tailored to the specific local context. The most effective combination relies on factors such as demand-side initiatives, enhancements in energy efficiency, the adoption of electrified heating, the utilisation of hydrogen (produced with zero-carbon electricity) as a feedstock or fuel, the use of biomass as feedstock or fuel, the introduction of CCS, and the integration of other cutting-edge innovations.

However, in most instances, low-carbon production processes are more expensive than conventional ones. Therefore, the realisation of industrial decarbonisation on a system-wide basis hinges on the synergistic alignment of three pivotal enablers:

1

Implementation of supportive public policy frameworks

Establishing the regulatory foundation including setting GHG emission reduction targets, providing subsidies, and fostering a conducive environment

2

Deployment of technological solutions

Adopting cleaner and more energy-efficient technologies, using renewables, and optimising production processes

3

Availability of capital to finance the transition

Offering the means to achieve tangible reductions in GHG emissions at scale

Together, these essential components form a triad that not only facilitates but accelerates the transition toward sustainable and low-carbon industrial practices.

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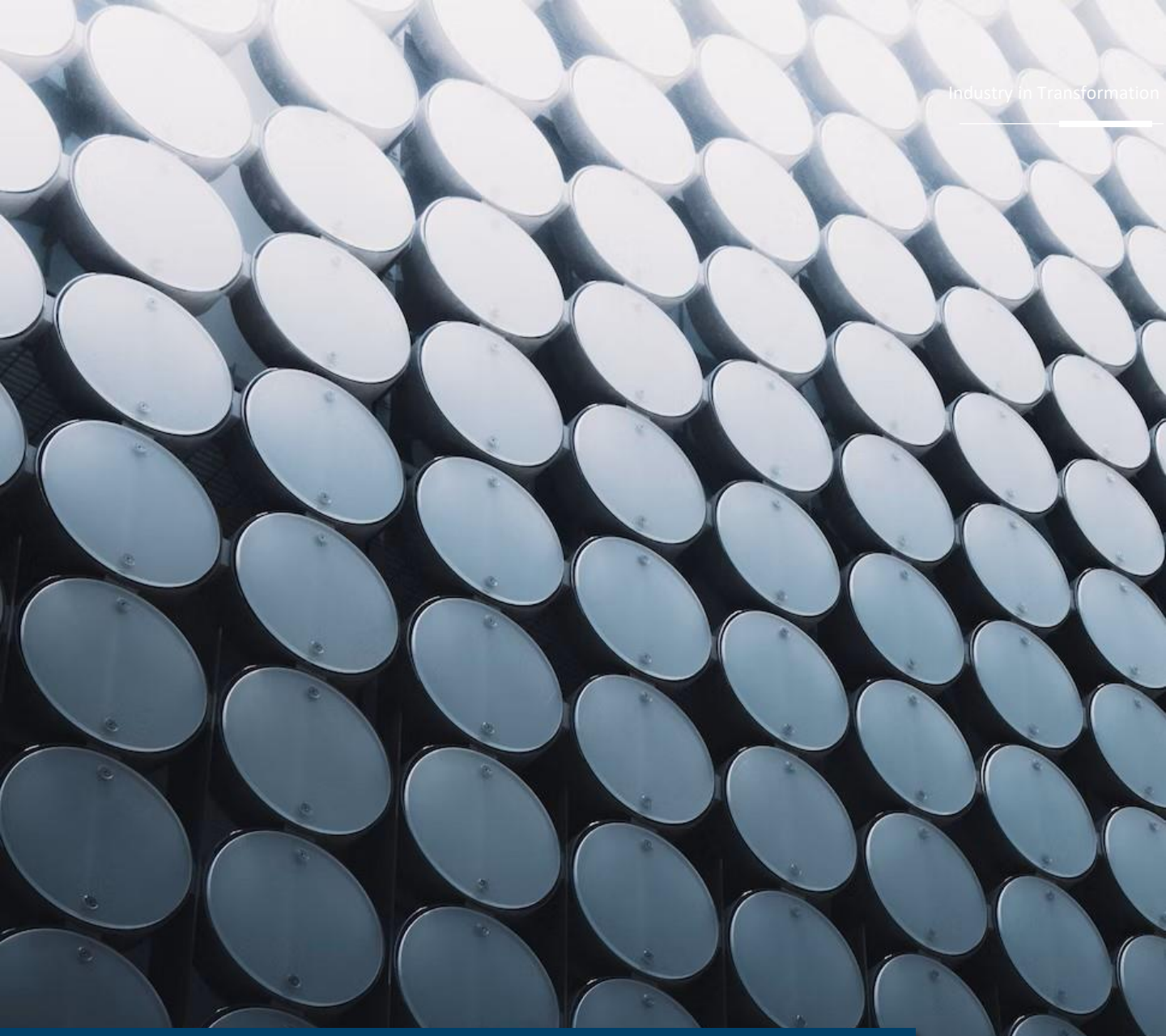


CHAPTER 2

Policymaking and Regulatory Interventions

Source: Unsplash

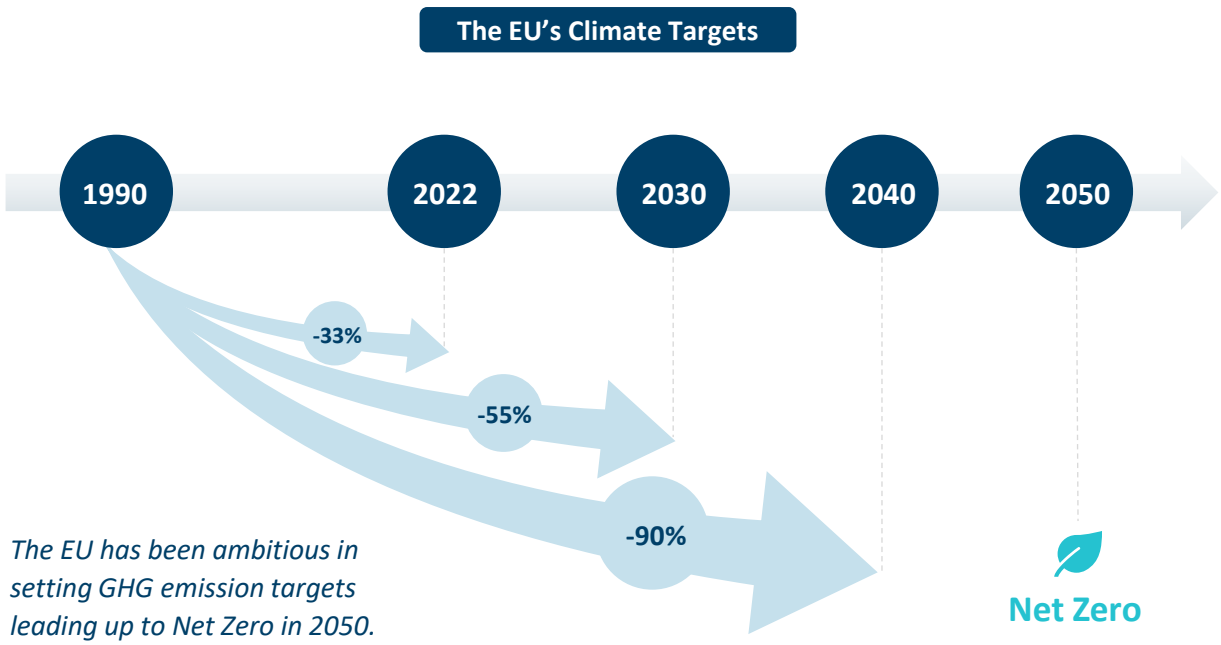
Policy and regulatory support play a crucial role in industrial decarbonisation by driving down costs of low-carbon technology and preserving competitiveness on the global scene. The recent geopolitical events have also shown that embracing the energy transition brings valuable benefits such as security of supply and, possibly, the opportunity to build new industries, which will play a leading role in a Net Zero economy.

To deliver on this promise, the US and Europe have been at the forefront of policy making and regulation, embarking on a competitive push to attract investment in new technologies such as electrolysers, batteries, renewable energy, and other technological developments with low-carbon industry applications.

The European Union's Green Transition

Europe is the world's climate leader with ambitious emissions reduction targets. GHG emissions have already fallen by 33% as of 2022 compared to 1990 levels. However, through the European Climate Law, the EU has set even more ambitious and legally binding targets that would aim to reduce net GHG emissions by at least 55% by 2030 relative to 1990 levels.

More recently, the Commission also proposed a radical 2040 target of reducing emissions by 90% compared with 1990 levels to pave the way for the already binding 2050 Net Zero target. Whilst it is early days and Europe's approval process is lengthy, this target comes with a proposal for an industrial carbon management strategy, highlighting the importance and emphasis placed on the decarbonisation of industry.



The EU has been ambitious in setting GHG emission targets leading up to Net Zero in 2050.

To achieve such targets, Europe has a comprehensive set of policy signals for industry: mandates, targets, carbon pricing and grants, which all weave a clear direction for the decarbonisation of industry.

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INDUSTRIAL EMISSIONS DIRECTIVE

- Aimed at minimising the impact of industrial emissions to the environment
- Sets strict standards and regulations for industrial facilities across various sectors
- Promotes the adoption of best available techniques (BATs) for emission control

EMISSIONS TRADING SCHEME (ETS)

- Europe's primary tool for reducing industrial emissions in sectors such as steel, cement, glass, etc.
- Initially protected various sectors from carbon cost through free allocation of allowances
- Varied timelines for the phase-out of free allocations see quicker reductions for different sectors

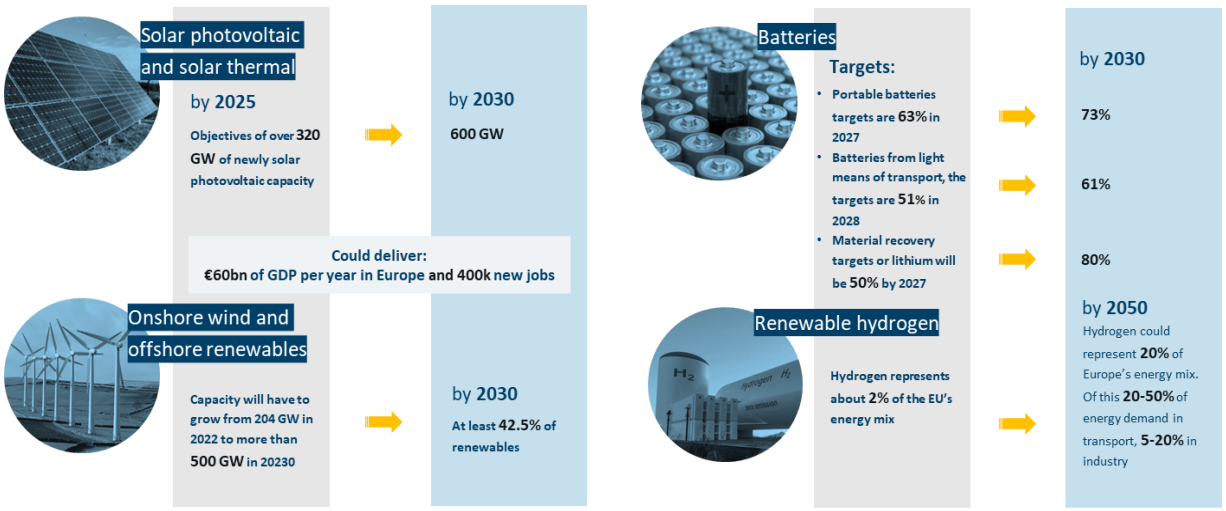
INNOVATION FUND

- Offers grants to finance industrial decarbonisation projects aiming to bridge the cost gap
- Awards funding targeting energy-intensive sectors such as steel, cement, and refining
- Differs from the US model by using competitive auctions rather than universal incentives

NET ZERO INDUSTRY ACT (NZIA)

- Provides support for manufacturing clean technologies to promote industrial decarbonisation
- Aims to achieve climate neutrality in by fostering the growth of green industry investments
- Enhances the EU's energy resilience through initiatives that support low-carbon technologies

Figure 13: Examples of Net Zero Technologies and EU Targets



Source: Council of the European Union

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The US Inflation Reduction Act

Source: Unsplash

USD 400 billion

Estimated IRA Funding

It is estimated that the Inflation Reduction Act will allocate close to USD 400 billion in federal funding toward clean energy investments, aiming to achieve a significant reduction in the United States' GHG emissions by the end of this decade (Jenkins et al., 2022).

The United States shares the EU's ambition to support and grow a strong decarbonised industrial base. Whilst the US is keen to reduce emissions, the primary driver is the desire to build a competitive and strong national low-carbon industry. The United States has established a goal to decrease GHG emissions by 50% to 52% below 2005 levels by 2030 (The White House, 2021).

The Inflation Reduction Act (IRA) is tasked with delivering on this ambition. The IRA is radically different to the EU's support framework in that funding is not competitive. It offers a 'one-stop shop' for project holders, unlike the EU where developers can secure support in various national and EU-wide pools of funding. Clean energy projects, from renewables, to CCS, are offered tax incentives that can be used or sold to other companies. The IRA is poised to facilitate the decarbonisation of industry through the support it offers to produce low-carbon hydrogen, install CCS, or switch to biogas or geothermal energy. However, concerns linger over the IRA depending on the 2024 election outcomes.

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Beyond Europe and the US

Whilst Europe and the US have made strides in climate action and industrial decarbonisation, further policy measures are needed to address remaining challenges. Enhanced international collaboration, alignment of climate policies with broader sustainability goals, and continued investment in research and development to advance low-carbon technologies remain crucial to support global industrial decarbonisation efforts.

Industry has emerged as the heart of policy efforts to reduce emissions. Numerous markets are introducing targets and mandates for industry, whilst offering financial support to bridge the cost gap. Japan, India, the United Kingdom, Canada, as well as numerous other countries have presented their investment plans in the realm of Net Zero technologies.

China in Focus

According to the EIA, China produces nearly 60% of the world's steel and cement, with a park of rather young industrial assets, i.e., not close to replacement and continuing to be emissions intensive.

In 2020, Xi Jinping pledged to "peak carbon emissions before 2030" and "achieve carbon neutrality before 2060". According to the study conducted by the Global Change Analysis Model, industrial decarbonisation is key if the country intends to achieve its carbon neutrality goal by 2060. The study underscores the role of hydrogen and CCS technologies to facilitate the transition, as well as maximising the emissions reduction potential in the sectors of cement, steel, and chemicals (Shao et al., 2022).

Solar cells, lithium-ion batteries, and electric vehicles (EVs) have been taking a leading role in driving China's economic growth and exports. However, the overall picture of China's public efforts to decarbonise remains quite qualitative and intention based at this stage, making it difficult to fully appreciate the scope of the commitment in the country.

For example, the 2021-2025 Five Year plan introduced the concept of an "absolute cap" of CO2 emissions but without setting a precise level of emissions, whilst China's national emissions trading system (ETS) currently only covers electricity generation (Carbonbrief, 2023).

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CHAPTER 3

Innovations for Industrial Decarbonisation

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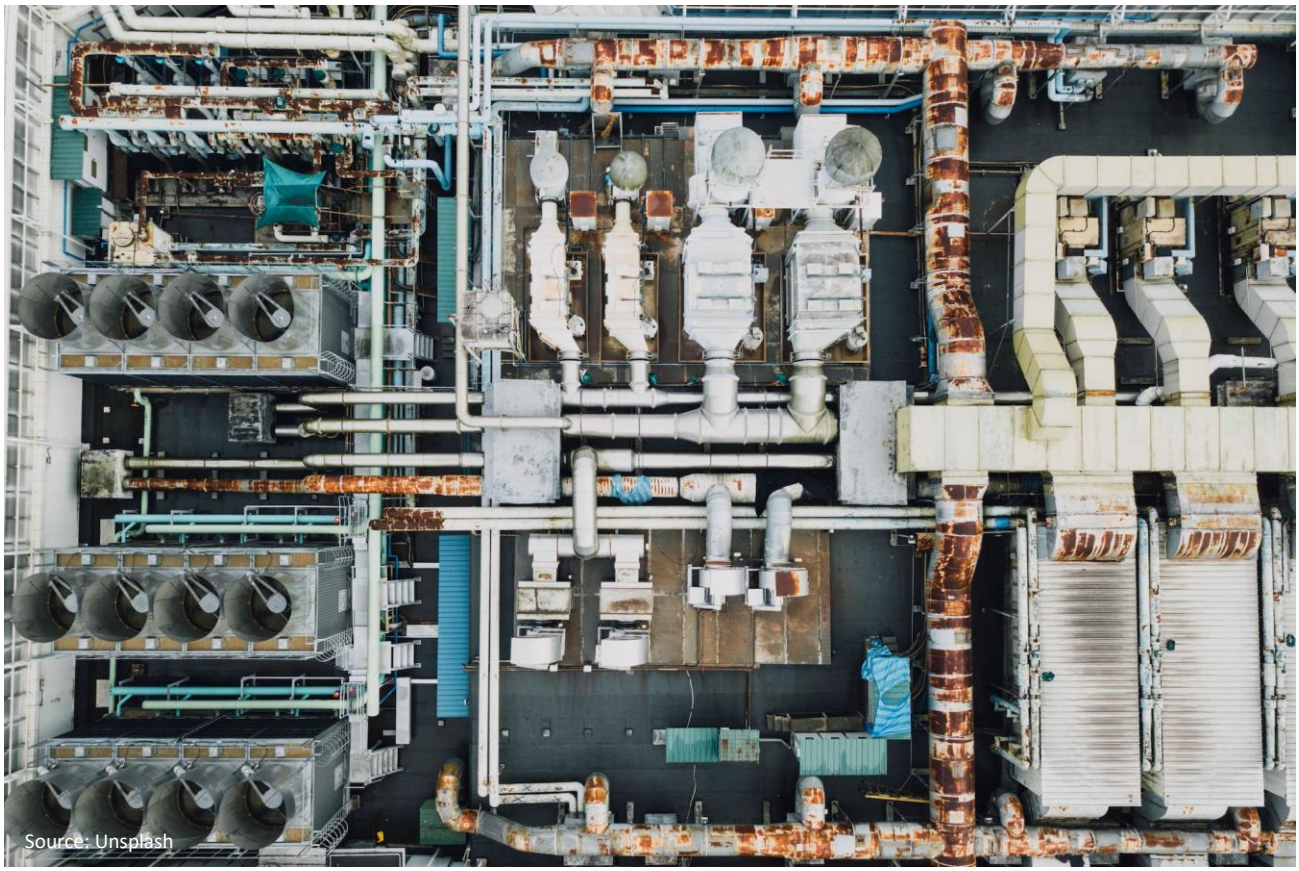
Source: Unsplash

Recall: Biggest Contributors to Industry CO2 emissions

30%	28%	10%	3%	1%
(2.8 Gton CO2)	(2.6 Gton CO2)	(0.9 Gton CO2)	(0.3 Gton CO2)	(0.1 Gton CO2)
Cement	Iron & Steel	Chemicals	Aluminium	Glass

**28% of total industrial emissions are aggregated into other industries*

The sectors above will be the focus of this chapter. To meet individual decarbonisation targets and national goals, these industries need to improve energy efficiency, enhance material efficiency and substitution along the value chain, replace traditional fossil fuel-based systems with electric alternatives (powered by renewable energy), implement carbon capture and storage, and increase recycling rates and reduce material use. These are the five main clusters of GHG Mitigation options for industrial decarbonisation (Fraunhofer Institute for Systems and Innovation Research, 2019).

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Five Main Clusters of GHG Mitigation Options for Industrial Decarbonisation

1

Process Improvement / Energy Efficiency

Improving energy efficiency has the potential to reduce fuel consumption for energy use by 15 to 20% across several sectors. The extent of gains in energy efficiency may vary among sectors and locations, with developed regions typically experiencing more modest reductions, whilst developing regions may achieve greater benefits. In Europe, the surge of gas prices during the 2022 energy crisis successfully drove industry to increase efficiency.

2

Material Substitution & Efficiency

The goal is to sustain the delivery of essential services provided by materials whilst concurrently curbing the overall production of new materials. This objective can be achieved through a spectrum of technical strategies, encompassing the prolongation of the lifespan of existing products, their intensified utilisation, the extraction and reuse of components from discarded items, and the design of products with reduced material requirements.

3

Fuel / Feedstock Switch

Shifting away from coal, refined oil products, and natural gas towards sustainable energy sources such as nuclear, renewables, biofuel, geothermal, sustainable hydrogen or ammonia, or Net Zero synthesised hydrocarbon fuels will contribute to a decrease in GHG emissions. The magnitude of GHG emission reduction depends on the nature of the chosen fuel as well as on the specific industrial sector under consideration.

4

CCS and CCU

Utilising carbon-capture technology enables the collection of CO2 from industrial process exhaust gases, preventing its release into the atmosphere. The captured CO2 can either be stored underground through Carbon Capture and Storage (CCS) or employed as a feedstock in other processes via Carbon Capture and Usage (CCU).

5

Recycling and Reuse

Increasing the circularity of products, such as boosting recycling or promoting the reuse of plastics and steel, contributes to CO2 emission reduction by diminishing the need for manufacturing virgin materials. Embracing these circular practices aligns with sustainability goals, mitigating environmental impact and fostering a more resource-efficient approach.

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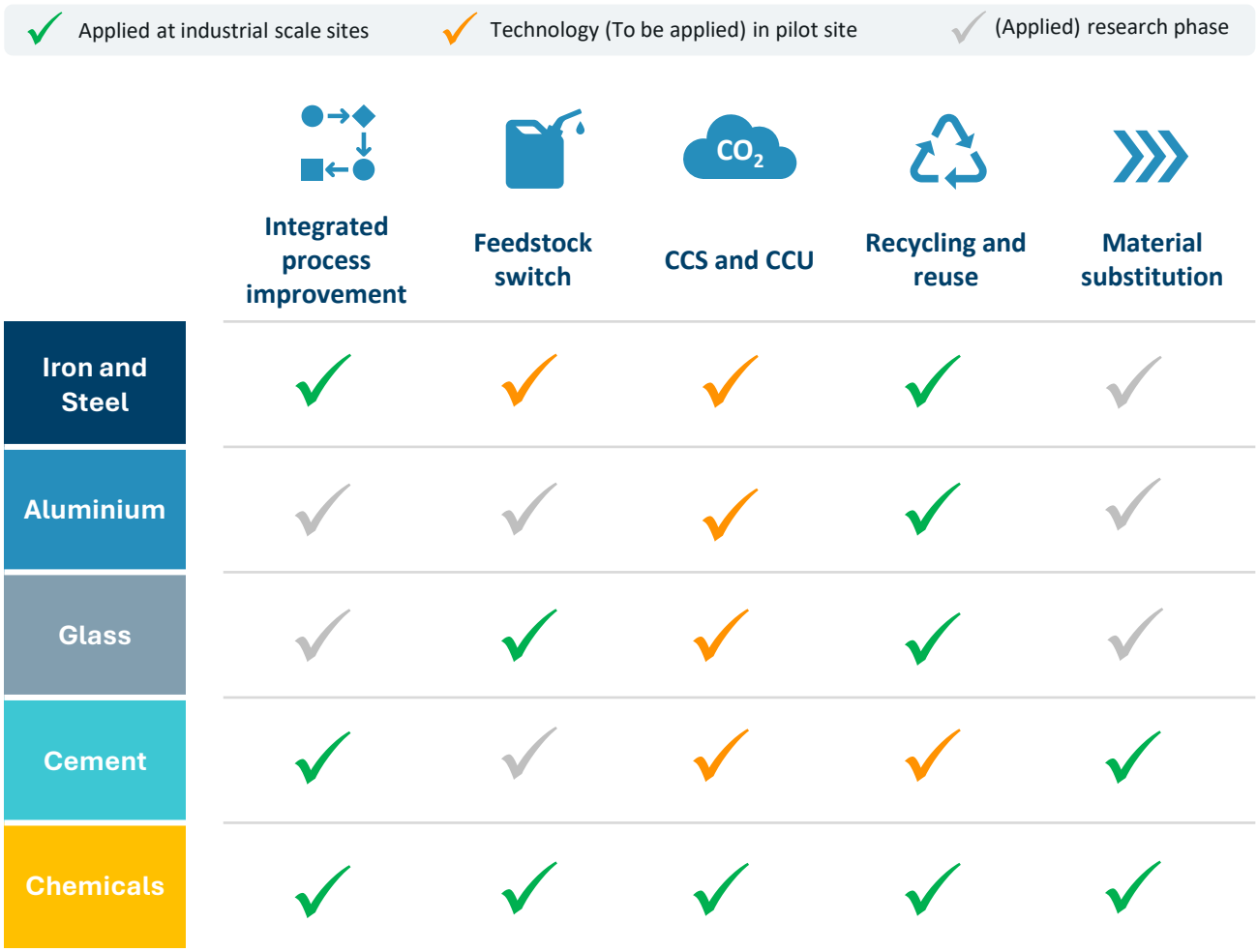
Sector-Specific Decarbonisation Technologies

Given the variability in the most effective blend of decarbonisation alternatives across industries, enterprises must make choices to concentrate on the most viable alternatives to decarbonise. The next section introduces a framework adapted from the Fraunhofer Institute for Systems and Innovation Research for deploying decarbonisation technologies across five industries: cement, iron and steel, chemicals, aluminium, and glass.

Figure 14: Overview of Fraunhofer's Decarbonisation Technology Analysis



Source: Fraunhofer Institute for Systems and Innovation Research, McKinsey

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Cement

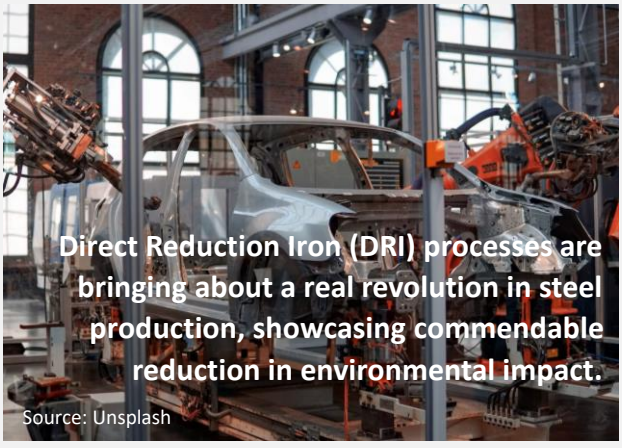
The production of cement primarily encompasses the energy-intensive process of heating limestone, clay, and shale to extremely high temperatures. The procedure, reaching approximately 1,450 °C, results in the creation of clinker, a crucial component in cement production. Introducing fundamental material efficiency practices, such as employing well-made concrete judiciously and opting for right-sized prefabricated components, holds the potential to significantly reduce emissions by 25-50% by curbing the demand for clinker (Fraunhofer Institute for Systems and Innovation Research, 2019).

Until the emergence of a commercially viable alternative binder to cement with very low GHG emissions — an event not anticipated in the foreseeable future — Carbon Capture and Storage (CCS) remains pivotal. CCS is indispensable for mitigating emissions from the limestone calcination process in clinker production, which presently accounts for 60% of GHG emissions in the most advanced technology-equipped plants (UNEP, 2016).

Substituting cementitious materials with alternatives like ground limestone and calcined clays also holds promise, capable of slashing process calcination emissions by up to 50% and in some cases even more.

Source: Unsplash

Iron & Steel



Direct Reduction Iron (DRI) processes are bringing about a real revolution in steel production, showcasing commendable reduction in environmental impact.

Source: Unsplash

The increased use of scrap through recycling represents a critical segment of steel decarbonisation. By engaging in recycling practices, steel mills can curtail their carbon footprint by as much as 60%, saving 1.5 tonnes of iron ore, 0.9 tonnes of metallurgical coal, and 0.3 tonnes of various additives for every tonne of scrap used (World Economic Forum, 2023).

On the other hand, by utilising natural gas reforming, DRI cuts CO2 emissions by about 50% compared to conventional coal or coke methods. Moreover, DRI technologies employing hydrogen as a reductant offer potential to all but eliminate CO2 output through renewable H2 use (Bailera *et al.*, 2021).

Carbon Capture and Storage (CCS) technology also holds immense potential, capable of reducing CO2 emissions in steel production by about 70%. However, the widespread implementation of CCS faces challenges tied to cost and infrastructure, necessitating comprehensive assessments to fully harness its potential (Williams *et al.*, 2021).

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Chemicals

Optimising energy efficiency for chemicals manufacturing holds appeal not only from a sustainability standpoint but also as a pragmatic response to escalating energy prices and natural gas supply constraints in Europe.

For example, leveraging shared infrastructure in chemical parks, coupled with strategic integration with power providers, offers a synergistic pathway to achieve significant emissions reductions, estimated at 5%-10% on an annualised basis.

The potential for immediate gains lies in digitalisation and circularity management within chemical plants, whilst more ambitious projects necessitate advanced technologies such as high-temperature heat pumps and mechanical vapor recompression systems for efficient waste heat recycling. The most substantial efficiency savings, however, hinge on a comprehensive overhaul of utilities management in chemical parks, introducing complexities in design but promising unparalleled emissions reductions (S&P, 2023).

Aluminium

Aluminium recycling is associated with a markedly diminished carbon footprint, 10 to 20 times lower than primary production, and a 95% reduction in energy consumption, contributing to significant environmental benefits (Billy and Muller, 2023).

CCS is also another viable decarbonisation technology for aluminium. However, the effectiveness of CCS heavily relies on infrastructure readiness and residual emissions from coal and gas processes.

Transitioning smelters' power supply to low-carbon alternatives, like electric and hydrogen boilers, shows promise, capable of eliminating direct emissions. Already applied at industrial scale sites, these advanced technologies exhibit a mature state and can be implemented seamlessly. For instance, incorporating electric and hydrogen boilers with low-carbon electricity and hydrogen sources have the potential to achieve 100% emissions reduction when coupled with low-carbon electricity and hydrogen (MPP, 2022).

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Glass

Process electrification offers a substantial avenue for reducing carbon emissions within glass production. Although this method demands substantial electricity, advancements in renewable energy adoption— which can offer up to 75% reduction in emissions totalling 5,561 kT of CO2 in the EU glass industry—align with the process's reliance on purely electric heating. However, the widespread adoption of all-electric systems necessitates a reinforced local grid infrastructure to accommodate the heightened power demand. Despite medium estimated costs ranging from EUR 100 to EUR 500 per ton of glass production capacity, this technology is already in use, albeit not as the norm (Fraunhofer Institute for Systems and Innovation Research, 2019; Furszyfer Del Rio et al., 2022).

Transitioning glass smelting furnaces from traditional oil or gas heating to all-electric systems yields an approximate 31% enhancement in energy efficiency compared to conventional methods.

Source: Unsplash

Hybrid furnaces represent an advanced technology in glass manufacturing technology, offering versatility and sustainability in energy usage. By harnessing both traditional fuels and electricity, these furnaces can supply a significant portion—between 20% to 80%—of the melting energy from electricity, leading to potential emission savings of up to 67% (Gailani et al., 2024). This innovative approach addresses a key challenge in decarbonising the glass sector, as it allows for futureproofing of furnaces to seamlessly transition to higher electricity usage as it becomes more cost-competitive with natural gas. Moreover, hybrid furnaces can be designed to accommodate hydrogen as a fuel source when it becomes available, further enhancing their flexibility and sustainability.

Simultaneously, glass recycling stands as another critical decarbonisation strategy. Recycling glass presents a well-established and energy-efficient approach, requiring 15% less energy compared to crafting products from virgin sand. As a mature technology, glass recycling is readily available, particularly for container glass, with collection rates estimated to exceed 50% in Western EU countries (Fraunhofer Institute for Systems and Innovation Research, 2019). However, the collection rate for flat glass remains relatively low, hovering around 11% (Harder, 2018).

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Case Study: Decarbonisation of Aluminium Processing

Jonathan Mrejen
Investment Team, Partner

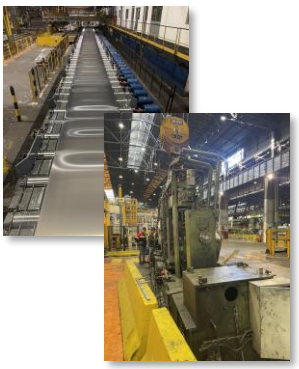
Fernanda Abdalla
Investment Team

Investment Opportunity:

- Financing the upgrade of an aluminium cast house and its furnaces to:
  - Move power source away from gas to electricity (gas currently providing 70% of heat generation); and to
  - Increase further the recycled aluminium intake (currently 70%)
- The casting part of the production process is the most carbon intensive and the financing and its dedicated use of proceeds are anticipated to enable a reduction in carbon of 40-60% versus current levels.

Assets:

Aluminium rolling table



Aluminium sheet cutter

Simplified Aluminium Production Process and Decarbonisation Opportunities

	Production Process	Carbon Intensity	Decarbonisation Opportunities
Procurement	Primary Aluminium (Inputs) + Recycled Aluminium (Inputs) → CO_2	++	• Recycled aluminium is substantially less carbon intensive
Transformation	Melting & Casting → CO_2	+++	**Financing Focus** • Proven melting technologies allow significantly less power use and further increase in scrap intake • Re-melting of scrap involves the use of power to heat at high temperatures
Rolling & Cutting	Rolling → Sheet Cutting → CO_2	+	• Reduction of waste from rolling and cutting operations reduce overall carbon emissions (aluminium tailings otherwise have to be on-sold, transported, and processed further at other facilities

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CHAPTER 4

Financing Industrial Decarbonisation

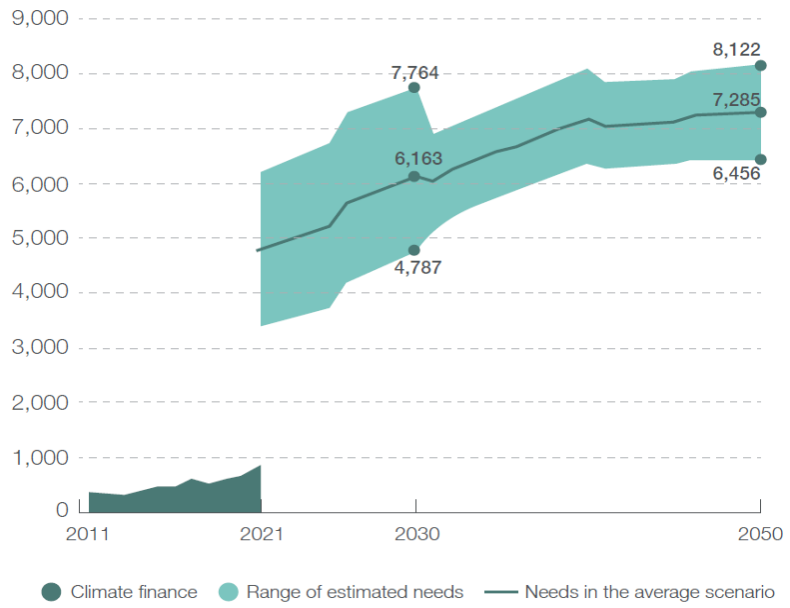
Source: Unsplash

Climate Financing Gap

The collective efforts of approximately 20,000 public and private investors have yielded USD 4.8 trillion being deployed in global climate finance over the past decade. Nearly half of this amount has been sourced from the private sector (Climate Policy Initiative, 2022).

Despite the headline figures, the current level of investment into global climate finance falls significantly short of meeting the goals set forth by the Paris Agreement, highlighting a substantial Net Zero financing gap.

Figure 15: Global Climate Finance vs. Forecasted 2050 Needs (USDm)



Source: Allen & Overy, Climate Policy Initiative

Global climate finance flows need to scale by 625% by 2030 to effectively align with the Paris Agreement objectives and keep global warming below 1.5 degrees when compared to pre-industrial baselines (Allen & Overy, 2023). This would require an estimated annual investment ranging between USD 4.8 trillion and USD 7.8 trillion, constituting approximately 5% of global GDP in 2023.

Despite the cost of decarbonising the global economy within the next 30 years, the potential economic gains, such as asset appreciation and productivity growth, far exceed these expenses (McKinsey, 2022). According to several studies, proactive climate action and investment have the potential to contribute a net USD 43 trillion to the global economy – equivalent to a rise of up to 3.8% in global GDP by 2070 (Deloitte, 2022).

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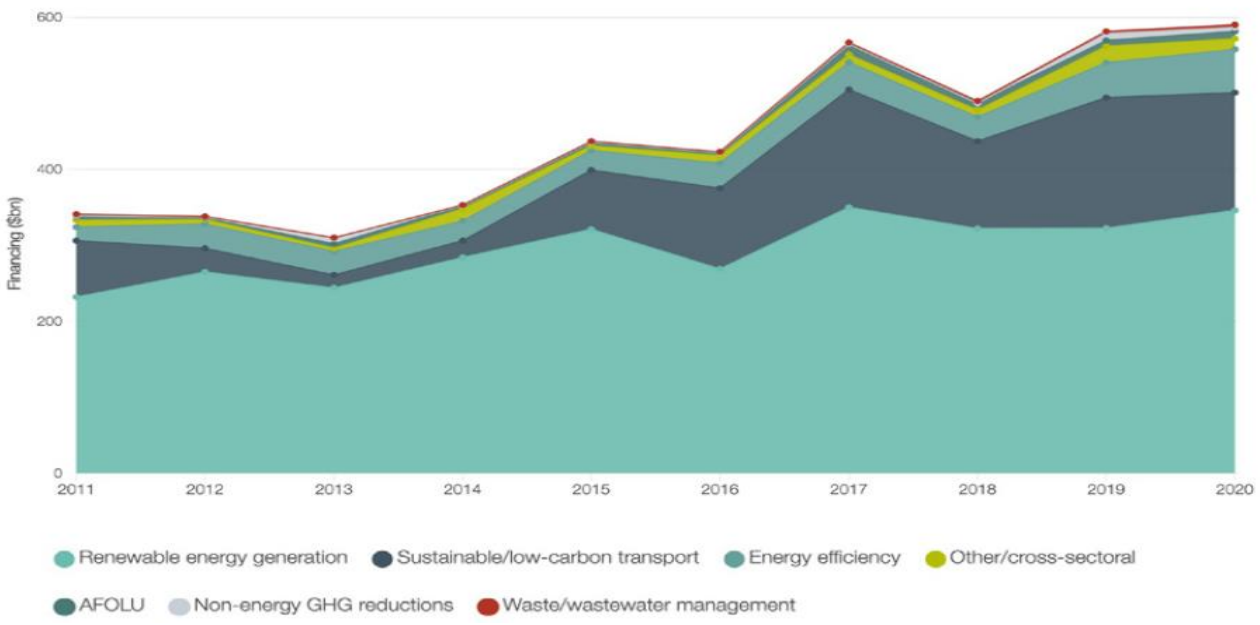
Renewable Energy in Focus

The distribution of climate finance reveals a material skew towards sectors such as renewable energy and low-carbon transportation. Whilst these are the foundations for advancing global decarbonisation, substantial investments are required to decarbonise industrial processes (Warren *et al.,* 2023).

Source: Unsplash

Renewable energy has dominated climate finance for the past 10 years, accounting for almost 70% of total capital deployed (Climate Policy Initiative, 2022). In 2020, the renewable energy sector secured 52% of the total climate finance deployed, whilst low-carbon transport came in second with a 23% allocation (Allen & Overy, 2023).

Figure 16: Analysis of Climate Mitigation Funding Across Solutions (2011-2020, USDbn)



Source: Allen & Overy, Climate Policy Initiative

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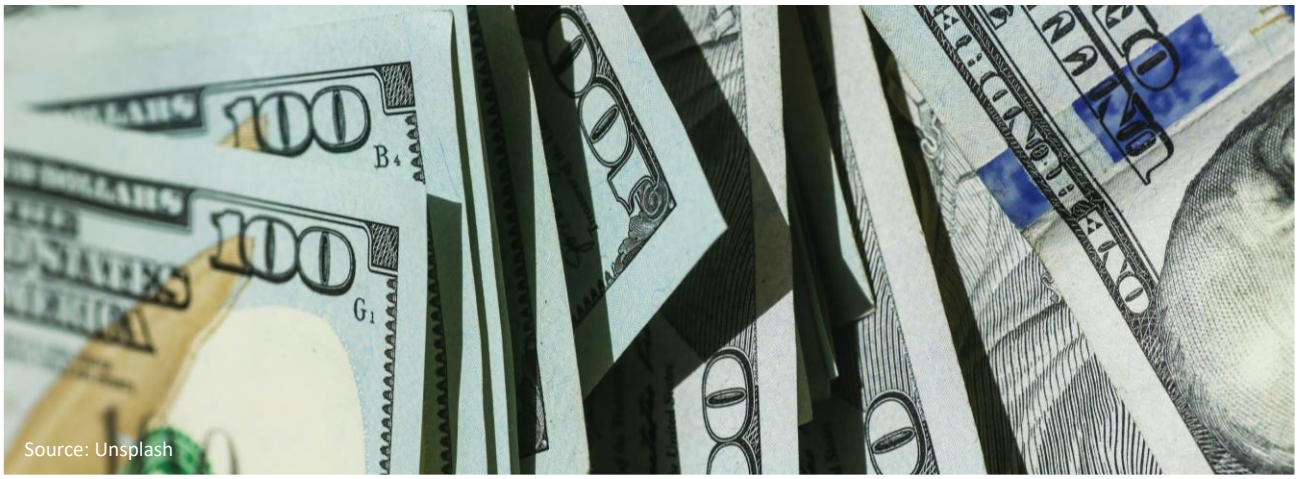
Financing Industrial Decarbonisation


Source: Unsplash

USD 125 billion

amount required by 2050

To effectively decarbonise the production of chemicals, steel, cement, and aluminium, the investments would need to scale up from USD 15 billion in 2022 to USD 70 billion per year by 2030 and USD 125 billion by 2050 (Cordonnier and Saygin, 2023).

Banking

Credit financing is well-suited to support industrial decarbonisation efforts, particularly for mature, asset-heavy businesses. By leveraging their existing assets, stable cash flows, and long-term investment horizons, industrial companies can access the capital needed to fund decarbonisation initiatives whilst mitigating financial risks and optimising their capital structure.

Banks are increasingly recognising the importance of financing industrial decarbonisation projects as part of their commitment to sustainability and climate action. There has been notable progress in this area, with banks developing specialised financing products and dedicating resources to support projects aimed at reducing carbon emissions across industrial sectors. These initiatives include funding for renewable energy installations, energy efficiency upgrades, carbon capture and storage projects, and the transition to cleaner production processes. However, significant challenges remain, including the complexity and scale of industrial decarbonisation efforts, the need for innovative financing mechanisms to address upfront investment costs, and the uncertainty surrounding regulatory frameworks and market incentives.

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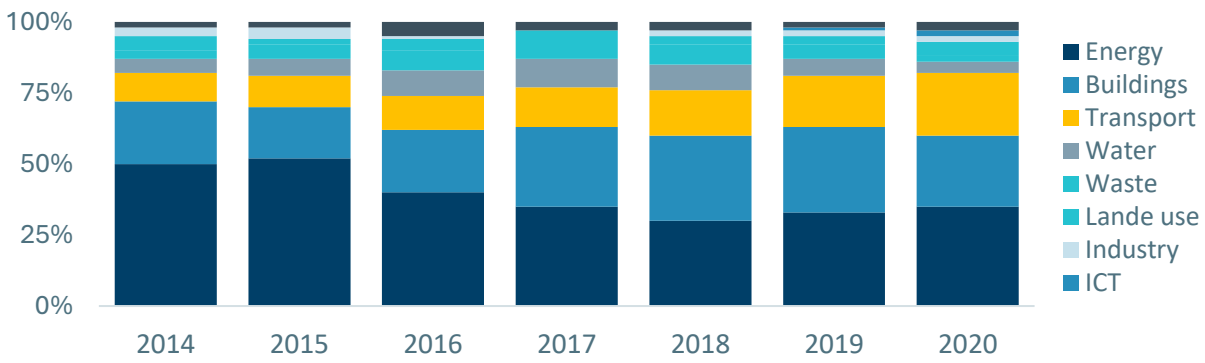
Financing Industrial Decarbonisation

As industries worldwide seek to transition to more sustainable and low-carbon practices, innovative financing mechanisms beyond traditional bank loans are becoming essential to meet the funding requirements for large-scale decarbonisation projects. These alternative finance options include:

Green Bonds and Sustainable Debt

Green bonds and other sustainable debt instruments offer companies access to capital markets specifically earmarked for financing environmentally friendly projects, including industrial decarbonisation initiatives. However, a closer look at green bonds, often lauded as pivotal tools for fixed income investors in financing the climate transition, display limited contributions toward industrial decarbonisation. This is highlighted by data from the Climate Bond Initiative presented in Figure 17. The very limited allocation to industrial decarbonisation projects is a trend notably observed since 2014.

Figure 17: Use of Proceeds (Up) of Climate Bonds 2014-2020 (USDbn)



Source: Chenavari, Climate Bonds Initiative

Private Equity and Venture Capital

Private Equity (PE) and Venture Capital (VC) firms have increasingly recognised the need to finance decarbonisation efforts. Whilst they have primarily focused on value creation in the past, there has been a shift towards supporting the climate finance ecosystem, particularly for infrastructure-focused PE firms and dedicated climate VC funds who are now at the forefront of decarbonisation.

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Financing Industrial Decarbonisation

However, it is evident that more investment is needed from the private markets especially as the decarbonisation landscape in the EU faces a €50 billion cleantech funding gap (Cleantech for Europe, 2024). Private credit will play a crucial role in complementing investments from PE and VC firms, ensuring that there will be sufficient capital to bring industrial decarbonisation initiatives to fruition.

Impact Investment Funds

Impact investment funds target investments that generate positive social and environmental impact alongside financial returns. These funds may invest in a wide range of projects aimed at industrial decarbonisation, including renewable energy installations, energy efficiency upgrades, and sustainable manufacturing processes. Whilst over USD80 billion has been raised in private impact funds of USD1 billion or more between 2017 and 2022 (World Economic Forum, 2023), the focus on industrial decarbonisation remains very niche with only a handful of strategies directly financing industrial decarbonisation being launched in 2022-2023.

The Role of Large Corporates: the "New Financiers" of Industrial Decarbonisation

ROLE AS "FINANCERS"

Large corporates are leveraging their financial resources and sustainability commitments to drive investment in clean technologies across their supply chains and operations, which has been critical in light of inadequate capital provided by banks and the capital markets.

FILLING IN THE FINANCING GAP

As major participants in global markets, large corporates are best placed to ignite industrial decarbonisation efforts as they possess significant capital, which allow them to allocate funds that would help decarbonise their own operations and supply chains.

STRATEGY INTEGRATION

By integrating decarbonisation strategies into their business models and procurement practices, large corporates are not only driving demand for clean technologies but also incentivising innovation and investment in the industrial sector.

NEED FOR COLLECTIVE ACTION

Despite the initial progress, the involvement of more large corporates is essential. Collective commitment and concerted action, especially on the financing front, are paramount in catalysing the transition towards a Net Zero economy.

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CHAPTER 5

Concluding Remarks

Source: Unsplash

Decarbonising industrial production processes is a complex task. The following recommendations can guide industrial companies on their journey toward sustainability.

Source: MS Office

Stay informed and adapt to regulatory changes

- Engage with policymakers on evolving environmental regulations and policies
- Consider participating in voluntary sustainability standards and certifications

Conduct a comprehensive carbon footprint assessment

- Perform a thorough assessment to identify major emissions sources within production processes
- Use this analysis as a baseline for setting realistic and measurable decarbonisation goals

Source: MS Office

Source: MS Office

Prioritise energy efficiency measures

- Implement energy-efficient technologies and optimise operations
- Conduct regular energy audits to significantly reduce energy consumption and emissions

Transition to renewable energy

- Invest in on-site renewable energy generations, such as solar or wind
- Explore opportunities for sourcing renewable energy from external providers to power manufacturing facilities

Source: MS Office

Source: MS Office

Explore electrification opportunities

- Investigate the potential for electrifying processes traditionally reliant on fossil fuels
- Transition to electric-powered machinery and equipment, particularly when coupled with renewable energy sources

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Implement Carbon Capture and Storage technologies

- Evaluate the feasibility of CCS to capture and store carbon emissions from industrial processes, especially in sectors with challenging decarbonisation pathways

Adopt circular economy practices

- Minimise waste and implement recycling initiatives
- Implement sustainable supply chain practices to reduce resource consumption and the environmental impact of raw material extraction

Invest in Research & Development

- Allocate resources to R&D initiatives focused on innovative technologies and processes towards decarbonisation
- Collaborate with industry partners, research institutions, and government agencies to accelerate progress

Engage capital providers and communicate progress

- Promote transparency and engagement with the banks, investors, and finance community when seeking investment
- Utilise novel financing tools and tailor-made financial products that incentivise decarbonisation

As with everything in industry, these recommendations should be tailored to the specific characteristics of each industrial company and its sector, considering factors such as size, industry, and geographic location. Collaboration with industry peers, sharing best practices, and staying informed about emerging technologies will further contribute to the success of decarbonisation efforts.

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Appendix

The US Inflation Reduction Act (IRA)

The US IRA allocates close to USD 400 billion in federal funding toward clean energy initiatives, aiming to achieve a significant reduction in the United States' GHG emissions by the conclusion of this decade (Jenkins *et al.,* 2022).

The United States has established a goal to decrease GHG emissions by 50% to 52% below 2005 levels by 2030 (The White House, 2021). Although the expected influence of the IRA doesn't fully meet this target, the IRA plays a central role in reducing the "implementation gap" and can potentially result in a reduction between 43% and 48% from 2005 levels by 2035 (Bistline *et al*., 2023).

To stimulate investments, the IRA utilizes a set of tax incentives designed to expedite the adoption of clean energy, along with clean vehicles, buildings, and manufacturing. These incentives encompass tax credits for investments in renewable energy projects and facilities producing clean electricity. The legislation offers tax breaks for the production of components related to solar and wind energy, including inverters, battery components, and critical minerals. Additionally, it establishes production tax credits for renewable and clean electricity, as well as power generated from qualified nuclear facilities (The White House, 2023).

The law's most significant influence is expected in the power sector. A total of 280 clean energy projects have been announced across 44 US states in the IRA’s first year, representing USD 282 billion of investment (Goldman Sachs, 2023).

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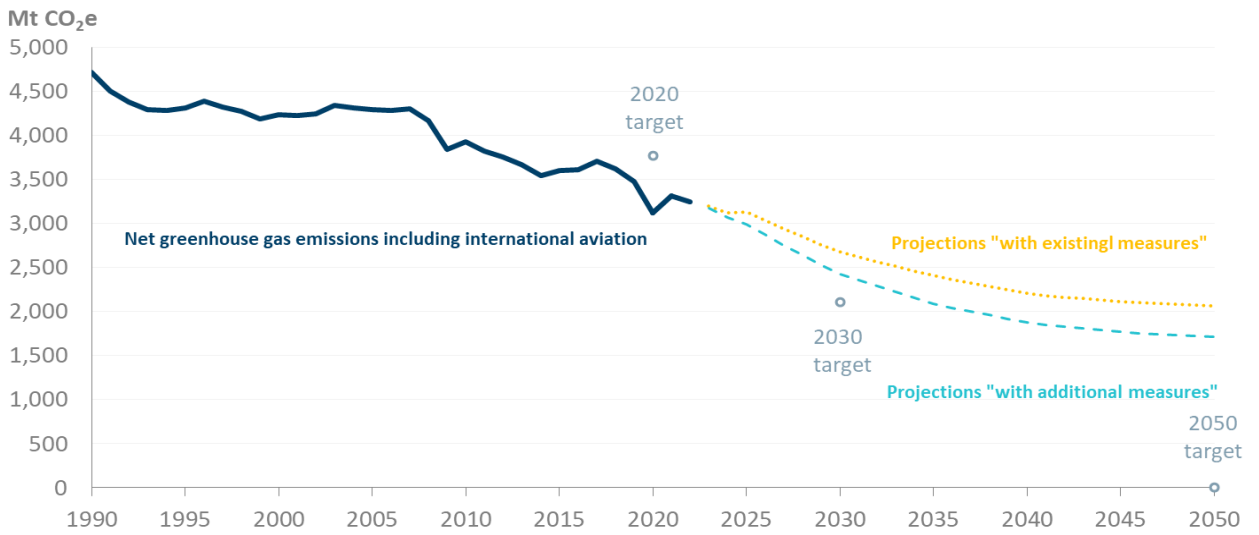
The EU Green Transition Agenda

The "Fit for 55" package, a cornerstone among climate policies, aimed to guide the EU toward a minimum 55% reduction in greenhouse gas emissions by 2030 and is nearing full adoption. By 2022, the region had already accomplished a 31% reduction compared to 1990, contrasting with a global increase of over 60% in emissions during the same period. Despite these efforts, additional measures will be needed for the region to meet its 2030 and 2050 climate targets.

Figure 18: Progress towards achieving climate targets in the EU-27



Source: Chenavari, European Environment Agency

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EU Emissions Trading System (EU ETS)

Originally set up in 2005, the EU Emissions Trading System (ETS) established a market mechanism designed to assign a value to CO2 emissions and incentivise emission reduction within power generation and energy-intensive sectors such as iron, aluminium, cement, civil aviation and other industries involved in the production of commodities like glass, cardboard, and acids (Dechezlepretre *et al.*, 2023).

Currently, the ETS accounts for approximately 40 percent of the total emissions produced within the EU region (PwC, 2021) and has accumulated over EUR 152 billion in revenues since 2013 (European Commission, 2023).

Operating on a 'cap-and-trade' principle, the ETS sets a diminishing cap on permissible CO2 emissions annually. Within the established cap, companies predominantly engage in the purchase of allowances from the EU carbon market, supplemented by a provision of some allowances at no cost (Hintermayer, 2020).

The gradual reduction in the cap acts as an incentive for EU-based industrial operators to curtail emissions. It also increases their cost of compliance, thereby putting them at a disadvantage vs their non-EU peer, prompting the occurrence of carbon leakages (Vollebergh and Brink, 2020).

On 14 July 2023, as part of the 'Fit for 55' package, the European Commission published a legislative proposal for a revision of the ETS, to align it with the target of a 55 % reduction of EU net GHG emissions by 2030, compared to 1990 levels. The modified ETS will encompass maritime and road transport. Buildings, and heating fuels, expanding its coverage beyond its previous scope (European Commission, 2023).

The Carbon Border Adjustment Mechanism (CBAM)

Carbon leakage arises when a decrease in domestic carbon emissions is partially or fully compensated by an increase in emissions in nations where climate mitigation policies are absent or less rigorous, such as China or South Korea (Aichele and Felbermayr, 2012). There is evidence to suggest that whilst nations in the European Union have successfully reduced their territorial emissions, this progress is somewhat counteracted by the incorporation of embodied carbon through imports (United Nations Environment Programme, 2019).

The Carbon Border Adjustment Mechanism (CBAM) is conceived by the EU as an integral aspect of the ETS aiming to prevent carbon leakage by creating a level playing field for EU producers operating within the ETS-covered sectors from 2026 onwards.

CBAM essentially substitutes the prevailing allocation of free ETS allowances given to EU producers identified as high-risk for carbon leakage and enforces a charge on non-EU imports, accommodating variations between the price within the ETS and the carbon price levied in the originating countries (Clora *et al.*, 2023).

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