STUDY

Transforming Energy-Intensive Industries in Germany and Canada

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Transforming Energy-Intensive Industries in Germany and Canada

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Content

List of figures

List of tables

List of Abbreviations

ACCIP	Alberta Carbon Capture Incentive Program
BAFA	Federal Office for Economic Affairs and Export Control (Bundesamt für Wirtschaft und Ausfuhrkontrolle)
BATs	Best Available Techniques
BECCS	Bioenergy with Carbon Capture and Storage
BMWE	Federal Ministry for Economic Affairs and Energy (Bundesministerium für Wirtschaft und Energie)
BOF	Basic Oxygen Furnance
CAD	Canadian Dollar
CAPEX	Capital Expenditures
CBAM	Carbon Border Adjustment Mechanism
CCfD	Carbon Contract for Difference
CCS	Carbon Capture and Storage
CCU	Carbon Capture and Utilization
CCS/CCU	Carbon Capture, Storage and/or Utilization
CCUS	Carbon Capture, Utilization and Storage
CDR	Carbon Dioxide Removal
CFF	Clean Fuels Fund
CGF	Canada Growth Fund
CHP	Combined Heat and Power
CIB	Canadian Infrastructure Bank
CIF	CleanBC Industry Fund
CIPEC	Canadian Industry Program for Energy Conservation
CTIPs	Clean Trade and Investment Partnerships
CO_2	Carbon Dioxide
CO_2e	Carbon Dioxide Equivalent
DRI	Direct Reduced Iron
EAF	Electric Arc Furnace
EMAS	Environmental Management and Audit Scheme
EPS	
ERP	Emissions Reduction Plan
ESPR	Ecodesign for Sustainable Products Regulation
ETS	Emissions Trading System
EU	European Union
EU ETS	EU Emissions Trading System
EUR	Euro
FEED	Front-End-Engineering-Design

GDP	Gross Domestic Product
GHG	Greenhouse Gas
GIFMP	Green Industrial Facilities and Manufacturing Program
H_2	Hydrogen
HVC	High-Value Chemical
IAA	Industrial Action Act
ICE	Innovative Clean Energy
IEA	International Energy Agency
IPCEIs	Important Projects of Common European Interest
KfW	(Kreditanstalt für Wiederaufbau)
LCEF	Low Carbon Economy Fund
LULUCF	Land Use, Land-Use Change and Forestry
Mt	Million Tonnes
MTO	Methanol-to-olefin
Mtoe	Million Tonnes of oil equivalent
NAPE	National Action Plan for Energy Efficiency
NDC	Nationally Determined Contribution
NRCan	Natural Resources Canada
NZA	Net Zero Accelerator
OBPS	Output-Based Pricing System
OPEX	Operational Expenditures
PSP	Public Sector Pension Investment Board
RED	Renewable Energy Directive
R&D	Research and Development
ENG	Renewable Natural Gas
SAF	Sustainable Aviation Fuel
SALCOS	Salzgitter Low CO_2 Steelmaking
SME	Small and Medium Sized Enterprises
SMR	Steam Methane Reforming
TIER	Technology Innovation and Emissions Reduction

1 Introduction

The transition towards climate neutrality presents both unprecedented challenges and significant new opportunities for industrial economies. Germany and Canada both have strong manufacturing sectors that hold large economic significance and create strong multiplier effects across their wider economies. They also have ambitious climate targets, which require a deep transformation of these industries over the coming decades.

While both countries have achieved meaningful emissions reductions in their industrial sectors since 1990 – Germany by 44% and Canada by 6.5% – the transition ahead demands more than incremental efficiency gains. The industrial transformation is especially challenging for the energy-intensive and emission-intensive secondary manufacturing industries, which are indispensable for the larger economy in both countries. In Germany, these industries employ around 16% of the total industrial workforce and contribute roughly 3.4% to national GDP. In Canada, the figures are similarly high, with such industries accounting for 15.6% of the industrial workforce and 2.6% of total GDP.

The most emission-intensive secondary manufacturing industries in both countries include chemicals and refining, steel and metals, cement and lime, and pulp and paper. Since 2000, emissions in these sectors in Germany have fallen by 11.4%, whilst emissions reductions in the same sectors in Canada amounted to 18.3%. Further decarbonising these sectors poses unique challenges. Unlike the power sector – where shifting to renewable energy provides a relatively straightforward pathway to reduce emissions – these industries face more complex barriers due to a challenging combination of intrinsic process emissions, molecular carbon requirements, and high-temperature, energy-intensive production methods.

Focusing on these four sectors in Germany and Canada, this comparative study assesses the industrial profiles, sector-specific economic trends, and progress towards climate targets. It further examines transformation pathways, including cross-cutting technologies and sectoral pathways, reviews the respective policy frameworks that support industrial transition in both countries, and identifies opportunities for future bilateral collaboration.

Despite differences in economic structure, resource endowment, trade relationships, and energy and industrial policy strategies, both countries face strikingly similar transformation challenges within their secondary energy-intensive industries. Meeting these will require a decisive shift from incremental improvements to the widespread deployment of innovative technologies and processes – combining electrification with climate-neutral electricity generation, utilising renewable and low-carbon hydrogen and its derivatives where molecules are required, applying carbon capture, utilisation and storage for unavoidable process emissions, scaling circularity and material efficiency, and deploying biomass selectively where it offers genuine lifecycle gains.

The insights gained from this study on the shared challenges and complementary strengths of Germany and Canada can guide targeted, near-term collaboration to accelerate industrial decarbonisation while preserving competitiveness – through shared technological expertise, alignment of policy frameworks, joint advancement of demonstration projects, and the exploration of new potential trade opportunities.

2 Industry profiles: A Snapshot of Germany and Canada

2.1 Germany: Sector Overview

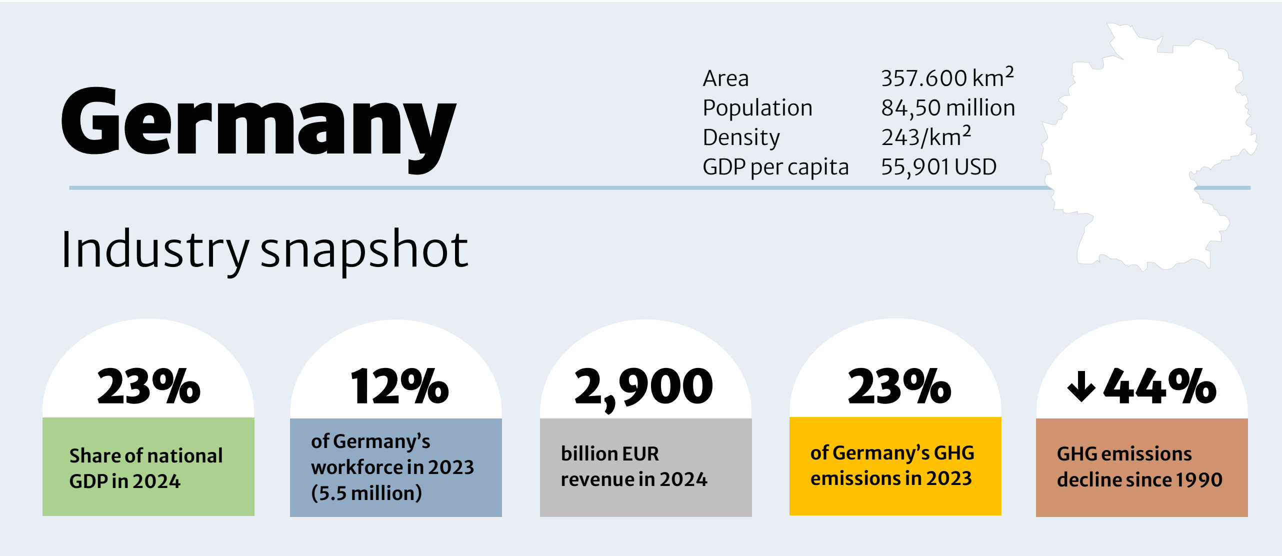

Figure 1: Germany's industry: facts and trends. Own depiction. Sources: Statista 2024a; Destatis 2025a, b; UBA 2025a; UBA 2014).

Germany, with a GDP of EUR 4.19 trillion (CAD 6.12 trillion) in 2023, is the third-largest economy globally and the largest in Europe (World Bank 2025a, b). Germany's industrial sector accounted for 23% of national GDP in 2024, making it the second-largest contributor to the economy after services (70%) (Statista 2025d). It comprises sectors such as automotive production, machinery and equipment, steel and metals, chemicals and petrochemicals, food, beverages and tobacco, electrical equipment, glass, ceramics, and smaller sectors like textiles.

When factoring in service sectors that depend on industry, nearly one in three euros generated in Germany can be directly linked to industrial activity (BDI, BCG & IW 2023). With 5.5 million people employed in 2023 – accounting for 12.2% of the country's workforce – and as the third-largest exporter globally, the sector is widely regarded as a "guarantor for value creation" as well as backbone of the country's innovation capacity and global competitiveness (Agora Energiewende 2020; Destatis 2024a).

Within the industrial sector, the energy-intensive industries (steel, construction materials, chemicals, glass, non-ferrous metals, and paper) employ 925,000 people, accounting for around 16% of the total industry's workforce and 3.4% of national GDP (Schaller and Schasching 2024). Importantly, every job in the energy-intensive industry secures two further jobs in the broader German economy (other industry sub-sectors and the services sector). Hence, the energy-intensive industries are indirectly responsible for the employment of about 2.5 million people (EID n.d.). In 2023, they generated a revenue of EUR 510 billion (CAD 757.3 billion), accounting for around 22% of the industry's revenue.

In terms of emission reductions, Germany's industry has made substantial progress, though it still trails slightly behind the broader economy. By 2023, Germany had reduced its overall greenhouse gas (GHG) emissions to 674 million tonnes of CO_2 equivalents (CO_2eq) – a 46% reduction compared to 1990 levels. Over the same time period, industrial emissions declined by approximately 44% (UBA 2025b; UBA 2014). Despite these achievements, industry remains the second-largest emitting sector, accounting for 23% of Germany's GHG emissions in 2023 (UBA 2025b).

For much of the past decades, the industrial sector was successful in reducing emissions while increasing output at the same time. Between 1995 and 2023, industrial emissions fell by around 35% while inflation-adjusted gross value-added increased by almost 32% (UBA 2024a). However, since 2021, emission reductions have been driven primarily by declines in production, triggered by surging natural gas prices following Russia's war in Ukraine (UBA 2024b).

Production in energy-intensive industries is, as the name implies, particularly demanding in terms of energy use and GHG emissions. Notably, these industries account for around 75% of the industrial sector's total energy demand and the majority of industrial GHG emissions (Destatis 2025c, KEI 2025a). In 2022, these sectors were responsible for 157 Mt CO_2eq or 21% of Germany's total GHG emissions. The largest emitters were the chemical and petrochemical industries (63 Mt), followed by steel and metals (57 Mt), cement and lime (23 Mt), and pulp and paper (14 Mt) (see Figure 2).

Their high energy intensity makes these sectors especially vulnerable to rising prices, which is why the energy crisis has hit them particularly hard. Between January 2022 – shortly before the onset of the war – and December 2023, production in energy-intensive industries declined by 21%, bringing output levels in 2023 below the lowest seen during the Covid-19 pandemic (BDI, BCG & IW 2023). Since then, production has only recovered slightly, with output in April 2025 still 18% below January 2022 levels (Destatis 2025c). Thus, emission reductions observed since 2021 should be viewed as exceptional, driven primarily by short-term economic pressures rather than progress in industrial decarbonisation.

All the same, between 2000 and 2021, the combined emissions from the energy-intensive industries declined by 11.4%, while their economic output increased by 10.5%, indicating a meaningful decoupling of emissions and economic growth (see Figure 2).

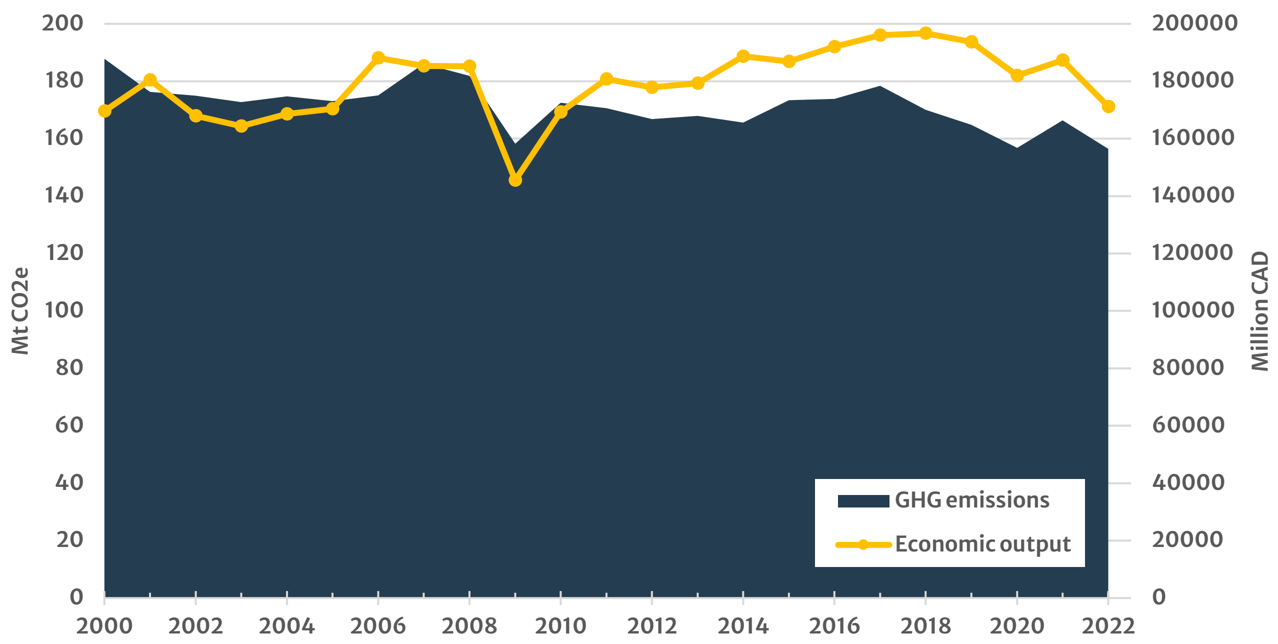

Figure 2: Germany's energy-intensive industries – GHG emissions and economic output, 2000-2022. Own depiction. Source: Destatis 2025d, e; DEHSt 2006-2023; VDZ e.V. 2001-2005. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross value added by industry, price-adjusted in chained (2020) EUR. Industries included: basic cheicals, pharmaceuticals, refineries and cokeries, steel and metals, cement and lime, pulp and paper.

2.2 Canada: Sector Overview

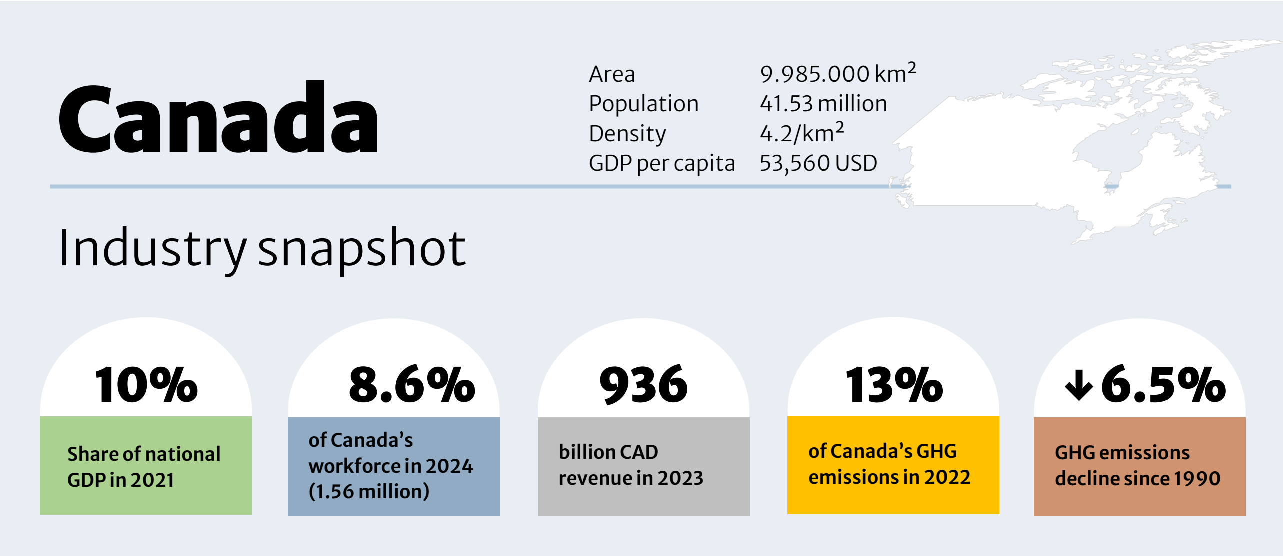

Figure 3: Canada's industry: facts and trends. Own depiction. Sources: ISED (2021); Statistics Canada (2024, 2025a); ECCC 2024; Canada 2024. The "industry" category includes secondary manufacturing sectors such as chemicals, petroleum refining, iron and steel, metal smelting and refining, pulp and paper, cement, and other manufacturing. It excludes primary industries like mining, quarrying, oil and gas extraction, forestry, and construction.

Canada, with a GDP of CAD 2.89 trillion (EUR 1.98 trillion) in 2023, ranks as the tenth-largest economy globally (World Bank 2025b, c). The country's economy is diverse and trade-oriented, with over 75% of Canadians employed in service industries, while manufacturing and the natural resource industries remain vital to economic output and international trade (Canada 2012).

The manufacturing sector – referred to in this study as the industrial sector– accounts for over 10% national GDP, generated a revenue of CAD 936 billion (EUR 641 billion) in 2023 and employed 1.56 million people in 2024 (ISED 2021; Statistics Canada 2024a, 2025). It supports an additional 3.43 million jobs, meaning 1 in 4 Canadian jobs is connected to the manufacturing sector (CMC 2025).

The sector includes industries engaged in the transformation of raw materials into secondary goods, covering a wide range of activities such as food and beverage production, textiles, wood and paper processing, chemicals and petroleum refining, plastics, metal and machinery manufacturing, non-metallic products, electronics, transportation equipment, and other goods (Statistics Canada 2025b). In 2024, the sector exported goods worth more than CAD 467 billion (EUR 315 billion), with over 80% of exports destined for the United States (CMC 2025; Statistics Canada 2025c).

Canada's energy-intensive industries – commonly referred to domestically as "heavy industry" – include chemicals, steel and metals[1], pulp and paper, cement, and lime and gypsum[2]. In 2024, these industries generated 29% of the industrial sectors' economic output and 2.6% of Canada's total GDP. They employed around 245,000 people, representing 15.6% of the industrial workforce and roughly 1.3% Canada's total labour force (Statistics Canada 2025b).

Notably, Canada's industrial sector has made greater strides in reducing GHG emissions than the rest of the economy. Between 1990 and 2022, industrial emissions fell by 6.5%, while nationwide emissions increased by 16%. Relative to 2005 – the baseline year for Canada's climate targets – total national emissions decreased by 8.2% and industrial emissions by 7.4% (Canada 2024; ECCC 2025a).

Energy-intensive industries are central to Canada's economy, producing key materials required for construction, infrastructure and manufacturing. However, like in Germany, their production processes remain highly energy- and emission-intensive. In 2023, these sectors emitted 85 Mt CO_2eq, accounting for 12% Canada's total GHG emissions. The largest

[1] Only including primary metal manufacturing, not fabricated metal product manufacturing.

[2] The "heavy industry" category often includes mining, but we exclude it from our definition of energy-intensive industries, as it is classified as a primary industry.

contributors were the chemicals and petrochemicals industry (40 Mt), followed by steel and metals (24 Mt), cement, lime and gypsum (13 Mt) and pulp and paper (8 Mt) (Canada 2025).

Between 2000 and 2023, the combined emissions from these energy-intensive industries declined by 18.3%, while their economic output decreased just by 3.1%, indicating a partial decoupling of industrial emissions from growth (see Figure 4).

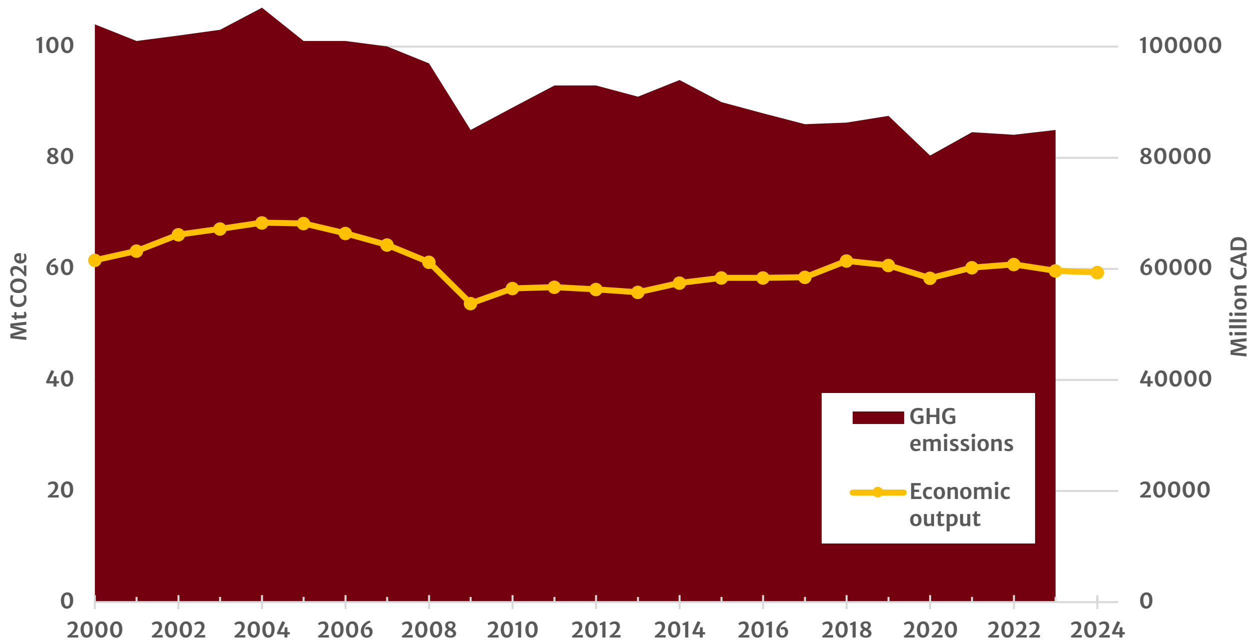

Figure 4: Canada's energy-intensive industries – GHG emissions and economic output, 2000-2024. Own depiction. Source: ECCC 2024, 2025; Statistics Canada 2025b. GHG emissions in million tonnes (Mt) CO2e. Economic output based on gross domestic product at basic prices by industry, seasonally adjusted in chained (2017) CAD. Industries included: basic chemicals, refineries, steel and metals, cement, lime and gypsum, pulp and paper.

3 Energy-Intensive Industries: Sector insights

The following chapters provide an in-depth analysis of four key energy-intensive industries in Germany and Canada, examining their sectoral characteristics, conventional production processes, economic importance in each country, and their respective climate and emissions profiles. These sectors rank among the highest-emitting secondary industries in both countries and are widely recognized as hard-to-abate, with particularly complex and challenging pathways to decarbonisation.

3.1 Chemicals and Refining

3.1.1 Sector Overview

The chemicals and refining industry produces a broad and diverse range of products. The chemicals sector can be divided into the production of basic chemicals – including fertilisers and nitrogen compounds, organic feedstocks, synthetic materials, inorganic precursors, pigments, and industrial gases – as well as the production of processed and formulated products, such as pesticides, paints and coatings, cleaning agents, and personal care products (Verpoort et al. 2024). The petrochemical industry, a subset of the basic chemicals sector, uses refined hydrocarbon products such as naphtha and ethane as feedstocks to produce high-value chemicals (HVCs) such as ethylene and propylene.

The chemical industry's production process is both complex and energy-intensive, making the industry one of the largest industrial contributors to GHG emissions. These emissions arise from two primary sources: energy use and process emissions, which occur during chemical and physical transformations that release CO_2 and other GHGs as byproducts.

Three production pathways dominate GHG emissions from basic chemicals:

- Ammonia production, responsible for approximately 45% of GHG emissions from the basic chemicals industry, typically involves the production of hydrogen through Steam Methane Reforming (SMR) of natural gas, followed by the Haber-Bosch process. This method is both energy-intensive and emits CO_2 as a byproduct of the reforming reaction. Ammonia is essential for chemical fertilisers and is also used in refrigerants, explosives, plastics and other chemicals (IEA 2025).
- Methanol production contributes roughly 28% of emissions from the sector. It is synthesised from syngas (a mixture of CO, CO_2, and H_2), which is produced from natural gas, coal or oil. Methanol serves as a building block for formaldehyde, acetic acid, and a wide range of resins and plastics (Tabibian and Sharifzadeh 2023).
- The production of HVCs such as ethylene, propylene, benzene, toluene, and mixed xylenes accounts for 27% of basic chemical emissions. HVCs are produced via steam cracking of fossil feedstocks, a process that requires extremely high temperatures (up to 870 °C) and thus large energy inputs. Ethylene, in particular, is a precursor for a wide variety of plastics and synthetic materials (IEA 2023; Verpoort et al. 2024).

A critical complexity in decarbonising the chemical industry lies in the dual role of fossil fuels: they serve both as energy sources and as feedstocks. Approximately half of the sector's total oil and gas use is not combusted for energy, but instead used as feedstock, making direct substitution challenging (IEA 2023a).

This dual dependence complicates emission reduction efforts, as it requires not only improving process energy efficiency and switching to low-carbon energy sources but also sourcing sustainable alternative feedstocks – such as biogenic carbon, green hydrogen, or captured CO_2 for chemical synthesis. In addition, scope 3 emissions remain high due to the carbon content of the chemical products, many of which release CO_2 at the end of their life cycle, particularly through disposal routes such like incineration (Agora Energiewende & Wuppertal Institut 2020).

In contrast to the petrochemical sector, the refining sector is primarily focused on converting crude oil into various hydrocarbon products, including "gasoline, diesel, jet fuel, and petrochemical feedstocks such as naphtha" (Aitani 2004). Refineries and chemical complexes are frequently co-located or integrated to optimize feedstock flows and energy use. The refining sector is the third-largest stationary source of GHG emissions (Ma et al. 2023). While the dominant source of these emissions is stationary fuel combustion – used to generate the high-temperature heat required for key processes such as distillation, cracking, coking and reforming – additional emissions arise from venting, flaring and fugitive leaks from equipment (EPA 2013).

3.1.2 Germany

Economic Relevance

The chemicals sector is a vital pillar of Germany's economy. In 2023, the industry generated a turnover of EUR 225.5 billion (CAD 334.8 billion) (2.2% of GDP in 2022) (Destatis 2024b). As of 2023, the sector employed around 480,000 people across 2,100 companies, many of which are located in one of Germany's 40 Chemical Parks. Major chemical hubs include North Rhine-Westphalia and the Rhine-Neckar region, with global players like BASF and Bayer headquartered there (VCI 2024a, c).

The most important chemical segments in Germany, based on 2023 production value, are fine and specialty chemicals (26%), pharmaceuticals (23%), polymers (18%), petrochemicals and derivatives (14%), inorganic basic chemicals (11%), and detergents and personal care products (7%) (VCI 2024a). Basic chemical production accounts for around 60% of total chemical output (Verpoort et al. 2024).

The chemicals industry has a strong multiplier effect, with each job creating approximately two additional jobs in the broader economy. Small and medium-sized enterprises (SMEs) play a crucial role, with 92% of companies employing fewer than 500 people. The petrochemical segment remains robust, contributing 16% of total production value in 2022 (VCI 2024b).

Germany ranks first in chemical production within Europe and third globally. In 2023, exports made up around 60% of the sector's total sales, with the European Union as the most important trading partner (Centurion Plus 2023). Key domestic customers include plastics processors (21%), the construction sector (17%), wood and furniture (10%), metal production and processing (9%), the automotive industry (7%), textiles and clothing (6%), and others (30%) (VCI 2024b).

However, the sector faces growing challenges. The high energy prices triggered by Russia's war in Ukraine, combined with structural problems such as tax burdens, bureaucratic hurdles, lengthy permitting procedures, and a shortage of skilled labour, has significantly affected the industry (Mewis and Zinn 2025). In 2023, the sector operated at only 77% of its capacity, with output levels 16% below pre-COVID levels (2018). Weak demand due to economic downturns in Germany and across Europe has further dampened profitability. By the third quarter of 2025, production in the German chemical industry was 1.5 percent lower than a year earlier, with the VCI expecting a 2 percent annual decline in chemical output partly offset by pharmaceuticals (VCI 2025).

Germany's refining sector also plays a significant role. It has the second-highest number of refineries and the largest crude oil refining capacity in Europe (Barthe et al. 2015). Currently, Germany operates 12 active refineries with a combined annual crude oil processing capacity of around 106 million tonnes. About 80% of refinery products are used as fuels for mobility and heating, with the remainder serving as petrochemical feedstocks and as other products such as lubricants, bitumen, and sulfur. In 2021, the refineries produced roughly 97.2 million tonnes of mineral oil products from around 84 million tonnes of crude oil (Artz et al. 2024).

Climate Targets and Progress

In 2022, the German chemicals and refining sector emitted 62.5 Mt CO_2eq, accounting for about 8.3% of Germany's total GHG emissions. From 2000 to 2022, the sector reduced its emissions by 23%, while its economic output increased slightly by 0.7% (see Figure 5). This reduction was primarily achieved through energy efficiency improvements, particularly advanced heat integration. Furthermore, the sector has decreased its dependence on fossil fuels by negotiating joint renewable energy procurement agreements within chemical parks. By 2045, the sector aims to achieve climate neutrality, in line with national climate targets (Dietrich et al. 2024).

The chemical industry accounts for around 8% of Germany's total energy demand and 22% of industrial energy demand. When the use of fossil fuels as feedstock is included, the sector's share rises to 30% of industrial energy demand. Since 1990, energy use in the sector has fallen by 22%, and CO_2 emissions have declined by 54% (VCI 2024a).

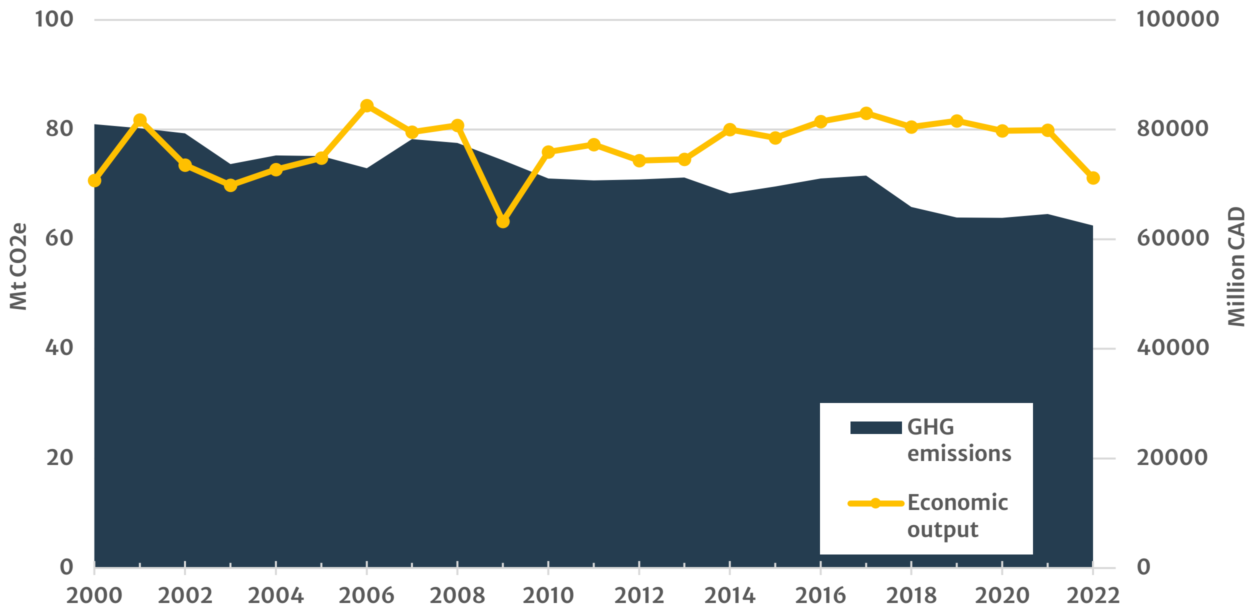

Figure 5: Germany's chemicals and refining sector – GHG emissions and economic output, 2000-2022. Own depiction. Source: Destatis 2025d, e; DEHSt 2006-2023. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross value added by industry, price-adjusted in chained (2020) EUR. Industries include basic chemicals, pharmaceuticals, and refineries and cokeries.

In 2022, basic chemical production alone was responsible for 39.6 million tonnes of CO_2-equivalent emissions – about two-thirds of the chemical industry's total and 23.6% of total industrial GHG emissions (KEI 2025b).

Refineries in Germany emitted 22.5 Mt CO_2eq in 2021, which corresponds to 19% of total industrial emissions – despite refineries representing only around 3% of Germany's industrial facilities. Accurate data on refinery energy demand is limited due to a lack of public reporting. Energy needs are largely met with oil and its products, varying significantly by site (acatech and DECHEMA 2023).

3.1.3 Canada

Economic Relevance

The chemical industry is a major contributor to Canada's economy, ranking as the third-largest industrial sector by revenue in 2023 (Statistics Canada 2024a). That year, the sector generated CAD 74.9 billion (EUR 50.5 billion) in turnover, accounting for around 1% of national GDP (Statista 2025e, Statistics Canada 2025).

As of 2023, Canada's chemical industry employed around 93,300 people, with each job in the sector supporting approximately five additional jobs across the broader economy (CIAC 2024). The industry comprised over 3,500 establishments, primarily small- to medium-sized companies, with major concentrations in Alberta and Ontario (440 Megatonnes 2025).

Canada's chemical industry includes a wide range of subindustries, including basic chemicals, synthetic resins and fibres, fertilisers and pesticides, pharmaceuticals, and formulated products such as paints and soaps. Domestically, the industry serves several key sectors, including manufacturers of plastic and rubber products, forest products, clothing, and construction materials, as well as the oil and gas extraction sector (CIAC 2024).

Canada is also a major exporter of chemical products. Most of Canada's chemical products are sold to international markets, with the United States being its largest trading partner. In 2023, chemical exports reached CAD 45.7 billion (EUR 30.8 billion) in 2023 (ISED 2024a). In total, 76% of Canadian chemical exports were destined for the United States (Statista 2025b).

Despite its export strength, Canada's chemical industry faces a range of challenges. High interest rates have dampened downstream demand, while slow global growth limits further expansion. The industry is also exposed to trade disputes with the United States, its largest export market. In addition, the sector must address the growing imperative to reduce emissions and shift toward low-emission products (CIAC 2025).

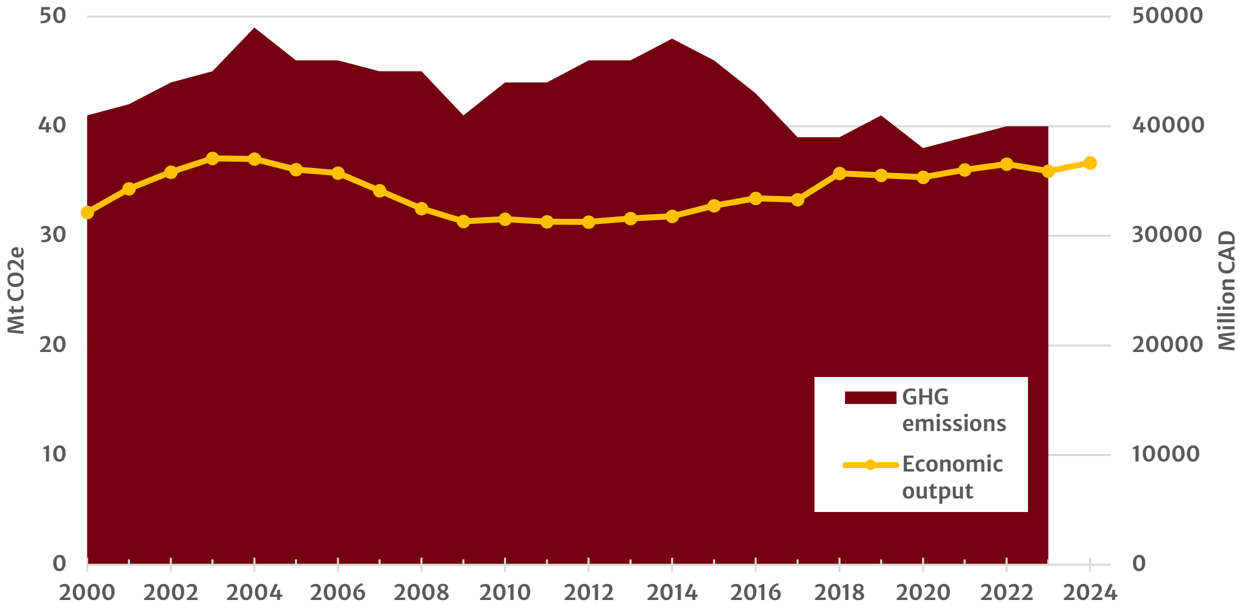

Figure 6: Canada's chemicals and refining sector – GHG emissions and economic output, 2000-2024. Own depiction. Source: ECCC 2024, 2025; Statistics Canada 2025b. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross domestic product at basic prices

Canada has a strong refining industry, ranking 11th globally in capacity (CER 2018). In 2021, the sector generated CAD 70.5 billion (EUR 47.6 billion) in revenue, contributing 0.6% to national GDP (ISED 2025a; Statistics Canada 2025b).

As of 2024, Canada operated 17 refineries with a total capacity of approximately 1.93 million barrels per day as of 2024 (CER 2025). Conventional light crude oil is mainly processed by refineries situated east of the Prairie Provinces, whereas refineries in the west process a larger proportion of oil sands crude than those in the east (CER 2018). Alberta has the largest share of refining capacity at 30%, followed by Ontario (21%) and Quebec (21%), New Brunswick (17%), Saskatchewan (8%), British Columbia (4%), and Newfoundland (1%) (CER 2025).

Climate Targets and Progress

In 2023, the Canadian chemicals and refining sector emitted 40 Mt CO_2eq – accounting for about 5.8% of Canada's total GHG emissions. (Environment and Climate Change Canada 2024). Between 2000 and 2023, the sector achieved a slight emission reduction of 2%, while its economic output increased by 12% over the same period (see Figure 6). These emission reductions were primarily achieved through investments in energy efficiency, as well as some degree of fuel switching (ibid.; 440 Megatonnes 2025). The Canadian chemical industry has committed to achieving net-zero emissions by 2050, in alignment with national climate goals (CIAC 2025).

In 2023, chemical manufacturing accounted for approximately 23 Mt CO_2eq, while refining operations contributed around 17 Mt CO_2eq. Furthermore, petroleum and coal product manufacturing and chemical manufacturing together made up 26.1% of total industrial energy consumption. Chemical manufacturing ranked as the fourth-largest industrial energy consumer in 2023, while petroleum and coal product manufacturing was the third-largest. (Statistics Canada 2024b). The chemical industry was also the largest consumer of natural gas.

3.2 Steel and Metals

3.2.1 Sector Overview

The steel and metals sector covers the production and processing of iron and steel, ferro-alloys, and non-ferrous metals such as aluminium, copper, nickel, lead and zinc. These materials form the foundation of industrial value chains across sectors like construction, manufacturing, automotive and energy.

Steel production primarily follows two routes: the Blast Furnace-Basic Oxygen Furnace (BF-BOF) route, which uses iron ore to produce new steel, and the Electric Arc Furnace (EAF) route, which uses recycled scrap steel. The BF–BOF route, used for 60% of steel production in the EU, is significantly more emission-intensive, relying heavily on coal as a reducing agent to extract iron from iron ore and to provide the carbon required to produce steel (IEA 2023).

The BF-BOF process begins with the conversion of coal into coke in coking ovens at 1,100°C, releasing impurities and CO_2 emissions. In the next step, iron ore is reduced to pig iron using coke and limestone in a blast furnace at temperatures of around 1,650°C. This molten iron is then transferred to the Basic Oxygen Furnace, where oxygen is blown through the liquid metal to remove impurities and adjust the carbon content, producing steel (LUX Metal 2025).

Each stage of this process releases significant CO_2 emissions, both from the combustion of fossil fuels and from the chemical reactions involved. Moreover, blast furnaces must operate continuously, as shutdowns risk damaging the furnace, which magnifies their overall emissions impact. The EAF route, by contrast, primarily uses scrap metal and electricity to melt steel, resulting in significantly lower emissions. Globally, the iron and steel industry accounts for 11% of CO_2 emissions (Lempriere 2023).

Non-ferrous metals are generally produced in smaller volumes compared to steel but often involve more energy-intensive processes, particularly in primary production (IPCC 2007). Like steel, non-ferrous metals can be manufactured from either primary or secondary (recycled) materials. Primary production begins with the extraction and initial processing of ores, which typically takes place in the country of origin.

A typical non-ferrous metal smelting facility includes several stages: raw material handling, pre-treatment processes such as roasting, sintering, or blending, and smelting in furnaces. Once in molten form, the metal undergoes further purification through thermal treatment in converters, rotary kilns, or induction furnaces. Electrolytic refining is also commonly used to achieve high purity before the metal is cast into bars, ingots, or semi-finished products (EPA 2025).

Aluminium production follows a slightly different path, as both smelting and electrolysis occur within specialized electrolysis cells. The resulting aluminium is then alloyed and processed into semi-finished goods.

Secondary (recycled) production of non-ferrous metals involves mechanical processing of scrap, followed by remelting and refining. These steps often take place within the same facilities and closely resemble the procedures used in primary production. Emissions are generated at nearly every stage of non-ferrous metal production, with fine dust particles – often containing heavy metals – posing a particularly significant environmental hazard (Umweltbundesamt 2024c).

3.2.2 Germany

Economic Relevance

Germany is the largest steel producer in Europe and ranks seventh globally (World Steel Association 2025). In 2023, the country produced 35.4 million tonnes of crude steel, generating a turnover of EUR 50.6 billion (CAD 75.1 billion) (Eurometal 2024; Statista 2025c). The sector contributed 2.2% to GDP in 2022 (Destatis 2024b). Of this output, 70% was primary steel, and 30% was secondary steel. The sector directly employs around 80,000 people, while over 4 million people work in steel-intensive industries across Germany. There are 25 steel production facilities in Germany, predominantly located in the country's industrial regions, particularly in the west (WV Stahl 2023). The largest German steelmaker is Thyssenkrupp, followed by Arcelor Mittal and Salzgitter (BMWE n.d.).

Germany exported 25.5 million tonnes of steel in 2023, making it the fourth-largest steel exporter worldwide (World Steel Association 2024). Domestically, two-thirds of steel demand comes from the construction and automotive sectors. Other major consumers include mechanical engineering, electrical engineering and the metal goods industry (WV Stahl 2024).

Germany is also a major producer of non-ferrous metals and hosts the second-largest number of non-ferrous production facilities in Europe (Wyns and Khandekar 2019). In 2023, the sector produced 5.9 milllion tonnes of non-ferrous metals in 2023, generating a revenue of EUR 64.3 billion (CAD 95.5 billion). The non-ferrous metals industry employed 107,000 people across 630 companies (WV Metalle 2024). When including indirect jobs, the non-ferrous metals industry supports around 245,000 jobs in Germany. Of the revenue, EUR 34.1 billion (CAD 50.6 billion) was generated through domestic offtake, while EUR 30.2 billion came from exports to foreign markets.

However, the steel and metals sector is facing several challenges, including rising energy prices, reduced demand from key sectors such as automotive and construction, increased competition from Asian imports, and the need to implement structural changes for climate-friendly production methods (WVS 2024).

By 2023, crude steel production had declined by 12% compared to pre-crisis levels in 2021 – falling from 40.2 million tonnes to 35.4 million tonnes – marking

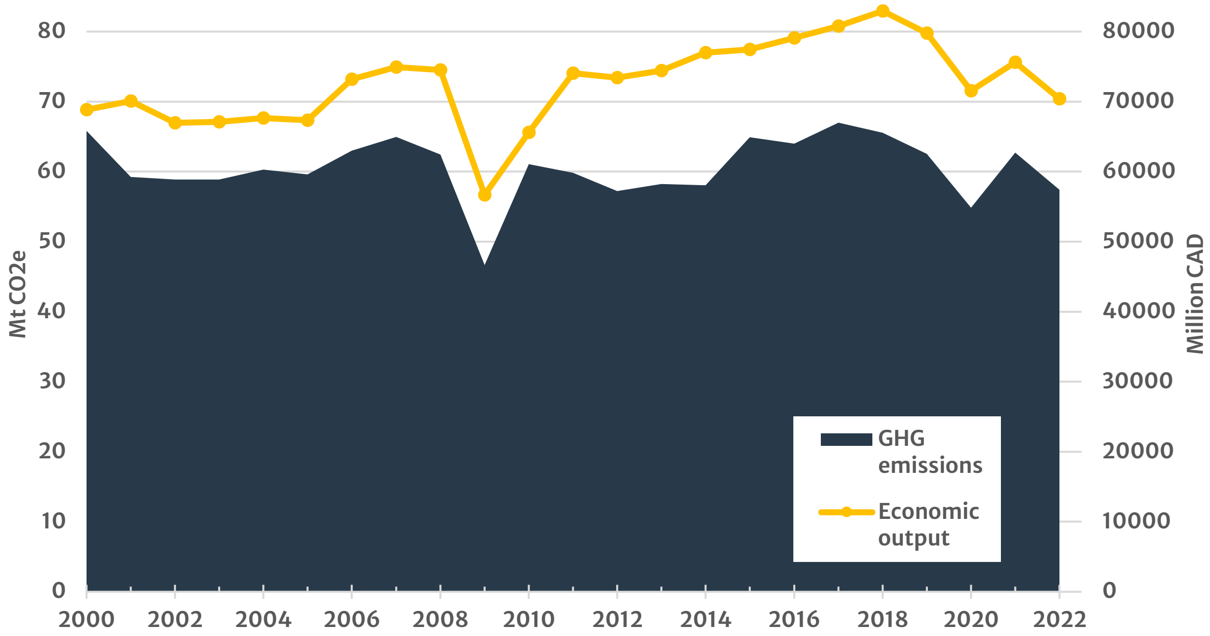

Figure 7: Germany's steel and metals sector – GHG emissions and economic output, 2000-2022. Own depiction. Source: Destatis 2025d, e; DEHSt 2006-2023. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross value added by industry, price-adjusted in chained (2020) EUR. Industries include production and processing of ferrous and non-ferrous metals.

the weakest output year since the 2009 financial crisis (WVS 2024; GMK Center 2024). The non-ferrous metals sector experienced an even steeper decline, with a 16% drop in production over the same period (WV Metalle 2022, WV Metalle 2024).

Climate Targets & Progress

In 2022, Germany's steel and metals sector emitted 57.4 Mt CO_2eq, accounting for about 7.7% of the country's total GHG emissions (Destatis 2025e). Of these emissions, 95% originated from iron and steel manufacturing, while the remaining 5% came from the non-ferrous metals sector. Between 2000 and 2022, the steel and metals sector reduced its emissions by 13%, while its economic output remained relatively stable, rising slightly by 0.2% (see Figure 7). Emissions from the steel industry alone accounted for 29% of Germany's total industrial emissions in 2022. Of this share, 69% were energy-related and 31% were process-related (KEI 2025c). The BF-BOF route accounted for roughly 46% of hard coal consumption in Germany in 2022.

Between 2000 and 2022, the steel industry reduced its emissions by 8% (Destatis 2025b), mainly through efficiency improvements in both integrated and electric steelmaking routes. Significant emission reductions were achieved by increasing the share of scrap used in crude steel production. However, the BF-BOF route has now reached its limit in terms of emissions reduction. Consequently, German steelmakers are increasingly turning to the direct reduced iron–electric arc furnace (DRI-EAF) route, though this transition is still in early stages (KEI 2025c).

The non-ferrous metals industry – starting from a lower emissions base – has been more successful in reducing GHG emissions. Between 2000 and 2022, it achieved a 75% reduction in emissions (KEI 2025d). This progress has been largely driven by the increasing use of recycled materials, which enable more energy-efficient production. The share of secondary raw materials in primary aluminium production is 58%, while in copper production it has reached 44% (KEI 2025d).

3.2.3 Canada

Economic Relevance

Canada's steel and metals sector plays a significant role in the economy, albeit on a smaller scale compared to Germany. In 2024, the sector accounted for 0.5% of the country's total GDP (Statistics Canada 2025b) and ranked as the seventh-largest manufacturing sector in Canada (CWB Group 2024). In 2023, it employed nearly 54,600 people, primarily in Ontario and Quebec.

Iron and steel production alone contributed 0.2% to Canada's GDP. In 2023, the steel industry produced approximately 12.3 million metric tonnes of crude steel (World Steel Association 2024). The sector provides over 23,000 direct jobs, with estimates suggesting that each of these supports between 3.3 and 7 additional jobs in the broader economy – translating to 80,000 to 160,000 indirectly supported jobs (USW 2024). The largest steelmakers in Canada are ArcelorMittal SA, Stelco Inc., and Algoma Steel Inc. (ITA 2025).

In 2024, Canada ranked as the world's sixteenth largest steel exporter, shipping 6.4 million metric tonnes abroad. The United States is the top destination, receiving 95% of Canadian steel exports, followed by Mexico and Bangladesh (ITA 2025). The steel industry is a critical supplier to key sectors within the Canadian economy, including automotive, energy, construction, and transportation (USW 2024).

The non-ferrous metal sector is also economically significant. The aluminium industry accounts for 0.2% of GDP, while other non-ferrous metal production contributed 0.1% (Statistics Canada 2025). Canada ranks fourth globally in aluminium production (AAC n.d.), with a total output of 3.3 million tons of primary aluminium. In 2024, 11,250 people were employed in aluminium production and processing, and another 11,280 worked in other non-ferrous metal production and processing (Statistics Canada 2025a). Across the country, there are about 50 non-ferrous metal production facilities (ISED 2025b; AAC 2025).

Canada's steel and metals sector experienced a GDP decline of 12.3% following the Covid-19 pandemic, falling from $12.7 billion in 2019 to $11.1 billion in 2020. Since then, output has not returned to pre-pandemic levels. Employment in the sector declined by 5.6% between 2019 and 2023, dropping from approximately 58,000 to 54,600 workers. The industry faces a number of challenges, including economic uncertainty, labour shortages, ongoing trade disputes with the United States (with 92% of Canadian aluminium exports going to the U.S.), geopolitical tensions, competition from low-cost imports – particularly from China – and stringent environmental regulations (CWB Group 2024).

Climate Targets & Progress

In 2023, Canada's steel and metals industry emitted 24 Mt CO_2eq, accounting for 3.5% of the country's total GHG emissions. Between 2000 and 2023, the sector reduced its emissions by 31%, while its economic output declined by 14%, indicating a moderate decrease in emission intensity (see Figure 8).

Metal manufacturing was the second-largest industrial energy consumer in 2023 (Statistics

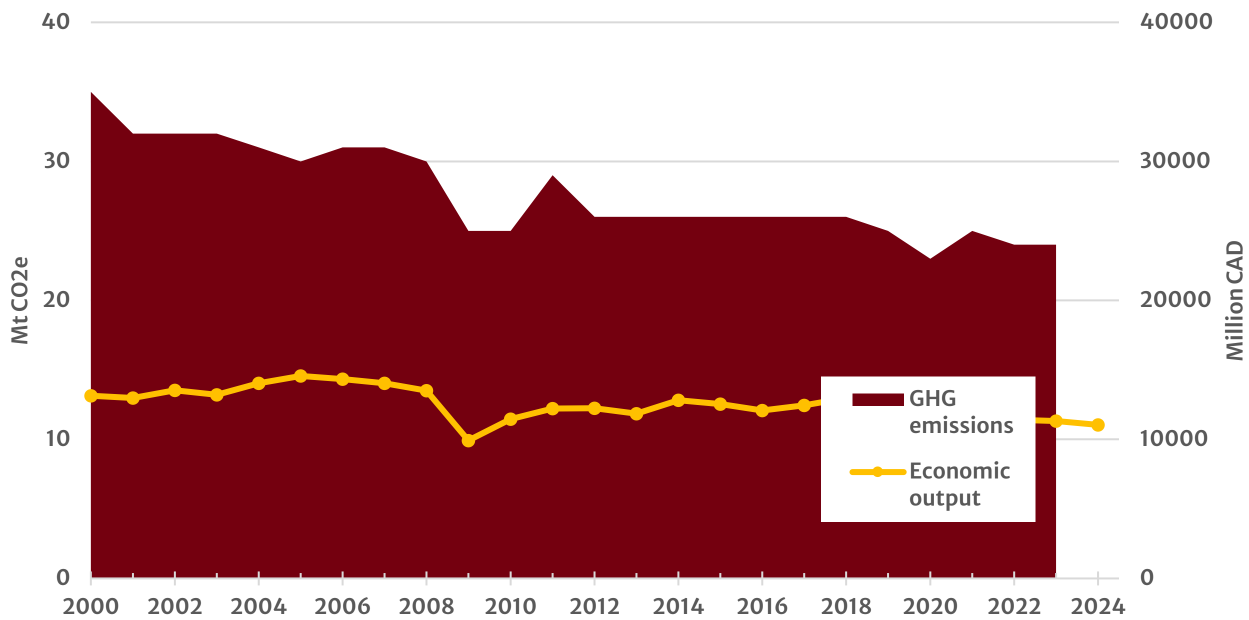

Figure 8: Canada's steel and metals sector – GHG emissions and economic output, 2000-2022. Own depiction. Source: ECCC 2024, 2025; Statistics Canada 2025b. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross domestic product at basic prices by industry, seasonally adjusted in chained (2017) CAD. Industries included: primary metal manufacturing.

Canada 2024c). Nonetheless, Canada's steel industry has significantly improved operational and energy efficiency in recent decades through better performance, energy management (including heat and by-product recovery with cogeneration), and more efficient production and raw material use. As a result, Canada now has the lowest GHG intensity for integrated steelmaking plants and the second-lowest for electric arc furnace plants among the ten largest steel-producing countries (CSPA 2021).

Similarly, the Canadian aluminium industry has one of the lowest carbon intensities globally, with an energy intensity per unit of production below the global average (AAC 2025). The steel and metals sector is committed to achieving climate neutrality by 2050, in line with Canada's national climate targets (NRCan 2025a).

3.3 Cement and Lime

3.3.1 Sector Overview

Cement and lime are essential to the modern economy. Cement is used in construction and civil engineering, while lime plays a critical role in the steel industry, as well as in the production of construction materials, paints, plastics and rubber (DG Grow 2025). Both products are highly emission-intensive due to their reliance on raw materials that release CO_2 during processing, combined with the high heat requirements of their production (Calix 2025).

The cement production process begins with quarrying limestone and clay, followed by grinding, blending, and feeding into a rotary kiln. The resulting cement clinker, rich in calcium silicates, is then ground and mixed with additives like gypsum to produce the final cement. In cement production, around 60% of CO_2 emissions stem from the calcination of limestone (calcium carbonate), which releases CO_2 when decomposed into lime (calcium oxide) at high temperatures. These are referred to as process-emissions. The remaining 40% comes from the combustion of fossil fuels used to heat kilns to 1,400–1,500°C (Mason and Lea 2025; Fennell et al. 2021).

Lime production, by contrast, involves a simpler process. It uses limestone as the sole raw material, which is heated in kilns at about 900–1,200°C. The thermal decomposition (calcination) of calcium carbonate yields quicklime (CaO) and CO_2. Although similar in its use of limestone and thermal requirements, lime production differs from cement production in that it produces a single product (lime) rather than clinker, and it is not blended with additional materials during production (MPA 2025).

3.3.2 Germany

Economic Relevance

Germany's cement and lime industry contributed less than 0.6% to national GDP in 2022 (Destatis 2024b). In 2023, the cement sector generated EUR 3.8 billion (CAD 5.6 billion) in revenue, producing 28.2 million tonnes of cement. The lime industry produced 6 million tonnes (Mt) of lime in 2021, with revenues of EUR 700 million (CAD 1 billion) (Bundesverband Kalkindustrie n.d.).

The cement sector employs about 8,000 people across 54 plants operated by 21 companies., including major players like Heidelberg Materials and Holcim as well as several medium-sized enterprises. Production is concentrated in southern and western Germany (Statista n.d.a; VDZ e.V. 2023; VDZ e.V. n.d.). In 2018, 57% of cement was supplied to domestic concrete producers, and 22% to manufacturers of concrete products. In 2023, Germany was Europe's second-largest cement exporter, with exports worth EUR 634 million (CAD 944 million), primarily to neighbouring countries like the Netherlands, Austria, and Poland (Statista n.d.b.; VDZ e.V. 2024).

The lime industry comprises 50 companies operating over 100 lime kilns and employing 3,100 people. Current production is around 6.4 Mt annually (Bundesverband Kalkindustrie n.d.). Major consumers include the iron and steel industry (2.1 Mt), construction (1.3 Mt), environmental protection (1.1 Mt), and other industries (0.7 Mt).

Both sectors have faced major headwinds in recent years, largely due to the economic fallout of Russia's war in Ukraine. Higher interest rates and inflation have weakened investment in construction and infrastructure, reducing demand for cement and lime (VDZ e.V. 2023; Bundesverband Kalkindustrie 2024).

Climate Targets & Progress

In 2022, the German cement and lime sector emitted 22.9 Mt CO_2eq – about 3.1% of the country's total GHG emissions. Cement alone accounted for 11% of Germany's industrial emissions, and lime for 4% (KEI 2025e). Despite stable output, emissions have fallen 23% since 2000 (see Figure 9).

The cement industry has pursued emission reductions for decades through various strategies.

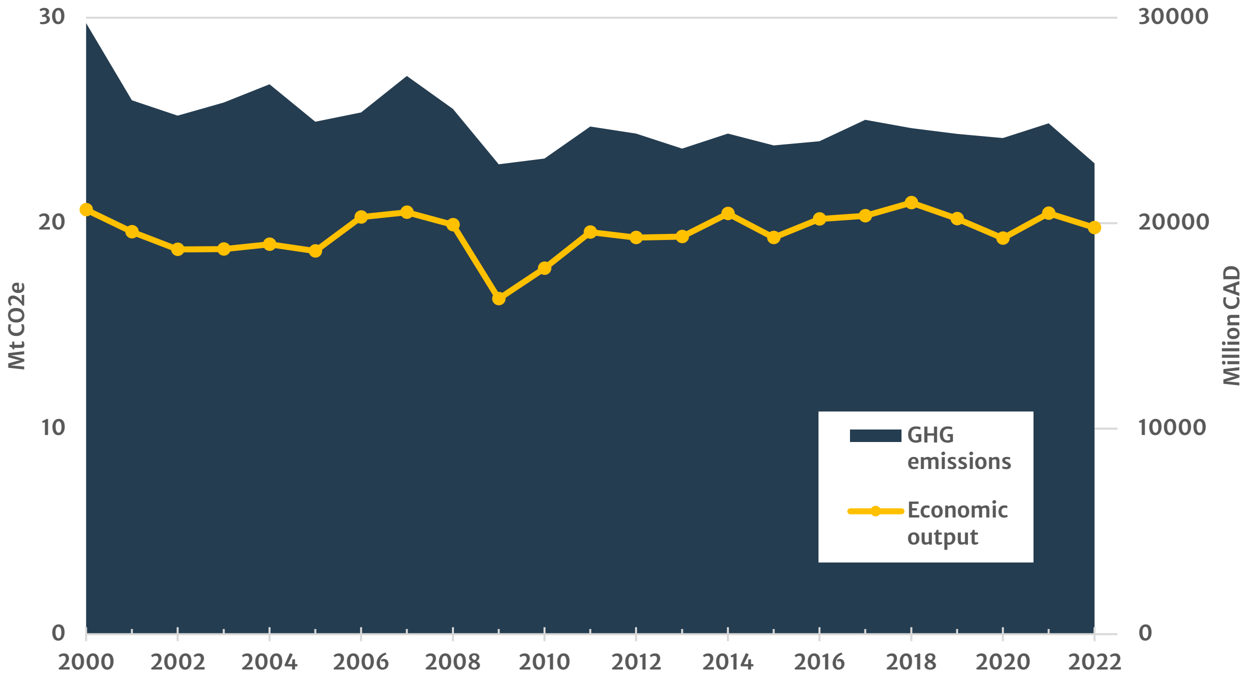

Figure 9: Germany's cement and lime sector – GHG emissions and economic output, 2000-2022. Own depiction. Source: Destatis 2025d, e; DEHSt 2006-2023; VDZ e.V. 2001-2005. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross value added by industry, price-adjusted in chained (2020) EUR. Due to data limitations, the economic output figures represent the entire "mineral processing, glass, and ceramics industry". Emissions data are provided specifically for cement and lime production.

These include improving energy efficiency (e.g. waste heat recovery and optimized electricity use), lowering the clinker content in cement, and replacing fossil fuels with alternative fuels, such as waste-derived materials or biomass (Climate Analytics 2025).

In the lime sector, roughly two-thirds of emissions stem from the calcination process–where CO_2 is chemically released from limestone at high temperatures. These process-related emissions are unavoidable. The remaining third is energy-related, resulting from fuel combustion to generate high heat.

3.3.3 Canada

Economic Relevance

Canada's cement and concrete sector contributed 0.2% of national GDP in 2023 (Statistics Canada 2025b) and has a comprehensive annual economic impact – direct, indirect and induced – of approximately CAD 76 billion (EUR 51.3 billion) (ISED 2022). Revenue reached CAD 11.2 billion (EUR 7.6 billion) in 2023, marking a modest 1.05% average yearly growth over the past decade (ReportLinker n.d.a).

The sector supports around 166,000 direct and indirect jobs across 1,564 establishments, with 96% classified as small businesses (ISED 2024c). The leading cement producers are Lafarge Canada, CRH Canada Group, and Heidelberg Materials. Canada was the world's 6th largest cement exporter in 2023, exporting CAD 784 million (EUR 526 million) mainly to the United States. Domestically, production primarily serves residential and non-residential construction markets (IBISWorld 2025a).

Looking ahead, the cement market is projected to grow by over 6% by 2030 (Bonafide 2024). Nonetheless, the industry faces challenges: substantial investment is needed for decarbonisation to meet environmental regulations (CAC 2023), and ongoing trade disputes with the U.S. could disrupt exports and raise costs (CemNet 2025).

Canada's lime sector is small but regionally significant, comprising 17 employer establishments nationwide in 2023, with the vast majority (76.5%) categorized as small firms employing 5–99 people, alongside modest numbers of micro- and medium-sized operations (ISED 2023).

Climate Targets & Progress

In 2023, Canada's cement, lime and gypsum industries collectively emitted 13.2 Mt CO_2eq, representing 1.9% of national GHG emissions (ECCC

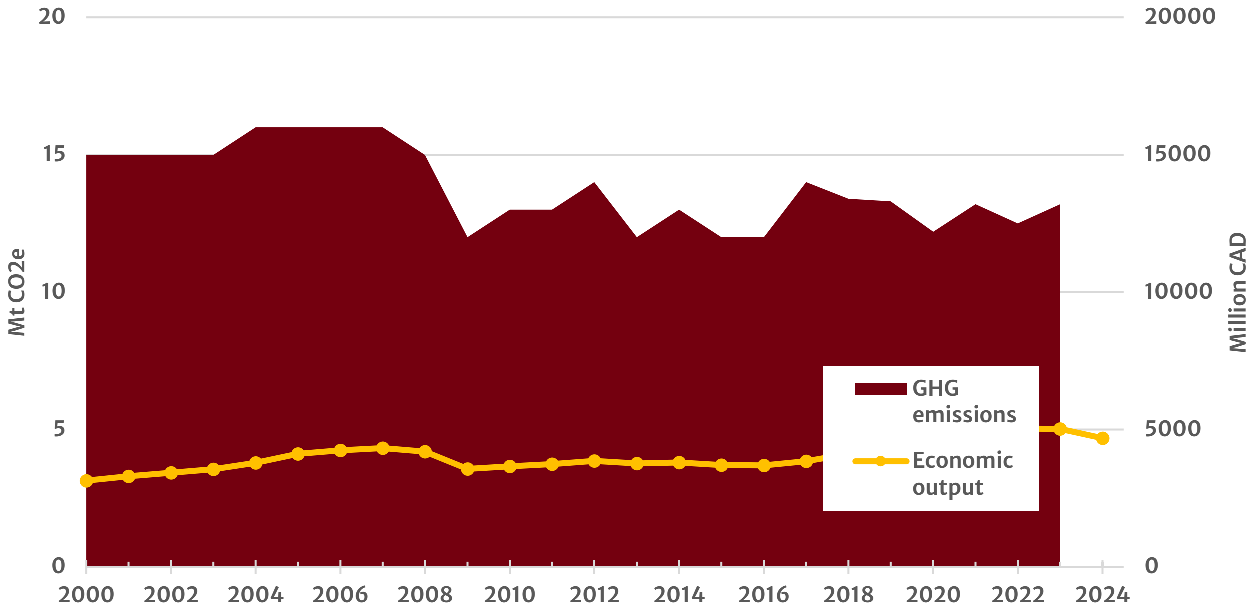

Figure 10: Canada's cement and lime sector – GHG emissions and economic output, 2000-2024. Own depiction. Source: ECCC 2024, 2025; Statistics Canada 2025b. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross domestic product at basic prices by industry, seasonally adjusted in chained (2017) CAD. Industry categories include "cement and concrete" for economic output and "cement, lime and gypsum" for GHG emissions.

2024, 2025). From 2000 to 2023, emissions dropped by 12%, while economic output increased by 60%, showing a strong decline in emission intensity (see Figure 10).

The cement sector improved energy efficiency by 20% over three decades and introduced Portland-limestone Cement, which cuts emissions by up to 10% versus conventional cement (CAC 2023). Now, the industry is advancing efforts by reducing clinker content, increasing use of alternative fuels like engineered biomass, and deploying CCS/CCU (carbon capture, utilization, and storage) technologies. However, fuel substitution stands at under 10% (as of 2020), well behind Europe's 40%+ average (ibid.)

Compared to cement, decarbonization in Canada's lime industry is less documented, but generally follows similar process fundamentals as described above. While precise numbers for energy or emission reductions in lime production aren't publicly available, the sector is engaged in decarbonization through efficiency improvements and collaboration via Canadian Industry Program for Energy Conservation (CIPEC) (see Section 4.2.3).

3.4 Pulp and Paper

3.4.1 Sector Overview

The pulp and paper industry converts raw wood materials into a wide range of paper-based products through several energy- and process-intensive steps. Every day, around 3,000 different types of paper, board, and cardboard – made from wood and pulp – are in circulation. These products are essential in modern life: as packaging materials, they enable the safe transport and protection of goods; as printed media, they are indispensable in publishing, and they play a crucial role in hygiene as tissues, kitchen towels, and toilet paper.

Paper production begins with the harvesting of trees, which are debarked and chipped at mills. The resulting wood chips are processed into pulp using either mechanical or chemical methods. Chemical pulping – commonly through the kraft process – uses heat, pressure, and chemicals to break down lignin and extract cellulose fibres. This process is particularly energy- and water-intensive and is primarily used for non-recycled paper. Mechanical pulping, by contrast, uses grinding to separate fibres and retains more of the original wood components, resulting in lower-strength, coarser paper used for products like newspaper (Vector Solutions 2024).

Once pulped, the material is washed, screened, and sometimes bleached to improve brightness. The pulp is then diluted with water and spread onto wire screens to form continuous sheets, which are then pressed and dried using steam-heated cylinders. Additional processing steps, such as calendaring and coating, may follow before the product is converted into its final form, e.g. packaging, printing paper, or hygiene articles (Deskera n.d.).

This entire process demands significant amounts of energy, especially for pulp drying, steam production, and chemical recovery. Many production sites are integrated mills, combining pulp and paper production, which allows for internal energy recovery but also increases overall energy intensity.

The pulp and paper industry is a major industrial consumer of energy and a notable source of GHG emissions. The most emissions-intensive stages of production include pulping, paper machine operations, and on-site energy generation. The scale of emissions largely depends on the fuel and electricity sources used. The primary sources of emissions are:

- Heat and power generation, which relies heavily on fossil fuels like natural gas, coal, and oil to produce process heat and steam– especially for drying, the most energy-intensive step.
- Chemical pulping, which emits greenhouse gases through the combustion of byproducts such as black liquor in recovery boilers.
- Mechanical pulping, which is highly electricity-intensive and thus emissions-heavy when powered by fossil-based grids.
- Bleaching and finishing, which also consume thermal and electrical energy, though to a lesser extent.

Overall, the sector's carbon footprint is strongly shaped by its energy mix and technological choices. As such, decarbonization strategies focus on improving energy efficiency, electrifying heat processes, shifting to renewable fuels, and deploying technologies like high-temperature heat pumps and thermal storage (IEA 2023b).

3.4.2 Germany

Economic Relevance

Despite recent challenges, Germany's pulp and paper industry continues to play a significant role in the country's industrial landscape. In 2023, the sector generated a turnover of EUR 15.5 billion (CAD 23 billion), producing 18.6 million tonnes of paper and board – making Germany the largest paper producer in Europe (Statista n.d.c.; SunSirs 2024). It employs around 46,000 people across nearly 150 paper mills, comprising a mix of integrated pulp and paper sites and just four dedicated pulp mills (IBISWorld 2024; SunSirs 2024). The industry primarily serves the domestic market, with 58.9% of total production used for packaging applications (Die Papierindustrie e.V. 2023).

The sector's structure is shaped by its strategic integration with other industrial value chains. Paper is essential across a wide spectrum of downstream sectors, including food and pharmaceutical packaging, publishing, hygiene, logistics, and e-commerce. About 85% of production remains within the EU, underscoring its regional relevance.

However, the industry is currently under pressure from several directions. In 2023, production volumes dropped by 14% compared to the previous year – the lowest output in over two decades – while revenues fell by 27% (SunSirs 2024). This sharp contraction reflects the broader slowdown of the German economy: falling industrial output and weak consumer spending directly reduced demand both for packaging and advertising material, two major products in the sector (Die Papierindustrie e.V. 2024). At the same time, structural changes continue to reshape the market – especially digitization, which has led to sustained decline in demand for graphic papers. Nonetheless, innovative paper-based packaging solutions may offer growth as the economy recovers, providing sustainable alternatives to plastic packaging (Birkner's PaperWorld 2024; Cepi 2023).

Climate Targets & Progress

In 2022, Germany's paper and pulp sector emitted 13.7 million tonnes CO_2eq, accounting for 1.8% of national GHG emissions and 7% of industrial emissions. Unlike other energy-intensive industries, the sector's process-related emissions are comparatively small; the vast majority of emissions arise from energy use, particularly for steam and heat generation.

Between 2000 and 2022, emissions from the sector increased by 26%, while economic output grew by 5% (see Figure 11). This development is primarily driven by an expansion in overall production, which has outpaced gains in energy efficiency. In 2022, production was 19% higher than in 2000, and 69% higher than in 1990, offsetting progress made in reducing energy consumption (Labelprint24 n.d.).

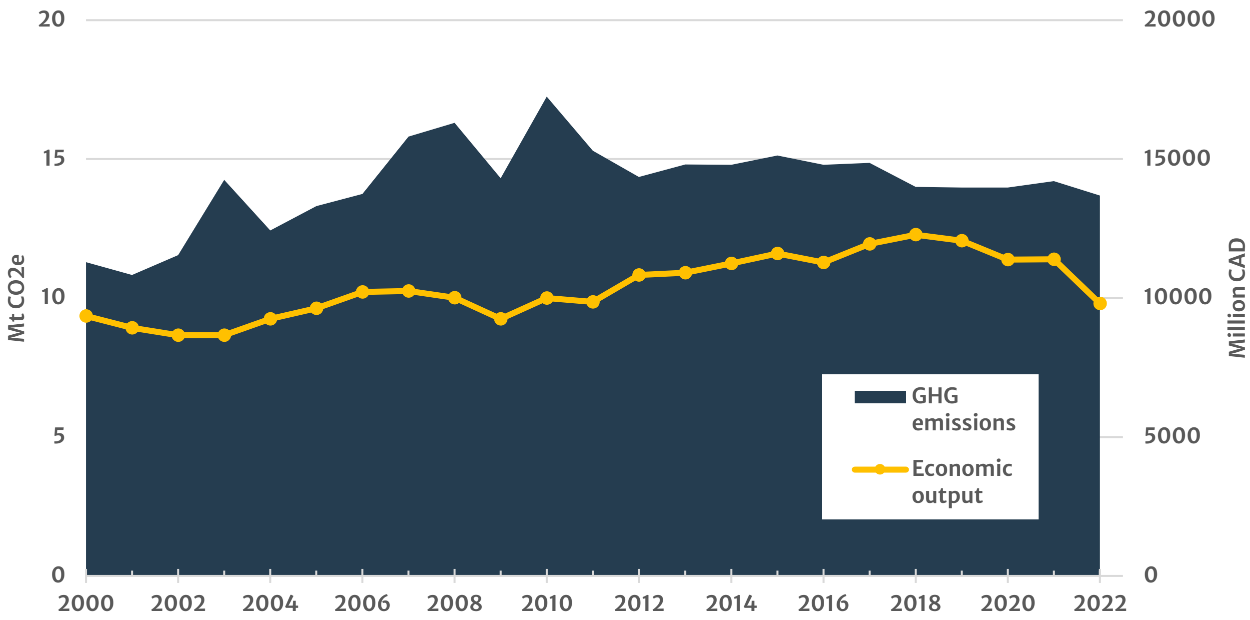

Figure 11: Germany's pulp and paper sector – GHG emissions and economic output, 2000-2022. Own depiction. Source: Destatis 2025d, e; DEHSt 2006-2023. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross value added by industry, price-adjusted in chained (2020) EUR.

Despite this trend, significant progress has already been made in terms of switching energy supply. Around 50% of the sector's energy needs are now met by renewable sources, supported largely by combined heat and power (CHP) plants. These plants cover around 42% of electricity demand and more than 80% of heating requirements through on-site generation, reducing dependency on external fossil-based energy (Die Papierindustrie e.V. 2024b; Energynest 2023).

The increasing use of wastepaper also plays a critical role in reducing the sector's carbon footprint. In 2023, the recycling rate reached 83%, up from 49% in 1990, contributing to a reduction in primary energy use, as well as lower wood and water consumption. Between 1955 and 2020, the sector reduced its energy input per tonne of paper by 66.5%, reflecting continuous efficiency gains over the long term (Umweltbundesamt 2024e).

3.4.3 Canada

Economic Relevance

Canada's pulp and paper industry remains a significant contributor to the national economy, despite ongoing structural challenges. In 2023, the sector generated CAD 22 billion (EUR 14.8 billion) in revenue and contributed approximately CAD 7.4 billion (EUR 5 billion) to Canada's real GDP – representing 0.3% of GDP, down from 0.9% in 2000 (ReportLinker n.d.b). This reflects a long-term decline in economic output as demand for certain paper products, particularly newsprint, continues to shrink amid accelerating digitalization (Statistics Canada 2025b).

The industry comprises around 80 pulp and paper mills across the country, employing approximately 20,000 people. Production is concentrated in key provinces with rich forest resources, notably British Columbia, Quebec, and Ontario, Alberta and New Brunswick. Mills are typically located in small towns, where they play a critical role in regional employment and economic activity by converting forest biomass into pulp, paper, and related products (440 Megatonnes 2024).

Canada is also a major exporter of pulp and paper. In 2023, the sector exported roughly CAD 13.6 billion (EUR 9.2 billion) worth of products, with the United States as the dominant trading partner (Statista 2024b). Other important destinations include the Netherlands, France, and Spain (WITS n.d.). Domestically, production focuses on newsprint, sanitary paper, and specialty papers. used in industrial and consumer applications (IBISWorld 2025b).

Although the sector experienced a 45% decline in economic output between its peak in 2004 and 2018, it continues to adapt by shifting toward value-added products, sustainable production, and bio-based innovations to stay relevant in a changing global market (CER 2019).

Climate Targets & Progress

In 2023, Canada's pulp and paper sector emitted approximately 8 Mt of CO_2eq, accounting for around 1.1% of national GHG emissions. While the industry reduced its emissions by 40% since 2000, this decline is largely attributable to a 47% decrease in economic output over the same period – indicating little progress in reducing emission intensity.

The sector has focused its decarbonisation efforts primarily on implementing energy efficiency measures and switching to less emission-intensive fuels. Companies have increased the use of biomass, switched to gas-fired boilers, and increasingly utilized hydroelectric power (Pulp & Paper Canada 2022). The increased use of cogeneration (combined heat and power) has also helped optimize energy use, though it has contributed to higher direct emissions at mill sites (440 Megatonnes 2024).

Despite these measures, the decline in emissions is largely a byproduct of reduced production levels, rather than a transformation in process efficiency or technology deployment. As of 2023, paper manufacturing remained the largest industrial energy consumer in Canada, underscoring the sector's continued reliance on high levels of thermal and electrical energy for processes such as pulping, drying, and chemical recovery (Statistics Canada 2025b).

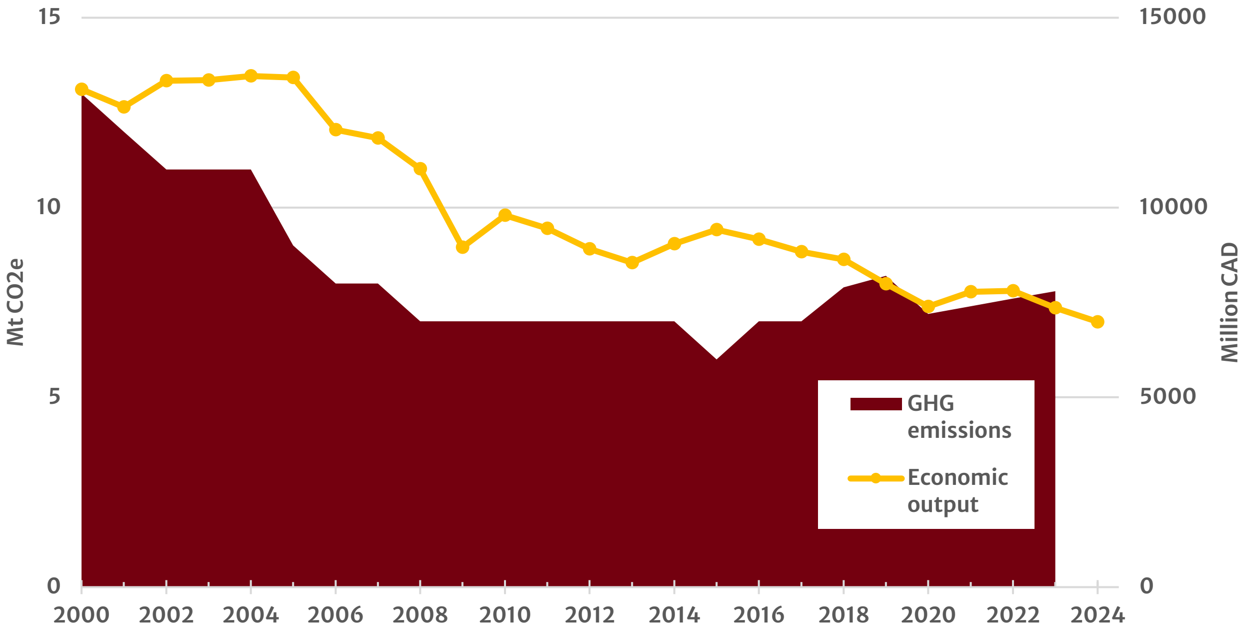

Figure 12: Canada's pulp and paper sector – GHG emissions and economic output, 2000-2024. Own depiction. Source: ECCC 2024, 2025; Statistics Canada 2025b. GHG emissions in million tonnes (Mt) CO_2eq. Economic output based on gross domestic product at basic prices by industry, seasonally adjusted in chained (2017) CAD.

4 Transformation Pathways

4.1 Technologies and Solutions

4.1.1 Electrification

Electrification refers to the replacement of fossil fuel-based production plants, technologies, or processes with those that directly use electricity. When the electricity is generated from renewable or climate neutral sources, industrial emissions can be significantly reduced (IEA 2023c). Additionally, electrified processes typically have a higher efficiency factor than those based on fossil fuel combustion, resulting in an overall reduction of energy demand (Jörg et al. 2024).

In heat generation, electrification technologies such as electric boilers and high-temperature heat pumps have the potential to replace most fossil fuel-based systems for low- to high-temperature heat (Agora Energiewende 2020, McKinsey 2024). While technical and economic feasibility for high-temperature applications have long been a concern, recent technological advances demonstrate that electrified systems can also meet these needs (McKinsey 2024). Electrification technologies for low- and medium-temperature heat are already commercially available, while solutions for high-temperature processes range in maturity. Power-to-heat plants offer the additional advantages by utilising excess heat and achieving greater efficiency through more precise heat generation compared to conventional combustion processes (Agora Energiewende 2020).

In energy-intensive industries, several examples of electrification technologies exist. In the chemical sector, electric steam crackers can replace conventional cracking in refineries and basic chemicals production. In cement production, electrified calciners can substitute fossil-fuel driven technology for clinker production. In steel manufacturing, electric arc furnaces can melt directly reduced iron into steel, replacing basic oxygen converters. In the pulp and paper industry, high-temperature heat generation can shift from combined heat and power plants to electric boilers and heat pumps (Agora Energiewende 2020).

Despite its benefits, widespread electrification of industrial plants and processes faces several challenges. First of all, there is the need to redesign or completely change entire production processes, which may require capital-intensive investments in new equipment and machinery. A significant barrier is also today's cost advantage of fossil fuels such as natural gas compared to electricity in many regions, leading to higher operating costs for electrified processes (Energy Innovation 2025).

In Germany, electricity prices for large industrial consumers averaged EUR 14.4 ct/kWh (CAD 23 ct/kWh) in 2025, compared to EUR 4.5 ct/kWh (CAD 7,3 ct/kWh) for natural gas (BDEW 2026; Destatis 2025f). In Canada, the gap is even larger, with electricity prices for industry ranging from CAD 5.69 to 14.60 ct/kWh (EUR 3.5 to 9.0 ct/kWh) in 2024, depending on the province, while the natural gas price for industrial consumers was approximately EUR 0.86 ct/kWh (equivalent to CAD 1.31 ct/kWh or 13.9 ct/m^3 in 2021, the latest available data) (NRCan 2025b; Statistics Canada 2023).

Securing sufficient low-cost electricity for electrification will require significant expansion of renewable or climate-neutral generation capacity, as well as the necessary grid infrastructure to connect industrial sites. In Germany, this poses a challenge given that the majority of wind electricity is generated in the country's north while the large industrial consumers are located in the south (BMWE 2025a). Furthermore, in countries with high shares of wind and solar in the electricity mix, such as Germany, fluctuations in electricity supply present an additional challenge. In the future, industries will have to adapt to this variable supply by increasing the flexibilization of their production processes and plant operations, which are today generally characterised by high-capacity utilisation (Fraunhofer ISI 2024).

4.1.2 Renewable and Low-Carbon Hydrogen and Hydrogen Derivatives

Renewable and low-carbon hydrogen and hydrogen derivatives will play a key role in decarbonising energy-intensive industries and may be preferred to direct electricity in certain applications due to their unique properties.

Generating process heat with hydrogen rather than electricity can offer advantages and thus be necessary for certain applications, particularly for processes that require hydrogen-based reactions (Agora Energiewende 2020). In direct reduced iron (DRI) production, for example, hydrogen would not only be used to generate high-temperature heat but also as a reducing agent to remove oxygen from iron ore. Due to its high energy density and storage capability, hydrogen could also be used for heat generation in combined heat and power (CHP) plants during periods of insufficient renewable electricity supply (Fraunhofer IEE 2020).

Renewable and low-carbon hydrogen and hydrogen derivatives will also be an important feedstock to decarbonise key processes in basic chemicals production. This applies to the production of nitrogen-based fertilizers, for which ammonia derived from renewable or low-carbon hydrogen will be needed. Also, for the manufacture of high-value chemicals (HVCs), conventional emission-intensive steam cracking could be replaced by methanol-based processes (Agora Energiewende 2020).

Today, industry in both Canada and Germany already consumes large amounts of hydrogen, almost entirely produced from natural gas through steam methane reforming (SMR) (BMWE 2023; NRCan 2020). Global production of this so-called grey hydrogen emits 830 million tonnes of CO_2 per year, equivalent to the combined emissions of the UK and Indonesia (IEA 2019a).

Decarbonisation of hydrogen production will require a shift to low-carbon and renewable hydrogen (IEA 2019b). Renewable, or green hydrogen, is produced by splitting water using renewable electricity via electrolysis. Low-carbon hydrogen, on the other hand, can be produced using several pathways, the most widely discussed being blue hydrogen. Blue hydrogen is produced by reforming natural gas, as in SMR, but with the added step of capturing and storing the associated CO_2 emissions (IRENA 2020).

While green hydrogen's production process is virtually emission-free, the climate impact of blue hydrogen can vary, potentially being higher or lower than that of fossil fuels (Parkes 2024). It largely depends on methane lifecycle emissions, the CO_2 capture rate, and the energy-related emissions for the CCS process. Blue hydrogen can only reach the low emission intensity of green hydrogen if methane leakages along the natural gas supply chain are kept below 1% and carbon capture rates reach 93% or more (Bauer et al. 2021).

Both Canada and Germany have published federal hydrogen strategies in 2020 and updates or progress reports in 2024 and 2023 respectively (BMWE 2023; BMWK 2020; NRCan 2020; NRCan 2024a). Canada is planning to both domestically use and export large amounts of so-called clean hydrogen, which includes both green and blue (NRCan 2020). Germany is focusing on green hydrogen in the long-term but sees blue hydrogen as an important transitional option, given that it is expected to be cheaper than green in the short term and that overall hydrogen supply will likely fall short of Germany's demand in the next decade (BMWK 2023).

To supply end-users of hydrogen and hydrogen derivatives, extensive infrastructure will be required to connect production and import points with industrial sites. Germany has decided to build a core hydrogen grid ("H2-Kernnetz") by 2032, consisting of 9,000 km of new and repurposed pipelines to link supply sources and major demand centres. To secure its future hydrogen supply, Germany is actively developing hydrogen partnerships with its European neighbours as well as third countries. Canada is an important partner country, having established a hydrogen partnership with Germany in 2022. In 2024, Canada and Germany agreed to establish a joint funding window for hydrogen trade projects through the H2 Global mechanism (BMWE 2024a).

While many countries have published hydrogen strategies and announced ambitious targets in the past years, the global market ramp-up has so far been slower than expected. According to the IEA's Global Hydrogen Review 2026 only "300ktpa of additional production has reached FID" since the 2025 report and projects with high likelihood of operation by 2030 have reduced from 10 Mt to 6 Mt because FIDs are delayed (IEA 2026). The ramp-up has been stalled by the high upfront investment costs on the supply side, but also by the shortage of offtakers willing to sign bankable offtake agreements, as well as the regulatory uncertainty, and the insufficient infrastructure for hydrogen transport and storage.

4.1.3 Carbon Capture, Utilization, and Storage (CCS/CCU)

Carbon capture, storage and utilisation (CCS/CCU) involves capturing CO_2 from fossil fuel combustion or industrial processes, followed by either underground storage (onshore or offshore) or utilisation in other processes, such as synthetic fuel production (IEA 2024).

From a technological perspective, CCS/CCU can be applied across various industrial sectors and plants. However, it is most viable for large point sources with high CO_2 concentrations, such as primary steel production or steam methane reforming. In processes with lower CO_2 concentrations in exhaust fumes, including steam cracking or combined heat and power generation, CCS/CCU could also be an option, although capture efficiency decreases and separation costs increase (Agora Energiewende 2020).

For all these industrial processes, however, whether it is steel production, power and heat generation, hydrogen production, or steam cracking, alternative decarbonisation pathways based on direct electrification or renewable hydrogen exist. There are, however, certain industries that produce process-related CO_2 emissions that are largely unavoidable, making CCS/CCU essential. These include cement and lime production, where more than two-thirds of emissions result from the chemical decomposition of limestone into lime and CO_2 (Wernicke 2024). Similarly, waste incineration may require CCS/CCU to capture CO_2 released from burning non-recyclable waste (UBA 2023).

CCS/CCU remains an emerging technology, and opinions differ on its breadth of application – whether it should be limited to specific sectors or broadly implemented across industries. One advantage of CCS/CCU is its relatively low CO_2 abatement costs, as it allows industrial facilities to maintain their core production processes (Agora Energiewende 2020). Additionally, captured CO_2 could be used in chemical or synthetic fuel production, where CO_2 serves as a key input.

However, there remain significant risks and challenges regarding CCS/CCU, which suggest limiting its use to hard- or impossible-to-abate sectors without viable alternatives. Most importantly, the climate impact of CCS/CCU remains a topic of debate. Available technologies capture about 50% to 90% of CO_2 emissions, and achieving a 100% capture rate is currently unrealistic, meaning that residual emissions will persist (IEA 2024). Moreover, when CCS/CCU is used for fossil fuel combustion, upstream and midstream GHG emissions, such as methane leaks during natural gas production and transport, remain unaffected. The energy required for capturing, transporting, and storing CO_2 could also result in additional emissions if fossil fuels are used. Consequently, a comprehensive lifecycle assessment is necessary to accurately evaluate the total GHG emissions associated with a given project or product utilising CCS/CCU (Agora Energiewende 2020).

Additional risks associated with CCS/CCU include potential lock-in effects that prolong reliance on fossil fuel-based technologies and infrastructure, hindering innovation in key technologies based on electrification or hydrogen (CIEL 2021; IEEFA 2022). Furthermore, underground storage requires suitable geological sites, which for Germany would be primarily offshore in the North Sea or in neighbouring European countries. This would necessitate the development of an extensive CO_2 pipeline infrastructure to transport captured CO_2 from industrial sites to Germany's coast (BMWE 2024b). Further, the risk of CO_2 leakage during transport and sequestration must also be taken into account (Gholami et al. 2021).

Canada is a global leader in CCS/CCU and has been active in the field for over fifteen years, with demonstration and large-scale projects (Eckardt et al. 2023). In the provinces of Alberta and Saskatchewan, there are four large operational CCS projects that capture CO_2 from refineries, steam methane reforming, and coal plants. While most captured CO_2 is used for enhanced oil recovery, the Quest project in Alberta permanently stores CO_2 underground. Canadian CCS/CCU projects benefit from Federal Investment Tax Credits, with CAD 8.6 billion allocated until 2030 (Canadian Climate Institute 2023).

Germany currently has no operational CCS/CCU projects, and underground CO_2 storage is prohibited in several federal states. However, perspectives on CCS/CCU in Germany have been shifting, with the Federal Government now recognizing it as an important climate mitigation tool (Blanchard et al. 2024). In May 2024, the Federal Government released its Carbon Management Strategy in order to allow the utilisation of CCS/CCU as well as transportation and storage offshore (BMWE 2024c). In the fall of 2025, the German Parliament passed a CCS/CCU law to legalise underground CO_2 storage and streamline regulations on sequestration and transport.

4.1.4 Energy Efficiency

Improving energy efficiency of industrial production – that is, reducing the energy required for each unit of production – is another important strategy for lowering emissions. However, in energy-intensive industries such as steel and cement, incremental efficiency improvements alone will not be sufficient to reach climate neutrality. That is why the other solution pathways mentioned – including electrification, renewable and low-carbon hydrogen, CCS/CCU, biomass, and circular economy – will be key so that these hard-to-abate sectors can meet their climate targets (Agora Energiewende 2020).

Industry-wide, the adoption of energy efficiency technologies would have an immense potential. In Germany, industry-wide adoption of readily available energy efficiency technologies could reduce final energy demand by 44% or energy costs by EUR 25 billion (CAD 40.5 billion), without compromising production. Process heating, motion energy (pumps, engines and machinery), and space heating have the largest efficiency potentials (Meyer et al. 2023).

In energy-intensive industry, however, key production processes remain largely unchanged for decades or even much longer. Physical and technical boundaries limit further efficiency gains in these conventional processes (Agora Energiewende 2020). Significant emission reductions will thus require innovative technologies, such as replacing blast furnaces with direct reduced iron (DRI) plants. Moreover, one-third of industrial emissions are process-related, meaning they are a by-product of chemical reactions. This results in energy efficiency improvements being insufficient for full decarbonization.

Therefore, while energy efficiency measures can still deliver immediate energy savings and emission reductions in the energy-intensive industry in the short term, they should only be made if they do not lead to a long-term lock-in of emission-intensive processes and infrastructures (Agora Energiewende 2020).

4.1.5 Circular Economy and Resource Efficiency

Circular approaches hold substantial potential to reduce emissions in industrial production. The primary production of materials is far more energy- and emission-intensive than recycling or reusing existing ones. Accordingly, circular economy strategies are particularly relevant in energy- and resource-intensive sectors such as steel, non-ferrous metals, cement, plastics, and chemicals (dena 2025a; Agora Energiewende 2019). According to one estimate, by 2050 recycling could reduce EU demand for primary materials by 75% for steel, 50% for aluminium, and 56% for plastics (Agora Energiewende 2019). Germany's steel industry already recycles around 90% of its steel scrap, whereas recycling rates in sectors such as cement and plastics remain significantly lower (dena 2025a).

Despite this potential, the transition towards a circular economy faces a number of obstacles. Recycling is often economically unattractive, as primary production from fossil sources is cheaper and less risky. Substitutes for primary materials are not always readily available and developing them often requires changes in product design, including greater transparency about material composition and easier disassembly at end-of-life. Technical barriers also exist, for example contamination of materials (e.g. copper in steel or impurities in plastics). Furthermore, current regulation still favours linear value chains and disposal rather than recycling, while the infrastructure and logistics required for circular value chains are underdeveloped. This means that first movers face disproportionately high investment costs (Agora Energiewende 2019, dena 2025a).

A related strategy is to increase resource efficiency to achieve the same function in a material or product with less material demand. Along the entire industrial production chain, material losses are significant: it is estimated that around one tenth of all paper, one quarter of all steel, and as much as two fifths of all aluminium are lost between basic material production and the finished product (Agora Energiewende 2019). Resource efficiency can also be improved by reducing material intensity in product design – something technically feasible in many sectors but often lacking economic incentives – and by intensifying product use. These measures not only lower material demand but also reduce the energy inputs and emissions associated with industrial production (ibid.).

4.1.6 Biomass

Biomass can substitute fossil fuels in generating process heat for industrial production, particularly in energy-intensive sectors such as cement and lime. When combined with carbon capture at the point of combustion (e.g. in cement kilns), it can even enable negative emissions (Bioenergy with Carbon Capture and Storage, or BECCS). Captured CO_2 can either be permanently stored or utilised, for instance in the production of synthetic fuels. Biomass further offers potential as a renewable carbon feedstock replacing fossil-based inputs, e.g. in the basic chemicals or steel industries. According to recent studies, by 2050 up to 20% of the global carbon demand in the chemical and materials sector could be met sustainably through biomass (Carus et al. 2025).

At the same time, the potential of biomass is constrained by resource availability. In Germany and Europe, sustainably available biomass is limited due to land-use competition with food production, biodiversity protection, and other ecosystem services. Cultivation can also carry environmental trade-offs, including impacts on water, soil quality, and biodiversity. Moreover, the climate benefit of biomass depends heavily on its lifecycle emissions, which can be significantly undermined by the use of fossil-based fertilisers and pesticides or by long-distance transport of the biomass (Agora Energiewende 2019).

Given these constraints, the overall use of biomass requires careful prioritisation. Studies suggest that allocating biomass to industrial applications – particularly as a renewable feedstock and in combination with BECCS – yields significantly higher system efficiency than traditional uses such as power generation, biofuels, or space heating, where other decarbonisation options exist (dena 2025b).

4.2 Sectoral Pathways

4.2.1 Chemicals and Refining

In the chemicals and refining industry, energy efficiency remains a central pillar of decarbonisation. Continuous optimisation of existing processes, alongside a shift towards lower-carbon fuels – e.g., from coal- to natural-gas – has already delivered measurable emission reductions. In Germany, the chemical industry significantly reduced its GHG emissions between 1990 and 2022 despite rising production volumes (KEI 2025b). However, to achieve substantial progress beyond incremental efficiency gains, the sector must fundamentally transform its production pathways and increase reliance on renewable energy and feedstocks.

Electrifying process heat through power-to-heat technologies could, in principle, eliminate combustion-related emissions. Yet such a transition also requires a major expansion of renewable electricity supply to ensure emissions are not merely shifted to the power sector (Agora Energiewende 2020). According to the IEA (2023d), approximately 30 percent of the process heat required in the sector is below 200 °C – making direct electrification via high-temperature heat pumps a highly effective solution for this segment. For higher-temperature processes, options include replacing existing gas-fired combined heat and power (CHP) units with power-to-heat systems such as electric boilers or resistance heating, or retrofitting CHP units with CCS/CCU technologies, which can technically achieve 90 percent capture efficiency.

In ammonia and methanol production, key decarbonisation pathways focus on replacing fossil-based hydrogen with low-carbon or electrolytic ("green") hydrogen. Currently, ammonia synthesis relies on hydrogen produced via steam methane reforming (SMR) of natural gas. Substituting this with green hydrogen could virtually eliminate process emissions. Transitional alternatives include blue hydrogen (SMR with CCS) and turquoise hydrogen (derived from methane pyrolysis) (Agora Energiewende 2020).

Petrochemicals present a more complex challenge, as carbon itself remains an essential building block of chemical products (Agora Energiewende 2020). Achieving net-zero therefore depends on replacing fossil feedstocks with sustainable carbon sources such as biogenic feedstocks or CO_2 captured from the atmosphere. Closing carbon loops through advanced recycling technologies is equally vital to building a circular carbon economy. Electrifying steam crackers with renewable power can further reduce emissions by eliminating the need to burn part of the feedstock to generate process heat.

In the plastics value chain, emissions originate not only from production but also from end-of-life incineration. Methanol-to-olefin (MTO) and methanol-to-aromatic (MTA) routes–based on green methanol synthesised from renewable hydrogen and non-fossil CO_2–offer a viable pathway to replace conventional naphtha-based feedstocks (Agora Energiewende 2020).

In Germany, the chemical industry continues to advance decarbonisation projects, though current efforts focus primarily on demonstration-scale projects. At Ludwigshafen, BASF commissioned its 54-megawatt proton exchange membrane electrolyser (the country's largest) in March 2025, reaching full operation by August 2025, and in May 2025 became the first producer of renewable ammonia in Central Europe (BASF 2025). Together with SABIC and Linde, BASF also opened the world's first electrically heated steam cracker demonstration plant in 2024, with the potential to reduce cracker emissions by more than 90 percent (BASF 2024). Complementing these efforts, TotalEnergies and RWE signed a long-term green hydrogen supply contract in March 2025 (2030–2044), in which RWE's 300-megawatt electrolyser in Lingen will deliver around 30,000 tonnes of hydrogen per year to decarbonise TotalEnergies' Leuna refinery (RWE 2025). Construction of the Lingen plant is already underway: commissioning of the first 100 MW phase began in December 2025, with commercial operation expected in 2026 and the full 300 MW targeted for 2027 (S&P Global 2025). In parallel, the Carbon2Chem consortium led by thyssenkrupp is demonstrating how CO_2-rich blast furnace gases from steel production can be converted into methanol and ammonia (thyssenkrupp 2025).

Canada's chemical sector benefits from abundant natural gas resources, established CCS/CCU infrastructure, and supportive federal and provincial incentives, positioning it for large-scale low-carbon hydrogen and integrated petrochemical projects. Dow's Path2Zero project at Fort Saskatchewan aims to create the world's first net-zero Scope 1 and 2 emissions integrated ethylene cracker and derivatives facility, using autothermal reforming with carbon capture to produce hydrogen as fuel for the site's furnaces (Dow 2024). Construction was paused in April 2025 due to weak market conditions and US tariff uncertainty, but restarted in January 2026 following a nine-month break, pushing back the start of Phase 1 by two years to the end of 2029 (ICIS 2026). Air Products is constructing a net-zero hydrogen energy complex in Edmonton that will capture CO_2 and supply low-carbon hydrogen to industrial customers including Imperial Oil's Strathcona refinery (Air Products 2025). Shell has taken final investment decision on the Polaris carbon capture project at its Scotford refinery and chemicals complex, designed to capture approximately 650,000 tonnes of CO_2 annually, with construction actively underway and operations expected by end of 2028 (Shell 2024).

4.2.2 Steel and Metals

The steel industry can achieve moderate emission reductions through efficiency measures such as process optimization, advanced monitoring systems, equipment upgrades, and waste-heat recovery. The International Energy Agency estimates that widespread adoption of modern technologies in blast furnace–basic oxygen furnace (BF-BOF) plants could reduce global energy demand in steelmaking by around 20% (IEA 2021).

However, the potential for emission savings in conventional production processes is limited. Secondary scrap-based steel production via electric arc furnaces (EAF) is less emission-intensive, but its potential is constrained by limited scrap availability and market demand for high-quality primary steel (Bellona 2018). A more promising pathway lies in replacing the BF-BOF route with hydrogen-based direct reduced iron (DRI) feeding into EAFs (DRI-EAF route). This approach can cut emissions by up to 86%, as hydrogen substitutes carbon as the reducing agent (Fan and Friedmann 2021). Other than hydrogen, biomass could also serve as an alternative for coal-based DRI in regions with abundant supply, while research is also underway on electrification through molten oxide electrolysis, which directly uses electricity to separate iron from ore (Soltoff 2022).

Carbon capture and storage (CCS) offers another pathway, enabling partial emission reductions of 15–57% when retrofitted to BF-BOF or DRI plants, but it cannot achieve full decarbonisation. Ultimately, no single option will be sufficient, and a combination of all these solutions will likely be required to reach net-zero steel production (Fan and Friedmann 2021).

In Germany, major producers such as Salzgitter are driving projects to replace blast furnaces with hydrogen-based DRI and EAF systems. Phase 1 of Salzgitter's SALCOS programme – comprising a DRI plant, an EAF, and a 100 MW electrolyser (cornerstone laid February 2025) – is under construction and on track, with DRI plant startup expected by mid-2026 and green hydrogen production from the electrolyser beginning the same year (Salzgitter n.d.). However, due to regulatory uncertainty and weak market conditions, Salzgitter announced in September 2025 that investment decisions on Phases 2 and 3 have been postponed to 2028–2029, approximately three years later than originally planned (Reuters 2025).

Canada, with its abundant iron ore and conventional and renewable energy resources, could become a highly competitive producer of decarbonised steel (Algers and Bataille 2025). Algoma Steel has made significant advances: EAF Unit 1 was successfully commissioned in July 2025, producing the company's first low-carbon steel, and Blast Furnace No. 7 and cokemaking operations were shut down and decommissioned from January 2026. A second EAF unit is on track for completion in the second half of 2026, which will complete the full transition and is expected to reduce Algoma's carbon intensity by up to 70% (Algoma 2026). ArcelorMittal Dofasco's transition project in Hamilton has faced significant revisions: the originally planned on-site DRI facility will not be built, with reduced iron to be sourced instead from ArcelorMittal's existing plant in Contrecoeur, Québec, and the federal funding agreement has been extended from 2028 to 2050. Some physical progress is underway, with the final coke push completed in April 2026, but no firm timeline for EAF construction has been confirmed (CBC 2026).

Emission reductions in the non-ferrous metals sector have in the past been achieved through efficiency improvements and recycling. In Germany, secondary materials already account for 58% of inputs in aluminium production and 44% in copper production. Recycling is especially impactful in aluminium, as secondary aluminium requires only about 5% of the energy needed for primary production (KEI 2025d).

At the same time, technology innovation is progressing. TRIMET Aluminium SE, for example, is developing an innovative inert-anode process at its Essen facility. Following successful pilot operation, the project was expanded in January 2025 into a demonstration plant at the Essen smelter (Trimet 2025). Traditional aluminium smelting releases substantial CO_2 during the combustion of carbon anodes, but by replacing these with inert materials, the process emits oxygen instead of CO_2, significantly reducing emissions.

In Canada, the ELYSIS joint venture between Rio Tinto and Alcoa, backed by the governments of Canada and Québec as well as Apple, is developing inert-anode electrolysis at industrial scale. The technology eliminates all direct greenhouse gas emissions from aluminum smelting by replacing carbon anodes with inert materials (Rio Tinto 2025). In November 2025, ELYSIS achieved a milestone with the successful start-up of a 450 kA commercial-size inert anode cell at Rio Tinto's Alma smelter in Québec, which represents the first deployment of this technology at commercial scale. Rio Tinto has also been granted the first ELYSIS smelter technology license for a 100 kA demonstration plant to be built at its Arvida site (ibid.).

4.2.3 Cement and Lime

In the cement industry, further efficiency gains can be achieved through advanced kiln designs, optimised maintenance, and improved grinding processes, while waste heat recovery systems can help reduce overall energy demand. Substituting part of the clinker with materials such as fly ash or blast furnace slag also lowers the energy intensity of production by reducing the clinker-to-cement ratio (IEA 2021).

However, because of the high share of process emissions in the production of both cement and lime, substantial decarbonisation will require more transformative production pathways based on CCS/CCU and alternative raw materials (IEA 2023e). Production processes using oxyfuel carbon capture technology conduct combustion using a mixture of oxygen and recycled CO_2 instead of air, producing exhaust with a high CO_2 concentration and enabling capture rates of around 90 percent of both process- and fuel-related emissions (Agora Energiewende 2020). Another approach, the LEILAC (Low Emissions Intensity Lime and Cement) process, uses indirect heating in a closed steel reactor to generate a pure CO_2 stream, thereby reducing the energy required for separation. The technology can also be powered by renewable electricity, potentially cutting kiln emissions by up to 80 percent (Agora Energiewende 2020). Beyond CCS, alternative binders offer a non-CCS route by replacing conventional clinker with materials that contain less limestone or require lower processing temperatures. Such binders can reduce emissions by up to 50 percent, although their deployment is expected to remain limited to niche applications due to differing performance characteristics (Agora Energiewende 2020).

The lime industry faces a similarly high proportion of process emissions: roughly two-thirds of its CO_2 output results from the chemical decomposition of limestone during calcination. Even with complete electrification or full substitution by renewable fuels, additional CO_2 capture will be required to achieve climate-neutral production (KEI 2025). Accordingly, strategies in this sector also centre on CCS/CCU technologies. Research is further exploring the carbonation potential of lime products – their chemical ability to reabsorb CO_2 – which has been observed across eight industrial applications, including steelmaking and flue-gas scrubbing. This provides an additional means to partially offset emissions by binding CO_2 back into lime-based products (KEI 2025f).

In Germany, cement and lime producers plan to implement several major CCS/CCU projects. Heidelberg Materials is advancing the GeZero project in Geseke, which will capture around 700,000 tonnes of CO_2 per year. Following completion of the FEED study in 2025, construction is scheduled to begin in 2026, with operations planned for 2029 (HM 2025). At Rüdersdorf, Cemex and Linde have formalised their full-chain CCS/CCU project – now named CO_2LLECT – with the EU Innovation Fund grant agreement signed in March 2025 (€157 million). The project is designed to capture 1.3 million tonnes annually; a final investment decision is expected in 2027, with full CCS operations targeted for 2030 (COLLECT 2025). Holcim's Carbon2Business project in Lägerdorf will apply oxyfuel technology, with operations expected to commence by the end of the decade (Holcim 2025). In the lime sector, Lhoist's EVEREST project at Europe's largest lime facility in Wülfrath aims to abate more than one million tonnes of CO_2 each year (Lhoist 2025).

In Canada, several cement producers are also scaling CCS/CCU technologies. In Edmonton, Heidelberg Materials is building what will become the world's first full-scale CCS installation at a cement plant. A government contribution agreement of up to CAD 226 million was finalised in March 2025, and a pilot capture system has been installed and is being tested on-site. Full-scale operations are now anticipated by late 2026 (HM 2025). Carbon Upcycling Technologies and Ash Grove have launched Carbon 1 Mississauga, a commercial CCU facility that converts captured CO_2 into low-carbon supplementary cementitious materials (Government of Canada 2025a). Meanwhile, at Richmond, Lafarge Canada's Project CO_2MENT employs Svante's solid-sorbent capture system at demonstration scale (Svante 2023).

4.2.4 Pulp and Paper

Nearly all emissions from the pulp and paper sector are energy-related, with process-based CO_2 emissions playing a comparatively minor role. Drying processes are particularly significant, accounting for an estimated 60–70 per cent of energy-related emissions (KEI 2025g).

As outlined in Chapter 3.4, both Germany and Canada have made progress on reducing pulp and paper emissions through incremental measures – Germany through high recycling rates, renewable energy integration, and combined heat and power, and Canada through energy efficiency measures, fuel switching, and cogeneration. However, the limits of these approaches are becoming apparent, underscoring the need for transformative technologies for deep decarbonisation.

The IEA (2023b) identifies several key technologies for deep decarbonisation in the sector. Since drying accounts for most energy consumption, innovations that reduce water evaporation or enhance waste heat recovery offer substantial improvements. High-temperature heat pumps are particularly promising: by capturing latent heat from drying and reusing it to generate steam, they could supply up to 65 percent of process heat while reducing energy demand by half. Emerging technologies such as superheated steam drying, non-thermal water removal using electric forces – which could reduce drying energy consumption by 30–90% – and waterless papermaking hold further potential, though most remain at pilot or early commercialisation stages. Expanding recycled pulp production can also reduce energy intensity but requires parallel switching to low-emission energy sources, since recycled production currently relies more heavily on fossil fuels than primary pulp production (IEA 2023b).

In Germany, the industry has largely exhausted conventional efficiency measures – with recycling rates at approximately 80%, further gains are constrained by the need for virgin fibres in products requiring high strength or hygiene standards (KEI 2025g). GHG emission reductions are therefore increasingly pursued through electrification, advanced drying technologies, and intelligent energy management. Innovations such as electrode boilers, high-temperature heat pumps, and hybrid systems could progressively replace fossil fuels (KEI 2025g).

Several pioneering projects illustrate this trajectory. The Voith–Essity pilot plant in Heidenheim, funded with EUR 14.5 million from the BMWE, is developing a fully electrified paper line that could reduce freshwater consumption by up to 95% and energy use by 40% (Voith 2025). At its Mainz-Kostheim facility, Essity became the first company globally to produce tissue using 100 per cent renewable hydrogen, replacing natural gas in the drying hood of the paper machine (Essity 2023). Furthermore, the EnEWA research project is investigating the recovery of paper fibres from mixed waste streams – a pathway that could cut the sector's annual CO_2 emissions by an estimated 2.5% (EurA 2022).

Beyond efficiency measures, the Canadian pulp and paper industry is exploring CCS/CCU technologies. At Kruger's Wayagamack Mill in Trois-Rivières, construction of the “world's first demonstration-scale carbon capture system in a pulp and paper setting” is progressing, with several major components delivered to site; the demonstration unit, using molten borates technology, is expected to begin capturing approximately 5 tonnes of CO_2 per day in 2026 for on-site utilisation (Kruger 2025). CO280 Solutions has made significant advances on its larger project targeting biogenic CO_2 capture from pulp and paper mills. This includes a successful field pilot using liquid amine technology was completed in November 2025, FEED contracts for the flagship project were awarded by March 2026, and the company has contracted over 4.3 million tonnes of CDR to date, including agreements with Microsoft and JPMorgan Chase (CO280 2025a; CO230 2025b; Carbon Herald 2025). Commercial operations are expected to begin around 2029.

In Canada, the pulp and paper industry faces persistent structural challenges. While emissions have fallen over recent decades, much of this decline is linked to reduced output (440 Megatonnes 2024). Looking ahead, further reductions will require a combination of electrification, fuel switching, and greater energy efficiency. Industrial heat pumps could supply medium-temperature heat, while electrified dryers may gradually displace fossil-fuel-fired systems where viable. In processes less suited to electrification, fuels such as biomass or renewable natural gas provide lower-emission alternatives – though the industry already makes extensive use of biomass, and opportunities for expansion are limited (440 Megatonnes 2024).

5 Policy Frameworks

5.1 Germany

As a member of the EU, Germany's energy policy is a shared competence with the EU. Thus, regulations and funding aimed at decarbonising the German industry sector, including its energy-intensive sectors, are a blend of EU and national legislation. There are both cross-sector and targeted policy frameworks, with the latter being sector- and technology-specific. Below, the cross-sector policy frameworks at both EU and national levels are outlined, followed by targeted frameworks. This sequence is mirrored in the funding and financing instruments discussed later in this chapter.

5.1.1 Cross-Sectoral Policy Frameworks

EU ETS & CBAM

The EU Emissions Trading System (EU ETS) is the primary instrument for reducing emissions across the EU, including in the industry sector. Launched in 2005 as the first ETS globally, it remains one of the largest, encompassing the EU27, Iceland, Liechtenstein, and Norway. It has been linked to the Swiss ETS since 2020 (European Commission n.d.a). The system covers the electricity, heating, aviation, and shipping sectors, operating on a cap-and-trade principle that sets emission limits aligned with the EU's overall emissions target.

In July 2026, the European Commission proposed a reform of the EU ETS. The linear reduction factor – which determines the yearly decrease in allowances on the market – is currently set at 4.3 per cent. Under the proposal, this would be reduced to 3.7 per cent between 2031 and 2035, and to 1.7 per cent between 2036 and 2040. The current ETS provides for no further allowances after 2039; the reform proposal would permit additional allowances after 2040. The aim is to increase flexibility and certainty for the affected industries (European Commission n.d.b; European Commission n.d.c; Tagesspiegel Background 2026).

The European Commission also intends to provide targeted support to energy-intensive industries by extending the availability of free allowances beyond 2030, on the condition that companies invest the full monetary equivalent in decarbonisation efforts within the EU. Flexibility would be increased further by permitting an EU body to purchase international allowances covering up to two per cent of the required 90 per cent reduction in emissions. Additionally, 250 Mt of negative emissions are to be integrated into the EU ETS to encourage the uptake of the necessary technologies. The reform proposal also envisages the establishment of an "Industrial Decarbonisation Bank" equipped with EUR 100 million to help finance industrial decarbonisation projects (Tagesspiegel Background 2026). The legislative process for the reform is expected to conclude in 2027, with the new rules coming into effect by mid-2028.

To maintain competitiveness for European producers, mitigate carbon leakage risks, and promote cleaner production in non-EU countries, the European Commission introduced the Carbon Border Adjustment Mechanism (CBAM) in 2023. Importers must account for their products' emissions by purchasing certificates for each tonne of CO_2. The CBAM aligns certificate prices with the weekly average ETS auction price, ensuring that international producers pay a carbon price equivalent to that faced by EU producers. During its transitional phase (2023–2025), importers in the cement, iron and steel, aluminium, fertilisers, electricity, and hydrogen sectors reported emissions without purchasing certificates. As of 1 January 2026, the CBAM has been in full effect (European Commission n.d.d).

EU Clean Industrial Deal

Published in February 2025, the EU's Clean Industrial Deal outlines a vision for reducing emissions while enhancing competitiveness in energy-intensive and clean-tech sectors as well as increasing circularity to reduce dependency on third-country resources. It focuses on six areas that the EU regards as the key drivers of business: affordable energy, lead markets for clean products, finance, circularity, global cooperation, and skills and jobs. The Affordable Energy Action Plan accompanies the deal and is intended to support energy-intensive sectors amid the ongoing crisis, with measures like counter-guarantees from the European Investment Bank for renewable electricity PPAs (worth EUR 50 billion) and PPAs by grid component manufacturer (worth

EUR 1.5 billion). Simplified state aid rules and new cross-border capacity allocation rules are planned to boost clean energy use. Member states are encouraged to lower electricity taxes, while the Industrial Decarbonisation Accelerator Act, also accompanying the deal, addresses permitting bottlenecks. Additionally, the internal energy market is to be strengthened through the European Grid Package (published in December 2025) and the functioning of the gas market to be improved through increased oversight.

Demand for cleaner products is essential for investment in cleaner production methods. Hence, sustainability, resilience, and made-in-Europe criteria were announced to be introduced for procurement, which has now been done through the Industrial Accelerator Act (see below). Meanwhile, the uptake of renewable and low-carbon hydrogen is to be encouraged further by the third auction round under the European Hydrogen Bank. In May 2026, nine projects with a production capacity of 1.4 Mt over their first ten years were announced to receive EUR 1.09 billion (European Commission 2026a).

Funding instruments will be reorganised to streamline access, with a Competitiveness Fund serving as a one-stop-shop and a Clean Industrial Deal State Aid Framework simplifying state aid approval as well as launching additional IPCEIs (for more details please refer to section 5.1.3.2.2.).

Circularity will be supported through the EU Critical Raw Materials Centre, enabling joint procurement of critical resources, and a Circular Economy Act in 2026. Global cooperation remains vital, with several Clean Trade and Investment Partnerships (CTIPs) envisioned and the first one launched with South Africa in November 2025, alongside strengthened trade-defence instruments and a simplification of the CBAM. Overall, the deal reflects a shift towards technology neutrality and increased flexibility for businesses. Sector-specific guidance is provided through the European Steel and Metals Action Plan and the Chemicals Industry Package (European Commission 2025a; 2025b; Tagesspiegel Background 2025).

EU Industrial Accelerator Act (IAA)

The European Commission announced the Industrial Action Act (IAA) in March 2026. It is currently under review by the European Parliament and the Council. If adopted, the IAA aims to strengthen EU competitiveness and industrial resilience in the face of growing global pressures. By 2035, industrial manufacturing is to contribute 20 per cent to EU GDP, up from 14.3 per cent in 2024. The sectors covered include energy-intensive industries, net-zero technologies, and the automotive industry (European Commission 2026b; European Parliament 2026). Key measures include:

- The introduction of "Made in EU" and low-carbon preferences in public procurement and public support schemes
- The establishment of Industrial Acceleration Areas
- The streamlining of permitting processes for industrial manufacturing projects
- The screening of foreign direct investments for benefits to the EU market

EU Industrial and Livestock Rearing Emissions Directive

This directive is targeted at a wide range of industrial sectors, including those covered in this study, to reduce local pollutants. It is therefore not aimed at GHG emissions per se, but its implementation often results in the lowering of GHG emissions as well. Companies must implement Best Available Techniques (BATs), which for instance entail measures to increase energy efficiency. Covering 37,000 industrial installations in the EU, its contribution to the saving of GHG emissions can be expected to be significant (European Commission n.d.e.).

Federal Climate Action Act

At the national level, sectoral emission reduction targets are set by the Federal Climate Action Act, with overall targets for Germany (-63% by 2030, -88% by 2040, net zero by 2045) and targets for the energy, industry, buildings, transport, agriculture, LULUCF, and waste sectors. The targets are expressed in tonnes CO_2eq that each sector is allowed to emit per year. For the industry sector, the target is 122 million tonnes CO_2eq by 2030. However, the sectoral targets are not binding, allowing compensation between sectors. The Federal Environment Agency annually assesses target achievement (Umweltbundesamt 2025).

5.1.2 Targeted Policy Frameworks

5.1.2.1 Energy Efficiency

EU Energy Efficiency Directive and Germany's Energy Efficiency Act

The Energy Efficiency Directive is central to the EU's energy efficiency framework, establishing the efficiency-first principle. This means that energy efficiency must be considered by member states in all decisions relating to energy policy. The directive's 2023 revision sets an ambitious target for the EU to achieve at least an 11.7 per cent reduction in both primary and final energy consumption by 2030, based on projected usage for that year in the 2020 scenario. Specifically, this translates to a target of 992.5 million tonnes of oil equivalent (Mtoe) for primary energy consumption and 763 Mtoe for final energy consumption by 2030 (European Commission n.d.f). The directive also introduces binding cumulative end-use energy savings for member states, which must be realised through energy efficiency measures. For the period 2026–2027, member states are required to achieve savings of at least 1.5 per cent, rising to 1.9 per cent in 2028–2030. Furthermore, companies in the industrial sector with energy consumption exceeding 10 TJ are required to conduct regular energy audits, while those consuming over 85 TJ must establish energy management systems (European Commission 2024; European Commission n.d.g).

Unlike regulations, EU directives do not apply directly to member states; instead, they must be transposed into national law within a specified timeframe. In Germany, the Energy Efficiency Directive is enacted through the Energy Efficiency Act. A revised version of the Act was approved by the Federal Cabinet in 2026; the Bundestag and Bundesrat are expected to pass their decisions by autumn, so further changes remain possible. Under the original legislation, Germany's final energy consumption must be reduced by at least 26.5 per cent by 2030 compared to 2008 levels, equating to 1,867 TWh, and primary energy consumption must decrease by 39.3 per cent, amounting to 2,252 TWh. Consistent with the directive, companies with an average annual energy consumption exceeding 2.5 GWh over the preceding three years are required to conduct energy audits. Additionally, those with an average consumption of 7.5 GWh must implement an Environmental Management and Audit Scheme (EMAS) (The Federal Government 2023; DLA Piper 2023; Federal Ministry of Justice and Consumer Protection 2023; Linklaters 2023).

The proposed revision raises the latter threshold from 7.5 GWh to 23.6 GWh. According to DENEFF, this would reduce the administrative burden on companies but risks foregoing opportunities for economic efficiency gains (DENEFF 2026).

National Energy Efficiency Strategy 2050

In 2019, the German government introduced the Energy Efficiency Strategy 2050, which includes the National Action Plan for Energy Efficiency 2.0 (NAPE) and the Roadmap for Energy Efficiency 2050. NAPE specifies the measures needed to achieve the targeted reduction in primary energy consumption set by the strategy–initially aimed at a 30% reduction by 2030 but later updated through the Energy Efficiency Act to align with EU standards (see above). The roadmap established a dialogue with industry representatives to explore ways to halve energy consumption by 2050. A key aspect of NAPE is the Initiative for Energy Efficiency and Climate Action Networks (BMWE 2019).

This initiative, a collaboration between the German government and 21 industry associations, has been in place since 2014, initially focusing solely on energy efficiency. Since 2021, it has expanded to incorporate climate-related measures. The initiative's goal is to create networks of companies–targeting the establishment of 300-350 new networks by the end of 2025–to collectively save nine to eleven TWh of final energy consumption or reduce greenhouse gas emissions by five to six million tonnes. Each network comprises five to 15 companies, serving as platforms for exchanging ideas and best practices. Participating companies conduct energy audits and engage in three to four years of regular collaboration to set energy-saving goals. Independent monitoring institutes periodically audit these firms to ensure compliance and progress (Fraunhofer ISI n.d.; IEA 2017; IEEN 2020; IEEKN n.d.)

5.1.2.2 Hydrogen

Hydrogen Strategies and Industry Targets in the Third Renewable Energy Directive (RED III)

The EU Hydrogen Strategy, unveiled in 2020, positions hydrogen as a pivotal solution for decarbonising hard-to-abate sectors, such as steel and chemicals. In these industries, renewable and low-carbon hydrogen is envisioned to replace fossil fuels in high-temperature processes, serve as a chemical feedstock, and substitute grey hydrogen entirely (European Commission 2020a). To foster the adoption of renewable and low-carbon hydrogen, the third revision of the Renewable Energy Directive (RED III) has established a target for 42% of hydrogen used in the industry sector to originate from Renewable Fuels of Non-Biological Origin, i.e. to be in the form of renewable hydrogen, by 2030. This target is set to rise to 60% by 2035 (EP & EC 2023).

At the national level, the German National Hydrogen Strategy and its update from 2023 complement the EU's initiative by similarly identifying the industry sector, particularly energy-intensive industries, as principal consumers of renewable and low-carbon hydrogen (The Federal Government 2020; 2023b).

5.1.2.3 Circular Economy

EU Circular Economy Action Plan

The EU's Circular Economy Action Plan comprises 35 strategic actions designed to enhance recycling, minimise waste, and optimise resource efficiency. Within the industrial sector, the plan advocates for a transition towards greater circularity in production processes. This is achieved by integrating circular economy practices into the Best Available Techniques (BAT) reference documents of the Industrial Emissions Directive, alongside promoting “digital technologies for tracking, tracing, and mapping resources” (European Commission 2020b).

Ecodesign for Sustainable Products Regulation (ESPR)

Implemented in 2024, the Ecodesign for Sustainable Products Regulation aims to enhance the circularity, energy performance, recyclability, and durability of all products manufactured within the European Union, excluding food, feed, and medicinal products. Digital product passports are gradually introduced for products, components, and materials, with the specific information varying per product. For energy-intensive industries covered in this study, this regulation will necessitate a significant shift towards recycled inputs (such as scrap steel, recycled chemicals, paper, and construction materials), product reformulations, energy efficiency measures to reduce energy consumption, and improvements in the recyclability of their products (European Commission n.d.h.).

National Circularity Strategy

In December 2024, the German government unveiled its national strategy to responsibly utilise and reuse resources, minimise waste, and preserve the value of products for extended periods. In addition to ecological objectives, the strategy explicitly aims to bolster German independence from resource imports. Aligning with EU provisions, it advocates the use of recycled and secondary materials across various sectors, including those examined in this study. In these sectors, employing recycled and secondary resources presents a significant opportunity to substantially reduce emissions and costs (BMUKN n.d.; 2024).

5.1.2.4 CCS/CCU

EU Industrial Carbon Management Communication and Certification Scheme for Carbon Capture

The Net Zero Industry Act, passed in 2024, envisions that the EU establishes a CO_2 storage capacity of at least 50 million tonnes (Mt) per year by 2030, expanding to 280 Mt by 2040 to achieve its greenhouse gas (GHG) reduction target of 90% below 1990 levels. The Commission’s Industrial Carbon Management Communication outlines a strategy to meet these targets, including the introduction of a CO_2 transport and storage regulatory package and an atlas for mapping potential storage sites within the EU. Additionally, CO_2 suppliers will be matched with transport and storage operators, as well as offtakers, through a planned aggregation tool, and an accounting framework will be developed to assess the climate benefits of using CO_2 as a resource in industrial processes. New funding opportunities will be explored (European Commission 2024b;c).

Meanwhile, the European Parliament approved the establishment of a certification scheme for carbon capture in 2024, aimed at accurately measuring removals and long-term storage. To obtain certification, the methods employed by companies must demonstrate the ability to store CO_2 for several decades, with products removing carbon from the atmosphere for a minimum of 35 years (European Parliament 2023). These initiatives are still in the development phase, marking the EU's early steps in regulating CCS/CCU measures. In December 2025, the EU passed the Implementing Regulation (EU) 2025/2358 establishing transparency standards for certification schemes and rules for certification bodies and audit processes (European Commission 2025c). Further existing regulations include the CCS Directive, which provides a framework for carbon transportation, while RED II governs the utilisation of carbon in relation to biomass fuels, biogas, and biomethane, incorporating emission savings from CO_2 capture and storage into their GHG emissions calculation methodology (EP & EUC 2009; 2018). The EU ETS Directive (Directive 2003/87/EC) established that if CO2 has been captured and is permanently stored in accordance with the CCS Directive, no ETS allowances need to be surrendered (dena 2025c).

National Carbon Management Strategy

Germany is in the process of developing its own carbon management strategy, with foundational elements already adopted. CCS/CCU is identified as a crucial measure for the industry sector, particularly in areas like cement production, waste incineration, and the chemicals industry. The strategy aims to ensure these industries remain competitive internationally amid increasing decarbonisation demands. It will outline plans to develop necessary infrastructure and adapt legislation, permitting offshore carbon storage outside marine protection areas, while onshore storage remains prohibited unless individual states (Bundesländer) opt-in. The government emphasises that carbon storage usage must not compromise genuine reductions in greenhouse gas emissions and prohibits its use at coal-fired power plants (Clean Energy Wire 2024a).

5.1.3 Funding and Financing Instruments

5.1.3.1 Cross-Sectoral Programmes

5.1.3.1.1 EU Programmes

EU Innovation Fund

The EU Innovation Fund is one of the largest funding programmes globally targeted at net-zero and low-carbon technologies. It forms part of the European Green Deal Industrial Plan and is financed through the revenues of the EU ETS. Specifically, revenues from 530 million ETS allowances flow to the fund. Accordingly, the estimated revenue for 2020 to 2030 is EUR 40 billion (assuming a carbon price of EUR 75/t). Funding is open to all EEA member states and is awarded in the form of grants through an auction system. Funding is open to all energy-intensive industries, renewables, energy storage, and CCS/CCU projects, as well as net-zero mobility and buildings projects (European Commission n.d.i; 2023).

Recovery and Resilience Facility

This is a temporary measure, which runs until 2026. Money is available for initiatives that make the MS's economies more sustainable, resilient, and prepared for the green and digital transitions. Funding is provided by borrowing on the capital markets and then made available in the form of loans or grants to the members states. To apply for funding, member states had to devise national recovery and resilience plans, in which they outline where the money would be spent. Only if the milestones and targets outlined in these plans are reached is the money paid out. This is not a funding instrument open to industry directly, but diverse industry sectors can profit indirectly, if their national governments decide to allocate money to the transformation of their facilities (European Commission n.d.j; EU Chemicals Platform 2025).

EU LIFE Programme

The EU LIFE Programme has been running since 1992 and has supported more than 6,000 projects. The current programme round is running from 2021 to 2027 and is divided into sub-programmes including circular economy and quality of life, climate change mitigation and adaptation, and clean energy transition. The circular economy sub-programme is for instance supporting the recovery of resources from waste while the climate change mitigation and adaptation sub-programme supports inter alia energy efficiency measures and the build out of renewables. The clean energy transition sub-programme has a budget of EUR 1 billion to support more energy-efficient, renewable energy-based, climate-neutral, and resilient approaches in diverse sectors, including the industry sector (European Commission n.d.k.; n.d.l.).

European Investment Fund

This fund provides EUR 26.2 billion across four areas: Sustainable infrastructure (EUR 9.9 billion), research, innovation, and digitisation (EUR 6.6 billion), SMEs (EUR 6.9 billion), social investment and skills (EUR 2.8 billion). Sustainable infrastructure projects eligible for funding include energy efficiency and circular economy measures (European Investment Fund n.d.).

5.1.3.1.2 National Programmes and Support Mechanisms

Industrial Electricity Price and Electricity Price Compensation

The industrial electricity price is a compensation payment available exclusively to energy-intensive industries for the period 2026 to 2028. Applications may be submitted from 2027 onwards and apply retrospectively to 2026. The maximum rebate amounts to 50 per cent of the wholesale electricity price, subject to a price floor of 5 ct/kWh. For 2026, the relief amount stands at approximately 3.75 ct/kWh. Up to 50 per cent of a production facility's electricity consumption, including indirect electricity consumption, is eligible for support.

Beneficiaries are required to invest 50 per cent of the compensation received in decarbonisation measures within 48 months. Eligible measures include investments in renewable energy, efficiency improvements, and power-to-heat applications, among others. An additional flexibility bonus is granted where companies allocate a significant portion of their investments to measures that increase demand flexibility. The bonus amounts to a ten per cent increase in the compensation payment (BMWE 2026b).

The industrial electricity price may only be applied to electricity volumes not already covered by the electricity price compensation scheme. The latter is a state aid scheme for energy-intensive companies, designed to offset the indirect CO_2 costs arising from the EU Emissions Trading System (EU ETS). Since 2013, power plants no longer receive free ETS allowances for electricity generation; the associated costs are passed on to customers, which is particularly burdensome for energy-intensive industries. Companies belonging to sectors identified by the European Commission as being at high risk of carbon leakage may apply for the compensation. The amount of aid is determined by electricity efficiency benchmarks, which prevent incentives to increase electricity consumption. The German government has allocated EUR 4 billion for 2026 to state aid (Deutsche Emissionshandelsstelle 2025).

Carbon Contracts for Difference Scheme

This funding programme is targeted at the energy-intensive industry and aims to avoid 350 million tonnes of CO_2eq emissions while ensuring that German businesses remain competitive internationally. It is organized in the form of auctions with the main criterium being the price per tonne of CO_2 saved. In their application, companies indicate the costs (both CAPEX and OPEX) that accrue with the changing of production processes towards greener methods compared to conventional production processes. The necessary state aid is granted to the cheapest bidder over a time of 15 years. If the cost difference between the greener and conventional production method decreases over the course of the 15 years, for instance because the CO_2 price increases or renewable energy sources become cheaper, the grant paid will decrease as well. If the greener production process even achieves to become cheaper than the conventional method, the direction of payment reverses, with the company paying the difference to the state. This ensures that state aid is only paid where it is truly needed (BMWE n.d.a.; CMS Law-Now 2024). The programme is set to run until 2045; the first 15 companies received their CCfDs in October 2024. Funding in this first round totalled EUR 2.6 billion and will help save 17 million tonnes CO_2eq over the next 15 years. Companies had until December 1, 2025, to participate in the preliminary procedure for the 2026 bidding round, which runs until September 2026. Unlike in the first bidding round, CCU/CCS technologies will also be eligible for funding in 2026 (BMWE 2025b; BMWE 2026a).

Federal Fund for Industry and Climate Action

The Federal Fund for Industry and Climate Action consist of two separate funding streams. Module 1 supports decarbonization efforts, while module 2 supports the application of CCU and CCS technologies. The programme is set to run until 2030 with yearly funding rounds. Over the entire term, EUR 3.3 billion are to be made available with funding starting at EUR 500,000 for SMEs and EUR 1 million for large companies. The maximum funding per project is EUR 200 million. The programme is open to all industry sectors and technology neutral. To be eligible, the proposed project must reduce emissions by at least 40% (Umweltbundesamt 2024d).

KfW Energy Efficiency Programme

The programme provides loans of up to EUR 25 million for energy efficiency and decarbonization measures in production facilities (e.g. electrification, CCS/CCU measures, hydrogen applications, process heat and cooling, etc.). The measures must achieve a reduction of GHG emissions of at least 15% compared to the average value over the past five years for the respective production process (KfW n.d.).

SME-innovative

This programme is run by the Federal Ministry of Research, Technology and Space (BMFTR) and is targeted specifically at SMEs to support them in developing new innovative technologies, production processes, and products that increase energy efficiency, protect the climate and help them adapt to climate change (BMFTR n.d.).

Environmental Innovation Programme

This federal programme has been running since 1979 and has thus far provided EUR 1,220 million to 809 projects. The aim is to support companies in bringing innovative approaches to application. To this end, large-scale industry plants that serve as demonstration plants, i.e. the technology is applied for the first time in Germany or known technologies are combined in a novel manner, can receive either an investment subsidy or an interest subsidy (to reduce the cost of a loan). In the past 16 years, the programme has resulted in the saving of 1,673 thousand tonnes of CO_2eq (Environmental Innovation Programme n.d.).

5.1.3.2 Targeted Programmes

5.1.3.2.1 Energy Efficiency

Modernisation Fund

The Modernisation Fund is specifically targeted at 13 lower-income member states and is financed through ETS revenues. It provides EUR 2.4 billion, that is 2% of the total quantity of EU ETS allowances auctioned between 2021 and 2030. The money may be spent on energy efficiency measures, the use of renewable energies (including renewable hydrogen), and heating and cooling systems based on renewable sources and is open to the industry sector. However, companies cannot apply for the funding directly. Instead, the respective member state applies and decides on the form of funding desired (grants, premium, guarantee instruments, loans, or capital injections), which is then provided to recipients within the member state (European Commission n.d.m).

Energy and Resource Efficiency in the Economy

This funding programme is a joint endeavour by the Federal Office for Economic Affairs and Export Control (BAFA) and the KfW. It consists of six modules: Module 1 is available for cross-cutting technologies (electric motors, ventilators, pumps etc.), module 2 is open to the establishment of process heat applications from renewable sources (heat pumps, geothermal plants, biomass plants….), module 3 is open to MSR, sensors, and energy management software, module 4 targets energy and resource related optimization of plants and processes (technology-neutral), module 5 supports companies in devising transformation plans, and module 6 targets small enterprises, providing support for their electrification. Under all these modules, companies can receive a loan of up to EUR 100 million, which is available for two to 20 years.

One additional component of the EEE is the Energy and Resource Efficiency Funding Competition. Similar to module 4, this competition is technology neutral, but companies can receive a grant of up to EUR 20 million. However, companies must be willing to participate in a competitive process. The funding is provided by the BMWE and a new funding competition of EUR 60 million each is launched every two months. The company with the most efficient reduction in CO_2 emissions: i.e. the highest CO_2 emission reduction at the lowest cost, will be chosen. The sole eligibility criteria is that the energy and resource cost-related amortisation period of the investment without subsidies must be at least four years (BAFA n.d.; BMWE n.d.b.).

5.1.3.2.2 Hydrogen

Important Projects of Common European Interest (IPCEIs)

IPCEI are a funding tool embedded in EU state aid law. Within the framework of the IPCEI, member states may provide state aid without violating EU competition law. IPCEIs are aimed at supporting economic growth, the creation of jobs, the green and digital transformation, and competitiveness in the EU. Thus far, four hydrogen-related IPCEIs encompassing 90 companies from 16 member states including Norway have been established. The total state aid provided totals EUR 18.9 billion (European Commission n.d.n.). The German government provides state aid under 3 IPCEIs:

- **Hy2Tech**: 41 projects on the development of hydrogen-related, innovative technologies, EUR 5.4 billion from 15 MS, 4 German companies (European Commission n.d.o.)

- **Hy2Infra**: 33 projects on the development of hydrogen infrastructure, EUR 4.6 billion, 23 German companies (European Commission n.d.p.)

- **Hy2Move**: 13 projects on hydrogen technologies and applications in the mobility sector, EUR 1.4 billion, 7 MS, 3 German companies (European Commission n.d.q.)

While some energy-intensive industries are directly involved and receive state aid, the wider impact of more renewable hydrogen becoming available in the market will profit the energy-intensive industry sector as a whole in the long-term.

5.1.3.2.3 Other funding

In addition to these funding programmes, the German Government is regularly supporting individual companies to transition to more sustainable production methods. For instance, Georgsmarienhütte GmbH received EUR 880,000 in 2022 to change the heat treatment of its steel from natural gas to renewable electricity (Rohstoff.net 2022). In 2023, thyssenkrupp steel received EUR 2 billion jointly from the Federal Government and the government of Northrhine Westphalia for its tkH2-Steel project (for more details please see Chapter 2), and the Stahl-Holding Saar received EUR 2.6 billion to switch to the EAF production route including the use of hydrogen and scrap steel, promising to reduce the company's CO_2 emissions by 55% by 2030 (SHS 2023; thyssenkrupp 2023). In the same year, Salzgitter AG received EUR 1 billion for its SALCOS projects, which also involves switching to the EAF route, including the use of hydrogen. This will help reduce yearly CO_2eq emissions by 95%, which in turn translates to saving 1% of Germany's total yearly emissions (Salzgitter AG 2023).

5.2 Canada

5.2.1 Political Targets, Strategies and Regulation

Canada has enshrined its commitment to achieving net-zero GHG emissions by 2050 in the Canadian Net-Zero Emissions Accountability Act (2021), which establishes a legally binding framework for emission reduction targets and progress reporting. The Act also sets a 2030 target to cut emissions by 40-45% below 2005 levels, as well as interim targets for 2035, 2040, and 2045, each supported by credible emission reduction plans and progress reports to Parliament (Government of Canada 2024).

To implement these commitments, the Canadian government launched the 2030 Emissions Reduction Plan (ERP) in 2022. The ERP outlines sectoral pathways across oil and gas, transportation, electricity, buildings, agriculture, and heavy industry for meeting the 2030 emission target. In the ERP, the Federal Government also sets sector-specific industrial emission pathways for 2030. Compared to the base year of 2005, they stipulate an emission reduction of -10% for chemicals and fertilizers, -53% for petroleum refining, -35% for iron and steel, -4% for non-ferrous metals, -49% for cement, lime and gypsum, and -60% pulp and paper (ECCC 2022).

Although the ERP sets sector-specific emission reduction targets, there exist no such decarbonisation roadmaps for individual industrial sectors, with the exception of cement (Roadmap to Net-Zero Carbon Concrete by 2050) (CEC 2025). Instead, the plan lays out federal investments in clean technologies, electrification, and low-carbon fuels. Key measures include the creation of the CAD 8 billion Strategic Innovation Fund – Net Zero Accelerator to support decarbonisation in large industrial facilities, and a CAD 194 million expansion of the Industrial Energy Management Programme to increase industrial energy efficiency. Additional initiatives comprised a Buy Clean Strategy to promote low-carbon materials in public procurement and a national CCS/CCU Strategy (ECCC 2022).

The ERP also explicitly references the Clean Electricity Standard and the National Hydrogen Strategy as key policy instruments for reaching net-zero. Together, these policy frameworks indirectly support industrial decarbonisation by enabling access to low-emission electricity and alternative fuels.

5.2.1.1 Climate Competitiveness Strategy

Under Prime Minister Mark Carney, the Federal Government launched the Climate Competitiveness Strategy through Budget 2025, redefining Canada's climate and energy policy around investment incentives, enhanced industrial carbon pricing, and federal–provincial collaboration (Government of Canada 2025b).

The strategy maintains the suite of Clean Economy Investment Tax Credits (see below) and extends the CCS/CCU Investment Tax Credit at full rates until 2035, delaying the previously planned phase-down. It also commits to developing a post-2030 carbon-pricing trajectory in cooperation with provinces and territories to provide long-term certainty for investors. Importantly, the strategy marks a move away from sector-specific regulatory caps: the proposed oil-and-gas emissions cap – focused on upstream activities – was dropped, with the government instead relying on industrial carbon pricing, tighter methane rules, and expanded CCS/CCU deployment to achieve emissions reductions across industry (ibid.).

5.2.1.2 National Electricity Strategy

Canada's National Electricity Strategy "Powering Canada Strong" sets out the ambition to double the capacity of the country's electricity grid by 2050 to meet projected demand, driven in large part by the electrification of transport, buildings, and industry, as well as growth in electricity-intensive sectors. While approximately 80% of Canada's current generation is already non-emitting and industrial electricity prices are among the second lowest in both the G7 and the OECD, the strategy frames grid expansion as a nation-building exercise estimated to require over CAD 1 trillion in investment through to 2050. The strategy is structured around four pillars: building new generation, transmission, distribution, and storage infrastructure; connecting Canada's currently fragmented provincial grids through expanded east-west-north transmission interties; training and retaining the more than 130,000 skilled workers required; and strengthening domestic manufacturing of grid components and clean technologies.

The strategy positions electrification as the primary mechanism for economy-wide decarbonisation. With electricity sector emissions representing only 7% of Canada's total, the principal opportunity lies in switching high-emitting industrial end uses from fossil fuels to electricity, with the potential to reduce economy-wide emissions by up to five times current electricity sector levels. The strategy also signals an intent to adjust the Clean Electricity Regulations to allow for greater flexibility, including a continued role for natural gas, to preserve affordability and system reliability as industrial demand scales up. The details of the proposed amendments are discussed in 5.2.1.3 below.

To support industrial electrification, the federal government is deploying a range of financial instruments, including clean economy Investment Tax Credits covering clean electricity, clean technology, and carbon capture, utilisation and storage; strategic financing through the Canada Infrastructure Bank (with a clean energy target of CAD 20 billion) and the Canada Growth Fund; as well as a new Productivity Super-Deduction allowing businesses to write off a larger share of capital investment immediately. (NRCan 2026; Prime Minister of Canada 2026).

5.2.1.3 Clean Electricity Regulations

The Clean Electricity Standard, committed in the ERP, evolved into the Clean Electricity Regulations, enacted in December 2024 under the Canadian Environmental Protection Act, 1999. These regulations set enforceable CO_2-intensity limits on electricity generation, applying to new fossil-fuel units commissioned after 2024 and extending to all remaining emitting facilities by 2035, effectively operationalising the ERP target of a net-zero electricity grid (Government of Canada 2025c).

Under these rules, generating units face a cap of 65 tonnes of CO_2 per GWh annually, with the option to exceed this by up to 35 t/GWh if matched by qualifying offset credits. From 2050 onward, the cap falls to zero, though some offset flexibility is retained. The final regulations also incorporate tradeable compliance credits for facilities performing below their limits, alongside phased compliance deadlines – the majority of units must meet requirements by 2035, while certain projects have until 2050.

In November 2025, following provincial resistance, Canada’s Federal Government reached an agreement with Alberta that effectively paused federal enforcement of the Clean Electricity Regulation in the province, substituting it with more stringent provincial carbon pricing for industry and support for CCS/CCU projects. Although the deal nominally upholds the 2035 net-zero objective, it replaces binding federal regulation with a negotiated provincial pathway (CanREA 2025).

Building on the Alberta agreement, the Carney government's National Electricity Strategy (May 2026) signals further amendments to the CER. These include extending the operational life of existing gas-fired assets beyond the transition periods already provided for in the regulations, permitting new natural gas units to be added in the near term, particularly to support reliability in Western Canada, and broadening the use of carbon offsets to allow residual emissions to be offset elsewhere rather than met solely through generation-side measures. Taken together with the Alberta MOU, these proposed changes indicate a shift away from the strict 2035 decarbonisation timeline towards a more flexible 2050 framework. The amendments are subject to a consu2026,ion process launched in May 2026 and no revised regulatory text has been published to date.

5.2.1.4 Hydrogen Strategy

The Hydrogen Strategy for Canada, published in December 2020, established the Federal Government’s long-term vision for hydrogen as a cornerstone of the country’s energy transition. The strategy identified hydrogen’s role across sectors – particularly in heavy industry, long-haul transport, heating, and electricity storage – and projected that hydrogen could meet up to 30 percent of Canada’s end-use energy needs by 2050 (NRCan 2020). A progress report was issued in 2024 (NRCan 2024a).

Since 2020, approximately 80 low-carbon hydrogen production projects have been announced, representing a combined capacity of more than 5 million tonnes of hydrogen per year. These projects span electrolysis and steam methane reforming (SMR) with CCS/CCU, targeting applications in refining, industry, transport, and ammonia exports. Eight hydrogen hubs are forming across the country, and 23 export-oriented projects are under development, with international agreements signed with Germany, the Netherlands, Japan, South Korea, and the EU to establish trade corridors (NRCan 2024b).

Federal policy support announced since then includes the Clean Hydrogen Investment Tax Credit, announced in 2022, the Clean Fuels Fund, the Canada Growth Fund, the Canada Infrastructure Bank, and complementary tax credits for clean electricity, clean technology manufacturing, and CCS/CCU. Six provinces – British Columbia, Alberta, Ontario, Québec, Nova Scotia, and New Brunswick – have published their own hydrogen strategies.

5.2.1.5 Roadmap to Net-Zero Carbon Concrete

As the only sectoral decarbonisation strategy for energy-intensive industry, the Roadmap to Net-Zero Carbon Concrete by 2050, published in 2022 by the Government of Canada, sets out a plan to decarbonise Canada's cement and concrete industry. The roadmap establishes milestones to reach net-zero emissions by 2050. It outlines an Action Plan to 2030, which targets a cumulative reduction of more than 15 Mt of CO_2 by that year and ongoing annual cuts exceeding 4 Mt thereafter. Three strategic themes guide the plan: driving domestic market transformation through low-carbon procurement and performance-based standards; accelerating innovation and industrial transition across the value chain; and positioning Canada as a global leader in low-carbon cement and concrete technologies (CEC 2025).

To achieve these outcomes, the roadmap promotes a suite of measures across production, construction, and policy. In the near term, efforts focus on reducing the clinker content of cement, switching to lower-carbon fuels such as biomass and hydrogen, and improving energy efficiency at plants. Over the longer term, the pathway relies heavily on the deployment of CCS/CCU to address process emissions that cannot otherwise be eliminated. Complementary innovations such as supplementary cementitious materials, admixtures, and carbon-mineralisation in concrete are expected to further cut embodied emissions.

Government actions – such as evolving building codes, implementing Buy Clean procurement policies, supporting R&D, and maintaining predictable carbon-pricing – are identified as critical levers for decarbonising cement and concrete.

The roadmap further links the cement and concrete decarbonisation agenda to the 2030 Emissions Reduction Plan and federal programmes like the Strategic Innovation Fund – Net Zero Accelerator and the CCS/CCU Investment Tax Credit (see Chapter 5.2.3).

5.2.1.6 Standard on Embodied Carbon in Construction

The Buy Clean Strategy announced in the 2030 Emissions Reduction Plan has been implemented through the Standard on Embodied Carbon in Construction, issued under the Treasury Board's Policy on Green Procurement. Effective since December 2022, the standard requires federal departments to disclose and reduce the embodied carbon of structural materials in major construction projects. Initially applying to projects valued at CAD 10 million or more (lowered to CAD 5 million from 2025) and covering only ready-mix concrete, the standard was updated in March 2025 to include structural and reinforcement steel and to require whole-building life-cycle assessments for buildings exceeding a certain size; these new requirements took effect in September 2025. The Greening Government Strategy sets a target of 30% reduction in the embodied carbon of major construction projects starting in 2025. By leveraging federal purchasing power, the standard creates demand-side incentives for low-carbon cement and steel production (Government of Canada 2025d).

5.2.2 Industrial Carbon Pricing

The principal policy instrument for advancing industrial decarbonisation in Canada is the industrial carbon pricing system. This so-called Federal Output-Based Pricing System (OBPS) applies to large industrial emitters and operates separately from the consumer fuel charge. Following the elimination of the federal fuel charge in April 2025, industrial carbon pricing through the Federal OBPS remains in place (Government of Canada 2025e).

The Federal OBPS covers facilities in emissions-intensive and trade-exposed industrial and electricity sectors that emit 50,000 t CO_2eq or more per year. Smaller facilities emitting at least 10,000 t CO_2eq annually may opt in if they operate in sectors exposed to carbon-leakage. The OBPS sets performance standards for specific sectors, which are based on the national production-weighted average emissions intensity (GHG emissions per unit of output) for that sector. Facilities exceeding their standard must compensate for excess emissions, while those performing below the standard generate credits that can be banked or traded (ICAP 2022).

Compliance can be achieved through several mechanisms: payment of an excess-emissions charge to the government at the prevailing carbon price, surrender of surplus credits acquired from other facilities or banked from previous compliance periods, or submission of eligible offset credits from recognised provincial or federal schemes.

Provinces and territories are allowed to establish their own industrial carbon pricing systems, provided these meet the federal benchmark. Where no compliant system exists, the federal OBPS functions as a backstop, resulting in a patchwork of federal and provincial approaches.

British Columbia continues to administer a provincial OBPS, having removed its consumer carbon tax in April 2025 (ECCC 2025b). Alberta regulates industrial emitters under its Technology Innovation and Emissions Reduction (TIER) regulation, which was frozen at CAD 95 per tonne in May 2025. Pursuant to a November 2025 Memorandum of Understanding with the federal government, Alberta has committed to strengthen TIER and increase the effective credit price to CAD 130 per tonne (Prime Minister of Canada 2025). Québec maintains a cap-and-trade programme linked with California, while Ontario operates an Emissions Performance Standards Program. New Brunswick, Newfoundland and Labrador, and Nova Scotia each administer their own provincial OBPSs. Saskatchewan suspended its system on 1 April 2025, placing the province in non-compliance with federal requirements (National Observer 2025). The Northwest Territories also removed its consumer carbon tax but continues to apply carbon pricing to large emitters (ECCC 2025b).

The federal OBPS continues to apply directly in Manitoba, Nunavut, Prince Edward Island, and Yukon, which do not operate equivalent provincial systems. As of 2025, these backstop jurisdictions include 41 covered facilities (Government of Canada 2025f). Approved provincial systems elsewhere remain valid until at least the end of 2026 (ICAP 2022).

Provinces and territories that voluntarily adopt the federal OBPS may choose to receive all proceeds directly for inclusion in their general budgets. In jurisdictions where the federal system acts as a backstop, proceeds are returned through the Output-Based Pricing System Proceeds Fund, which supports projects that lower industrial emissions. The fund’s two main streams are the Decarbonization Incentive Program and the Future Electricity Fund (Government of Canada 2025e).

Independent analysis by the Canadian Climate Institute (2024) finds that large-emitter trading systems, which include the Federal OBPS and its provincial counterparts, are the most significant contributors to Canada’s projected emissions reductions by 2030.

5.2.3 Funding and Financing Instruments

5.2.3.1 Federal Programmes

Canada has several federal funding instruments combining direct public investment with fiscal incentives to advance industrial decarbonisation.

Strategic Innovation Fund – Net Zero Accelerator (NZA)

The Strategic Innovation Fund – Net Zero Accelerator (NZA) is Canada's flagship programme for industrial decarbonisation. Launched in December 2020 with an initial CAD 3 billion and expanded to CAD 8 billion through Budget 2021, the NZA is administered by Innovation, Science and Economic Development Canada (ISED). It targets the country's heaviest-emitting manufacturing sectors – steel, aluminium, cement, mining, mineral processing, and chemicals – which collectively account for 13.6% of national GHG emissions (ISED 2025c).

The NZA operates across three investment pillars: (1) near-term emissions reduction in large industrial emitters, (2) industrial transformation of sectors such as automotive and aerospace toward low-carbon production, and (3) clean technology development, including hydrogen, CCS/CCU, and a domestic battery supply chain. Signature projects include CAD 400 million for ArcelorMittal Dofasco's transition from coal-fired blast furnaces to hydrogen-ready electric arc furnaces in Hamilton and CAD 420 million for Algoma Steel's similar conversion in Sault Ste. Marie. The NZA has also committed CAD 300 million to Air Products' Edmonton blue-hydrogen facility, which uses autothermal reforming with CCS to supply refineries.

Clean Fuels Fund (CFF)

Complementing the NZA, the Clean Fuels Fund (CFF) allocates CAD 1.5 billion over five years through Natural Resources Canada to expand domestic production of low-carbon fuels – hydrogen, renewable diesel, cellulosic ethanol, renewable natural gas (RNG), and sustainable aviation fuel (SAF). Launched in June 2021 and extended to 2030 under Budget 2024, the fund de-risks capital investment by covering up to 50% of project costs (75% for Indigenous-led projects), with individual grants capped at CAD 50 million. Recent CFF investments include CAD 4.6 million for StormFisher Hydrogen's green-hydrogen-to-RNG facility in Thorold, Ontario and funding for Azure Sustainable Fuels' SAF plant (NRCan 2025b).

Canada Growth Fund (CGF)

Established in December 2022, the Canada Growth Fund (CGF) is a CAD 15 billion investment vehicle for advancing major decarbonisation projects. Managed by a subsidiary of the Public Sector Pension Investment Board (PSP Investments), the CGF deploys blended-finance instruments – equity stakes, concessional debt, and carbon contracts for difference (CCfDs). Up to CAD 7 billion of its capital is earmarked for CCfDs. The fund's inaugural CCfD, signed with Calgary-based Entropy Inc. in December 2023, commits the CGF to purchase up to 185,000 tonnes of carbon credits generated annually by the company over 15 years at CAD 86.50 per tonne – enabling Entropy's Glacier CCS project in Alberta. Subsequent deals include CAD 137 million for Svante, a Burnaby-based manufacturer of modular carbon-capture filters. By May 2026 the CGF has announced 23 investments totalling CAD 5 billion (CFG 2026).

Low Carbon Economy Fund (LCEF)

The Low Carbon Economy Fund (LCEF) was launched in 2017 with CAD 2 billion over five years and recapitalised in Budget 2022 with an additional CAD 2.2 billion over seven years – bringing total investment to CAD 4.2 billion through 2028–29. The LCEF operates through four funding streams: the Leadership Fund (CAD 1.4 billion for provincial and territorial programmes), the Challenge Fund (CAD 500 million for competitive grants to municipalities, businesses, and non-profits), the Champions stream (over CAD 450 million for projects from any eligible applicant), and the Indigenous Leadership Fund (CAD 180 million for Indigenous-owned renewable energy, energy efficiency, and low-carbon heating projects). To date, the original LCEF has supported 138 projects (ECCC 2025c).

Clean Economy Investment Tax Credits (ITCs)

Another group of instruments consists of several refundable investment tax credits (ITCs), enacted through Bills C-59 and C-69 in June 2024, which function as performance-based fiscal incentives (CRA 2025). Budget 2024 projects these credits will cost CAD 93 billion over 2022–23 to 2034–35 – a figure the Parliamentary Budget Officer estimates may run CAD 10 billion higher (Office of the Parliamentary Budget Officer 2024).

The *Carbon Capture Utilisation and Storage ITC* offers up to 60% on direct air capture equipment, 50% on other carbon-capture equipment, and 37.5% on transportation, storage, and utilisation infrastructure, applying to expenditures incurred between 1 January 2022 and 31 December 2040.

The *Clean Hydrogen ITC* is tiered by lifecycle carbon intensity: 40% for projects producing hydrogen below 0.75 kg CO_2e/kg H_2 (typically electrolysis running on renewable electricity), 25% for 0.75–2 kg (blue hydrogen with high-capture CCS), and 15% for 2–4 kg; production at or above 4 kg CO_2e/kg H_2 is ineligible.

The *Clean Technology Manufacturing ITC* grants 30% on machinery for producing solar panels, wind turbines, batteries, electrical-storage systems, heat pumps, small modular reactors, and CCS/CCU equipment – as well as on critical-mineral extraction and processing.

Two additional credits include the *Clean Technology ITC* (30% for capital investments in renewable energy generation, battery storage, and zero-emission vehicles) and the *Clean Electricity ITC* (15% for non-emitting electricity generation, including for provincial Crown corporations).

All credits carry labour requirements – prevailing wages and a minimum 10% apprenticeship hours in specific trades – which if not met reduce the credit rate by one-third. For all Investment Tax Credits, the rates begin phasing down in 2032 (to 20%), 2033 (10%), and 2034 (5%), falling to zero thereafter. With the Climate Competitiveness Strategy, the full CCS/CCU ITC rates were extended until 2035.

Green Industrial Facilities and Manufacturing Program

Energy-efficiency and process-optimisation measures are supported through Natural Resources Canada's Green Industrial Facilities and Manufacturing Program (GIFMP), launched in February 2023 (NRCan 2025c).

The programme operates through two tracks: the Industrial Facility Track provides up to 50% of eligible costs (up to 100% for Indigenous or not-for-profit organisations) to a maximum of CAD 5 million per project for facility-level retrofits – including boiler systems, compressed air, process furnaces, kilns, refrigeration, and waste-heat recovery (ibid.).

The Energy Efficiency Solutions Track funds utilities, governments, and non-profits at up to 75–100% of costs to a maximum of CAD 20 million per proposal for programmes that aggregate demand across multiple facilities. In October 2024, NRCan announced CAD 40 million to Emissions Reduction Alberta to develop a province-wide industrial efficiency programme under this track (ibid.).

Canada Infrastructure Bank

The Canada Infrastructure Bank (CIB) is a federal Crown corporation established in 2017 with CAD 35 billion in authorised capital to mobilise private and institutional investment in public-interest infrastructure (Government of Canada 2025g). Unlike grant programmes, the CIB provides repayable financing – primarily loans, but also equity investments and loan guarantees – to make capital-intensive projects commercially viable.

Budget 2022 expanded the CIB's mandate to include private sector-led decarbonisation projects, enabling investments in small modular reactors, hydrogen and clean fuel production and distribution, as well as CCS/CCU. Budget 2023 further directed the CIB to invest at least CAD 10 billion through its Clean Power priority area and at least CAD 10 billion through its Green Infrastructure priority area (Government of Canada 2022).

Notable industrial decarbonisation financing includes a CAD 220 million loan to Algoma Steel to support its transition to electric arc furnace steelmaking, a CAD 660 million loan to Irving Pulp & Paper for large-scale mill modernisation in New Brunswick, and CAD 277 million for the Varennes Carbon Recycling biorefinery and electrolyser project in Québec. By fiscal year 2023–24, the CIB had reached approximately CAD 9.7 billion in cumulative investment commitments, with a growing share directed toward clean power and clean energy infrastructure (ibid.).

5.2.3.2 Provincial Programmes

In addition to federal funding and tax incentives, Canada's provinces have established complementary programmes that recycle carbon-price revenues and target region-specific decarbonisation priorities. These initiatives vary in scale and governance but operate with similar aims: to lower industrial emissions, stimulate innovation, and adapt national objectives to local resource and energy contexts.

Alberta administers its industrial innovation funding primarily through Emissions Reduction Alberta (ERA), which allocates proceeds from the provincial TIER carbon-compliance system to technology deployment in CCS/CCU, methane abatement, hydrogen, and process electrification. Since 2009, ERA has committed CAD 986 million toward 299 projects with a combined value of CAD 8.6 billion, projected to deliver cumulative GHG reductions of 37.7 Mt by 2030. Payments into Alberta's industrial carbon-pricing fund totalled approximately CAD 4 billion between 2007 and 2022. Alberta has also launched the Alberta Carbon Capture Incentive Program (ACCIP), providing a 12% grant for eligible CCS/CCU capital costs, designed to stack with the federal CCS/CCU ITC (ERAlberta 2025).

British Columbia channels carbon-price revenues through the CleanBC Industry Fund (CIF), which since 2019 has invested more than CAD 244 million into projects that reduce industrial emissions (BC 2025). The fund operates through four streams: Emissions Performance, Innovation Accelerator, Feasibility Studies, and Industrial Electrification – the latter jointly administered with the Province's State Electricity Provider BC Hydro. The Innovative Clean Energy (ICE) Fund has committed over CAD 124 million since 2008 to pre-commercial clean-energy demonstrations.

Québec reinvests proceeds from its cap-and-trade system – which has raised more than CAD 9.9 billion since inception – into the Fonds d'Électrification et de Changements Climatiques (FECC). Under the *Plan pour une économie verte 2030*, the province allocated over CAD 2.1 billion for 2022–2027 to reduce emissions from industry and buildings through electrification and energy efficiency (Gouvernement du Québec 2025).

Ontario supports industrial efficiency through the Emissions Performance Standards (EPS) Program, which in 2024 launched the Emissions Performance Program to reinvest compliance payments into capital projects at eligible facilities. Furthermore, the Province's Electricity System Operator, the IESO, administers the Save on Energy Industrial Energy Efficiency Program, offering up to CAD 5 million per industrial energy efficiency project, with total funding of nearly CAD 80 million (Ontario 2025).

6 Conclusion and Areas for Future Cooperation

Germany and Canada both rely on their industrial sectors as key economic pillars, though at markedly different scales. Secondary manufacturing accounts for 23% of GDP in Germany, compared with around 10% in Canada. Their emission reduction trajectories, however, diverge considerably. Germany has reduced industrial emissions by 44% since 1990, closely mirroring its economy-wide progress. Canada's industrial emissions have fallen by 6.5% over the same period – still outperforming the national trend, which saw overall emissions rise by 16%. Notably, Germany's recent industrial emission reductions are fragile, as they stem largely from production declines triggered by the energy crisis rather than structural decarbonisation.

When it comes to the transformation of industry, each country has distinct vulnerabilities. Germany's energy-intensive industries are highly exposed to energy price volatilities and supply disruptions, as demonstrated by Europe's recent gas price crisis. Canada, meanwhile, faces trade concentration risk, with over 80% of manufacturing exports destined for the United States. These differing preconditions will shape each country's strategic priorities as they pursue industrial decarbonisation.

This study has focused specifically on energy-intensive industries, which hold comparable economic significance in both countries. These sectors contribute 3.4% to national GDP in Germany and 2.6% in Canada, while representing around 16% of the industrial workforce in each country. Across both economies, chemicals and refining, steel and metals, cement and lime, and pulp and paper dominate the emissions profile of energy-intensive industries.

The findings show that both countries have achieved a degree of decoupling between emissions and economic activity in these sectors over the past two decades. Since 2000, in Germany's chemicals and refining sector, emissions fell by 23% while production increased slightly; in Canada, they declined by 2% as sectoral growth reached 12%. In steel and metals, Germany showed a 13% reduction in emissions with stable production levels, whereas Canada achieved a 31% emission reduction alongside a 14% contraction in manufacturing. Germany's cement and lime industry reduced emissions by 23% while maintaining steady output, while Canada's fell by 12% even as the sector expanded by roughly 60%. The pulp and paper industry shows a different pattern: in Germany, emissions rose by 26% against 5% higher production, whereas in Canada they dropped by 40%, reflecting a substantial 47% decrease in industry output.

In both countries, the energy-intensive industries face similar decarbonisation challenges. Production processes are largely the same – steam cracking for high-value chemicals, blast-furnace routes for primary steel, and calcination for cement and lime – and both countries confront the same core obstacle: fossil fuels serve not only as energy sources but also as feedstocks, making substitution particularly complex. To meet these challenges, incremental efficiency gains alone will not be sufficient.

Instead, both countries require the deployment of transformative production technologies, including electrification, hydrogen, CCS/CCU, enhanced energy efficiency, circular economy approaches, and the use of biomass. Across all four sectors, these transformative technologies remain largely at the demonstration or early investment stage. Electric steam crackers, large-scale electrolysers, hydrogen-based steelmaking, cement CCS installations, and electrified paper-drying plants have been announced or are under construction, but few yet operate at commercial scale.

Each country brings distinct strengths and resource endowments to this transformation. Germany benefits from dense industrial clusters, such as integrated chemical parks that enable efficient energy and material flows between facilities, as well as a highly skilled workforce and well-established innovation ecosystems linking industry with research institutions. However, Germany remains a resource-poor country whose energy demand exceeds its domestic renewable generation potential. To this day, it is still heavily dependent on price-volatile fossil fuel imports – a vulnerability exposed by the post-2022 gas crisis, which triggered large production declines in energy-intensive industries, and again this year by the war in Iran and associated blockade of the Strait of Hormuz, although gas price increases have (thus far) been far less pronounced.

Canada possesses several advantages for industrial decarbonisation. Its abundant natural gas resources, leading CCS/CCU initiatives, and access to hydroelectricity position the country well for production pathways based on renewable and low-carbon energy carriers. For example, Canada's aluminium industry already operates with some of the lowest carbon intensities globally, benefiting from Québec's hydroelectric grid. However, fragmentation across provincial markets remains a structural weakness for domestic industry. Interprovincial trade continues to be hindered by regulatory inconsistencies, differing standards, and overlapping permitting regimes, while heavy trade dependence on the United States creates strategic vulnerabilities amid shifting U.S. climate and trade agendas.

The path forward will require sustained policy support, significant capital investment, and coordination across complex industrial value chains. Both Germany and Canada will have to achieve industrial decarbonisation, while safeguarding competitiveness and avoiding carbon leakage. In this transformation, the two countries have the opportunity to expand their strategic partnership – sharing technological expertise, aligning policy frameworks, jointly advancing demonstration projects, and pursuing trade opportunities – to accelerate the joint progress towards industrial decarbonisation. Building on this study, the following sections outline key areas where Germany and Canada can deepen their cooperation.

Stimulating demand for green industrial products

Both Germany and Canada face a shared challenge: transformative technologies remain mostly at the demonstration stage because demand for low-carbon industrial products is still limited. Joint work on demand-side policy instruments – such as lead markets, green public procurement, and product quotas – could help create the offtake certainty needed to de-risk private investment and accelerate deployment. Both countries have valuable experience with Carbon Contracts for Difference (CCfDs), blended finance tools, and other incentive schemes that could be shared for mutual learning. Aligning regulatory standards, including the mutual recognition of certification schemes and accounting methodologies, would further lower trade barriers.

Scaling CCS/CCU deployment and decarbonising cement production

Canada leads in commercial-scale deployment of carbon capture, utilisation and storage, particularly in the cement sector. Heidelberg Materials' Edmonton facility will become the world's first full-scale CCS installation at a cement plant. Germany has recently adopted legislation for building CO_2 transport and storage infrastructure and could benefit from Canada's experience in infrastructure planning, regulatory design, permitting, and project execution. Both countries would further gain from joint research and development on key technologies such as carbon capture and compression systems and CO_2 purity management.

Accelerating industrial electrification

In Canada, provinces such as Québec have long powered energy-intensive industries with hydroelectricity, giving them deep practical experience in planning and investing in industrial electrification. Germany, by contrast, has developed sophisticated mechanisms for maintaining grid stability amid high shares of variable wind and solar generation. Closer bilateral exchange on integrating renewable energy into the electricity grid, enhancing flexibilization of industrial loads, and advancing sector coupling could generate valuable insights for both sides, as they pursue the electrification of process heat and other industrial applications.

Advancing hydrogen cooperation

Hydrogen cooperation represents one of the longest standing areas of bilateral engagement between Germany and Canada. Canada, with its excellent wind resources, remains a promising partner for Germany in the future supply of renewable ammonia and other hydrogen-based products. While current progress is constrained by the absence of firm offtake agreements – reflecting today's price gap between renewable and conventional ammonia – upcoming support through H2Global is expected to help bridge this divide and enable first projects to move forward.

Further exchanges could deepen knowledge sharing on domestic hydrogen scale-up – for instance comparing hydrogen hub development in Alberta's Industrial Heartland and the Atlantic cluster with Germany's hubs in North Rhine-Westphalia and Hamburg. Other relevant topics for exchange are grid infrastructure planning and repurposing, as well as the alignment of hydrogen standards and certification schemes – specifically harmonizing the requirements and GHG calculation methodologies under Canada's ITCs with the EU's Delegated Acts RFNBOs.

Decarbonising iron and steel production

Both countries are advancing hydrogen-based direct reduced iron (DRI) production combined with electric arc furnaces (EAF) as the main pathway to decarbonise steelmaking. Exchanges drawing on projects such as Salzgitter's SALCOS programme in Germany and ArcelorMittal Dofasco's transformation in Canada would support shared learning and help reduce technical and financial risks. Cooperation on the development of harmonised standards and certification schemes for green steel could further improve market compatibility.

Germany's priority remains maintaining domestic iron production, making use of its industrial clusters and skilled workforce to keep value creation within the country. At the same time, Canada's combination of high-grade iron ore and abundant renewable energy – both in the geographically proximate province of Newfoundland and Labrador – positions it as a potential supplier of green hot-briquetted iron (HBI). Exploring how such trade might complement domestic iron production could provide Germany's steel industry with greater flexibility during the transition.

Accelerating permitting and regulatory approvals

In both Germany and Canada, long approval processes remain a major obstacle to industrial transformation. Hence, both countries have introduced new approaches to speed up permits for critical infrastructure. Germany's LNG Acceleration Act showed that large energy projects can be approved and built within months instead of years when they are declared to be of overriding public interest and when licensing procedures are accelerated and simplified. Germany is now applying the same principle to renewable energy, grid infrastructure, hydrogen and CCS/CCU infrastructure.

Canada's Building Canada Act and its Major Projects Office take a similar approach, streamlining federal approvals for projects deemed to be in the national interest. To reduce administrative barriers, both countries could benefit from exchanging practical experience on how to balance faster permitting with environmental protection, manage legal challenges, and strengthen administrative capacity. Such cooperation would help refine their respective approaches to help accelerate approvals for transformative industrial projects.

Strengthening cooperation on critical minerals

Although this study has focused on hard-to-abate industries, cooperation on critical minerals remains central to the wider industrial transformation. The August 2025 Joint Declaration of Intent on Critical Minerals Cooperation commits Germany and Canada to strengthening supply chains for materials essential to renewable energy technologies, electric vehicles, and advanced manufacturing. The partnership could help diversify Germany's raw material supply away from highly concentrated sources while supporting value-added processing and refining in Canada.

7 References

AAC (Aluminium Association of Canada) 2025. The Industry. Accessed 17 Mar. 2025. https://aluminium.ca/en/the-industry/.

acatech, DECHEMA (Hrsg.) 2023. Wasserstoff-Kompass – Handlungsoptionen für die Wasserstoffwirtschaft. https://www.wasserstoff-kompass.de/handlungsfelder.

Agora Energiewende 2020. Klimaneutrale Industrie: Schlüsseltechnologien und Politikoptionen für Stahl, Chemie und Zement. https://epub.wupperinst.org/frontdoor/deliver/index/docId/7675/file/7675_Klimaneutrale_Industrie.pdf.

Air Products 2025. Canada Net-zero Hydrogen Energy Complex. https://www.airproducts.com/energy-transition/canada-net-zero-hydrogen-energy-complex

Aitani 2004. Oil Refining and Products. Encyclopedia of Energy 2004, Pages 715-729. https://www.sciencedirect.com/science/article/abs/pii/B012176480X00259X.

Algers, J., Bataille, C. 2025. Strategic decarbonisation of the Canadian iron and steel industry. A worker-centered path to cut emissions, increase value added and strengthen global supply chains. University of Lund. https://lucris.lub.lu.se/ws/portalfiles/portal/218312088/Algers_Bataille_2025_Strategic_decarbonisation_ENG_CLEAN.pdf

ArcelorMittal 2022. ArcelorMittal breaks ground on first transformational low-carbon emissions steelmaking project. https://corporate.arcelormittal.com/media/press-releases/arcelormittal-breaks-ground-on-first-transformational-low-carbon-emissions-steelmaking-project.

BAFA (Federal Office for Economic Affairs and Export Control) n.d. Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft – Zuschuss und Kredit. https://www.bafa.de/DE/Energie/Energieeffizienz/Energieeffizienz_und_Prozesswaerme/energieeffizienz_und_prozesswaerme_node.html.

Barthe et al. 2015. Best Available Techniques (BAT). Reference Document for the Refining of Mineral Oil and Gas. https://eippcb.jrc.ec.europa.eu/sites/default/files/2019-11/REF_BREF_2015.pdf.

BASF 2024. BASF, SABIC, and Linde celebrate the start-up of the world's first large-scale electrically heated steam cracking furnace. https://www.basf.com/global/en/media/news-releases/2024/04/p-24-177

BASF 2025. BASF nimmt 54-Megawatt-Wasserelektrolyseur in Betrieb. https://www.basf.com/global/de/media/news-releases/2025/03/p-25-046

Bauer, C., Treyer, K., Antonini, C., Bergerson, J., Gazzani, M., Gencer, E., Gibbins, J., Mazzotti, M., McCoy, S. T., McKenna, R., Pietzcker, R. C., Ravikumar, A. P., Romano, M. C., Ueckerdt, F., Vente, J., van der Spek, M. (2022): On the climate impacts of blue hydrogen production. - Sustainable Energy and Fuels, 6, 1, 66-75. https://doi.org/10.1039/D1SE01508G

BC 2025. Clean-industry projects strengthen climate action, support good jobs. https://news.gov.bc.ca/releases/2025ECS0035-000761

BDI, BCG, and IW 2023. Transformationspfade für das Industrieland Deutschland. Industrie unter Spannung: Deutsche Strompreise im internationalen Vergleich. https://www.iwkoeln.de/fileadmin/user_upload/Studien/Gutachten/PDF/2023/Gutachten-Transformationspfade-Industrieland-D.pdf.

Bellona 2018. An Industry's Guide to Climate Action. https://network.bellona.org/content/uploads/sites/3/2018/11/Industry-Report-final.pdf

Birkner's PaperWorld 2024. Paper industry 2023: Significant decline after a race to catch up. https://www.paper-world.com/en/newsdetail/paper-industry-2023-significant-decline.

Blanchard et al. 2024. CCS om Germany's Decarbonisation Pathway: State of Play and Way Forward. Global CCS Institute. https://kh.aquaenergyexpo.com/wp-content/uploads/2025/01/CCS-in-Germanys-Decarbonisation-Pathway-State-of-Play-and-Way-Forward.pdf

BMFTR (Federal Ministry of Research, Technology and Space) n.d. KMU-innovativ: Energieeffizienz, Klimaschutz und Klimaanpassung. https://www.bmbf.de/DE/Forschung/Gesellschaft/ZukunftDerArbeit/KmuInnovativ/kmu-innovativ-klima/kmu-innovativ-klima_node.html.

BMJ (Federal Ministry of Justice and Consumer Protection) 2023. Gesetz zur Steigerung der Energieeffizienz in Deutschland. https://www.gesetze-im-internet.de/enefg/BJNR1350B0023.html.

BMUKN (Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety) n.d. The National Circular Economy Strategy (NCES). Framework conditions for a circular economy. https://www.bundesumweltministerium.de/en/topics/circular-economy/circular-economy-strategy.

BMUKN (Federal Ministry for the Environment, Climate Action, Nature Conservation and Nuclear Safety) 2024. Nationale Kreislaufwirtschaftstrategie. https://www.bmuv.de/fileadmin/Daten_BMU/Download_PDF/Abfallwirtschaft/nationale_kreislaufwirtschaftsstrategie_bf.pdf.

BMWE (Federal Ministry for Economic Affairs and Energy) n.d.a. Carbon Contracts for Difference. https://www.klimaschutzvertraege.info/en/home.

BMWE (Federal Ministry for Economic Affairs and Energy) n.d.b. Bundesförderung für Energie- und Ressourceneffizienz in der Wirtschaft (EEW). https://www.energiewechsel.de/KAENEF/Redaktion/DE/Dossier/eew-energie-und-ressourceneffizienz-in-der-wirtschaft.html#:~:text=Mit%20der%20Bundesf%C3%B6rderung%20f%C3%BCr%20Energie-%20und%20Ressourceneffizienz%20in,mit%20ihren%20Investitionen%20Energie-%20und%20Ressourcenverbr%C3%A4uche%20zu%20senken.

BMWE (Federal Ministry for Economic Affairs and Energy) n.d. Stahlindustrie. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Artikel/Branchenfokus/branchenfokus-stahl-und-metall-01.html.

BMWE (Federal Ministry for Economic Affairs and Energy) 2019. Energieeffizienzstrategie 2050. https://www.bmwk.de/Redaktion/DE/Publikationen/Energie/energieeffiezienzstrategie-2050.pdf?__blob=publicationFile&v=1.

BMWE (Federal Ministry for Economic Affairs and Energy) 2023. Fortschreibung der Nationalen Wasserstoffstrategie. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Publikationen/Energie/fortschreibung-nationale-wasserstoffstrategie.html

BMWE (Federal Ministry for Economic Affairs and Energy) 2023. Fortschreibung der Nationalen Wasserstoffstrategie. Fortschreibung der Nationalen Wasserstoffstrategie | BMWE

BMWE (Federal Ministry for Economic Affairs and Energy) 2024a. Canada and Germany launch joint funding window for hydrogen export projects. https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Pressemitteilungen/2024/03/20240319-canada-and-germany-launch-joint-funding-window-for-hydrogen-export-projects.html

BMWE (Federal Ministry for Economic Affairs and Energy) 2024b. CCU/CCS: Baustein für eine klimaneutrale und wettbewerbsfähige Industrie. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Artikel/Industrie/weitere-entwicklung-ccs-technologien.html

BMWE (Federal Ministry for Economic Affairs and Energy) 2024c. Cabinet clears path for CCS in Germany. https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Pressemitteilungen/2024/05/20240529-cabinet-clears-path-for-ccs-in-germany.html

BMWE (Federal Ministry for Economic Affairs and Energy) 2025a. Ein Stromnetz für die Energiewende. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Dossier/netze-und-netzausbau.html.

BMWE (Federal Ministry for Economic Affairs and Energy) 2025b. Vorbereitendes Verfahren für CO2-Differenzverträge startet. https://www.klimaschutzvertraege.info/news/vorbereitendes-verfahren-co2-differenzvertraege-startet.

BMWE (Federal Ministry for Economic Affairs and Energy) 2026a. BMWE startet Gebotsverfahren 2026 der CO-Differenzverträge. https://www.bundeswirtschaftsministerium.de/Redaktion/DE/Pressemitteilungen/2026/05/20260505-bmwe-startet-gebotsverfahren-2026-der-co2-differenzvertraege.html

BMWE (Federal Ministry for Economic Affairs and Energy) 2026b. Im Fokus: Wettbewerbsfähige Strompreise – Industriestrompreis entlastet die Industrie. Im Fokus: Wettbewerbsfähige Strompreise - Industriestrompreis entlastet die Industrie | BMWE

Bonafide 2024. Canada Cement Market Overview, 2029. https://www.bonafideresearch.com/product/6402697118/canada-cement-market.

Bundesverband Kalkindustrie n.d. Die Branche. https://www.kalk.de/verband/die-branche.

Bundesverband Kalkindustrie 2024. Mitgliederversammlung des Bundesverbandes der deutschen Kalkindustrie e.V.: Die deutsche Kalkindustrie stellt sich den Herausforderungen der Zukunft. https://www.kalk.de/wissensportal/pressemitteilungen/2024/mitgliederversammlung-des-bundesverbandes-der-deutschen-kalkindustrie-e-v.

CAC 2023. Concrete Zero: Canada's cement and concrete industry action plan to net-zero. https://cement.ca/wp-content/uploads/2023/05/ConcreteZero-Report-FINAL-reduced.pdf.

Calix 2025. Cement & lime. https://calix.global/cement-lime/

Canada 2012. Discover Canada - Canada's Economy. https://www.canada.ca/en/immigration-refugees-citizenship/corporate/publications-manuals/discover-canada/read-online/canadas-economy.html.

Canada 2024. Biennial Transparency Report (BTR). BTR1. CTF-NDC. https://unfccc.int/documents/645112.

Canadian Climate Institute 2023. Comparing Canadian and American Financial Incentives for CCS/CCU in the Oil Sector. https://climateinstitute.ca/wp-content/uploads/2023/03/comparing-canadian-and-american-incentives-CCS/CCU-oil-sector.pdf

Canadian Climate Institute 2024. How to modernize Canada's large-emitter trading systems. https://climateinstitute.ca/reports/the-state-of-carbon-pricing-in-canada-2024/

CanREA 2025. STATEMENT: Alberta-federal MOU: cautious optimism amid ongoing uncertainty. https://renewablesassociation.ca/statement-alberta-federal-mou-cautious-optimism-amid-ongoing-uncertainty/

Carbon Herald 2025. CO280 And JPMorgan Chase Sign New CDR Agreement Priced At Under $200p/t. https://carbonherald.com/co280-and-jpmorgan-chase-sign-new-cdr-agreement-priced-at-under-200p-t/

Carbon Upcycling 2025. Carbon Upcycling and Ash Grove Break Ground on Canadian First-of-Its-Kind Carbon Capture and Utilization Facility. https://carbonupcycling.com/2025/07/29/carbon-upcycling-and-ash-grove-break-ground-on-canadian-first-of-its-kind-carbon-capture-and-utilization-facility/

Carus, Michael, Olaf Porc, Christopher vom Berg (nova-Institute), Markus Kempen (EuroCare), Franziska Schier (TI-WF) and Julia Tandetzki 2025. Is there Enough Biomass to Defossilise the Chemicals and Derived Materials Sector by 2050? – A Joint BIC and RCI Scientific Background Report. https://renewable-carbon.eu/publications/product/is-there-enough-biomass-to-defossilise-the-chemicals-and-derived-materials-sector-by-2050-a-joint-bic-and-rci-scientific-background-report/

CEC 2025. Roadmap to Net-Zero Carbon Concrete by 2050. https://ised-isde.canada.ca/site/clean-growth-hub/en/cement-and-concrete-canada/roadmap-net-zero-carbon-concrete-2050

CemNet 2025. PCA responds to proposed US tariffs on Canadian and Mexican cement. https://www.cemnet.com/News/story/178606/pca-responds-to-proposed-us-tariffs-on-canadian-and-mexican-cement.html.

Centurion Plus 2023. The Backbone of Germany's Economy: Exploring the Chemical Industry's Impact and Future Prospects. https://centurionlgplus.com/the-backbone-of-germanys-economy-exploring-the-chemical-industrys-impact-and-future-prospects/.

Cepi 2023. Preliminary Statistics 2023. European pulp & paper industry. https://www.cepi.org/wp-content/uploads/2024/02/Cepi-Preliminary-Statistics-report-2023.pdf.

CER (Canada Energy Regulator) 2018. Canadian Refinery Overview 2018 – Energy Market Assessment. https://www.cer-rec.gc.ca/en/data-analysis/energy-commodities/crude-oil-petroleum-products/report/archive/2018-refinery-report/canadian-refinery-overview-2018-energy-market-assessment-executive-summary.html.

CER (Canada Energy Regulator) 2019. Market Snapshot: The pulp and paper sector uses less energy and produces less material than it did 20 years ago. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/market-snapshots/2019/market-snapshot-pulp-paper-sector-uses-less-energy-produces-less-material-than-it-did-20-years-ago.html.

CER (Canada Energy Regulator) 2025. Provincial and Territorial Energy Profiles – Canada. https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-canada.html?=undefined&wbdisable=true.

CFG (Canada Growth Fund) 2026. Government welcomes Canada Growth Fund investment to support the expansion of Canada's largest operating lithium mine. Government welcomes Canada Growth Fund investment to support the expansion of Canada's largest operating lithium mine - Canada.ca

CGF 2025. Canada Growth Fund (CGF), is a $15 billion independent investment fund, operating at arm's length from the Government of Canada. https://www.cgf-fcc.ca/en/

CIAC (Chemistry Industry Association of Canada) 2020. Canada's chemistry sector sees opportunities and challenges on the road to carbon zero. https://canadianchemistry.ca/canadas-chemistry-sector-sees-opportunities-and-challenges-on-the-road-to-carbon-zero/.

CIAC (Chemistry Industry Association of Canada) 2021. Chemistry Industry: Vital to achieving Canada's net-zero emissions targets. https://canadianchemistry.ca/wp-content/uploads/2021/09/Chemistry_Net-Zero-Emissions_ENG_web.pdf.

CIAC (Chemistry Industry Association of Canada) 2024. Economic Review of Chemistry. https://canadianchemistry.ca/wp-content/uploads/2023/06/2023-Economic-Review-of-Chemistry.pdf.

CIAC (Chemistry Industry Association of Canada) 2025. 2025 Economic Outlook for Industrial Chemicals and 2024 Year in Review. https://canadianchemistry.ca/wp-content/uploads/2024/12/2025-Outlook-for-Industrial-Chemicals-FINAL.pdf.

CIEL 2021. Over 500 Organizations Call on Policymakers to Reject Carbon Capture and Storage as a False Solution. https://www.ciel.org/organizations-demand-policymakers-reject-carbon-capture-and-storage/

Clean Energy Canada 2024. Future-proofing Canadian chemicals for a net-zero world: report. https://cleanenergycanada.org/future-proofing-canadian-chemicals-for-a-net-zero-world-report/.

Clean Energy Wire 2024a. Q&A – Germany's draft Carbon Management Strategy. https://www.cleanenergywire.org/factsheets/qa-germanys-draft-carbon-management-strategy.

Clean Energy Wire 2024b. Germany awards first companies with pioneering 'climate contract' scheme to slash industry emissions. https://www.cleanenergywire.org/news/germany-awards-first-companies-pioneering-climate-contract-scheme-slash-industry-emissions.

Climate Analytics 2025. Decarbonising cement: A review of EU and German policies and regulations, with recommendations for China. https://www.international-climate-initiative.com/fileadmin/iki/Dokumente/Publikationen/Projekte/20_I_423/20250918_giz_China-Cement-Emissions-2025.pdf

CMC (Canadian Manufacturing Coalition) 2025. Manufacturing in Canada. https://manufacturingourfuture.ca/manufacturing-in-canada/.

CMS Law-Now 2024. After EU Commission's first decision on Carbon Contracts for Difference, Germany initiates bidding of EUR 4bn. https://cms-lawnow.com/en/ealerts/2024/03/after-eu-commission-s-first-decision-on-carbon-contracts-for-difference-germany-initiates-bidding-of-eur-4bn.

CRA 2025. Clean Economy Investment Tax Credits (ITCs). https://www.canada.ca/en/revenue-agency/services/tax/businesses/topics/corporations/business-tax-credits/clean-economy-itc.html

Collect 2025. CO2LLECT Innovationsfonds Projekt CO2 Abscheidung und Speicherung. https://www.co2llect.de/

CO280 2025a. CO280 Awards Pre-FEED Contracts for an 800,000 Tonnes per Year Carbon Removal Project at a Pulp and Paper Mill in Canada. https://www.co280.com/post/co280-awards-pre-feed-contracts-for-an-800-000-tonnes-per-year-carbon-removal-project-at-a-pulp-and

CO230 2025b. CO280 successfully completes carbon capture field pilot at a U.S. pulp and paper mill. https://www.co280.com/post/co280-successfully-completes-carbon-capture-field-pilot-at-a-u-s-pulp-and-paper-mill

CSPA (Canadian Steel Producers Association) 2021. Canadian Steel Industry Energy & Greenhouse Gas Emissions Intensity, Technology and Carbon Reduction Roadmap. https://canadiansteel.ca/files/resources/Golder-Report-CSPA-NRCan.pdf.

CSPA (Canadian Steel Producers Association) and CISERA (Canadian Iron & Steel Energy Research Association) 2024. Steel Industry GHG Reduction R&D Overview. https://canadiansteel.ca/files/resources/A3-CISERA-Net-Zero-Emission-Steel-Research-Program-November-2024.pdf.

CWB Group 2024. Canada's Metals Industry: A Global and Domestic Analysis. https://www.cwbgroup.org/files/documents/canadian_metal_industry_english.pdf.

Dena 2025a. Kreislaufwirtschaft als Zukunftsstrategie. https://www.dena.de/infocenter/kreislaufwirtschaft-als-zukunftsstrategie/

Dena 2025b. Gezielte Nutzung von Biomasse für eine klimaneutrale und wettbewerbsstarke Industrie. https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2025/Gezielte_Nutzung_von_Biomasse_fuer_eine_klimaneutrale_und_wettbewerbsstarke_Industrie.pdf

Dena 2025c. Integration of carbon capture utilisation/storage in emissions trading scheme. https://www.dena.de/fileadmin/dena/Publikationen/PDFs/2025/ENTRANS/Etntrans_FACTSHEET_INTEGRATION_OF_CARBON_CAPTURE_UTILISATION_STORAGE_IN_EMISSIONS_TRADING_SYSTEMS.pdf

Deskera n.d. Paper Manufacturing Process: How Paper is Made? https://www.deskera.com/blog/paper-manufacturing-process-how-paper-is-made/

Destatis 2024a. Pressemitteilung Nr. 058 vom 15. Februar 2024. https://www.destatis.de/DE/Presse/Pressemitteilungen/2024/02/PD24_058_421.html.

Destatis 2024. Beschäftigte im Verarbeitenden Gewerbe im Dezember 2023: +0,5% zum Vorjahresmonat. https://www.destatis.de/DE/Presse/Pressemitteilungen/2024/02/PD24_058_421.html.

Destatis 2024b. Volkswirtschaftliche Gesamtrechnungen 2023, Tab 3.2.1. https://www.destatis.de/DE/Themen/Wirtschaft/Volkswirtschaftliche-Gesamtrechnungen-Inlandsprodukt/Publikationen/Downloads-Inlandsprodukt/inlandsprodukt-endgueltig-xlsx-2180140.xlsx?__blob=publicationFile.

Destatis 2025a. Pressemitteilung Nr. 127 vom 2. April 2025. https://www.destatis.de/DE/Presse/Pressemitteilungen/2025/04/PD25_127_421.html.

Destatis 2025b. Branchen und Unternehmen. Industrie, Verarbeitendes Gewerbe. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Industrie-Verarbeitendes-Gewerbe/_inhalt.html.

Destatis 2025c. Bedeutung der energieintensiven Industriezweige in Deutschland. https://www.destatis.de/DE/Themen/Branchen-Unternehmen/Industrie-Verarbeitendes-Gewerbe/produktionsindex-energieintensive-branchen.html

Destatis 2025d. VGR des Bundes - Bruttowertschöpfung (nominal/ preisbereinigt): Deutschland, Jahre, Wirtschaftsbereiche. https://www-genesis.destatis.de/datenbank/online/url/4b6732ae.

Destatis 2025e. Treibhausgasemissionen: Deutschland, Jahre, Treibhausgasarten, Wirtschaftszweige. https://www-genesis.destatis.de/datenbank/online/url/63753b91.

Destatis 2025f. Erdgaspreise für Nicht-Haushalte: Deutschland, Halbjahre, Jahresverbrauchsklassen, Preisarten. GENESIS-Online - Tabelle 'Erdgaspreise für Nicht-Haushalte: Deutschland, Halbjahre, Jahresverbrauchsklassen, Preisarten'

Deutsche Emissionshandelsstelle 2025. Understanding electricity price compensation (SPK). DEHSt - Understanding electricity price compensation (SPK).

DG Grow 2025. Cement and Lime. https://single-market-economy.ec.europa.eu/sectors/raw-materials/related-industries/non-metallic-products-and-industries/cement-and-lime_en

Die Papierindustrie e.V. 2023. Statistiken zum Leistungsbericht Papier 2023. https://www.papierindustrie.de/fileadmin/0002-PAPIERINDUSTRIE/07_Dateien/XX-LB/PAPIER2023-Statistik-digital.pdf.

Die Papierindustrie e.V. 2024a. Leistungsbericht "Papier 2024" – Die Papierindustrie in Zahlen. https://www.presseportal.de/pm/16061/5775496.

Die Papierindustrie e.V. 2024b. Climate Study for the Paper Industry. Transformation to Climate Neutrality. https://cdn.prod.website-files.com/64baba653b7c9d6adfd30828/66ba3f65a8e68f1691d02904_240104%20Klimastudie%20EN-komprimiert.pdf.

Dietrich et al. 2024. Towards a Greener Industry Sector. Existing and Potential Approaches to Decarbonisation in Germany and New Zealand. https://adelphi.de/system/files/document/dekarbonisierung_industrie_nz_de_final.pdf.

DLA Piper 2023. Part 1: Energy Efficiency Act (EnEfG) – New legal requirements for companies. The Bundestag debates the Energy Efficiency Act (EnEfG) for the first time. https://www.dlapiper.com/en-de/insights/publications/2023/05/energieeffizienzgesetz-enefg-neue-gesetzliche-anforderungen-fur-unternehmen.

Dow (2024). Fort Saskatchewan Path2Zero. https://ca.dow.com/content/dam/corp/documents/ehs/066-00393-01-fort-saskatchewan-path-2-zero.pdf.

ECCC 2022. 2030 EMISSIONS REDUCTION PLAN. Canada's Next Steps for Clean Air and a Strong Economy. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf

ECCC 2024. National Inventory Report 1990-2022: Greenhouse Gas Sources and Sinks in Canada. https://publications.gc.ca/collections/collection_2024/eccc/En81-4-2022-3-eng.pdf.

ECCC 2025a. National Inventory Report 1990-2023: Greenhouse Gas Sources and Sinks in Canada. https://publications.gc.ca/collections/collection_2025/eccc/En81-4-2023-1-eng.pdf.

ECCC 2025b. Carbon pricing systems across Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work.html

ECCC 2025c. The Low Carbon Economy Fund. https://www.canada.ca/en/environment-climate-change/services/climate-change/low-carbon-economy-fund.html

Eckardt, Jakob, Jannik Hoehne, Saskia Lengning, Dr. Christian Kluge, Lea Mohnen, Marie Münch, Bastian Stenzel. CCS/CCU in Nordamerika – Lessons Learned für Deutschland. https://climateandenergypartnerships.org/de/studies/CCS/CCU-in-nordamerika-lessons-learned-fuer-deutschland/

EID n.d. Die energieintensiven Industrien in Deutschland sind der industrielle Kern unserer Volkswirtschaft. https://www.energieintensive.de/ueber-uns.

Energy Innovation 2025. Overcoming All Barriers to Industrial Electrification. https://energyinnovation.org/report/overcoming-all-barriers-to-industrial-electrification/

Energynest 2023. Energieverbrauch in der Papierindustrie nachhaltig und zukunftssicher gestalten. https://energy-nest.com/de/energieverbrauch-papierindustrie/.

Environment and Climate Change Canada 2022. 2030 Emissions Reduction Plan: Canada's Next Steps for Clean Air and a Strong Economy. https://publications.gc.ca/collections/collection_2022/eccc/En4-460-2022-eng.pdf.

Environment and Climate Change Canada 2024. National Inventory Report, 1990–2022: Greenhouse Gas Sources and Sinks in Canada. https://publications.gc.ca/collections/collection_2024/eccc/En81-4-2022-3-eng.pdf.

Environmental Innovation Programme n.d. Wir fördern Innovationen. https://www.umweltinnovationsprogramm.de/.

EPA (US Environmental Protection Agency) 2013. PETROLEUM REFINERIES SECTOR. https://www.epa.gov/sites/default/files/2016-11/documents/refineries_2013_112516.pdf.

EPA (US Environmental Protection Agency) 2025. Nonferrous Metals Manufacturing Effluent Guidelines. https://www.epa.gov/eg/nonferrous-metals-manufacturing-effluent-guidelines.

ERAlberta 2025. Alberta Invests Almost $30 Million in Two New Programs to Reduce Methane Emissions from the Oil and Gas Industry. https://www.eralberta.ca/media-releases/alberta-invests-almost-30-million-in-two-new-programs-to-reduce-methane-emissions-from-the-oil-and-gas-industry/

ESG Post 2025. CO280 advances Canadian carbon removal project with Pre-FEED contracts. https://esgpost.com/co280-advances-canadian-carbon-removal-project-with-pre-feed-contracts/

Essity 2023. Essity first to produce tissue in a CO2-free production process using renewable hydrogen. https://www.essity.de/presse/press-release/essity-first-to-produce-tissue-in-a-co2-free-production-process-using-renewable-hydrogen/62674d3e67dfbd0b/

EU Chemicals Platform 2025. Recovery and Resilience Facility: driving Europe's post-pandemic transformation. https://transition-pathways.europa.eu/eu-funding-mechanism/recovery-and-resilience-facility-driving-europes-post-pandemic-transformation.

EurA 2022. How Paper Industry Can Be More Resource-Efficient in the Future. https://www.eura-ag.com/en/blog/how-paper-industry-can-be-more-resource-efficient-in-the-future

Eurometal 2024. Germany's crude steel output in 2023 at lowest since 2009, WV Stahl says. https://eurometal.net/germanys-crude-steel-output-in-2023-at-lowest-since-2009-wv-stahl-says/.

European Commission n.d.a. About the ETS. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/about-eu-ets_en.

European Commission n.d.b. EU ETS emissions cap. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/eu-ets-emissions-cap_en.

European Commission n.d.c. Auctioning of allowances. https://climate.ec.europa.eu/eu-action/eu-emissions-trading-system-eu-ets/auctioning-allowances_en.

European Commission n.d.d. Carbon Border Adjustment Mechanism. https://taxation-customs.ec.europa.eu/carbon-border-adjustment-mechanism_en.

European Commission n.d.e. Industrial and Livestock Rearing Emissions Directive (IED 2.0). https://environment.ec.europa.eu/topics/industrial-emissions-and-safety/industrial-and-livestock-rearing-emissions-directive-ied-20_en.

European Commission n.d.f. Energy efficiency targets. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-targets_en.

European Commission n.d.g. Energy Efficiency Directive. https://energy.ec.europa.eu/topics/energy-efficiency/energy-efficiency-targets-directive-and-rules/energy-efficiency-directive_en.

European Commission n.d.h. Ecodesign for Sustainable Products Regulation. https://commission.europa.eu/energy-climate-change-environment/standards-tools-and-labels/products-labelling-rules-and-requirements/ecodesign-sustainable-products-regulation_en.

European Commission n.d.i. Innovation Fund. https://commission.europa.eu/funding-tenders/find-funding/eu-funding-programmes/innovation-fund_en.

European Commission n.d.j. The Recovery and Resilience Facility. https://commission.europa.eu/business-economy-euro/economic-recovery/recovery-and-resilience-facility_en.

European Commission n.d.k. LIFE Programme. EU's funding instrument for the environment and climate action. https://cinea.ec.europa.eu/programmes/life_en.

European Commission n.d.l. LIFE programme. https://single-market-economy.ec.europa.eu/industry/strategy/hydrogen/funding-guide/eu-programmes-funds/life-programme_en.

European Commission n.d.m. Modernisation Fund. https://climate.ec.europa.eu/eu-action/eu-funding-climate-action/modernisation-fund_en.

European Commission n.d.n. Approved IPCEIs in the Hydrogen value chain. https://competition-policy.ec.europa.eu/state-aid/ipcei/approved-ipceis/hydrogen-value-chain_engen value chain - European Commission.

European Commission n.d.o. Commission approves up to €5.4 billion support by 15 Member States for an Important Project of Common European Interest (IPCEI) in the Hydrogen Technology value chain "IPCEI Hy2Tech". https://competition-policy.ec.europa.eu/document/download/4ad0b496-a442-476a-a915-46be570d5d10_en?filename=2022_IPCEI_hydrogen_by_member_states_en.pdf.

European Commission n.d.p. IPCEI Hy2Infra workstreams. https://competition policy.ec.europa.eu/document/download/72658017-0480-4f7d-9675-cb4bf87136bc_en?filename=2024_IPCEI_Hy2Infra_workstreams_en.pdf.

European Commission n.d.q. IPCEI Hy2Move Ecosystem. https://competition-policy.ec.europa.eu/document/download/cf40be22-41ea-47c5-8654-54e8a3293ee9_en?filename=Hy2Move_Ecosystem_en.pdf .

European Commission 2020a. A hydrogen strategy for climate-neutral Europe. EUR-Lex - 52020DC0301 - EN - EUR-Lex.

European Commission 2020b. A new Circular Economy Action Plan. For a cleaner and more competitive Europe. eur-lex.europa.eu/legal-content/EN/TXT/HTML/?uri=CELEX:52020DC0098.

European Commission 2023. EU-Innovationsfonds: 4 Mrd. Euro Förderung für Projekte zu Dekarbonisierungs-Technologien. https://germany.representation.ec.europa.eu/news/eu-innovationsfonds-4-mrd-euro-forderung-fur-projekte-zu-dekarbonisierungs-technologien-2023-11-23_de?prefLang=en.

European Commission 2024. Commission Recommendation (EU) 2024/2002 of 24 July 2024 setting out guidelines for the interpretation of Article 11 of Directive (EU) 2023/1791 of the European Parliament and of the Council as regards energy management systems and energy audits. EUR-Lex - 32024H2002 - EN - EUR-Lex.

European Commission 2024b. Towrads an ambitious Industrial Carbon Management for the EU. EUR-Lex - 52024DC0062 - EN - EUR-Lex.

European Commission 2024c. Commission sets out how to sustainably capture, store and use carbon to reach climate neutrality by 2050. https://ec.europa.eu/commission/presscorner/detail/en/ip_24_585.

European Commission 2025a. The Clean Industrial Deal: A joint roadmap for competitiveness and decarbonization. EUR-Lex - 52025DC0085 - EN - EUR-Lex.

European Commission 2025b. EU and South Africa sign first-ever Clean Trade and Investment Partnership (CTIP). https://policy.trade.ec.europa.eu/news/eu-and-south-africa-sign-first-ever-clean-trade-and-investment-partnership-ctip-2025-11-20_en.

European Commission 2025c. Commission adopts rules and launches initiatives to boost carbon removals and carbon farming in the EU. https://climate.ec.europa.eu/news-other-reads/news/commission-adopts-rules-and-launches-initiatives-boost-carbon-removals-and-carbon-farming-eu-2025-12-01_en.

European Commission 2026a. European Hydrogen Bank. https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/european-hydrogen-bank_en

European Commission 2026b. The Industrial Accelerator Act. Growing Eu Industry, Securing Jobs for the Future. 9c7fa301-c4cf-4600-8c00-34243ee26e45_en

European Investment Fund n.d. Climate and Infrastructure Funds. https://www.eif.org/flagship-initiatives/investeu/climate-and-infrastructure.

European Parliament 2023. CO2-Abbau: zusätzliche Maßnahmen zur Verwirklichung der Klimaneutralität. https://www.europarl.europa.eu/topics/de/article/20231109STO09918/co2-abbau-zusatzliche-massnahmen-zur-verwirklichung-der-klimaneutralitat.

European Parliament 2026. Legislative Train Schedule. Industrial Accelerator Act. Carriages preview | Legislative Train Schedule.

European Parliament (EP) & Council of the EU (EUC) 2009. Directive 2009/31/EC. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A32009L0031.

European Parliament (EP) & Council of the EU (EUC) 2018. Directive (EU) 2018/2001. https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02018L2001-20181221&qid=1647270042844#E0001.

European Parliament (EP) & Council of the EU (EUC) 2023. Directive (EU) 2023/2413. https://eur-lex.europa.eu/eli/dir/2023/2413/oj/eng.

Fan, Z., Friedmann, S.J. 2021. Low-carbon production of iron and steel: Technology options, economic assessment, and policy. Joule. Volume 5, Issue 4, p829-862. https://www.cell.com/joule/fulltext/S2542-4351(21)00095-7

Fennell, Davis and Mohammed 2021. Decarbonizing cement production. Joule, Volume 5, Issue 6, 16 June 2021, Pages 1305-1311. https://www.sciencedirect.com/science/article/pii/S2542435121001975

Fraunhofer IEE 2020. Green hydrogen or green electricity for building heating? https://www.iee.fraunhofer.de/en/presse-infothek/press-media/overview/2020/Hydrogen-and-Heat-in-Buildings.html

Fraunhofer ISI n.d. IEEN: Monitoring of the Initiative Energy Efficiency Networks. https://www.isi.fraunhofer.de/en/competence-center/energietechnologien-energiesysteme/projekte/IEEN-Monitoring-der-Initiative-Energieeffizienz-Netzwerke.html.

Fraunhofer ISI 2024. Flexibilisation of electrified industrial processes - An analysis of the technical and economic challenges from a company and system perspective. https://www.isi.fraunhofer.de/en/competence-center/energietechnologien-energiesysteme/projekte/Flexibilisierung-elektrifizierter-Industrieprozesse.html#3

Gholami et al. 2021. Leakage risk assessment of a CO2 storage site: A review. https://www.sciencedirect.com/science/article/abs/pii/S0012825221003500

GMK Center 2024. Germany reduced steel production by 3.9% y/y in 2023. https://gmk.center/en/news/germany-reduced-steel-production-by-3-9-y-y-in-2023/.

Gouvernement du Québec 2025. The Carbon Market, a Green Economy Growth Tool!. https://www.environnement.gouv.qc.ca/changementsclimatiques/marche-carbone_en.asp

Government of Canada 2022. Clean Air and a Strong Economy. https://www.budget.canada.ca/2022/report-rapport/chap3-en.html

Government of Canada 2024. Net-zero emissions by 2050. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/net-zero-emissions-2050.html

Government of Canada 2025a. Canada partners with Heidelberg Materials to drive cement industry decarbonization. https://www.canada.ca/en/innovation-science-economic-development/news/2025/03/canada-partners-with-heidelberg-materials-to-drive-cement-industry-decarbonization.html

Government of Canada 2025b. Canada’s new Climate Competitiveness Strategy. https://www.canada.ca/en/immigration-refugees-citizenship/news/2025/11/canadas-new-climate-competitiveness-strategy.html

Government of Canada 2025c. Canada's clean electricity future. https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/clean-electricity.html

Government of Canada 2025d. Standard on Embodied Carbon in Construction. https://www.tbs-sct.canada.ca/pol/doc-eng.aspx?id=32814

Government of Canada 2025e. Industrial carbon pricing in Canada. https://www.canada.ca/en/environment-climate-change/services/climate-change/pricing-pollution-how-it-will-work/putting-price-on-carbon-pollution/industry.html

Government of Canada 2025f. Regulations Amending the Output-Based Pricing System Regulations: SOR/2025-108. https://gazette.gc.ca/rp-pr/p2/2025/2025-03-15-x2/html/sor-dors108-eng.html

Government of Canada 2025g. Canada Infrastructure Bank. https://housing-infrastructure.canada.ca/CIB-BIC/index-eng.html

Heidelberg Materials n.d. Edmonton CCS/CCU: Unlocking the Future of Carbon Capture, Utilization, and Storage. https://www.heidelbergmaterials.us/home/edmonton.

HM 2023. First global net-zero carbon capture and storage facility in the cement industry: Heidelberg Materials partners with the Government of Canada. https://www.heidelbergmaterials.com/en/pr-2023-04-06

HM 2025. GeZero: Wegbereiter für die dekarbonisierte Zementindustrie. https://www.heidelbergmaterials.de/de/zement/zementwerke/geseke/gezero-projekt

Holcim 2025. CARBON2BUSINESS carbon capture and utilization project. https://www.holcim.com/what-we-do/green-operations/CCS/CCU/carbon2business

Hydrogen Europe 2025. EU makes €6 billlion available to hydrogen sector with launch of 3rd Hydrogen Bank auction and Innovation Fund call. https://hydrogeneurope.eu/eu-makes-e6bn-available-to-hydrogen-sector-with-launch-of-3rd-hydrogen-bank-auction-and-innovation-fund-call/

ICAP 2022. Canada Federal Output-Based Pricing System. https://icapcarbonaction.com/system/files/ets_pdfs/icap-etsmap-factsheet-135.pdf

IBISWorld 2024. Pulp Manufacturing in Germany – Market Research Report (2014-2029). https://www.ibisworld.com/germany/industry/pulp-manufacturing/736/.

IBISWorld 2025a. Cement Manufacturing in Canada - Market Research Report (2015-2030). https://www.ibisworld.com/canada/industry/cement-manufacturing/551/.

IBISWorld 2025b. Paper Mills in Canada - Market Research Report (2015-2030). https://www.ibisworld.com/canada/industry/paper-mills/406/.

ICIS (Independent Commodity Intelligence Services) 2026. Dow greenlights Path2Zero cracker project after delay, Phase 1 start-up for end-2029. https://www.icis.com/explore/resources/news/2026/01/29/11175679/dow-greenlights-path2zero-cracker-project-after-delay-phase-1-start-up-for-end-2029/

IEA (International Energy Agency) 2017. Energy Efficiency Networks Initiative. https://www.iea.org/policies/2306-energy-efficiency-networks-initiative.

IEA (International Energy Agency) 2019a. The Future of Hydrogen. https://www.iea.org/reports/the-future-of-hydrogen

IEA (International Energy Agency) 2019b. The clean hydrogen future has already begun. https://www.iea.org/commentaries/the-clean-hydrogen-future-has-already-begun

IEA (International Energy Agency) 2021. Driving Energy Efficiency in Heavy Industries. https://www.iea.org/articles/driving-energy-efficiency-in-heavy-industries

IEA (International Energy Agency) 2023a. Chemicals. https://www.iea.org/energy-system/industry/chemicals.

IEA (International Energy Agency) 2023b. Pulp & paper. https://www.iea.org/energy-system/industry/paper.

IEA (International Energy Agency) 2023c. Electrification. https://www.iea.org/energy-system/electricity/electrification

IEA (International Energy Agency) 2023d. Chemicals. https://www.iea.org/energy-system/industry/chemicals

IEA (International Energy Agency) 2023e. Cement. https://www.iea.org/reports/cement-3

IEA (International Energy Agency) 2024. Carbon Capture Utilisation and Storage. https://www.iea.org/energy-system/carbon-capture-utilisation-and-storage

IEA (International Energy Agency) 2025. Ammonia Technology Roadmap. Executive Summary. https://www.iea.org/reports/ammonia-technology-roadmap/executive-summary.

IEA (International Energy Agency) 2026. Global Hydrogen Review 2026. Global Hydrogen Review 2026

IEEFA 2022. The carbon capture crux: Lessons learned. https://ieefa.org/resources/carbon-capture-crux-lessons-learned

IEEN (Energy Efficiency Networks Initiative) 2020. Wir machen weiter! Ab 2021 als Inititiative Energieeffizienz- und Klimaschutz-Netzwerke. https://www.effizienznetzwerke.org/app/uploads/2020/09/200910-IEEN_FS_Wir_machen_weiter_Final.pdf.

IEEKN (Energy Efficiency and Climate Networks Initiative) n.d. Über die Initiative. https://www.effizienznetzwerke.org/initiative/.

Investopedia 2025. The Top 25 Economies in the World. https://www.investopedia.com/insights/worlds-top-economies/.

IRENA 2020. Green Hydrogen. A Guide to Policy Making. https://www.irena.org/-/media/Files/IRENA/Agency/Publication/2020/Nov/IRENA_Green_hydrogen_policy_2020.pdf

ITA (International Trade Administration) n.d. Canada Steel Export Report. https://www.trade.gov/data-visualization/canada-steel-exports-report.

ISED (Innovation, Science and Economic Development Canada) n.d. Trade Data Online. https://ised-isde.canada.ca/app/ixb/tdo/crtr.html?&productType=NAICS&lang=eng.

ISED (Innovation, Science and Economic Development Canada) 2021. Canadian manufacturing sector gateway. https://ised-isde.canada.ca/site/canadian-manufacturing-sector-gateway/en.

ISED (Innovation, Science and Economic Development Canada) 2022. Roadmap to Net-Zero Carbon Concrete by 2050. https://ised-isde.canada.ca/site/clean-growth-hub/en/cement-and-concrete-canada/roadmap-net-zero-carbon-concrete-2050.

ISED (Innovation, Science and Economic Development Canada) 2024a. Summary - Canadian Industry Statistics: Chemical manufacturing. https://ised-isde.canada.ca/app/ixb/cis/summary-sommaire/325.

ISED (Innovation, Science and Economic Development Canada) 2024b. Summary - Canadian Industry Statistics: Non-ferrous metal (except aluminum) smelting and refining. https://ised-isde.canada.ca/app/ixb/cis/summary-sommaire/33141.

ISED (Innovation, Science and Economic Development Canada) 2024c. Summary - Canadian Industry Statistics: Cement and concrete product manufacturing. https://ised-isde.canada.ca/app/ixb/cis/summary-sommaire/3273.

ISED (Innovation, Science and Economic Development Canada) 2025a. Manufacturing - Canadian Industry Statistics. https://ised-isde.canada.ca/app/ixb/cis/manufacturing-fabrication/32411.

ISED (Innovation, Science and Economic Development Canada) 2025b. Summary - Canadian Industry Statistics. Non-ferrous metal (except aluminium) smelting and refining – 33141. https://ised-isde.canada.ca/app/ixb/cis/summary-sommaire/33141.

ISED (Innovation, Science and Economic Development Canada) 2025c. Net Zero Accelerator Initiative. https://ised-isde.canada.ca/site/ised/en/programs-and-initiatives/strategic-response-fund/net-zero-accelerator-initiative

ITA 2025. Canada Steel Exports Report. https://www.trade.gov/data-visualization/canada-steel-exports-report.

Jörg et al. 2024. Short Study: Energy-Efficient and CO2-Free Process Heat. Hochschule Niederrhein, SWK E. https://deneff.org/wp-content/uploads/2024/09/Short-Study_Energy-Efficient-and-CO2-Free-Process-Heat.pdf

Journal of Commerce 2021. Lafarge plant wraps second phase of carbon capture project. https://canada.constructconnect.com/joc/news/projects/2021/01/lafarge-plant-wraps-second-phase-of-carbon-capture-project.

KEI 2025a. Klimaneutrale Industrie. https://www.klimaschutz-industrie.de/themen/klimaschutz-in-der-industrie/.

KEI 2025b. Grundstoffchemische Industrie. https://www.klimaschutz-industrie.de/themen/branchen/grundstoffchemische-industrie/.

KEI 2025c. Stahlindustrie. https://www.klimaschutz-industrie.de/themen/branchen/stahlindustrie/

KEI 2025d. Nichteisenmetallindustrie. https://www.klimaschutz-industrie.de/themen/branchen/nichteisenmetallindustrie/

KEI 2025e. Zementindustrie. https://www.klimaschutz-industrie.de/themen/branchen/zementindustrie/

KEI 2025f. Kalkindustrie. https://www.klimaschutz-industrie.de/themen/branchen/kalkindustrie/

KEI 2025g. Papier- und Zellstoffindustrie. https://www.klimaschutz-industrie.de/themen/branchen/papier-und-zellstoffindustrie/

KfW n.d. KfW-Energieeffizienzprogramm – Produktionsanlagen/-prozesse. Energiekosten im laufenden Betrieb einsparen. https://www.kfw.de/inlandsfoerderung/Unternehmen/Energie-Umwelt/F%C3%B6rderprodukte/EE-Produktion-292/.

Kruger 2025. Kruger innovates and diversifies production at its Wayagamack Mill.

https://www.kruger.com/news/wayagamack-diversifies-production/

Labelprint24 n.d. Die deutsche und europäische Papierindustrie – Themen, Zahlen und Zukunft. https://www.labelprint24.com/de/magazine/die-deutsche-und-europaeische-papierindustrie-themen-zahlen-und-zukunft-771.

Lafarge n.d. Project CO2MENT. https://www.lafarge.ca/en/project-co2ment.

Linklaters 2023. The new German Energy Efficiency Act: Implications for data centers and other companies. The new German Energy Efficiency Act: Implications for data centers and other companies, Ruth Losch.

Lhoist 2025. Everest. https://www.lhoist.com/en/everest

LUX Metal 2025. China's Revolutionary Coal-Free Steel Production: 3600 Times Faster and Transforming the Industry. https://luxmetalgroup.com/chinas-revolutionary-coal-free-steel-production-3600-times-faster-and-transforming-the-industry/

Ma et al. 2023. Global oil refining's contribution to greenhouse gas emissions from 2000 to 2021. The Innovation. Volume 4, Issue 1, 30 January 2023, 100361. https://www.sciencedirect.com/science/article/pii/S2666675822001576.

Mason, Thomas O., Lea, Frederick M.. "cement". Encyclopedia Britannica, 27 Nov. 2025, https://www.britannica.com/technology/cement-building-material

McKinsey 2024. Net-zero electrical heat: A turning point in feasibility. https://www.mckinsey.com/capabilities/sustainability/our-insights/net-zero-electrical-heat-a-turning-point-in-feasibility

Mewis and Zinn 2025. Chemie: Innovationstreiber mit globaler Strahlkraft. https://www.deutschland.de/de/topic/wirtschaft/deutsche-chemieindustrie-innovation-herausforderungen.

Meyer, J., Madsen, M., Saars, L. 2023. Kurzstudie Energieeffizienzmaßnahmen in der Industrie Marktnahe und wirtschaftliche Energieeinsparpotentiale in der Industrie. Hochschule Niederrhein, SWK E. https://deneff.org/wp-content/uploads/2023/04/HSNR-Kurzstudie-EnEffPotentiale-Industrie-2023-03-31.pdf

MHI (Mitsubishi Heavy Industries) 2023. Heidelberg Materials North America and MHI Are Working Toward First Full-Scale Carbon Capture, Utilization and Storage Solution for Cement Industry. https://www.mhi.com/news/23081702.html.

MPA 2025. Making Lime. https://mpalime.org/About-Us/Making-Lime.aspx

National Observer 2025. Feds will work with provinces rather than enforce industrial price backstop: environment minister. https://www.nationalobserver.com/2025/12/11/news/feds-provinces-industrial-price-backstop-dabrusin

NRCan (Natural Resources Canada) 2020. Hydrogen Strategy for Canada. https://natural-resources.canada.ca/sites/nrcan/files/environment/hydrogen/NRCan_Hydrogen-Strategy-Canada-na-en-v3.pdf

NRCan (Natural Resources Canada) 2024a. Hydrogen Strategy for Canada: Progress Report. Hydrogen Strategy for Canada: Progress Report - Natural Resources Canada

NRCan (Natural Resources Canada) 2024b. Hydrogen Strategy for Canada: Progress Report. https://natural-resources.canada.ca/energy-sources/clean-fuels/hydrogen-strategy/hydrogen-strategy-canada-progress-report

NRCan (Natural Resources Canada) 2025a. Canada's Steel Industry aiming for net zero CO2 by 2050. https://natural-resources.canada.ca/stories/cipec-news/canada-s-steel-industry-aiming-net-zero-co2-2050.

NRCan (Natural Resources Canada) 2025b. Clean Fuels Fund. https://natural-resources.canada.ca/energy-sources/clean-fuels/clean-fuels-fund.

NRCan (Natural Resources Canada) 2025c. Green Industrial Facilities and Manufacturing Program. https://natural-resources.canada.ca/energy-efficiency/industry-energy-efficiency/green-industrial-facilities-manufacturing-program.

NRCan (Natural Resources Canada) 2026. Powering Canada Strong: A National Strategy for an Electrified Canadian Economy. Powering Canada Strong: A National Strategy for an Electrified Canadian Economy - Natural Resources Canada

OEC World n.d. Canada. Accessed 17 March 2025. https://oec.world/en/profile/country/can.

OEC World n.d. Cement in Canada. Accessed 17 March 2025. https://oec.world/en/profile/country/can.

Office of the Parliamentary Budget Officer 2024. Long-Term Fiscal Cost of Major Economic Investment Tax Credits. https://publications.gc.ca/collections/collection_2024/dpb-pbo/YN5-287-2024-eng.pdf

Ontario 2025. Emissions Performance Standards program. https://www.ontario.ca/page/emissions-performance-standards-program

Parkes 2024. 'Blue hydrogen could be beneficial or disastrous for the climate, depending on how accurately lifecycle emissions are measured', in Hydrogen Insight. https://www.hydrogeninsight.com/production/blue-hydrogen-could-be-beneficial-or-disastrous-for-the-climate-depending-on-how-accurately-lifecycle-emissions-are-measured/2-1-1601621

Prime Minister of Canada 2025. Canada-Alberta Memorandum of Understanding. https://www.pm.gc.ca/en/news/backgrounders/2025/11/27/canada-alberta-memorandum-understanding.

Prime Minister of Canada 2026. Prime Minister Carney announces forthcoming National Electricity Strategy. Prime Minister Carney announces forthcoming National Electricity Strategy | Prime Minister of Canada.

Pulp & Paper Canada 2022. Towards net zero: Industry perspectives on achieving net zero in Canada's pulp and paper sector. https://www.pulpandpapercanada.com/towards-net-zero/.

Recycling Today 2024. A time of transition: Examining Canada's move toward EAF-based steelmaking and what it means for scrap flows. https://www.recyclingtoday.com/article/a-time-of-transition-for-canada-steelmaking/.

ReportLinker n.d.a. Forecast: Cement and Concrete Product Manufacturing Revenue in Canada. https://www.reportlinker.com/dataset/87a0ab2cfee650e91a28648f2f3c4a147852db4e.

ReportLinker n.d.b. Forecast: Pulp, Paper and Paperboard Mills Revenue in Canada. https://www.reportlinker.com/dataset/9fa810fe464dd68a92738f65db9f2a304bad2ab0.

Reuters 2025. Salzgitter delays later stages of green steel project due to economic and regulatory conditions. https://www.reuters.com/sustainability/climate-energy/salzgitter-delays-later-stages-green-steel-project-due-economic-regulatory-2025-09-18/

RioTinto 2024. Rio Tinto to install carbon free aluminium smelting cells using first ELYSIS technology licence. https://www.riotinto.com/en/news/releases/2024/rio-tinto-to-install-carbon-free-aluminium-smelting-cells-using-first-elysistm-technology-licence.

Rio Tinto 2025. ELYSIS achieves breakthrough with commercial-size cell: a first in aluminium production using the inert anode technology. https://www.riotinto.com/en/news/releases/2025/elysis-achieves-breakthrough-with-commercial-size-cell

Rohstoff.net 2022. Bund fördert klimafreundliche Stahlproduktion. https://rohstoff.net/bund-foerdert-klimafreundliche-stahlproduktion/.

RWE 2025. RWE and TotalEnergies agree groundbreaking long-term offtake agreement for green hydrogen. https://www.rwe.com/en/press/rwe-ag/2025-03-12-rwe-and-totalenergies-agree-long-term-offtake-agreement-for-green-h2/

Salzgitter n.d. SALCOS Transformation Program. https://salcos.salzgitter-ag.com/en/salcos.html

Salzgitter AG 2023. Salzgitter AG erhält Bescheid für staatliche Förderung des SALCOS-Programms zur CO2-armen Stahlproduktion. https://www.salzgitter-ag.com/de/newsroom/pressemeldungen/details/salzgitter-ag-erhaelt-bescheid-fuer-staatliche-foerderung-des-salcosr-programms-zur-co2-armen-stahlproduktion-20702.html.

Schaller, D. and Schasching, M. 2024. Energieintensive Industrie unter Druck. https://www.ifo.de/DocDL/sd-2024-06-schaller-schasching-energieintensive-industrie.pdf.

Shell 2024. Shell to build carbon capture and storage projects in Canada. https://www.shell.com/news-and-insights/newsroom/news-and-media-releases/2024/shell-to-build-carbon-capture-and-storage-projects-in-canada.html.

SHS (Stahl-Holding Saar) 2023. Robert Habeck stellt 2,6 Milliarden Euro Förderung für die saarländische Stahlindustrie in Aussicht. Meilenstein auf dem Weg zur grünen Transformation. https://www.stahl-holding-saar.de/shs/de/presse/pressemitteilungen/robert-habeck-stellt-2-6-milliarden-euro-foerderung-fuer-die-saarlaendische-stahlindustrie-in-aussicht-110202.shtml.

Soltoff, B. 2022. Green steel without green hydrogen – can it work?. Canary Media. https://www.canarymedia.com/articles/clean-industry/green-steel-without-green-hydrogen-can-it-work

Statista n.d.a Zementproduktion in Deutschland in den Jahren von 2000 bis 2023. https://de.statista.com/statistik/daten/studie/161717/umfrage/zementproduktion-in-deutschland-seit-2000/.

Statista n.d.b. Export value of cement from Europe in 2023, by leading country. https://www.statista.com/statistics/1493605/countries-cement-export-value-europe/.

Statista n.d.c. Paper and board production of Confederation of European Pulp and Paper Industries (CEPI) member in 2024, by country. https://www.statista.com/statistics/1255830/paper-board-production-country-europe/.

Statista 2024a. Germany: Share of economic sectors in gross domestic product (GDP) in 2024. https://www.statista.com/statistics/295519/germany-share-of-economic-sectors-in-gross-domestic-product/.

Statista 2024b. Export value of pulp and paper from Canada from 2010 to 2023. https://www.statista.com/statistics/1456823/export-value-of-pulp-and-paper-products/.

Statistics Canada 2024c. Top eight energy consumers in manufacturing sector, 2022 and 2023. https://www150.statcan.gc.ca/n1/daily-quotidien/241030/cg-c002-eng.htm.

Statista 2025a. Chemical industry in Canada - statistics & facts. https://www.statista.com/topics/9807/chemical-industry-in-canada/#topicOverview.

Statista 2025b. Export value of the chemical industry in Canada in 2023, by country of destination. https://www.statista.com/statistics/1311395/chemical-industry-export-value-by-destination-country-canada/.

Statista 2025c. Umsatz der Stahlindustrie in Deutschland in den Jahren 1995 bis 2024. https://de.statista.com/statistik/daten/studie/74060/umfrage/umsatzerloese-in-der-stahlindustrie-in-deutschland-seit-1995/.

Statista 2025d. Germany: Share of economic sectors in gross domestic product (GDP) in 2024. https://www.statista.com/statistics/295519/germany-share-of-economic-sectors-in-gross-domestic-product/.

Statista 2025e. Chemical industry in Canada - statistics & facts. https://www.statista.com/topics/9807/chemical-industry-in-canada/#topicOverview.

Statistics Canada 2024. Annual Survey of Manufacturing Industries, 2023. https://www150.statcan.gc.ca/n1/en/daily-quotidien/241218/dq241218c-eng.pdf?st=ojCtD4x.

Statistics Canada 2024b. Energy consumption by the manufacturing sector, 2023. https://www150.statcan.gc.ca/n1/daily-quotidien/241030/dq241030c-eng.htm.

Statistics Canada 2025a. Employment by industry, annual. https://www150.statcan.gc.ca/t1/tbl1/en/cv.action?pid=1410020201.

Statistics Canada 2025b. Gross Domestic Product (GDP) at Basic Prices, by Industry, Annual Average (x 1,000,000)." Table 36-10-0434-03. Accessed 17 Mar. 2025. https://www150.statcan.gc.ca/t1/tbl1/en/tv.action?pid=3610043403.

Statistics Canada 2025c. Monthly Survey of Manufacturing, April 2025. https://www150.statcan.gc.ca/n1/daily-quotidien/250613/dq250613a-eng.htm.

SunSirs 2024. The German Paper Industry has Experienced a Significant Decline: Production has hit a New Low in 20 Years. https://www.sunsirs.com/commodity-news/petail-17285.html.

Svante 2023. Lafarge Canada Collaborates with Svante and Dimensional Energy. https://www.svanteinc.com/press-releases/lafarge-canada-collaborates-with-svante-and-dimensional-energy-to-begin-utilization-of-co2-captured-at-richmond-cement-plant/

S&P 2025. RWE commissioning Europe's largest green hydrogen plant in Germany. https://www.spglobal.com/energy/en/news-research/latest-news/energy-transition/122225-rwe-commissioning-europes-largest-green-hydrogen-plant-in-germany

Tabibian and Sharifzadeh 2023. Statistical and analytical investigation of methanol applications, production technologies, value-chain and economy with a special focus on renewable methanol. Renewable and Sustainable Energy Reviews. Volume 179, June 2023, 113281. https://www.sciencedirect.com/science/article/abs/pii/S1364032123001375.

Tagesspiegel Background 2025. Wie die EU-Kommission die Industrie umbauen will. https://background.tagesspiegel.de/energie-und-klima/briefing/wie-die-eu-kommission-die-industrie-umbauen-will.

Tagesspiegel Background 2026. Emissionshandel: Industrie uneins über ETS-Reformvorschlag. utf.rdir.de/form.action?agnCI=1024&agnFN=fullview&agnUID=F.hqJfY80EAKJfbAGiX23OABc9LKJfcs4AB14lol9zzmpdmbyiX3XOArtEdg.dVwGYZfneUs3Bnm1rEt-SlCQXUPPJUt0RzPoRGO3wTQEFCVGadzTnCNvZDlDIzoN4a6OhMqOOr3RLCs53whCMQ#a5mKgbP7Wv1rz83BTFlnUXc.

The Federal Government 2020. The National Hydrogen Strategy. https://www.giz.de/en/downloads/giz2020-en-national-hydrogen-strategy.pdf.

The Federal Government 2023. Energy Efficiency Act. The public sector set to become a role model. https://www.bundesregierung.de/breg-de/service/archiv-bundesregierung/the-energy-efficiency-act-2184958.

The Federal Government 2023b. National Hydrogen Strategy Update. https://www.bundeswirtschaftsministerium.de/Redaktion/EN/Publikationen/Energie/national-hydrogen-strategy-update.pdf?__blob=publicationFile&v=2.

Thyssenkrupp 2023. Bundesminister für Wirtschaft und Klimaschutz Robert Habeck besucht thyssenkrupp: thysssenkrupp Steel erhält Förderung in einer Gesamthöhe von rund zwei Milliarden Euro durch Bund und Land. https://www.thyssenkrupp-steel.com/de/newsroom/pressemitteilungen/thyssenkrupp-steel-erhaelt-foerderung-in-einer-gesamthoehe-von-rund-zwei-milliarden-euro-durch-bund-und-land.html.

Thyssenkrupp 2025. Carbon2Chem. Leading the Way to a Low-Carbon Future. Transforming Emissions into Business Opportunities. https://www.thyssenkrupp-carbon2chem.com/

Trading Economics 2025. Canada Exports of Iron and Steel. https://tradingeconomics.com/canada/exports/iron-steel.

Trimet 2025. CO2-freie Aluminiumproduktion. Metallische Anoden für CO2-freies Aluminium. https://www.trimet.eu/de/trimet/nachhaltigkeit/umwelt-und-klimaschutz/herstellung-von-inerten-metallischen-anoden

Umweltbundesamt (UBA) 2014. Entwicklung der Treibhausgasemissionen in Deutschland nach Sektoren: 1990 bis 2012. https://www.umweltbundesamt.de/bild/entwicklung-der-treibhausgasemissionen-in.

Umweltbundesamt (UBA) 2023. CO2-Speicherung darf Ausstieg aus fossilen Energien nicht behindern. https://www.umweltbundesamt.de/presse/pressemitteilungen/co2-speicherung-darf-ausstieg-aus-fossilen-energien

Umweltbundesamt 2024a. Indikator: Treibhausgas-Emissionen der Industrie. https://www.umweltbundesamt.de/daten/umweltindikatoren/indikator-treibhausgas-emissionen-der-industrie#die-wichtigsten-fakten.

Umweltbundesamt 2024b. Europäischer Emissionshandel: Rekordrückgang der Treibhausgasemissionen in Deutschland. https://www.umweltbundesamt.de/presse/pressemitteilungen/europaeischer-emissionshandel-rekordrueckgang-der.

Umweltbundesamt 2024c. Nichteisenmetallindustrie. https://www.umweltbundesamt.de/themen/wirtschaft-konsum/industriebranchen/herstellung-verarbeitung-von-metallen/nichteisenmetallindustrie#die-nichteisenmetallindustrie-in-deutschland.

Umweltbundesamt 2024c. Nichteisenmetallindustrie. https://www.umweltbundesamt.de/themen/wirtsch aft-konsum/industriebranchen/herstellung-verarbeitung-von-metallen/nichteisenmetallindustrie#die-nichteisenmetallindustrie-in-deutschland.

Umweltbundesamt 2024d. Bundesförderung Industrie und Klimaschutz gestartet. https://www.umweltbundesamt.de/themen/bundesfoerderung-industrie-klimaschutz-gestartet.

Umweltbundesamt 2024e. Altpapier. https://www.umweltbundesamt.de/daten/ressourcen-abfall/verwertung-entsorgung-ausgewaehlter-abfallarten/altpapier#vom-papier-zum-altpapier.

Umweltbundesamt (UBA) 2025a. Finale Daten für 2023: klimaschädliche Emissionen sanken um zehn Prozent. https://www.umweltbundesamt.de/presse/pressemitteilungen/finale-daten-fuer-2023-klimaschaedliche-emissionen.

Umweltbundesamt 2025b. Treibhausgasminderungsziele Deutschlands. https://www.umweltbundesamt.de/daten/klima/treibhausgasminderungsziele-deutschlands.

USW (United Steel Workers) 2024. Stand up for Steel: Significant Progress on Key Demands. https://usw.ca/wp-content/uploads/2024/05/StandUpForSteel-Backgrounder-PRINT-1.pdf.

VCI (Verband der Chemischen Industrie) 2023. Stormy times for the industry. https://www.vci.de/vci-online/presse/pressemitteilungen/stormy-times-for-the-industry-stock-taking-of-the-chemical-pharmaceutical-industry-2023.jsp.

VCI (Verband der Chemischen Industrie) 2024a. Portrait of the German Chemical Industry. https://www.vci.de/ergaenzende-downloads/portrait.pdf..

VCI (Verband der Chemischen Industrie) 2024b. Chemiewirtschaft in Zahlen. https://www.vci.de/services/publikationen/broschueren-faltblaetter/chemiewirtschaft-in-zahlen.jsp?fsID=36189.

VCI (Verband der Chemischen Industrie) 2025. https://www.vci.de/presse/pressemitteilungen/quartalsbericht-32025-wirtschaftliche-lage.jsp

VDZ e.V. n.d. Zementindustrie in Deutschland. https://www.vdz-online.de/zementindustrie/zahlen-und-daten/zementindustrie-in-deutschland.

VDZ e.V. 2001-2005. Umweltdaten der deutschen Zementindustrie 2002-2006. https://www.vdz-online.de/wissensportal/publikationen.

VDZ e.V. 2023. Zementindustrie im Überblick – 2022/2023. https://www.vdz-online.de/fileadmin/wissensportal/publikationen/zementindustrie/zementindustrie_ueberblick/VDZ_Zementindustrie_im_Ueberblick_2022-2023.pdf.

VDZ e.V. 2024: Zementindustrie im Überblick 2023/2024. https://www.vdz-online.de/wissensportal/publikationen/zementindustrie-im-ueberblick-2023-2024.

Vector Solutions 2024. Navigating the Papermaking Process: A Step-by-Step Guide. https://www.vectorsolutions.com/resources/blogs/papermaking-process/.

Verpoort et al. 2024. Ariadne- Report: Transformation der energieintensiven Industrie – Wettbewerbsfähigkeit durch strukturelle Anpassung und grüne Importe. https://ariadneprojekt.de/publikation/report-transformation-der-energieintensiven-industrie/.

Voith 2025. Voith and Essity receive funding from the German Federal Ministry for Economic Affairs and Climate Action to research a process for sustainable paper production. https://www.voith.com/corp-en/news-room/press-releases/2024-05-08_VZ_Brantner.html

Wernicke, Dr. Hans Jürgen 2024. CO2-Emissionen der Kalk und Zementindustrie. https://global-energy-solutions.org/wp-content/uploads/2024/01/240130kalk_zement_wernicke.pdf

WITS (World Integration Trade Solution) n.d. Canada Moulded or pressed articles of paper pulp exports by country in 2023. https://wits.worldbank.org/trade/comtrade/en/country/CAN/year/2023/tradeflow/Exports/partner/ALL/product/482370.

World's Top Exports n.d. Canada's Top 10 Exports. https://www.worldstopexports.com/canadas-top-exports/#google_vignette.

Worldbank n.d. GDP (current US$). Accessed 17 March 2025. https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?locations=CA.

World Bank 2025a. Germany. https://data.worldbank.org/country/germany.

World Bank 2025b. GDP (current US$). https://data.worldbank.org/indicator/NY.GDP.MKTP.CD?most_recent_value_desc=true&year_high_desc=true.

World Bank 2025c. Canada. https://data.worldbank.org/country/canada.

World Steel Association 2024. December 2023 crude steel production and 2023 global crude steel production totals. https://worldsteel.org/media/press-releases/2024/december-2023-crude-steel-production-and-2023-global-totals/.

World Steel Association 2025. World Steel in Figures 2024. https://worldsteel.org/data/world-steel-in-figures/world-steel-in-figures-2024/.

WV (Wirtschaftsvereinigung) Metalle 2022. 21.22 Der Geschäftsbericht der Nichteisen-Metallindustrie. https://www.wvmetalle-geschaeftsbericht.de/21-22/die-deutsche-nichteisen-metallindustrie.

WV (Wirtschaftsvereinigung) Metalle 2024. 23.24 Der Geschäftsbericht der Nichteisen-Metallindustrie. https://www.wvmetalle-geschaeftsbericht.de/23-24/k-s-die-deutsche-nichteisen-metallindustrie

WV (Wirtschaftsvereinigung) Stahl 2023. Fact and Figures about the Steel Industry in Germany. https://www.wvstahl.de/wp-content/uploads/202312_Facts_Figures_Steelindustry_Germany_WEB.pdf.

WV (Wirtschaftsvereinigung) Stahl 2024. Daten und Fakten zur Stahlindustrie in Deutschland. https://issuu.com/stahlonline/docs/wv-stahl_daten-und-fakten-2024_rz-web.

Wyns and Khandekar 2019. Metals for a Climate Neutral Europe. A 2050 Blueprint. https://www.eurometaux.eu/media/2005/full-report-8-56-17.pdf.

440 Megatonnes 2024. Finding a Path to Net Zero in the Pulp and Paper Industry. https://440megatonnes.ca/insight/finding-path-net-zero-pulp-paper-industry/.

440 Megatonnes 2025a. Cutting Carbon from Canada's Chemicals. https://440megatonnes.ca/insight/cutting-carbon-from-canadas-chemicals/?utm_source=newsletter&utm_medium=email&utm_campaign=440nfeb25chem.

440 Megatonnes 2025b. The Steel Industry is on Track for Major Emissions Reductions. https://440megatonnes.ca/insight/steel-industry-on-track-emissions-reductions/