Decarbonising energy-intensive industries in Germany

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1 Introduction

Aims of the study

As part of a wider initiative convened by ETUI – covering other countries: Spain, France and Poland as well - the objective of the study was to map the current situation of energy-intensive industries (EII) in Germany. The main aim of the analysis was to provide evidence on the labour market and economic impacts of different decarbonisation pathways for the basic metals, chemicals and mineral sectors and for the wider economy.

German context

The first chapter provides a thorough revision of the German policy landscape, the main national strategies and plans highlighting the uniqueness of the national ETS complementing the EU ETS but acting as a tax-like system.

Then the sectoral landscape is presented, focusing on the EII generating about two thirds of industry emissions. The industry composition and employment structure are presented for each sector.

The last section puts the results in the context of recent geopolitical developments, namely the impact of the Russian-Ukranian war on the German economy, highlighting the need for even faster decarbonisation. Our simulation analysis was run prior to the events, so this discussion is more qualitative.

Our approach

The E3ME macroeconometric model was used to simulate direct and indirect effects of such sectoral transitions as well as to give insights into the induced effects: such as how supply-chain effects and changing energy demand from the EII sectors impact the economy, how potential lay-offs or sectoral transformation has spill-over effects in other sectors or how changing ETS revenues has socio-economic impacts.

Three scenarios were designed representing alternative decarbonisation pathways for each industry based on different assumptions, namely, the type and share of technologies adopted, and the time profile and costs of emissions abatement.

The study also analysed the proposed carbon border adjustment mechanism (CBAM) and the effects in interaction with the different decarbonisation pathways.

Structure of the report

After the detailed presentation of the E3ME model and the scenarios analysed, the fifth chapter discussed the modelling results, not only for the sectors in question, but also wider economic effects, labour market impacts, the difference caused by assumptions focusing on who pays for the investment needed for such decarbonisation, and finally the CBAM impacts.

2 German policy landscape

2.1 Climate Protection Act 2021

German society and government are increasingly active in climate protection. On the regulatory level, this is mirrored in the latest update of the Climate Protection Act (Klimaschutzgesetz – KSG) in 2021. In line with Germany's international obligations and the goal of the Paris Agreement to limit the global temperature rise to 1.5 °C, it raises the ambition on the reduction of greenhouse gas (GHG) emissions and stipulates that Germany should reach climate neutrality by 2045 and negative net emissions after 2050. As intermediate goals, it sets targets for economy-wide GHG emission reductions by 65% in 2030 and by at least 88% by 2040, relative to 1990.

The KSG also specifies sectoral targets for maximum annual emissions until 2030 (see Table 1), while the targets for the period 2031-2040 are to be defined in 2024, and the targets for 2041-2045 – by 2034. In industry, GHG emissions must be reduced to 118 Mt CO_2-eq by 2030, which includes emissions from both, energy use and industrial processes, and corresponds to a reduction by 39%, relative to the 2019 level (see also Figure 1).

The KSG also foresees continuous monitoring, whereby the GHG emissions by sector are reported annually and, in addition, bi-annual assessment reports evaluate goal achievement, measures and trends in emission reduction. In case the goals are not reached by some sector in any of the years, the responsible ministry has to propose short-term corrective measures to return the sector on track.

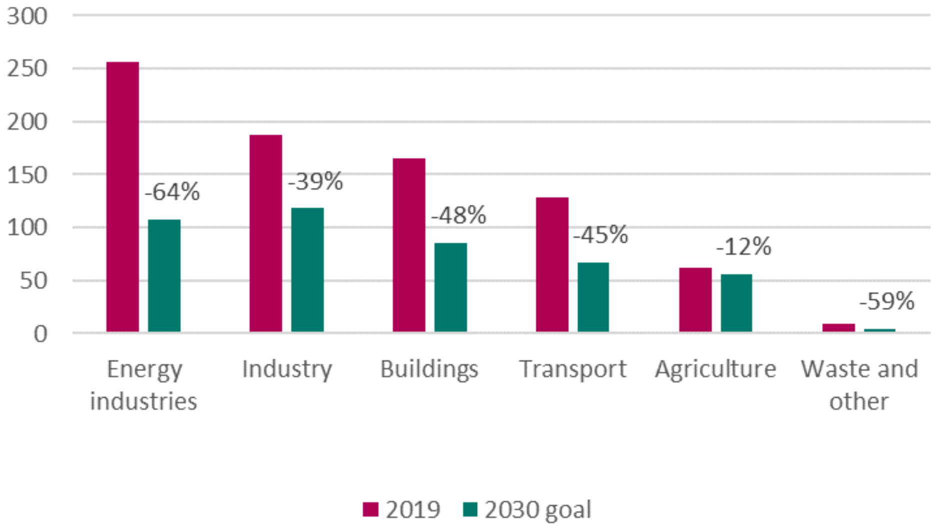
The KSG is complemented by a variety of short- to mid-term programmes and support packages.

Table 1. Regulated maximum of annual emissions by sector as updated in KSG 2021, Mt CO_2-eq

	2020	**2021**	**2022**	**2023**	**2024**	**2025**	**2026**	**2027**	**2028**	**2029**	**2030**
Energy industries	280		257								108
Industry (energy use + IPPU)	186	182	177	172	165	157	149	140	132	125	118
Buildings	118	113	108	102	97	92	87	82	77	72	67
Transport	150	145	139	134	128	123	117	112	105	96	85
Agriculture	70	68	67	66	65	63	62	61	59	57	56
Waste and other	9	9	8	8	7	7	6	6	5	5	4
Total	813	517	756	482	462	442	421	401	378	355	438

Source: Climate Protection Act 2021

Figure 1. Comparison of current (2019) and target (2030) emissions by sector, Mt CO_2-eq



Source: own work based on data from the National Inventory Report (2019) and Climate Protection Act (2030)

1.1 2030 Climate Action Programme

The Climate Action Programme until 2030 constitutes a roadmap for achieving the targets set in the KSG in the short to middle term. Adopted 2019, it is based on the older KSG version and, therefore, less ambitious. However, the measures outlined in the Programme remain highly relevant and build an important basis for more ambitious emission reduction. It is most explicit with respect to decarbonisation in the energy sector, the largest GHG emitter in Germany (compare Figure 1), but also lists the most important technologies and changes in industry.

In energy, the relevant targets and measure include:

Coal phase-out: capacity of coal-fired power plants is to be reduced from approx. 40 GW in 2019 to 30 GW by 2022, 17 GW by 2030 and zero by 2038. There is, however, a discussion about speeding up the process and phasing out coal power generation already by 2030.[1] Plant decommissioning can be carried out by shutting down the respective power plants but also by switching to low-carbon fuels.

Scale-up of renewables: the target for scaling up renewable electricity generation was set in the 2030 Climate Action Programme and later affirmed in the updated Renewable Energy Sources Act (EEG), which stipulates reaching the renewables share of 65% in gross electricity consumption in 2030 and emission-neutral power generation before 2050.

[1] Bloomberg Green. “German Coalition Eyes 2030 Coal Exit, Eight Years Ahead of Plan”. October 15, 2021. https://www.bloomberg.com/news/articles/2021-10-15/german-coalition-eyes-2030-coal-exit-eight-years-ahead-of-plan

Further measures in the Programme include:

- Development of combined heat and power generation;
- Conversion of heat networks to accommodate renewable and waste heat;
- Improvements in energy efficiency (overall reduction in total primary energy consumption by 30% in 2030, relative to 2008).

In industry, the 2030 Climate Action Programme highlights a number of improvements and new technologies to allow for significant emission reductions:

- Extending and increasing energy efficiency, which can continuously be achieved through implementation of best available techniques;
- Utilisation of waste heat, which is still relatively underused and, thus, has significant expansion potential;
- Fuel substitution with renewable and low-emission fuels like biomass, natural gas and hydrogen;
- Process conversions or substitutions from current energy- and emission intensive technologies to low- or zero-carbon technologies innovative solutions (e.g., shift towards hydrogen-based direct reduction of iron for steel production);
- Extending and increasing material efficiency and material substitution, which can reduce demand for emission-intensive raw materials and, thus, energy- and process-related emissions;
- Increasing the flexibility of energy demand (including prospects for power-to-X), which would allow to gear industrial energy consumption to variable supply of renewable electricity (see also information on the National Hydrogen Strategy below);
- Carbon capture, utilization and storage, which is no universal solution to preventing GHG emissions but is crucial in areas where emissions cannot be completely avoided (e.g., production of cement).

In the evaluation of the 2030 Climate Action Programme, the investment necessary to reduce emissions in industry (as a whole) to 140 Mt CO_2-eq by 2030 was estimated at about EUR 4-4.8 bn in 2026-2030. Given the more ambitious targets provided by the new Climate Protection Act in 2021, this significantly underestimates the necessary financing and can only be viewed as the lower boundary.[2]

On a cross-sectoral level, the 2030 Climate Action Programme also highlights the importance of carbon pricing in providing economic incentives for investments into emission reduction.

1.2 Carbon pricing

Germany is a participant of the European Emission Trading System (EU ETS), which covers about 1,817 facilities in the country, together emitting 320 Mt CO_2-eq in 2020. The 914 industrial facilities account, with 114 Mt CO_2-eq, for about one-third of emissions covered by the EU-ETS. Of those, almost three quarters

2 See also information on government support programmes below and estimates by industry representatives in respective sections.

are emitted by the relevant EIIs: 30% accrue to the minerals production, 28% to iron and steel production and 15% to chemical industry. Since 2013, however, there has been little reduction in the overall emission level of industrial facilities.[3]

The carbon price in the EU ETS has increased substantially in the last year: from around EUR 33 per permit in January 2021, the current price is close to EUR 60.[4]

Starting from 2021, carbon pricing through EU ETS is complemented by the national ETS (nETS), covering fuel combustion in heating and transport. Unlike the EU ETS, it operates in an upstream principle, i.e. it is not the entities combusting the fossil fuels but those put these fuels in the market that pay the carbon price, passing the tax through to the consumers. In its first phase, the nETS operates at a fixed price, which is set at EUR 25 per tonne CO_2 in 2021 and increased stepwise to EUR 55 per tonne CO_2 in 2025:

Year	2021	2022	2023	2024	2025
Price, €/t CO2	25	30	35	45	55

In 2026, certificate trading will take place within a price corridor of EUR 55 to 65 per tonne CO_2. After that, the carbon price should be defined by the competitive "cap-and-trade" market, as in the EU ETS. However, there is a caveat in the law, allowing to set price corridors after 2026 as well, which leaves room for keeping nETS as a tax-like system. The decision on whether minimum and maximum prices are needed in 2027 is to be made in 2025.[5]

1.3 Support plans and additional strategies

The Climate Protection Act is accompanied by a variety of plans and strategies aimed at supporting the decarbonisation and introduction of innovative technologies and processes in industry as well as creation of markets for "green" products.

In summer 2020, to counteract the negative economic effects of the COVID-19 lockdowns, a large **stimulus package** of about EUR 130 bn was adopted, of which approx. EUR 55 bn were devised for "investments for future", such as green transformation and digitalisation. Based on this package, the **German Recovery and Resilience Plan** (DARP) of about EUR 27 bn was developed by the end of 2020, which is to be financed from the EU recovery fund. Some measures appear in both, i.e., will be funded from both, the EU and German own sources. The main measures relating to industry include:

- **National Hydrogen Strategy**, for which a total of EUR 7 bn will be financed from DARP and the stimulus package. The national hydrogen

[3] Umweltbundesamt. "Der Europäische Emissionshandel". July 15, 2021. https://www.umweltbundesamt.de/daten/klima/der-europaeische-emissionshandel

[4] Forecast by Trading Economics: https://tradingeconomics.com/commodity/carbon

[5] Umweltbundesamt and DEHSt. „Nationales Emissionshandelssystem. Hintergrundpapier". November 2020.

strategy aims at making hydrogen a competitive alternative to fossil fuels and at establishing national and international markets for green hydrogen. Specific measures within the strategy are to provide regulatory and financial support for: research and development (R&D); switching to hydrogen-based technologies, especially in industry and transport; establishment of production capacities in Germany. An important instrument in the strategy is a pilot introduction of carbon contracts for difference (CCfD).

- **International partnerships for hydrogen** (EUR 2 bn) complements the national hydrogen strategy in the stimulus package, specifically targeting establishment of green hydrogen production in other countries, with the help of German technologies and the goal of supporting German demand for hydrogen.
- Support for **R&D programmes** in industry (EUR 1 bn) and **research** in non-university research institutions (EUR 1 bn) should make possible and speed up development and introduction of new technologies and processes leading to GHG emission reductions.
- Support of **project research and pilot programmes** for digitalization and sector coupling (EUR 300 mn) specifically aims at introducing new solutions in communities and markets.
- Investment programme for **automobile producers and automotive supply industries** (EUR 2.44 bn) should support green transformation in one of the largest industries in Germany.

While DARP and the stimulus package aim at boosting recovery from the COVID-19 crisis and devote only a part of the funds to climate action, the **immediate climate action programme** for 2022, totalling EUR 8 bn is specifically devised to achieve the goals set by the Climate Protection Act. Measures to encourage emission reduction in industry include:[6]

- Additional funds for the decarbonisation of industry programme (**carbon contracts for difference**), EUR 650.2 mn: Expansion of the CCfD pilot scheme;
- **Investment funding** programme for the **steel industry**, EUR 100 mn: Support of transition to hydrogen-based technologies;
- **Energy efficiency in industry / waste heat**, EUR 30 mn: Coverage of 30% (SMEs: 40%) of eligible investment costs for the development of industrial waste heat sources. The funding rate for the use of off-site waste heat (district heating) is to be increased to 40% (SMEs: 50%) in order to leverage the potential of industrial waste heat;
- **Lead markets for green steel**, EUR 28.8 mn: Pilot scheme for the consumption of "green steel" to be set up, e.g., in the automotive industry.

[6] Federal Ministry of Finance "Immediate climate action programme for 2022". June 2021. https://www.bundesfinanzministerium.de/Content/EN/Standardartikel/Topics/Priority-Issues/Climate-Action/immediate-climate-action-programme-for-2022.html

This includes introduction of product quotas for carbon-efficient products and funding to cover the additional costs in a transitional period;

- **Investment funding programme** for the **chemical industry**, EUR 50 mn: Investment support for projects aimed at achieving carbon-neutral chemical production (such as electrification of production processes, closure of carbon cycles, substitution of fossil raw materials with renewable resources);
- **Carbon footprint certification** system for certain materials: Development of a database-supported system for labelling the carbon footprints of certain frequently used materials.

Moreover, several measures in the energy sector will have direct relevance for the industry:

- Funding for **green hydrogen production** (offshore electrolysers), EUR 50 mn: Support for the development of national structures for the additional production of hydrogen from offshore wind;
- **Hydrogen Global** (H2Global), EUR 15 mn: purchasing scheme for hydrogen and hydrogen derivatives in order to kick-start the international hydrogen market for the import of green hydrogen;
- **Renewable energy expansion**: Adjustment of expansion trajectories for renewable energy upscaling and acceleration of planning, authorisation and implementation processes for climate-friendly infrastructure at all government levels.

Other programmes include running support for increasing energy efficiency and research and development. Total financing by the ministry of environment for investment costs and CCfDs in industry is expected to amount to EUR 3.5 bn in 2021-2025[7]

[7] https://www.bmu.de/pressemitteilung/novelle-des-klimaschutzgesetzes-vom-bundestag-beschlossen/

2. Sectoral landscape

Industry plays an important role in Germany, generating 22% of GDP and 12.6% of employment in 2019. At the same time, it was also responsible for 187 Mt CO_2-eq, or 24% of all GHG emissions in the country. The emission reduction target set for industry by the Climate Protection Act was overfulfilled in 2020 by 8 Mt CO2-eq, but to a large extent thanks to the economic downturn caused by the COVID-19 pandemic.[8] It is expected that, with economic recovery and increasing production, the 2021 target will be missed by 8 Mt CO2-eq.[9]

Energy-intensive industries (EIIs) together generate about two-thirds of emissions in the industry sector. Overall, there is high level of awareness about sustainability topics among EEI enterprises, and many large enterprises have set targets and/or outlined strategies for emission reduction (see sections below). A number of sectoral associations and the umbrella organisation, the Federation of German Industries (BDI), have proposed pathways to reach deep emission reduction or carbon neutrality. The report for BDI suggests that industry would have to invest additional EUR 50 bn in climate protection between 2021 and 2030.[10]

At the same time, it is commonly voiced that deep emission reduction in these industries will require significant government support, especially for the market roll-out of environmentally friendly materials (e.g., market creation for green steel[11] and low-carbon cement[12]) and covering additional costs of low-carbon technologies, e.g., through carbon contracts for difference[13]. No less important is the role of German and EU governments in setting the regulatory frameworks

[8] Umweltbundesamt. „Treibhausgasemissionen sinken 2020 um 8,7 Prozent". Press release 07/2021 from March 15, 2021. https://www.umweltbundesamt.de/presse/pressemitteilungen/treibhausgasemissionen-sinken-2020-um-87-prozent

[9] Agora Energiewende. "Deutschland steht 2021 vor dem höchsten Anstieg der Treibhausgasemissionen seit 1990". August 16, 2021. https://www.agora-energiewende.de/presse/neuigkeiten-archiv/deutschland-steht-2021-vor-dem-hoechsten-anstieg-der-treibhausgasemissionen-seit-1990/

[10] BCG. „Climate Paths 2.0. A Program for Climate and Germany's Future Development". October 2021. https://english.bdi.eu/publication/news/climate-paths-2-0-a-program-for-climate-and-germanys-future-development/

[11] See e.g. Wirtschaftsvereinigung Stahl. „Politische Positionen der Stahlindustrie zu grünen Leitmärkten". Position paper, March 2021. https://www.stahl-online.de//wp-content/uploads/202103_Positionspapier_WVS_Leitmaerkte.pdf

[12] VDZ. „Positionen der Zementindustrie zur Bundestagswahl 2021". Position Paper. June 2021. https://www.vdz-online.de/wissensportal/publikationen/positionen-der-zementindustrie-zur-bundestagswahl-2021

[13] See, e.g., Wirtschaftsvereinigung Stahl. „Beihilferahmen für Investitionen in eine CO2-arme Stahlproduktion". Position paper, November 19, 2020. https://www.stahl-online.de/wp-content/uploads/202011_ Positionspapier_EU_Beihilferahmen_Investitionen-CO2-arme-Stahlproduktion.pdf; VCI. "The Green Deal needs all strength". Political Briefing, June 2021. https://www.vci.de/vci/downloads-vci/publikation/politikbrief/englisch/vci-political-briefing-june-2021-green-deal.pdf

and providing planning certainty.[14] Under the existing regulation, few mitigation options are economically attractive in industry, except energy efficiency. This leaves a regulatory gap of EUR 11 bn in 2030, which must be closed if the industry is to invest sufficient funds in climate protection.[15]

The next three sections review the main EIIs – production of basic metals, chemicals and minerals – in more detail.

2.1 Basic metals

In metallurgy, iron and steel industry is larger and historically covered almost two thirds of both employment and value added in the sector.[16] In non-ferrous metallurgy, aluminium covered some 48% of gross value added and two thirds of employment[17], though among the largest enterprises in Germany branches of international companies (e.g., from Norway) are actively present.

Overall, the sector is characterized by rather large enterprise size. According to Eurostat data, almost a quarter of all enterprises in metallurgy are rather large (with more than 50 employees), covering 92% of all employment and 95% of all value added in the sector (see Figure 2).

The three major steel producers in Germany as of 2019 are thyssenkrupp Steel, employing over 27 thousand people and producing 11 Mt crude steel (28% of German steel production)[18]; ArcelorMittal with 9 thousand employees and production volume of 7.6 Mt crude steel (19%)[19]; and Salzgitter AG, employing about 25 thousand people and producing 7 Mt steel (18%)[20].

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[14] Neuhoff, K., O. Chiappinelli, M. Kröger, F. Lettow, J. Richstein, F. Schütze, J. Stede, and X. Sun. „Green Deal for industry: a clear policy framework is more important than funding”. DIW Weekly Report 10/2021. March 2021. See also the following sections on individual industries.

[15] See footnote 10.

[16] Based on 2012-2018 data from Eurostat.

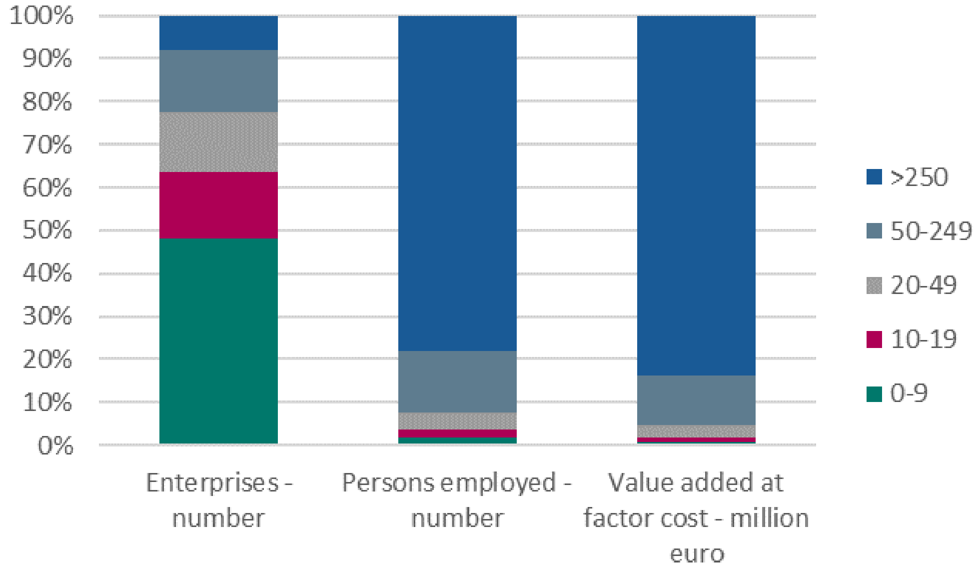
[17] Based on data from the Federal Statistical Office for enterprises with 20 employees or more.

[18] https://www.thyssenkrupp-steel.com/de/unternehmen/
Comparison with German total is based on Wirtschaftsvereinigung Stahl. „Fakten zur Stahlindustrie in Deutschland 2020“, August 2020. https://www.stahl-online.de//wp-content/uploads/WV-Stahl_Fakten-2020_rz_neu_Web1.pdf

[19] https://germany.arcelormittal.com/Ueber-uns/Auf-einen-Blick/

[20] Salzgitter AG. Annual report 2019. https://www.salzgitter-ag.com/fileadmin/finanzberichte/2019/gb2019/de/downloads/szag-gb2019-gesamt.pdf

Figure 2. Structure of the metallurgy sector in 2018 by enterprise size



Source: Own work based on Eurostat data

The largest producers of aluminium in Germany are TRIMET SE and Hydro (subsidiary of the Norwegian Norsk Hydro ASA), together covering about 10% of employment in industry.[21] In production of other non-ferrous metals, Aurubis AG is the largest player (with main product being copper), covering a fifth of the remaining employment in non-ferrous metallurgy.

With respect to climate action and emission reduction, the steel industry appears more active and ambitious, though – in contrast to non-ferrous metallurgy – it also has ready technological solutions for carbon-neutral production: direct reduction of iron (DRI) combined with electric arc furnaces (EAF). At the same time, presently, 30% of crude steel is being produced in EAF (either through DRI or from steel scrap)[22], which is slightly above the world average and well below the European average[23]. The German Steel Federation estimates the capital costs of switching to low- and zero-carbon production of steel at EUR 30 bn until 2050 (of which EUR 10 bn are required until 2030), not including the expected increase in operating costs.[24] The main strategies the steel producers pursue focus on using DRI (based on hydrogen or, as a potential intermediate solution, on natural gas or a mix of hydrogen and natural gas) and carbon capture, usage and/or storage (CCU/S). Some enterprises also actively invest in own hydrogen production.[25]

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[21] Based on the 2020 annual reports by TRIMET SE, Norsk Hydro ASA and Aluminium Deutschland e. V.

[22] Wirtschaftsvereinigung Stahl. „Fakten zur Stahlindustrie in Deutschland 2020“, August 2020. https://www.stahl-online.de//wp-content/uploads/WV-Stahl_Fakten-2020_rz_neu_Web1.pdf

[23] ESTEP.” Green steel by EAF route: a sustainable value chain in the EU Circular Economy scenario”. Workshop Report. November 2019. https://www.estep.eu/assets/Uploads/20191129-WorkshopReport-ESTEP-EAFGreenSteel-FinalDraft.pdf

[24] See footnote 22.

[25] See, e..g., thyssenkrupp Steel: https://www.thyssenkrupp-steel.com/de/unternehmen/nachhaltigkeit/klimastrategie/; Salzgitter AG: https://www.green-industrial-hydrogen.com/

In non-ferrous metallurgy, main strategies for GHG reduction outlined by enterprises are primarily related to energy use, such as introduction of energy or environmental management according to ISO standards, more flexible use of electricity, energy efficiency projects,[26] but also include increased recycling and, in case of aluminium production, research on inert anodes, which allow to avoid the process emissions when extracting aluminium from bauxite.[27]
While there is high potential for electrification and new technologies and, in steel production, existing technologies already allow for carbon-neutral production, implementation of these technologies is slow. The steel industry voices the following barriers, which may impede the transition to carbon-free steel currently as well as in future:

- high capital and operation costs of green technologies and insufficient markets for green steel;[28]
- increasing electricity costs, while electrification is necessary for green steel;[29]
- insufficient hydrogen supply;[30]
- political and legal uncertainties;[31]
- long duration of approval procedures and lack of coordination and planning;[32]
- availability of high-quality and cost-competitive scrap for higher circularity of production;[33]
- uncertainties about the future carbon price (calling for implementation of CCfDs), concerns about international competitiveness and carbon leakage.[34]

[26] See, e.g., Aurubis AG: https://aurubis.com/verantwortung/nachhaltigkeitsstrategie/ma-nahmen-und-ziele; LEONI AG: https://www.leoni.com/de/unternehmen/nachhaltigkeit/oekologische-verantwortung/

[27] See, e.g., TRIMET SE: https://www.trimet.eu/de/ueber_trimet/nachhaltigkeit/umwelt-und-klimaschutz

[28] See footnotes 24 and 11.

[29] Wirtschaftsvereinigung Stahl. „Ein Transformationsprogramm für die Stahlindustrie in Deutschland: 10 Forderungen an eine neue Bundesregierung für die ersten 100 Tage“. October 2021. https://www.stahl-online.de/wp-content/uploads/WV-Stahl_Positionspapier_Transformationsprogramm_2021-RZ_Web.pdf

[30] Wirtschaftsvereinigung Stahl. „Wasserstoff als Basis für eine klimaneutrale Stahlproduktion“. Position paper, March 2021. https://www.stahl-online.de//wp-content/uploads/202103_Positionspapier_WVS_Wasserstoff.pdf

[31] Wirtschaftsvereinigung Stahl. „Politische Handlungsempfehlungen der Stahlindustrie in Deutschland für die 20. Legislaturperiode des Deutschen Bundestags“. June 2021. https://www.stahl-online.de/wp-content/uploads/WV-Stahl_Positionspapier_Handlungsempfehlungen_20_Legislaturperiode_2021-RZ-Web_NEU.pdf

[32] See footnote 29.

[33] See footnote 29.

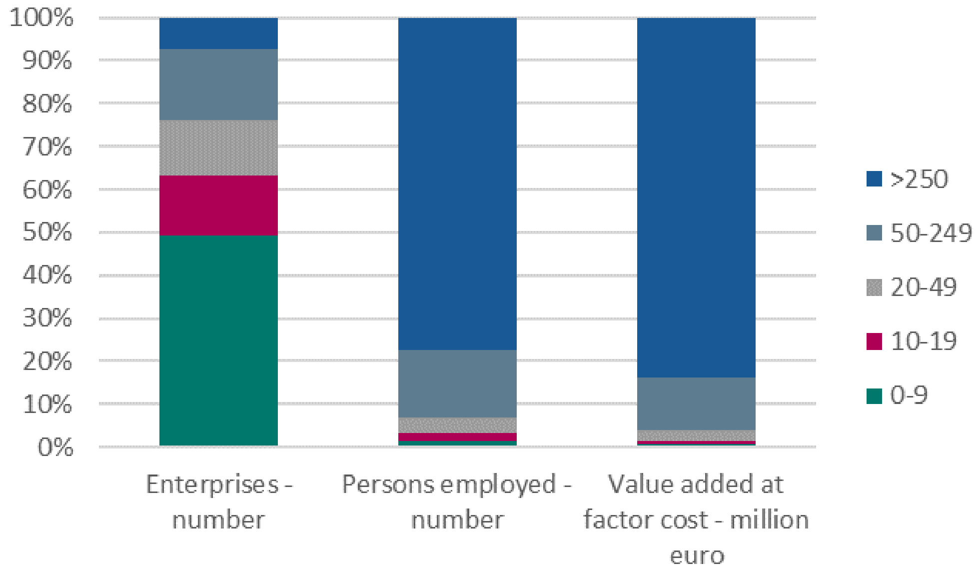
[34] See footnote 29.

These concerns are to a large extent also shared by the producers of non-ferrous metals.[35]

2.2 Chemicals

Similar to the production of basic metals, the chemical industry is dominated by large enterprises: 24% of enterprises employ more than 50 persons and together generate 96% of value added and provide 93% of employment in the sector (Figure 3). The sector is primarily represented by production of basic chemicals, with 31% of enterprises, 54% of employment and 62% of value added. Significant employment is also generated by production of paints and coatings (12.6%) as well as cleaning items and perfumes (15.4%), though they represent less than 1% of enterprises and 3% of value added in the sector.[36]

Figure 3. Structure of the chemical industry in 2018 by enterprise size



Source: Own work based on Eurostat data

BASF Group is the largest producer of chemicals in Germany and among the largest in the world. The main enterprise of the group – BASF SE – employed almost 35 thousand people and had a turnover of almost around EUR 22 bn in 2019. With EUR 5.4 bn in the German market in 2019, it has a market share of about 4%. The next largest companies (e.g., Henkel AG & Co KGaA and Evonik Industries AG) are significantly smaller, both in terms of employment and turnover.[37]

The chemical industry is very active in projects and research, including those reducing its carbon footprint. Together with pharmaceutical producers, the chemical industry spent EUR 521 mn (or 21.8% of all such spending in German manufacturing) on new equipment for improving environmental and climate

[35] See, e.g., reports by VWMetalle, https://www.wvmetalle.de/geschaeftsfelder/energie-und-klimapolitik/

[36] As of 2018, based on Eurostat data.

[37] Based on statista Company Databank and annual reports of the three companies.

protection in 2017.[38] Of producers active in R&D, a quarter researched on climate and sustainability topics in 2017, while in 2016, 11% of all climate-related patents in the global chemical industry came from Germany. The German Chemical Industry Association (VCI) actively addresses climate action in the sector and has published a roadmap for reaching carbon neutrality by 2050. The investments into transforming the processes in basic chemicals production to reach this goal are estimated at EUR 45 bn.[39]

Presently, many enterprises have already set ambitious emission reduction targets, including some aiming at reaching climate neutrality between 2040 and 2050 (e.g., BASF and Henkel). The main enterprise strategies for reducing emissions revolve around reducing energy use and avoiding fossils for both energy use and as a feedstock:[40]

- Widespread electrification of production, with the use of renewable electricity;
- Improvement of energy efficiency, e.g., through process optimization and new technologies;
- Use of renewable sources where fuel combustion remains necessary;
- Use of biological and alternative feedstocks for production;
- Further development of chemical recycling (though currently rather voiced by VCI as policy proposal and not as part of enterprises' strategies);
- Carbon capture and storage (similarly to the above, currently at a policy proposal level).

Similar to basic metal production too, there is a number of obstacles that need to be addressed for a transition to carbon neutrality in the chemical industry, according to industry representatives. Moreover, these barriers are, in fact, quite similar to those outlined for steel production and include:[41]

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[38] CWS & ZEW. „Innovationsindikatoren Chemie 2020. Schwerpunktthema: Innovationen zu Klimaschutz und Nachhaltigkeit". Mannheim und Hannover: October 2020. https://www.vci.de/vci/downloads-vci/publikation/innovationsindikatoren/innovationsindikatoren-chemie-2020-schwerpunkt-klimaschutz-und-nachhaltigkeit.pdf

[39] VCI. "Working towards a greenhouse gas neutral chemical industry in Germany". Summary of the DECHEMA and FutureCamp study for the VCI. September 2019. https://www.vci.de/langfassungen/langfassungen-pdf/vci-study-greenhouse-gas-neutrality-in-the-german-chemical-industry.pdf

[40] See, e.g., BASF SE: https://www.basf.com/global/de/who-we-are/sustainability/we-produce-safely-and-efficiently/energy-and-climate-protection/carbon-management.html;
Henkel AG & Co KGaA: https://www.henkel.de/nachhaltigkeit/positionen/klimapositiv#Tab-805122_6;
Evonik Industries AG: https://corporate.evonik.com/en/responsibility/cr-at-evonik;
German Chemical Industry Association (VCI): https://www.vci.de/themen/energie-klima/uebersicht.jsp

[41] VCI. "Time for an immediate action programme in the industrial policy". Political Briefing, October 2021.
https://www.vci.de/vci/downloads-vci/publikation/politikbrief/englisch/vci-pb-2021-6-en-time-for-an-immediate-action-programme.pdf;
VCI. "The Green Deal needs all strength". Political Briefing, June 2021.
https://www.vci.de/vci/downloads-vci/publikation/politikbrief/englisch/vci-political-briefing-june-2021-green-deal.pdf

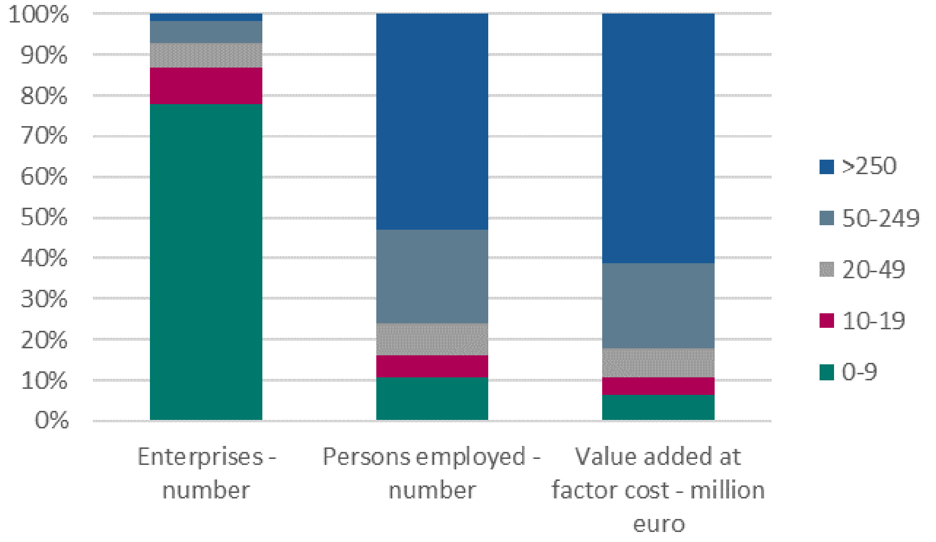
- Availability of vast amounts of cheap renewable electricity;
- Availability of hydrogen and hydrogen infrastructure;
- Political acceptance of CCUS and planning (certainty) for CO_2 infrastructure, together with hydrogen infrastructure;
- Circularity and bioeconomy: reliable and cost-effective supply of feedstocks;
- Uncertainties and complexity of the regulatory and legal framework, which especially strain SMEs in the sector;
- Complicated and inefficient approval procedures;
- Insufficient funding and too high tax burden for additional investments in innovation and new solutions;
- Concerns about international competitiveness and carbon leakage.

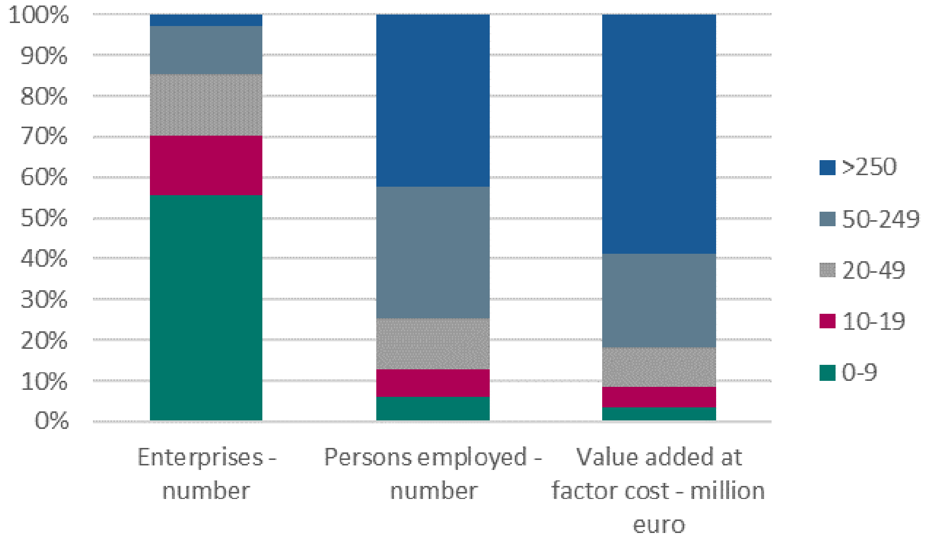
2.3 Minerals

The mineral industry is characterized by an overall higher share of small enterprises, both by their number as well as employment and value added they cover. Overall, only 7% of enterprises employ over 50 persons, and they cover 76% of sectoral employment and 82% of value added (Figure 4). At the same time, unlike in the metals and chemicals industries, there is variation in enterprise sizes by subsector. The major segment is cement and concrete production, represented by 19% of enterprises generating 36% of employment and 38% of value added in the industry. Although the share of large enterprises by their number is highest at 15% in this subsector, employment and value added are distributed more in favour of SMEs. In the next largest groups of glass and ceramics production, large enterprises dominate both employment and value added more strongly. In contrast, in the remaining segments (stonework and other mineral products), small enterprises (under 10 employees) prevail with 34% of all employment and 22% of all value added.[42]

[42] As of 2018, based on Eurostat data.

Figure 4. Structure of the minerals sector as a whole (left) and subsector of cement and concrete production (right) in 2018 by enterprise size





Source: Own work based on Eurostat data

By far the largest producer in the sector is HeidelbergCement AG. In 2019, it produced about 126 Mt of cement and clinker globally,[43] which is larger than the whole cement and clinker production in Germany (almost 70 Mt in 2019).[44] In Germany, the company employs around 4 thousand people (about 1.5% of employment in the whole minerals sector). Other producers (such as Dyckerhoff, Opterra, Holcim or CEMEX) are significantly smaller and mostly have under one thousand employees.

The largest producers of cement form an association, VDZ, which is active in climate issues and diverse research projects on possibilities to reduce the industry's carbon footprint.[45] Most large enterprises have defined emission

[43] HeidelbergCement AG annual report 2019

[44] VDZ. "Zementindustrie in Deutschland". https://www.vdz-online.de/zementindustrie/zahlen-und-daten/zementindustrie-in-deutschland

[45] See https://www.vdz-online.de/en/knowledge-base for the list of current projects.

reduction as one of their strategic priorities, though relatively few have set specific emission targets or the goal of achieving carbon neutrality. The major approaches to emission reduction include:[46]

- Substitution of raw materials (especially, clinker) with alternative and recycled materials;
- Use of alternative fuels, especially biomass;
- Energy efficiency improvement and use of waste heat;
- Increase in use of electricity, with focus on renewables;
- Use of CCU/S technologies;
- Improved design of buildings / construction parts, optimizing the raw material use (which, however, concerns not only the optimization of the sector's finished products but also collaboration on the demand side).

The barriers to reducing GHG emissions in mineral production echo those outlined for the two other industries:[47]

- Insufficient markets for low-carbon building materials;
- Availability of cost-efficient renewable electricity and fuels;
- Regulatory frameworks and long duration of approval procedures, especially with regard to recycling and development of innovative solutions;
- Political acceptance of CCUS and planning (certainty) for CO_2 infrastructure;
- Concerns about international competitiveness and carbon leakage.

2.4 Conclusion

Overall, the EIIs in Germany show high awareness about the climate issues and, where technologies for carbon-free production are not yet available on industrial scale, are active in research on new solutions. Among large enterprises, the necessity to reduce own carbon footprint is clear, though there is significant variation in ambition and clear target setting. At the same time, in all three EIIs, despite market domination of large enterprises, there is a **significant number of SMEs**, who should not be left behind in the transformation process. This relates to both, their lower capacity to invest heavily in innovative zero-carbon solutions and the challenges of green transition for the industry as a whole. The latter are to a large extent similar across all three industries and require **cross-sectoral cooperation and active government involvement**:

[46] See, e.g., HeidelbergCement: https://www.heidelbergcement.com/en/energy-and-climate-protection; Dyckerhoff: https://www.dyckerhoff.com/nachhaltigkeit; OPTERRA: https://www.opterra-crh.com/ueber-uns/nachhaltigkeit/energie-und-umwelt/; SCHWENK: https://www.schwenk.de/en/company/sustainability/;

[47] bbs. "Positionen des Bundesverbandes Baustoffe–Steine und Erden (bbs) zur Bundestagswahl 2021". Position paper. 2021. https://www.baustoffindustrie.de/fileadmin/user_upload/bbs/Dateien/Downloadarchiv/Verbandspublikationen/Positionen_Bundestagswahl.pdf

- The three industries described cause a significant portion of emissions through their intensive energy use and will rely on steady supply of affordable clean energy to reduce these emissions. Thus, reduction of their carbon footprint is dependent on the **green transformation in energy industries.**
- To invest in green production techniques, EII enterprises require clear signals and planning certainty with regard to the **price of carbon** and resolution of **carbon leakage**.
- Favourable **regulatory frameworks, infrastructure development and planning** are needed with respect to a variety of mitigation techniques, including hydrogen as energy source, carbon capture, transportation and storage as well as reuse and recycling of materials.

3 Modelling EII decarbonisation with E3ME

To capture the sectoral and economy-wide impacts, whether they are direct or indirect, of the potential decarbonisation pathways of energy intensive industries (EII) this report uses a macroeconometric model. The E3ME model integrates simulation of the economy, energy system as well as certain environmental outcomes (focusing on GHG emissions). Furthermore, it is extended with bottom-up technology models for power generation and steel production to represent innovation and technology diffusion.

These characteristics enable the model to simulate direct and indirect effects of a sectoral transition as well as to give insights into the induced effects: such as how supply-chain effects and changing energy demand from the EII sectors impact the economy, how potential lay-offs or sectoral transformation has spill-over effects in other sectors or how changing ETS revenues has socio-economic impacts. Due to its multiregional structure (covering 70 world regions, including member state level treatment for all EU members) the model is also capable of giving insights into the expected trade impacts, i.e. if a pathway changes relative competitiveness of the domestic sector, how that will feedback to the economy. This also gives as an ample opportunity to introduce the proposed carbon border adjustment mechanism to the modelling and analyse the effects of that in interaction with the different decarbonisation pathways.

3.1 The E3ME model

This modelling uses the **E3ME model** (www.e3me.com), a macroeconomic model owned and maintained by Cambridge Econometrics. E3ME is a global, macro-econometric model that is designed to address the major economic, social and environmental challenges in the coming decades. Developed over the last 25 years, it is one of the most advanced models of its type. For the full model description see Appendix A.

E3ME's key strengths for this analysis are:

- A high level of disaggregation, enabling detailed analysis of sectoral and country-level effects from a wide range of scenarios.
- Detailed technology indicators for the energy and steel sectors. A wide range of economic indicators can be used as selected outputs.
- A combination of methods provide robustness and versatility. E3ME has macroeconometric modules and bottom-up simulation of technological change. This provides a strong empirical bases based on historical data and a robust tool to analyse technological progress in the future.

Using E3ME we are able to analyse the impacts of policies or technological developments on selected sectors, including the sectors relevant from the viewpoint of the current study: production of metals, mineral products or chemicals; using the model we can quantify direct employment and economic impacts on the industries as well as on the wider economy.

The core of E3ME's economic structure rests on econometrically estimated parameters, based on historical data and is a top-down modelling framework. Input-output relationship determine the linkages across sectors and represent value chains. This is complemented by the FTT submodels within E3ME which describe the take-up of emerging technologies in the power, transport, heating and steel sectors. The FTT model classes follow a bottom-up logic and integrate the framework of technology diffusion models into E3ME. The FTT models are robust tools to explore the impacts of decarbonisation policies focusing on specific sectors and provide an understanding of technology transition. Using the FTT suite of models we can model the diffusion and take up of emerging and new technologies, where historical data is lacking.

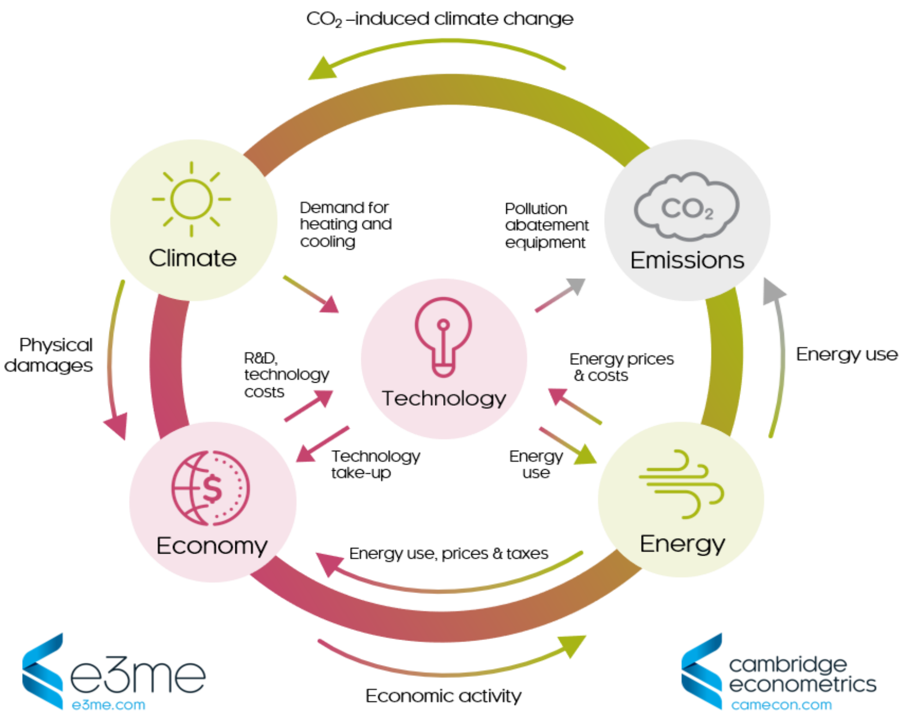
Figure 5 shows the basic structure of the E3ME model. E3ME is an E3 model linking the economy, energy and emissions in a complete framework, with two-way feedbacks connecting these pillars. Technological change and innovation captured by the FTT models link all areas of the model.

Strength of E3ME for the current study

The E3ME model's detailed coverage makes it a suitable tool for the modelling needed to identify the key impacts of the sectoral decarbonisation pathways.

- E3ME has a specific detailed treatment of the steel sector through its FTT:Steel submodel. FTT:Steel explicitly models the development of 26 steel production technologies as shown in *Table 3*. With FTT:Steel E3ME

Figure 5 - Feedbacks in E3ME and FTT models, connecting new technologies, the energy system, environmental and economic impacts



can explore scenarios representing the spread of different steelmaking technologies in the coming decades.

- E3ME includes 70 industry sectors and covers all relevant energy intense sectors. This is shown in *Table 2*.
- E3ME covers 70 regions which allows capturing global value chains. Trade links are important even for single country analysis to account for spill overs affecting the decarbonisation process as well as to be able to simulate the effects of trade measures (such as the proposed CBAM).

E3ME is commonly used for evaluating the impacts of an economic, technology or policy shock through a scenario-based analysis. In these cases for the ex-ante analysis we set up a baseline forecast up to 2050 first. E3ME is usually calibrated to match a set of projections that are published by the European Commission and the International Energy Agency, then we adjust this baseline to fit the needs of the simulation exercise – as it is the case in our current setup.

Then the modelling sets up "scenarios" which represent alternative versions of the future based on a different set of assumptions. In the current report this translates to different EII decarbonisation pathways, where the assumptions – as it will be discussed in the scenario design section – are the type and share of technology adopted and used by the EII sectors as well as the time profile and cost of these abatement actions. By comparing the outcomes from simulations (i.e. scenarios are simulated in the model) to the specified baseline the impacts of the "shocks" or changes can be determined and analysed.

Table 2 - Mapping between E3ME sectors and key energy intensive industries (EII) covered in the modelling

E3ME sector	Key EII
13 Other chemicals	Chemicals
	Fertilizers
	Plastics
16 Non-metallic mineral products	Cement
	Lime
	Glass
	Ceramics
17 Basic metals	Iron and steel
	Aluminium
	Non-ferrous metals

4 Scenario design

This chapter introduces the scenario design of the analysis with the assumptions used and description of each pathway. We have modelled a reference scenario, and compared the three sectoral decarbonisation pathways to this reference case. We have also modelled various sensitivities in terms of how the needed investment for such decarbonisation takes place (different financing options). Finally, we ran simulations on the introduction of the proposed carbon border adjustment mechanism.

In this exercise the E3ME macro-model was used as an ex-ante impact assessment, to run simulation scenarios as economic-energy-environment outlooks, based on assumptions about technology trajectories, adopted policies and other factors. The scenarios shown in *Section 4.6*, are the simulated decarbonisation pathways that are not necessarily based on existing policies but show what socio-economic impacts may be expected if certain policies shape the development of these sectors in a given way.

4.1 Naïve decarbonisation pathway (reference scenario)

We compare the sectoral decarbonisation scenarios to a so-called reference scenario. This approach is adopted in order to take into account those developments / trends that are *already shaping* the economy, including decarbonisation and relevant climate policies, even in EII sectors. Therefore, when we discuss results from the different sectoral decarbonisation pathways and talk about difference from the reference scenario we consider the socio-economic impacts of the *additional effort* that is needed to reach these higher sectoral decarbonisation goals and the *additional impact* these pathways has on the overall economy.

Thus, changes and trends considered in the reference scenario and impacts in the sectoral decarbonisation scenarios together show how socio-economic indicators could be impacted compared to the situation that we have today. The reference scenario is built on the EU Reference Scenario, which is one of the European Commission's key analysis tools in the areas of energy, transport and climate action (EU REF2020 scenario).[48] **with additional policies to achieve net-zero targets within the EU and in Germany**. *Figure 6* provides an overview of trends and forecasts in the reference scenario. In the text we will call this scenario reference scenario or naïve decarbonisation scenario. The idea underlying this scenario is that trends follow current directions, but also follow from policies that are aimed at decarbonisation. As it can be seen from the figures, the reference scenario also considers the shock of COVID-19 in 2020.

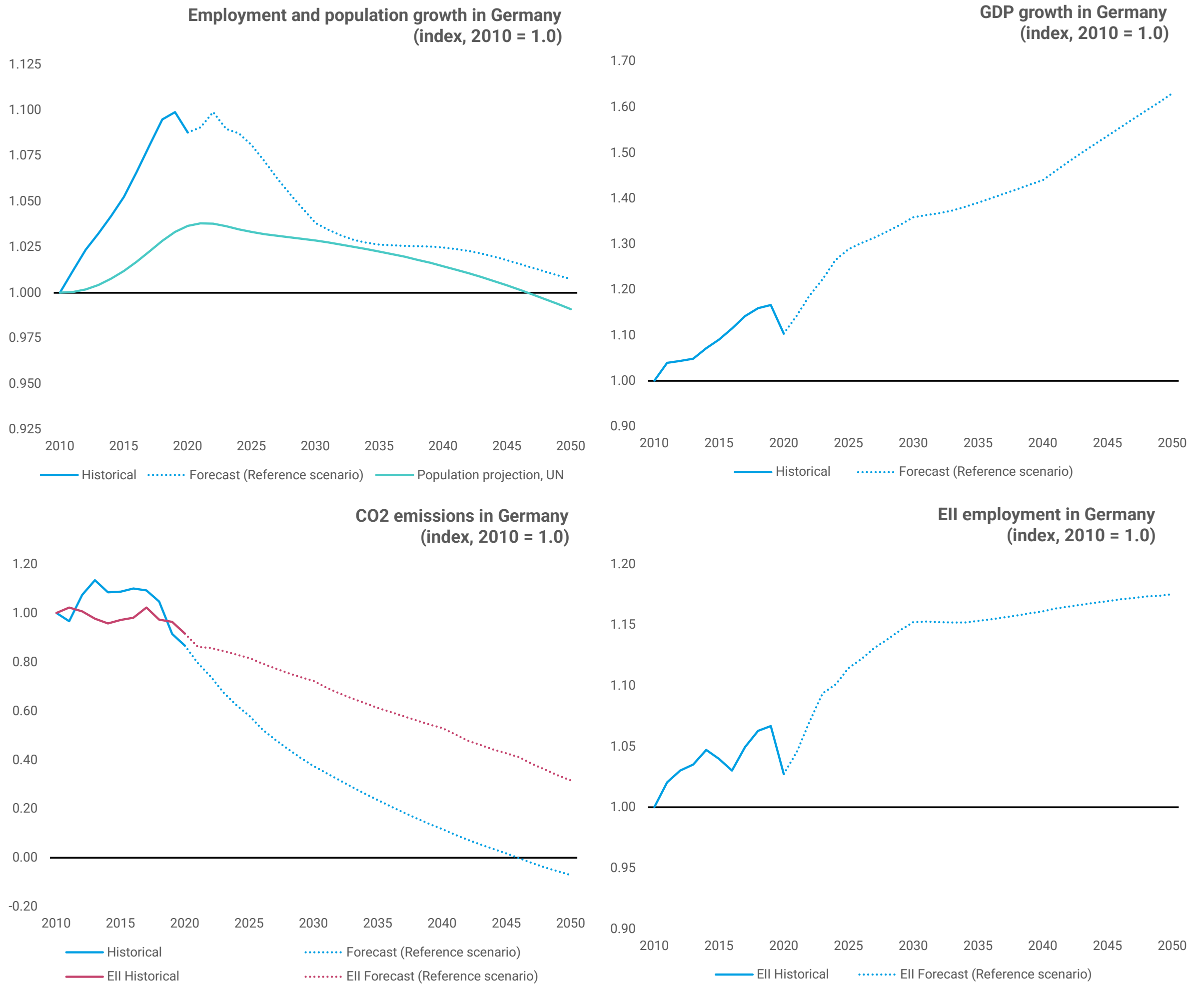
The scenario assumes that employment will decrease in the long term as a result of the aging population of Germany and the, on overall, decreasing population. GDP, however, is expected to continue to grow. At the same time

[48] https://energy.ec.europa.eu/data-and-analysis/energy-modelling/eu-reference-scenario-2020_en

emissions are expected to shrink considerably. Net-zero emissions are to be reached, in order with announced German plans, by 2045. This happens in the scenario, due to high-level policies, nevertheless these policies are not targeted, which means, as it can be seen in the figure, that for example emissions in EII sectors decrease much less than in the overall economy.

This is why we call this a naïve decarbonisation scenario – the scenario reaches the expected net-zero target in Germany, but does this without sufficiently decarbonising EII sectors. Therefore, we use this scenario as a reference, a starting point when considering the sectoral decarbonisation pathways and their impacts.

Figure 6 - Overview of the reference scenario (naive decarbonisation)



4.2 Sectoral decarbonisation pathways

In this part we first provide an overview of the possible sectoral decarbonisation pathways. Our pathways focus on the decarbonisation of EII sectors. We define these sectors, in line with the model characteristics, as NACE Rev. 2 sectors.

Therefore, our targets for decarbonisation are the chemicals, non-metallic minerals and basic metals sectors. We use the name "EII sectors" in the following pages to refer to the aggregate of these industries together. Our sectoral decarbonisation scenarios, that we present here, aim for reducing emissions from these sectors by 80% or more compared to 2010 levels in Germany.

We use a number of technology, energy use and material use levers to reach the target. In the scenarios we also consider the energy-mix and cost implications of these different pathways, as well as the more indirect socio-economic effects. As it will be shown later, we consider multiple options for financing the necessary investments and we consider how the implementation of a carbon border adjustment mechanism would interact with these pathways. However, we do not consider exact policies in the scenarios that would be needed to attain these changes.

Measures

"Measures" considered in each of the pathways can be loosely classified into seven categories:

- (1) level of electrification,
- (2) hydrogen use,
- (3) biomass use,
- (4) alternative design or materials,
- (5) energy efficiency,
- (6) recycling and
- (7) use of CCS technologies.

Pathways

In each of the scenarios there is a mix of these factors, resulting in different pathways. The overall cost of each pathway is calculated using an abatement cost approach: we set up the pathway with these actions (e.g. using (a) high level of electrification and (b) CCS technologies), then we calculate the marginal contribution of each of the actions to CO_2 emission reduction in EII sectors (e.g. 30%-70%). After that, using cost estimates from the available literature we calculate a weighted abatement cost (e.g. 0.3x50 + 0.7x95 = 81.5), which we then use for calculating investment and O&M costs (e.g. assuming that CAPEX-OPEX rate is 70:30). Investment costs are paid once (when the abatement happens), while O&M costs are applied to the cumulated abatement level over the period. Both CAPEX and OPEX costs have a pre-determined structure of how they generate sales / revenues in supplying sectors. Sources used for informing the scenarios are listed in the Appendix.

Figure 8 shows a high-level overview of the different technology / behavioural choices used in the defined pathways. A fully filled circle represents heavy use of the choice in the scenario, while an empty circle represents the opposite. A detailed description of the scenario assumptions can be found in the Appendix.

Figure 7 - High-level overview of actions used in the decarbonisation pathways

	Innovation led INNO	Circularity and efficiency CIRC	Carbon capture CCS
Electrification	◑	○	◔
Hydrogen use	◑	○	○
Biomass use	◔	◑	◔
Alternative design / materials	○	◑	○
Energy efficiency	◕	●	◔
Recycling	○	◑	○
CCS	◑	○	●

Scenario 1. Innovation led

First, the innovation led scenario is focusing on the adaptation of new technologies and fuel types: a higher electrification across the EII, the use of hydrogen in production processes, as well as energy efficiency and the deployment of CCS technologies. What sets this scenario apart from the others is the role of hydrogen and electrification as the primary energy sources in it. Nevertheless, the scenario uses CCS to reach the high sectoral goals, not to a degree as it is used in the CCS pathway, but the contribution is substantial. The scenario basically simulates a world where technologies, that are currently seen as "having potential", reach the level of market adaptation and diffusion that they can be considered common. But, due to the mix of technologies being used for abatement, this scenario is less reliant on a single technological breakthrough as the CCS scenario does. Importantly, we assume that most of the technologies considered in the pathway are available (and being adopted) from 2025 and follow an S-shaped curve – in line with thinking about technology diffusion.

Scenario 2. Circularity and efficiency

In the Circularity and efficiency scenario the main actions are energy efficiency, alternative design and/or materials and recycling. This is the most "incremental" scenario, with actions that mostly require no new technological developments, hence we assume that impacts in the pathway start from 2023 and follow a linear adaptation curve. This is the only pathway that does not use CCS to decarbonise, but it uses a behavioural change action that needs to happen outside of EII. Alternative design / materials choices, especially when thinking about cement or steel, need to be made in the downstream industries (e.g. construction) rather than in EII themselves. The pathway assumes that these choices are made, thus decreasing demand for some products of the target industries. However, this on the one hand boosts production in other industries (e.g. wood products) and on the other hand, can cause cost savings, some of which is passed through to consumers, resulting in consumption being shifted to other sectors as well.

Importantly, we define two scenarios for this pathway: the CIRC and CIRC_cons scenarios differ in what they assume about cost savings. CIRC assumes no pass through for cost savings, which means that if firms can save costs because of design choices, alternative materials or recycling it will only increase their profit, but will have no bearings on customers (they will face the same price). Contrasting this, the CIRC_cons assumes cost pass through for cost savings, reaching up to 80%, i.e. 80% of the cost savings is channelled through to customers. This means that cost savings due to these actions would show up as price decreases for the consumer as well, therefore the consumers disposable income increases with the level of the saving. The literature indicate that cost pass through is likely to happen and to happen in both directions (i.e. both savings and cost increases are channelled through).

Scenario 3. Carbon-capture and storage

This is the pathway that relies the most on a single technology: carbon capture and storage. As the technology is not yet ready to be adopted by most of the market, in this case we consider most of the impacts to start in 2030, again following an S-shaped curve. In this case production processes and energy / fuel use is largely untouched. CCS reduces emission, while it mostly keeps current processes in place. We do consider some increased electrification in the scenario though and take into account the fact that CCS can increase electricity and transport demand.

4.3 Financing setup

For all the sectoral decarbonisation pathways we have considered multiple financing options, to show how different option can alter the outcomes both for EII and for the overall economy.

No-crowding out

By default in the main scenarios we use a no-crowding out, endogenous money assumption. This means, that abatement (both investment and O&M type) is financed from “new money”. One can consider how retail banks create money for projects that they deem to be profitable to understand this notion. In our case, green finance, the idea of financing green / decarbonisation projects in a targeted way can be one of such avenues of financing. We need to consider that in this case overall investment / spending of the EII actually grows (compared to the reference case) as more money is used for financing abatement investment and operating expenses.

Crowding out

Nevertheless, we also consider other financing options. It can be argued that EII firms should finance the abatement, in this case we can consider firms redirecting their investment funds for these actions from business-as-usual (BAU) investments. This would mean adopting a “crowding-out” assumption: basically, this means that we assume that EII firms does not increase their investments from reference scenario levels, but the composition of those investments is going to change. While in the reference case they might have spent investments on expanding in this case they will spend a substantial amount of them on decarbonisation, other BAU investments are “crowded-out”, hence the name.

Government pays

Finally, we consider a case where the government pays for EII decarbonisation. In this case abatement costs are paid by the public, but to maintain government budget neutrality we assume an increase of taxes (sales, labour, income). This scenario basically assumes that the public takes up the cost of abatement actions directly.

Importantly, in all cases we also assume revenues from ETS auctions to be recycled towards taxes, i.e. ETS revenues decrease tax rates (sales, labour, income). In the public financing case, however, there is an ambiguous effect on these tax rates – as the public financing of abatement increases, but ETS revenues decrease taxes.

4.4 Carbon border adjustment mechanism

In the modelling we also consider the potential effects of the carbon border adjustment mechanism (CBAM), proposed by the European Commission. The proposal aims to address concerns around carbon leakage, especially in EII. The modelling considers the introduction of a CBAM system from 2026 onwards. The simulated CBAM covers the three NACE sectors that were considered to be EII decarbonisation targets as well: iron & steel, non-metallic minerals (cement) and chemicals.[49]

Technically, the CBAM is modelled as a tax on import prices for EU countries, with exceptions for announced third-party countries and with decreased rates for those countries who have adopted a net-zero carbon pledge. If a country exporting to the EU belongs to none of those categories, then a tax, equivalent with the ETS price, is applied onto its products. The total amount of the tax is calculated from the estimated carbon intensity of the exporting sector in its home country and the EU ETS price.

It needs to be noted that this modelling approach is a simplification of how the CBAM will be implemented in reality. First, CBAM, based on the current proposal, will include electricity imports as well, but due to the nature of electricity interconnections and the high-volatility and high-variability of electricity trade pricing we do not consider electricity imports here.

Second, CBAM coverage will likely be specified on the CN product code level[50] and it will likely be levied on certain products. NACE sectors (and their E3ME equivalents) are broader categories that necessarily include more than the selected products (*Table 1* shows the correspondence). In the modelling we apply the CBAM to these broader categories. This leads to over- and underestimation at the same time, with these two effects balancing out much of each other. On one hand, due to applying the CBAM to a larger sector, we might overestimate its effects, but on the other hand, we apply the CBAM to a carbon intensity that is calculated based on the whole sector, therefore likely to be much

[49] The overall method for simulating the CBAM in the E3ME model, as well as results from some global simulations and a discussion of legal and political issues with the CBAM proposal can be found in *Markkanen, S., Viñuales, J., Pollitt, H., Lee-Makiyama, H., Kiss-Dobronyi, B., Vaishnav, A. et al. (2021). On the Borderline: the EU CBAM and its place in the world of trade. Cambridge, UK: Cambridge Institute for Sustainability Leadership, University of Cambridge.* https://www.cisl.cam.ac.uk/files/cbam_report.pdf

[50] The Combined Nomenclature (CN) is a tool for classifying goods, set up to meet the requirements both of the Common Customs Tariff and of the EU's external trade statistics

lower than if we took the product level emission intensity. Thus, these two effects act in opposite directions and might cancel each other out, leading to less biased estimation.

Table 3 – CBAM coverage (CN codes) and E3ME/NACE sectors

Products	Relevant E3ME sector / NACE sector	EU imports of products covered by CBAM (€bn 2020 prices)	EU imports of products in E3ME sector (€bn 2020 prices)	Share of CBAM product trade in the broader E3ME sector
• Iron and steel • Iron and steel articles • Aluminium	Basic metals	89.2	114.9	77.6%
• Fertilizers • Inorganic chemicals	Other chemicals	17.9	152.1	11.8%
• Cement	Non-metallic mineral products	0.2	21.8	1.1%
• Electrical energy	Electricity	3.6	4.2	85.4%

Concerning the introduction of CBAM, free ETS allocations also need to be considered. It has been suggested that the introduction of a CBAM system will be followed by the complete phasing-out of free allocations from the ETS system. Crucially, in the modelling we assume that firms take an "opportunity cost" approach to the costs of the ETS system.[51] Meaning that regardless of them getting the necessary permits through auctioning or through free allocations from the government they factor in permit costs to their prices. The underlying assumption is the opportunity cost treatment of the free allocations on the firms' side: as they are able to trade with permits they should be able to sell free allocations if there was overallocation in the system, hence by emitting and then surrendering the permits for their own emissions carries opportunity costs – forfeited revenues from the sale of the permits.

Nevertheless, our understanding is that the opportunity cost approach might not cover all sectoral behaviours. There are two factors that need to be considered: (1) low ETS price through the last decade due to overallocations, (2) higher corporate profits through sales of free permits and cost passthrough. These together might lead to expectations of higher baseline profit levels and low or no ETS awareness on the corporate side. Therefore, we posit that the phasing-out of free allocations might act as a shock to the system, which might cause ETS price hikes. To test the effect of this we also report simulation results from a scenario where the ETS price increases above expected levels, due to the joint introduction of CBAM and phasing-out of free allocations.

[51] See *Verde, S.F., Teixidó, J., Marcantonini, C., Labandeira, X., 2019. Free allocation rules in the EU emissions trading system: what does the empirical literature show? Climate Policy 19, 439–452. https://doi.org/10.1080/14693062.2018.1549969* for a discussion on ETS costs as opportunity cost.

4.5 Assumptions outside Germany

The modelling generally assumes that EU27 countries follow similar decarbonisation pathways then Germany, i.e. in the INNO scenario we assume that hydrogen and electrification takes a bigger role in EII sector development all over the EU. As it was noted that naïve decarbonisation scenario also assumes general policies towards a net-zero emission goal in all jurisdictions that have such pledges. These assumptions are adopted to (1) avoid simulating a scenario where Germany bear losses or achieve gains due to the effects of decarbonisation on trade, (2) be able to simulate how decarbonisation in other countries interacts with German decarbonisation (induced trade effects).

4.6 All scenarios modelled

Scenario name	Type	CBAM	Financing
Naïve net-zero	Baseline		
CCS	CCS		Private, no crowding-out
CCS CO100	CCS		Private, sectoral crowding-out
CCS GO100	CCS		Public, ETS + tax balancing
CCS CBAM	CCS	Yes	Public, ETS + tax + CBAM
CCS CBAM shock[52]	CCS	yes, free allocations shock	Public, ETS + tax + CBAM
CIRC	CIRC		Private, no crowding-out
CIRC consumer (CIRC_cons)	CIRC		Private, sectoral crowding-out
CIRC consumer CO100	CIRC		Private, sectoral crowding-out
CIRC consumer GO100	CIRC		Public, ETS + tax balancing
CIRC consumer CBAM	CIRC	Yes	Public, ETS + tax + CBAM
CIRC consumer CBAM shock[52]	CIRC	yes, free allocations shock	Public, ETS + tax + CBAM
INNO	INNO		Private, no crowding-out
INNO CO100	INNO		Private, sectoral crowding-out
INNO GO100	INNO		Public, ETS + tax balancing
INNO CBAM	INNO	Yes	Public, ETS + tax + CBAM
INNO CBAM shock[52]	INNO	yes, free allocations shock	Public, ETS + tax + CBAM

[52] Free allocation shocks of the CBAM scenarios are not discussed in this version of the report draft.

5 Results

This section introduces the simulation results. We focus on several indicators both on the economy and on the EII aggregate level. Economy level results gross domestic product (GDP) changes and employment changes (both level and structure). While EII aggregate level results include impacts to sectoral output, employment and emissions. It should be reiterated that results presented, when shown as difference from the reference scenario, represent the impacts of additional effort for sectoral decarbonisation on top of the naïve decarbonisation (net-zero by 2045) that is already bound to happen in the economy (at least in announcements and pledges).

The order of the sub-sections is as follows: first, we start with a discussion of the impacts of the different simulated pathways in EII, then we shift our focus to the economy-wide impacts, discussing economic results and how the labour market changes due to the decarbonisation actions. This is followed by a discussion of how the different financing options change the results. The fourth, final, sub-section then reviews how the results are impacted if the proposed CBAM is introduced.

5.1 Impacts in energy-intensive industries

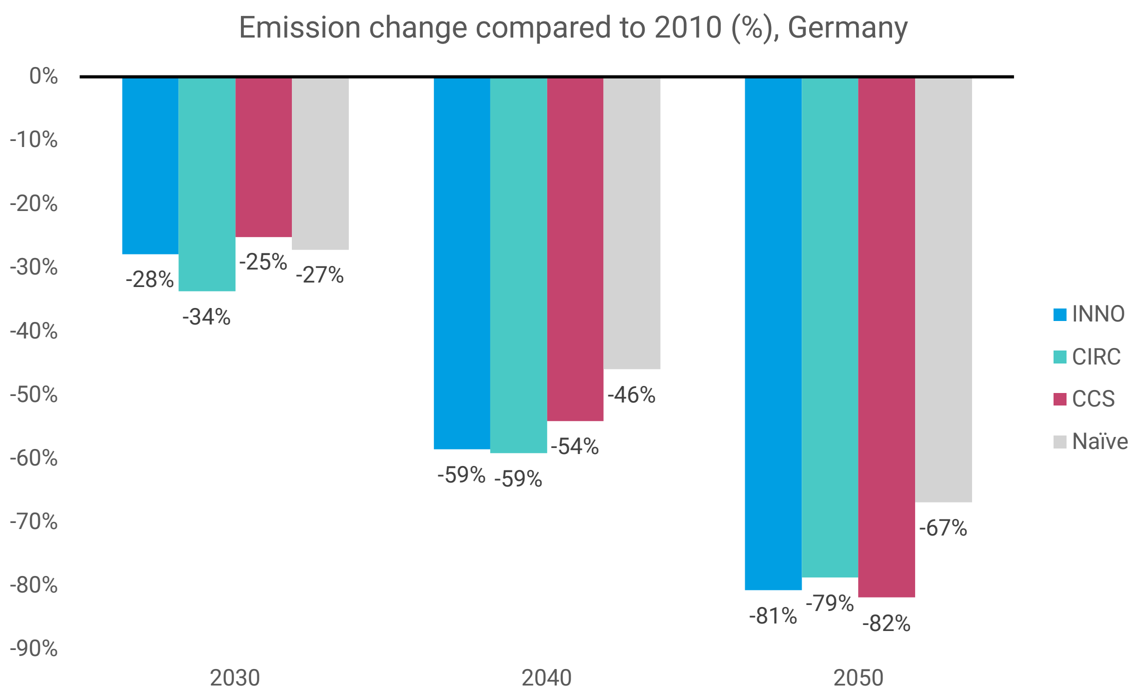
Emission impacts

The sectoral decarbonisation pathways are designed to reach emission reduction from the sectors close to or over 80% by 2050. As it can be observed on *Figure 9* the naïve scenario (reference scenario) already creates substantial emission reductions (68% by 2050), but the sectoral decarbonisation pathway scenarios are able to achieve the targeted higher ambitions.

The innovation led (INNO), circularity and efficiency (CIRC) and CCS scenarios add 9 to 14 percentage points by 2050 on top of the naïve decarbonisation reductions. Notably, there are differences in the temporal distribution of the effects. As it was discussed earlier the CIRC scenario brings emission reduction results as soon as 2030 but ends up with a more muted impact than the others by 2050. Meanwhile the INNO scenario reaches its peak emission reductions (compared to others) by 2030 and the CCS reaches its highest emission reduction (compared to others) by 2050.

Combined emission reduction in the 2020-2050 amount to 107-114 $MtCO_2$ in the pathways, with CCS being the upper, while CIRC being the lower bound.

Figure 8 – Reduction of CO_2 emissions compared to 2010 in EII sectors, Germany

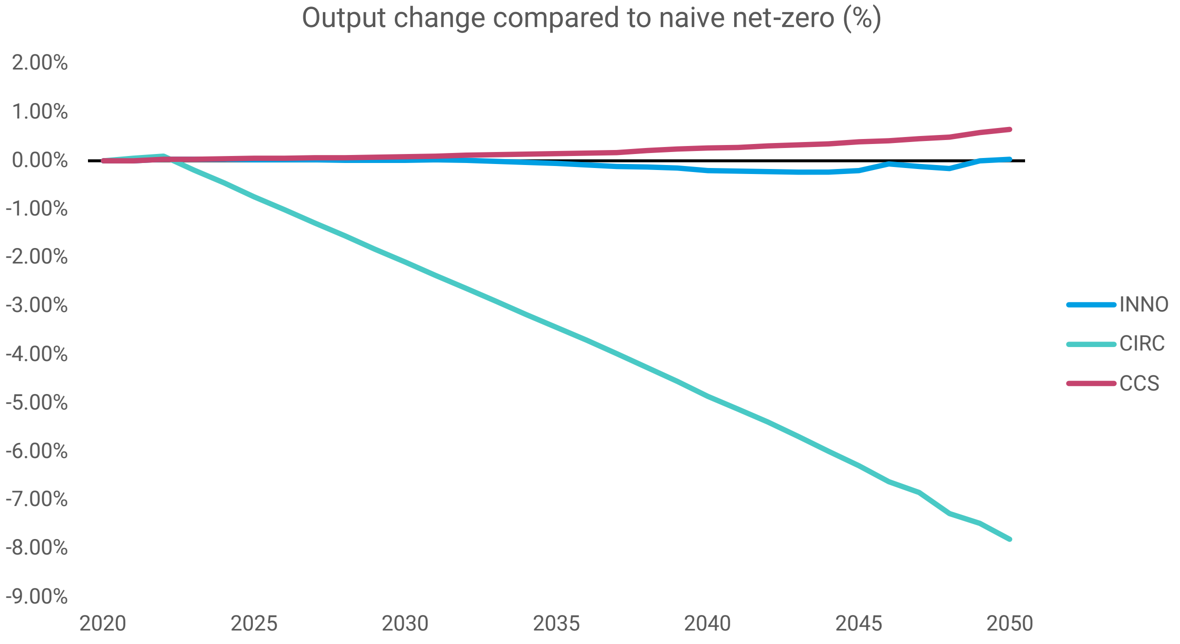


Economic output

The impact on economic output in the EII sectors varies across the decarbonisation pathways. The economic response also varies across sectors and results are not always point in the same direction (i.e. impact in chemicals might be negative, while in steel it might be positive at the same time). Abatement related economic activity, demand reduction due to alternative materials and material efficiency and trade impacts due to decreasing ETS costs and energy price differences drive the economic results. *Figure 10* shows an overview of the impact of the pathways on EII sectoral output.

The INNO scenario brings close to zero or slightly negative impacts, which is the net effect of differing sectoral impacts. Trade impacts explain the results to some degree, e.g. in chemicals decarbonisation, while somewhat decreases intermediate demand for chemicals, also causes differences in unit costs across the EU. Importantly, ETS cost on sectors decrease as they shrink their emissions, which lead to price decreases across Europe. However, the magnitude of this decrease is dependent on a number of local factors (e.g. energy mix in line with electrification needs, cost pass through to prices and labour / tax / material input ratio of final prices. This for example in the case of chemicals leads to a lower German production and higher production in other countries, which complemented with a relatively stable intermediate demand means that Germany imports more chemicals in the scenario. The opposite can be observed in the steel sector: domestic production grows due to price differentials, while the rate of imports decreases. At the same time non-metallic minerals export grows, for similar reasons. Overall, these impacts largely balance each other out in the scenario, but do have trade implications.

Figure 9 – Impacts on aggregated sectoral output for EII sectors, Germany, difference from reference scenario



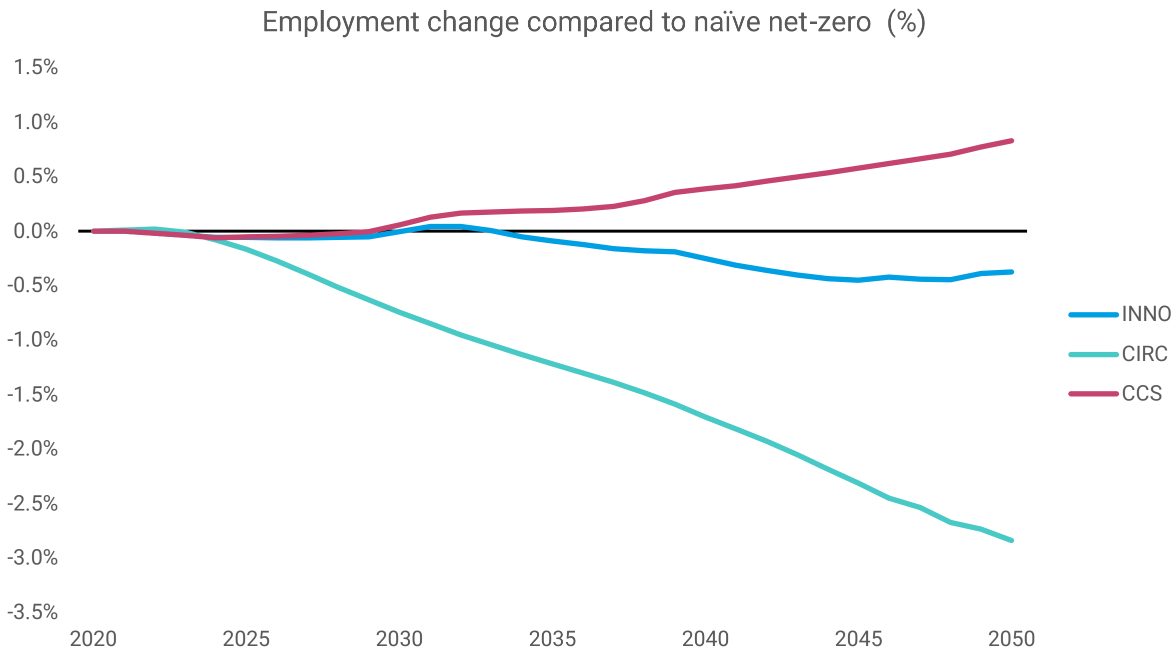
The CCS scenario brings a slight increase in sectoral output, this is because the scenario reduces emission and hence ETS costs, while it does not need a large-scale restructuring of the industries in question. This results in decreasing prices, but again the price change differs across countries and dependent on various factors, such as labour content of prices. Nevertheless, for German production, the results are positive here: in non-metallic minerals exports grow, while in steel domestic production outplaces imports. Meanwhile in chemicals the economic activity that is induced by CCS operation induces some positive impacts. Additional output compared to the reference scenario reaches over 0.6% by 2050.

Finally, in the CIRC scenario results are negative, reaching an about 8% reduction in economic output compared to the reference scenario. This, however, is driven by our assumptions in the decarbonisation pathway: the scenario assumes both a shift to alternative materials, and a general demand reduction due to material efficiency in downstream industries (such as construction) and alternative design choices. Although, for the sectors targeted this causes a drop in economic activity, as we will later see, this could boost other sectors (suppliers of alternative materials) as well as general consumption (due to cost savings).

Labour market impacts

Employment impacts are generally in line with economic impacts. Looking at *Figure 11* we indeed see that the direction of the impacts are similar. However, magnitude of the impacts are different. In the case of the CCS scenario employment impact is somewhat higher (0.8%) than the output impact was, while in the case of the CIRC scenario the labour market impact is less than half (-2.8%) of the economic output effect. Finally, while the economic output for the INNO pathway was close to zero, here it is slightly negative, at -0.4% by 2050.

Figure 10 - Impacts on aggregated sectoral employment for EII sectors, Germany, difference from reference scenario



Therefore, in the CCS we see an effect higher than in output, in INNO as well, but in the CIRC scenario we see a muted effect compared to output. First, in the CCS scenario employment is largely driven by the steel sector, where CCS based technology is deemed to be more labour intensive, hence the higher gain.

In the INNO scenario there are impacts going in opposite directions. Bottom-up modelling for steelmaking technologies again show gains due to switching to electric and hydrogen based technologies. But, both in the chemicals and in the non-metallic mineral products (NMMP) sectors we observe the opposite: employment is slightly shrinking. In the chemicals sector this is in line with changes in domestic output, while in the NMMP sector despite a growing output (driven by exports), which is in turn explained by prices decreasing EU-wide.

Finally, in the CIRC pathway the negative effect on economic output is much higher than the employment output. This, however, is explained by varying employment responses to economic shocks. In output terms chemicals looses the most, but the sector also has the lowest estimated labour elasitcity across the sectors (i.e. if labour elasticity is high it means that an economic shock will cause equal or higher employment impacts, if labour elasticity is lower, than the employment shock will be lower than the economic, this is what happens here). Therefore, we can say that the composition of the overall EII and sectoral employment elasiticites drive this result. However, it should be noted, that, as we will see later, in this scenario there is substantial substitions across sectors (i.e. alternative materials, reduced costs), which have positive labour outcomes in other parts of the economy.

Summary of EII impacts

Table 5 shows the summary of the results in EII sectors in 2030 and 2050. As it was discussed, all three pathways reach close to 80% emission reduction from the sectors by 2050. The INNO scenario has overall limited economic and employment impacts in the sector, while the CCS has mostly positive impacts (as investment paying for CCS implementation is flowing in to the sectors, which is followed by investment for operating CCS). Finally, the CIRC scenario, the only pathway that does not depend on technological breakthroughs, has negative economic impacts (within EII sectors) and negative, but lower, employment impacts.

Table 4 – Summary of results in EII sectors

Year	*2030*			*2050*		
Sectoral pathway	**INNO**	**CIRC**	**CCS**	**INNO**	**CIRC**	**CCS**
Emission reduction compared to 2010	-28%	-34%	-25%	-81%	-79%	-82%
Economic output compared to reference	+0.01%	-2.09%	+0.08%	-0.11%	-7.79%	+0.65%
Employment compared to reference	0%	-0.73%	+0.06%	-0.52%	-2.90%	+0.84%

5.2 Comparison of economy-wide impacts

An important feature of this modelling approach is that the model does not only calculate with impacts in the targeted sectors (EII), but also in the wider economy, therefore accounting for impacts stemming from indirect effects such as cost-savings induced consumption, supply-chain impacts or induced impacts in the energy system and industry.

Economic impacts (GDP)

Figure 12 shows an overview of the economy level impacts on gross domestic production (GDP). As it can be seen on the figure the simulation results indicate that the CIRC scenario creates strong positive impacts, while the CCS and INNO scenarios create much weaker close to zero or slight negative results. In exact numbers, by 2050, results from the CIRC are 0.6% above the reference scenario, while the result in the INNO and CCS scenarios are around -0.1%.

Explanations for these effects vary. In the case of the CCS it initially boosts the economy somewhat, but by 2040 and especially by 2050 it outplaces investments and employment opportunities that are happening in the reference scenario. Basically, the reference scenario assumes investments and related employment to happen in the time-frame of the modelling to transition the German economy into a decarbonised one. However, with CCS being introduced and driving emission reductions much less of this economic activity and labour heavy transformation is happening. The scenario sees lower employment and lower wages in multiple industries that are supposed to benefit from the climate transition (e.g. construction, power generation). At the same time, in the scenario prices are quickly rising as CCS related costs channel in to prices, which again depresses consumption. From about 2040, imports drop, which provides some positive effects to the overall GDP result.

Figure 11 – Economic impacts (GDP) compared to reference scenario, Germany

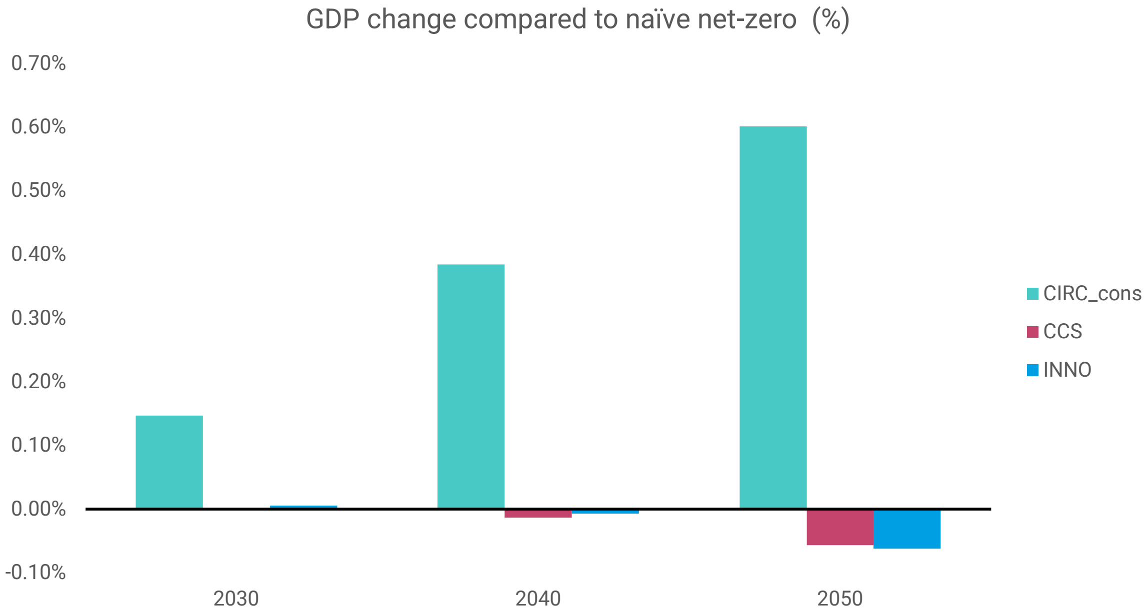
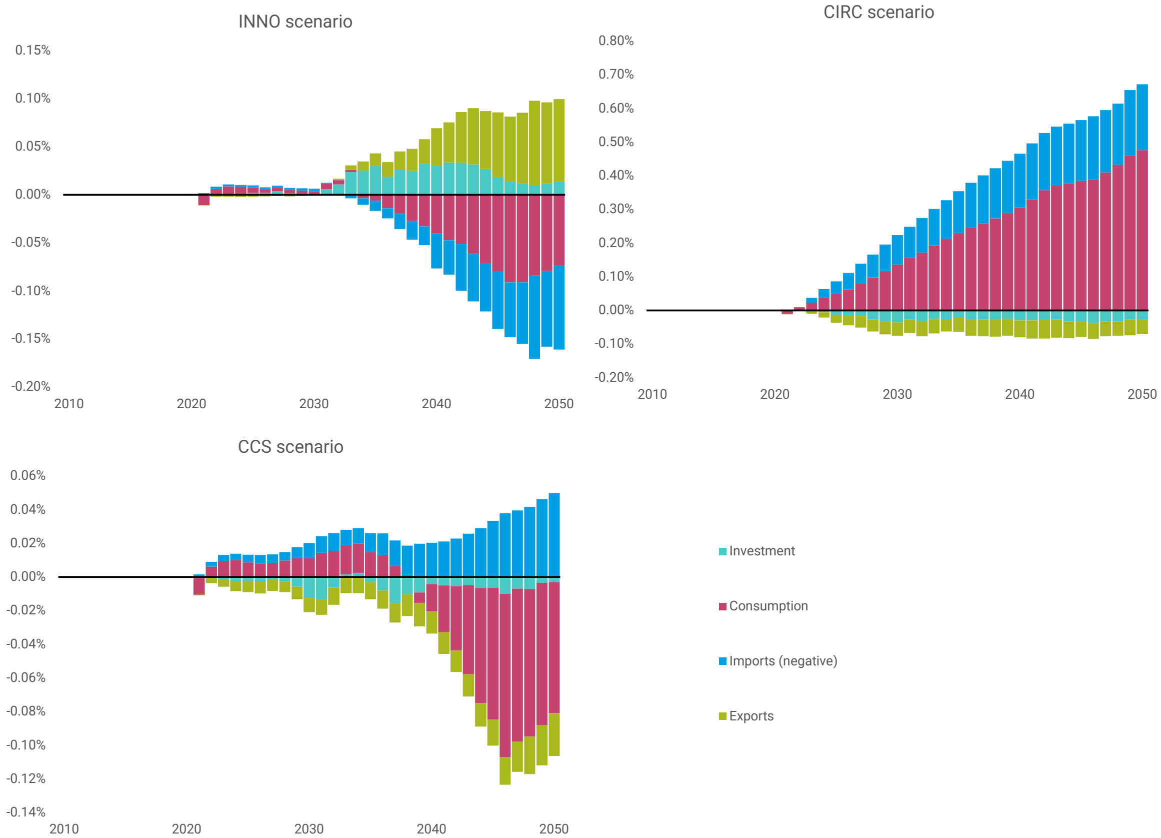


Figure 12 – Decomposition of GDP impacts by scenario, Germany



In the case of the INNO scenario, *Figure 12* only tells one side of the story. There are actually impacts in opposite directions as *Figure 13* shows. With the increasing electricity and hydrogen demand new investments are needed to fulfil demand, this is what is reflected in the growing investment. At the same time both exports and imports increase, but the net trade effect is negative. As investments increase consumption decreases in the scenario: prices of services grow as the investment costs are channelled through to consumer prices, leading to a lower level of consumption. This, combined with the deteriorating trade balance leads to GDP results below the reference scenario.

Last, in the case of the CIRC scenario consumption effects coming from cost-savings dominate the results. This scenario produces the highest GDP impacts, mainly due to two positive impacts. First, the decreased consumption of EII products means lower imports, which contribute to the positive GDP result. Second, cost-savings from alternative materials, material efficiency, alternative design choices as well as from recycling are assumed to channel through the economy reaching consumers. We assume that about 80% of the cost saving is factored in to prices therefore, by these assumption 80% of the cost savings will be channelled back to spending, this drives the consumption impacts here.

Labour market implications

Figure 14 shows the whole-economy labour market implications. We have included the three main pathway scenarios and both version of the CIRC pathway to show the variation in impacts.

First, while its economic impacts were negative, the CCS scenario produces weak positive and close to zero (2050) results. The explanation is quite similar than it was for the economic results, only the compositional effects lead to different outcomes. In economic terms (compared to the reference scenario) consumer sectors were loosing out because of increasing prices, while other sectors were gaining less than in the reference scenario because of a more limited “green” transformation. In labour terms we observe the similar effects, only in employment the loss is lower and the gains in EII (or lack of losses) are balancing this out.

In the INNO scenario, we have close to zero economic outcomes and here we get slightly negative employment outcomes. The reason here is again in the sectoral composition of the impact: as it was discussed in the INNO pathway investment grows, while consumption shrinks somewhat. Now, in the labour outcomes sectors implementing the investments (construction) and supplying energy (electricity, hydrogen production) show growth, but consumer sectors (services) shrink. In net employment terms, services being more labour intensive, this leads to a net negative impact. While in economic terms the two sides of the equation are balanced out, i.e. as much is lost in consumer services / goods, is gained back in investment products.

Finally, the CIRC and CIRC_cons scenarios show the highest impacts. We have to first consider that in the case of the CIRC scenario there is cost reduction in EII downstream industries, but there is no cost savings for the consumers. This means a reduction of revenues, a reduction of incomes and finally a reduction of spending, which leads to stark employment outcomes. In the CIRC_cons scenario however, as we channel those cost savings through to consumers their spending on goods and services increase, which drives economic activity and thus employment. The sectoral profile of the jobs gained confirms this: retail, tourism and entertainment sectors drive employment gains.

Figure 13 – Employment compared to reference scenario, Germany

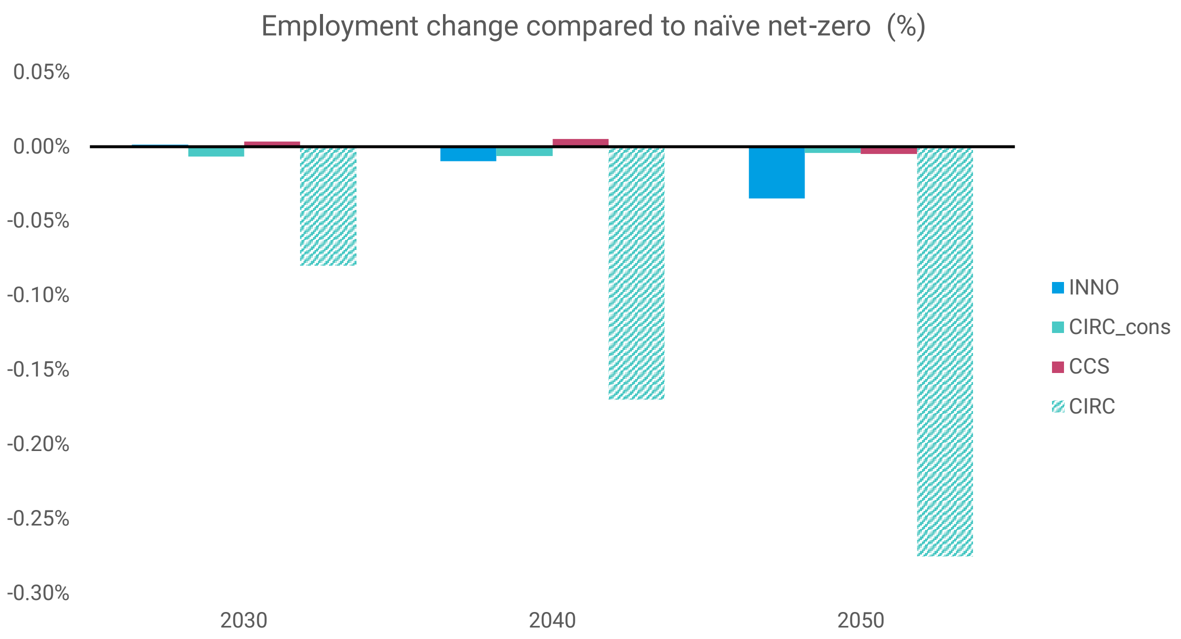


Figure 14 – Composition of employment changes compared to the reference scenario ('000 people)

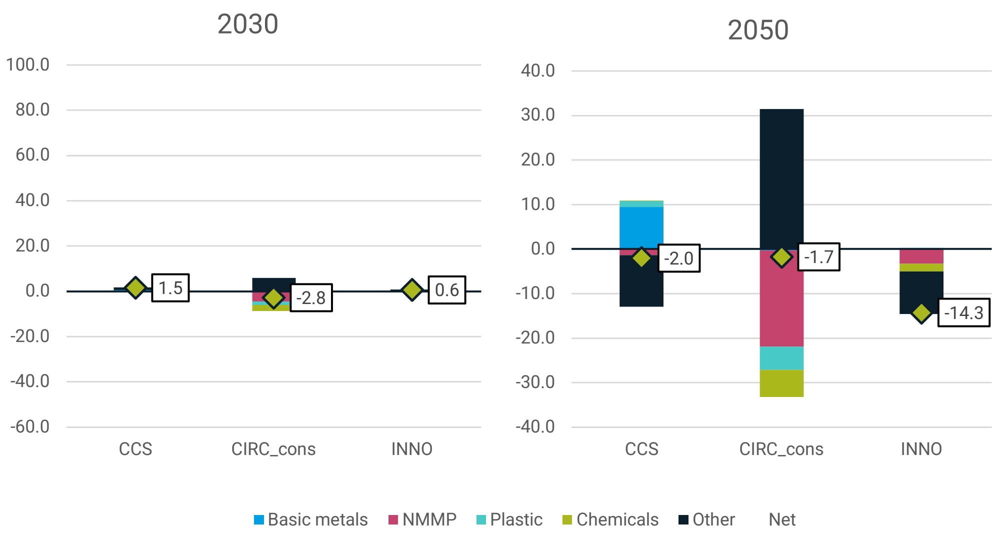


Figure 15 shows the composition of the employment effects. As it was discussed, in the CIRC pathway there is an economic transformation, which shifts away employment from the EII sectors towards service sectors. In the INNO scenario the shrinking consumption impacts the labour market and while investments drive economic outcomes they are not large enough to balance out employment. Finally, in the CCS scenario gains from EII sectors, particularly

from iron and steel balance out losses, that are suffered due to increasing price levels and lower effort energy and industry transformation.

Summary of economy-wide impacts

Economy-wide impacts paint a diverse picture: there are substantial difference between the pathways, but the direction of the economy-wide impacts are usually points in the same direction.

First, as *Table 6* shows there are differences in the magnitudes of the impacts. This can be expected, in E3ME modelling we often see that due to labour market rigidities and different sectoral employment elasticities labour market impacts are smaller than economic impacts.

Impacts are the strongest in the CIRC scenario, but one needs to consider here, that this scenarios assumes a large-scale transformation of the economy, shifting consumption from EII sectors (due to downstream efficiency and design) to other sectors of the economy. Also, as it has been observed, the scenario causes strong negative impacts within the EII sectors.

The CCS scenario, while on the level of the EII sectors has provided positive results on a whole economy level results in close to zero and or weak negative impacts. However, it does lead to a substantial price increase, that decreases consumption in the economy.

Finally, the INNO pathway resulted in weak positive economic and weak negative employment impacts on the EII sector level, now on the economy level it results in slight negative outcomes both for GDP and for employment. Although investments related to electricity and hydrogen supply increase in the scenario brining economic activity and jobs, trade impacts and shrinking consumption lead to net negative outcomes.

Table 5 - Summary of results in the whole economy

Year	*2030*			*2050*		
Sectoral pathway	**INNO**	**CIRC**	**CCS**	**INNO**	**CIRC**	**CCS**
GDP compared to reference	0%	+0.15%	0%	-0.06%	+0.60%	-0.06%
Employment compared to reference	0%	-0.01%	0%	-0.03%	0%	0%

5.3 Impacts of financing options

This section introduces results for the different tested financing options. These financing options simulate what happens is if the abatement is financed from different sources, through different channels. The main scenarios (shown in the above results) use the financing assumptions of endogenous money creation and no crowding-out. This means that in these scenarios we assume that new money, external financing is bought in to pay for the abatement costs. This is as realistic assumption as much as these abatement operations can be covered from so-called dedicated green sources (e.g. green bonds) or from loans, equity that is brough in to finance these projects.

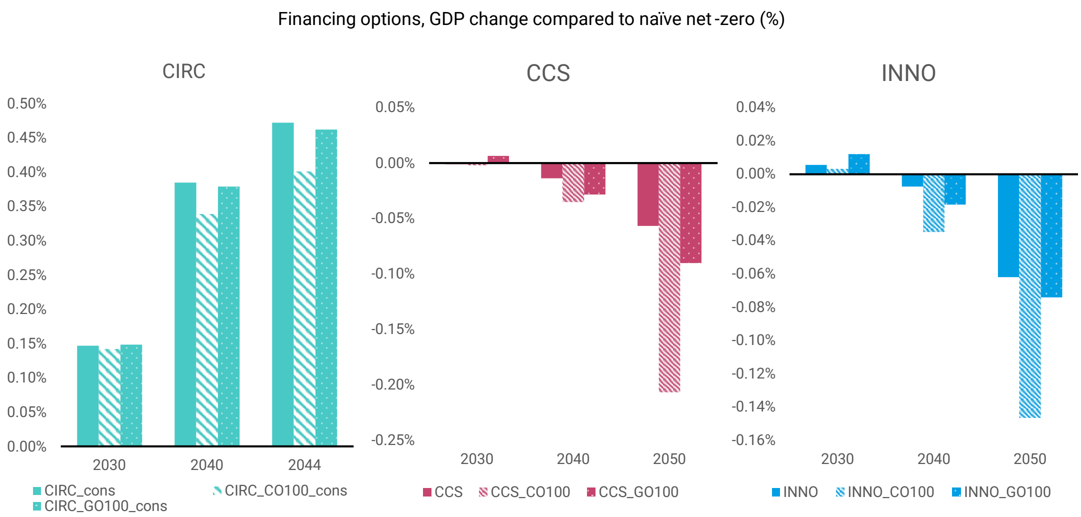
However, it can be considered that the abatement needs to be financed from other sources, such as public funding or within sector private investment that crowds-out other sectoral investments. The scenarios consider extreme versions of these options:

- **CO100** versions considers the pathways being implemented with private investment, which 100% crowds out baseline investment within the target sectors. This basically simulates the case when EII has to pay for abatement without increasing its investment levels.
- **GO100** versions considers the pathways being implemented fully with public investment. This means that 100% of the abatement costs are paid from public funds, which are raised through increased tax levels (labour, sales and income tax).

Economic results

Figure 15 shows the high-level economic results (GDP) for each of the financing options and for each of the pathways. In all pathways, applying public financing (GO100) worsens the result somewhat. In this case of the CIRC pathway, this means a reduction of the otherwise positive result, in the other cases, this increase the magnitude of the negative impact. Nevertheless, these results do

Figure 15 – Impacts of different financing options on GDP compared to reference scenario, Germany*



Note: * for the CIRC pathway results are only shown up to 2044, because the model failed to converge for the CO100 scenario.

not compare to the magnitude of the impact from the full within industry crowding-out scenarios (CO100). In these cases, GDP is severely negatively impacted.

In both cases, the CIRC scenario is affected the least by the financing options. In this public financing reduces the positive result by only 0.01pp, while full crowding-out reduces the result by 0.07pp. In contrast, the CCS pathway suffers the most, especially with full crowding-out. In it an original -0.06% decreases by 0.03pp to -0.09% in the public financing case, while in the crowding-out case it suffers a 0.15pp reduction to -0.21%. The INNO pathway sees smaller, but similar effects. From the original -0.06% the public financing option decreases the result to -0.07% by 0.01pp, while the crowding-out drives down the result to -0.15%, with a negative 0.09pp effect. The explanation of this is the variety in the total abatement cost of the pathways. The CCS abatement altogether costs the most, therefore we see the strongest impact here. Similarly, the CIRC costs the least, therefore we see the weakest effect here.

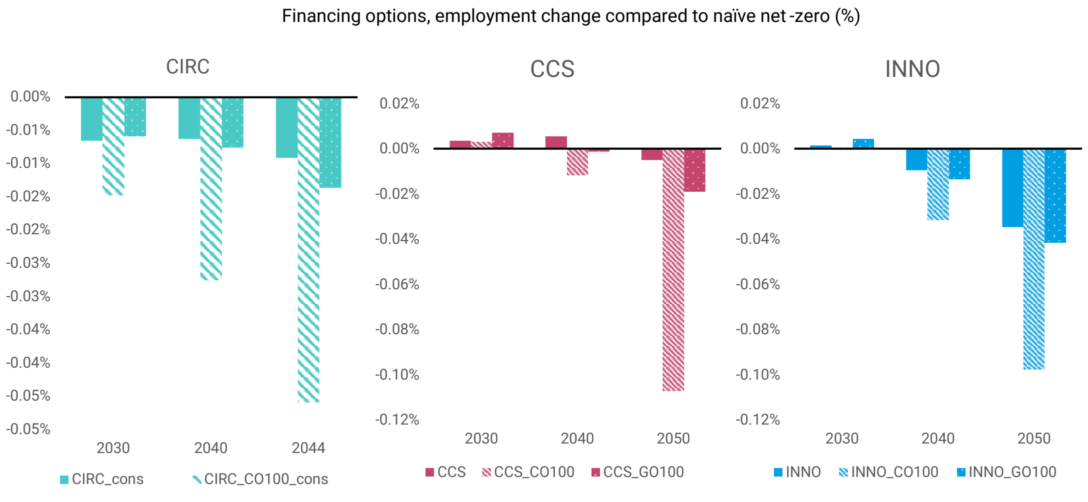
Employment results

Figure 16 shows the employment results of the financing options. The overall pattern largely follows the economic results. Both public financing and private financing with full within sector crowding-out negatively impact the main scenario results. With the CCS and INNO pathways having the strongest and the CIRC scenario having the weakest results, for reasons explained above.

However, while employment results are smaller in magnitude the impact of the financing options is comparable in magnitude to those of the economic impacts. While for GDP the crowding-out option decreased results by 0.07pp, 0.15pp and 0.09pp respectively for the CIRC, INNO and CCS pathways for employment these numbers are 0.04pp, 0.11pp and 0.07pp. This means that in relative terms (compared to the main scenario impact) the impact of the financing options is stronger for employment than it was for economic activity.

This is specifically true for the crowding-out scenarios, but not necessarily for the public financing scenarios. There the impacts of the financing options are somewhat higher on the economic results (0.01-0.03pp), while lower on the

Figure 16 – Impacts of different financing options on employment compared to reference scenario, Germany*



Note: * for the CIRC pathway results are only shown up to 2044, because the model failed to converge for the CO100 scenario.

employment results (0.0-0.01pp). The crowding-out scenarios produce this effect, because their effects are concentrated to a handful of industries (EII). In these industries the strong effect leads to substantial employment impacts, which is reflected in the economy-wide results.

Summary

By assumption, the “default” mode of financing (endogenous money, no crowding-out) has better economic and labour outcomes that any other mode of financing, because this option assumes that money will be created for these abatement projects.

If however, we think it is more realistic, that these investments will (at least partially) need to be financed either from public sources or that they will create within sector crowding-out, outplacing investments that otherwise would happen and would contribute to extensive and intensive sectoral growth, then we need to consider the effects of financing modes.

Through the scenarios we have seen that public financing of the measures generally lead to better outcomes, mostly because in these cases the impact is distributed across the economy. While in the case of private financing with full within sector crowding-out the impacts and the costs of abatement are concentrated in a handful of sectors (EII), thus inducing stark impacts in those particular sectors.

5.4 Carbon border adjustment impacts

Carbon border adjustment mechanism (CBAM), as it was proposed by the European Commission (EC) as part of the EC’s Fit-for-55 agenda, is a tool that is primarily aiming to limit carbon leakage. The goal of the CBAM is to ensure the competitiveness of European industry, who face higher environmental regulations than third-party countries, while limiting carbon-leakage stemming from either offshore production or imports of goods from countries with inadequate environmental regulations.

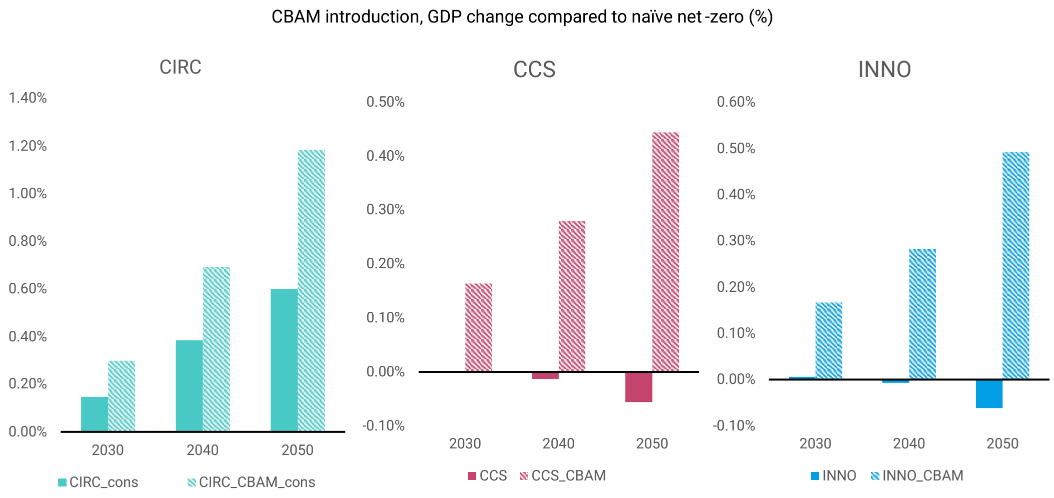
Current EC plans aim to establish a fully operational CBAM from 2026, while phasing-out the current system of free allocations given to emitters. Nevertheless, there are still various questions surrounding the implementation and introduction of the CBAM system. These include possible legal challenges, unilateral responses from trade partners as well as questions about the feasibility of implementation (e.g. reliably measuring carbon intensity and acknowledging third-party emission permits).

In the modelling, we consider a simplified CBAM version, which is introduced from 2026 and covers the target EII sectors, the technical aspects of the modelling are introduced in *Section 4.4.* Crucially, we exclude any electricity trade from the coverage of the implemented CBAM in order to be able to carry out the modelling with this simplified approach.

Economic and employment results

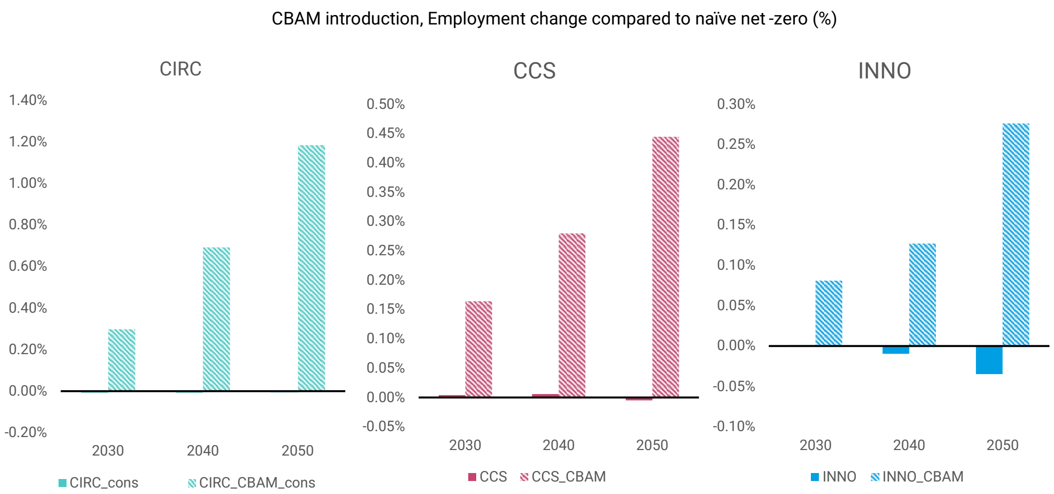
Figure 17 shows an overview of the GDP impacts. GDP outcomes are about 0.5pp higher in all cases with the CBAM introduction than without it. The impacts are consistent across pathways and across time (i.e. they are ~ 0.23pp in 2040, increasing to 0.5-0.6pp by 2050). Imports (and exports) of the EII sectors shrink, but due to the revenue recycling (collected CBAM revenues are used for decreasing labour and consumption taxes) consumer sectors boost their sales, production and even their trade activity. This is explained by increasing import prices combined with the opportunity cost approach treatment of ETS costs, which cause relative prices of domestically produced EII goods to decrease. This is further complemented with a growth of domestic investment as steel producers shift away from scrap metal importing and recycling due to increasing costs and favour other types of production.

Figure 17 – Impacts of CBAM introduction on economic activity (GDP) to reference scenario, Germany



Employment impacts, shown on *Figure 18* again show substantial positive impacts of the CBAM introduction. Most of the realized employment gains are, however, due to the revenue recycling mechanism. Revenues collected on a member state level from CBAM are recycled towards tax decreases, which substantially boosts production, this again is complemented with above stated effects.

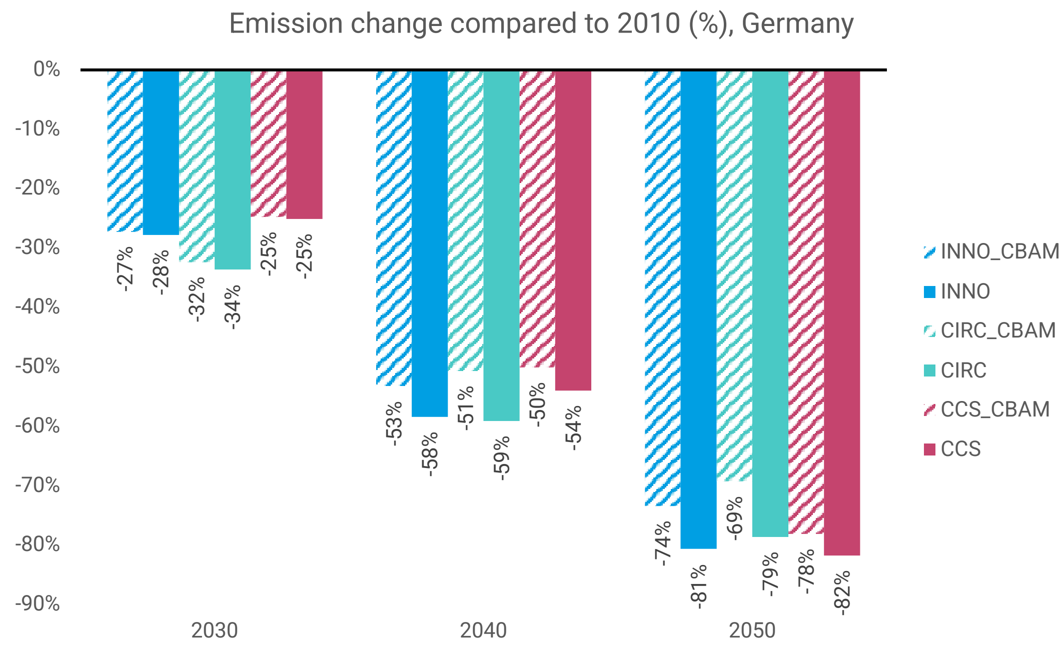
Figure 18 – Impacts of CBAM introduction on economic activity (GDP) to reference scenario, Germany



Environmental impacts

Nevertheless, these developments also have environmental impacts. Due to (a) the rebound effects of revenue recycling (resulting in more consumption) and the (b) technology change in steel production. Domestic emissions increase, especially in the pathways that were employing scrap metal recycling as a means of steel production.

Figure 19 – Impacts of CBAM introduction on economic activity (GDP) to reference scenario, Germany



As *Figure 19* shows, this might result in lower emission reductions, especially in the case of the CIRC and INNO pathways. Here, *assuming that a relevant part of the scrap metal used in the recycling process is imported*, we arrive at reduction numbers up to 10pp lower by 2050 than in the case of no CBAM implementation.

5.5 Impacts of the Ukraine-Russia conflict on EII decarbonisation

On 2022 February 24 Russia began a military invasion of Ukraine. The ensuing war has resulted in the loss of lives, it has crippled civilian infrastructure in Ukraine and has caused the stop of economic activity in the region. At the same time, as a response to Russian aggression, a large number of countries, including the US, Japan, Canada and the EU has sanctioned Russian trade- and economic activity.

Germany, as the EU's leading economy, plays a leading role in implementing these sanctions, nevertheless, faces a challenging situation as the country's reliance on Russian fossil energy carriers is still substantial. However, despite these challenges, Germany has already put the contentious Nord Stream 2 pipeline project, which was supposed to bring Russian gas through a new pipeline to Europe, on hold. The government in Berlin has also announced the creation of strategic reserves and has signalled its commitment to build new terminals for importing liquified natural gas (LNG), therefore diversifying its sources of natural gas. Complementing these measures, the government has announced its plans to speed up a shift towards renewable energy and to increase efforts for energy efficiency gains, thus reducing dependency on fossil fuels.[53]

All these plans are aiming for a less fossil dependent Germany, that sources its remaining natural gas from diversified sources through LNG (e.g. US, Qatar). However, these plans will still need years to be fully implemented. That is why Germany has triggered the first stage of its national gas supply emergency plan, requesting consumers to save energy and why there are calls for delayed decommissioning of lignite power plants in the country. This also explains why Germany is against the sanctioning of imports of Russian energy carriers, which is advocated by multiple EU members states. There is a notion, that given the current dependence and the potential speed of system transformation a ban on Russian fossil sources would cause enormous economic impacts in the German economy.[54]

Meanwhile, it is evident, that especially with the departure from the tight fiscal policy approach and the increased government spending on areas such as energy security, infrastructure and defence, Germany is committed to move towards more self-reliance and to cut (energy dependency) ties with Russia. This will likely mean more public support for decarbonisation, including EII decarbonisation, but also an expectation for transition to happen as quick as it is possible.

This can ramp up pressure on EII sectors to decrease their consumption of energy sources that now are not only seen as harmful for the environment, but also an energy security risk, because of how their price and availability is dependent on Russian geopolitics. Switching to LNG and sources other than current pipelines will increase costs of natural gas, which can limit its role as a "transition fuel". However, hydrogen might gain even more traction (e.g. pipeline plans from Norway) both due to the energy security opportunities (more diversified sourcing) and due to the LNG infrastructure that is being developed. There is a potential to repurpose LNG and natural gas infrastructure for hydrogen transport and use, therefore if current LNG projects are implemented with this in mind hydrogen can gain a substantial infrastructure advantage.

Concerning the relation of the pathways that were presented in the modelling for EII decarbonisation: given what we described above about the situation, the CCS pathway has become less politically feasible, because it is still largely dependent on fossil imports. If the cost of fossil imports increases significantly or their availability comes into question, then technology that uses these resources might going to be in jeopardy, regardless of CCS use. Even though, in the short-term the current situation might convince decision makers to allow the use of technologies that otherwise would be considered environmentally

[53] Clean Energy Wire. "Ukraine war: Tracking the impacts on German energy and climate policy". Apr 7, 2022, https://www.cleanenergywire.org/news/ukraine-war-tracking-impacts-german-energy-and-climate-policy

[54] Clean Energy Wire. "Russia's invasion of Ukraine forces Germany to come clean on energy transition strategy". Feb 28, 2022, https://www.cleanenergywire.org/news/russias-invasion-ukraine-forces-germany-come-clean-energy-transition-strategy

harmful (e.g. reopening of lignite plants). But this does not expected to be sustainable on the long-term.

The other two pathways considered might be impacted less by these developments. The CIRC pathway mostly considers reduction of energy needs, through material and energy efficiency and alternative design. Here we are already aiming for decreasing demand and thus dependency. However, in this pathway a challenging point could be the development of the steel sector. The scenario assumes a high share of scrap metal recycling in steel production, which (scrap metal imports) could be impacted by the ongoing war.

Finally, the INNO pathway might even be able to gain from this situation. As it was discussed above, the current situation in Germany are already prompted a weakening of the government's tight fiscal policy approach and it has led to new hydrogen and LNG developments. These developments are all beneficial for the INNO scenario: a more mature hydrogen infrastrucutre, an LNG infrastructure that can be repurposed for other uses and higher public spending on R&D, infrastructure and decarbonsation can both quicken the deployment of new technologies and make it cheaper for EII to transition to them.

6 Conclusions

German context The EIIs in Germany show high climate awareness and large enterprises are active in research on new solutions for carbon-free production technologies at industrial scale. The challenges of green transition for the industry are to a large extent similar across all three industries and require cross-sectoral cooperation and active government involvement. Due to their intensive energy use their decarbonisation also depends on the green transformation of energy production. To invest in green production, clear market signals and certainty is needed, also for the price of carbon and resolution of carbon leakage. Favourable regulatory frameworks, infrastructure development and planning are needed with respect to a variety of mitigation techniques, including hydrogen as energy source, carbon capture, transportation and storage as well as reuse and recycling of materials.

Sectoral impacts The sectoral decarbonisation pathways are designed to reach emission reduction from the sectors close to or over 80% by 2050 but there are differences in the temporal distribution of the effects. Employment impacts are generally in line with economic impacts.

The scenario relying on material and energy efficiency and recycling (CIRC) brings emission reduction results as soon as 2030 but ends up with a more muted impact than the others by 2050. Economic impacts are negative driven by the assumptions, ie. shift to alternative materials, and a general demand reductrion due to more efficient production. On the other hand, this scenario could boost other sectors as well as general consumption due to cost savings.

The innovation-led scenario (INNO) reaches its peak emission reductions by 2030, it has unsignificant economic impacts although has trade implications for Germany.

The CCS-scenario reaches its highest emission reduction by 2050 and brings a slight increase in output as it does not require a major restructuing of the analsed industries.

Economy-wide impacts There are substantial differences between the pathways, but the direction of the economy-wide impacts are usually points in the same direction. The CIRC scenario assumes a large-scale transformation of the economy, shifting consumption from EII sectors (due to downstream efficiency and design) to other sectors of the economy.

The CCS scenario has close to zero or weak negative impacts on the economy. However, it does lead to a substantial price increase, which may lead to decreased consumption in the economy.

Finally, the INNO pathway resulted in slight negative outcomes both for GDP and for employment.

Impact of financing options The study has looked at three different ways in financing the needed investment for such green transition. The scenario where money is available and does not crowd out other investment options, provides the best economic and labour outcomes. We have also looked at two, more realistic options, as these investments will need to be financed either from public or private sources and will create within sector crowding-out, outplacing investments that otherwise would happen and would contribute to extensive and intensive sectoral growth. Through the scenarios analysed, public financing of the measures generally leads to better outcomes, mostly because in these cases the impact is distributed across the economy.

CBAM effects

The study models a simplified version to the CBAM system proposed by the Commission. The simulation assumes that the CBAM is introduced from 2026 onwards and it covers EII sectors, increasing import prices for third-country goods. It also assumes that revenues, captured through the CBAM, are recycled towards tax measures, to maintain budget neutrality.

The simulation results show, that given these assumptions, the CBAM can result in substantial economic and employment gains as it decreases relative prices for domestic production and therefore shifts demand from imports to local production. Meanwhile, the collected and recycled revenues create excess consumption, thus driving the economy and employment. Nevertheless, the results also show, that if the CBAM leads to technological changes (due to increasing factor prices) it can decrease the impacts of environmental measures, thus increasing local emissions.

Current developments

Germany, as the EU’s leading economy, faces a challenging situation as the country’s reliance on Russian fossil energy carriers is still substantial. Germany has already put the contentious Nord Stream 2 pipeline project on hold. The government has announced the creation of strategic reserves and has signalled its commitment to build new terminals for importing liquified natural gas (LNG), therefore diversifying its sources of natural gas. Already announced plans need to be sped up accompanied by a shift towards the use of renewable energy and to increase efforts for energy efficiency gains, thus reducing dependency on fossil fuels.

7 Appendix A

7.1 Steelmaking production routes captured in FTT:Steel

Technology group	Individual FTT:Steel technologies
BF-BOF	Conv. BF-BOF (D, BB, CCS, BBCCS), BF TGR-BOF (CCS, BBCCS)
DR-EAF (gas)	DR-EAF (gas) (D, BB, CCS, BBCCS)
DR-EAF (coal)	DR-EAF (coal) (D, BB, CCS, BBCCS)
DR-EAF (H2)	DR-EAF (H2)
SR-BOF	SR-BOF (D, BB, CCS, BBCCS)
SR-BOF (adv)	SR-BOF (adv) (D, BB, CCS, BBCCS)
Recycling	Scrap-EAF
Other	Conv. BF-OHF/MOE

D=Default; BB=Bio-based; CCS=Carbon Capture & Storage, BF=Blast furnace; TGR=Top gas recycling; DR=Direct reduction; SR=Smelt reduction; OHF=Open hearth furnace; BOF=Basic oxygen furnace; EAF=Electric arc furnace; MOE=Molten oxide furnace

7.2 Sources informing measures and costs in the decarbonisation pathways

Steel

Vercoulen, P., Markkanen, S., 2020. Technology, employment, and climate change mitigation: Modelling the iron and steel industry. Technical Report. Cambridge, UK: CLG Europe. *https://www.corporateleadersgroup.com/system/files/documents/steel-modelling-paper.pdf*

Cement (NMMP)

Habert, G., Miller, S.A., John, V.M., Provis, J.L., Favier, A., Horvath, A., Scrivener, K.L., 2020. Environmental impacts and decarbonization strategies in the cement and concrete industries. Nat Rev Earth Environ 1, 559–573. *https://doi.org/10.1038/s43017-020-0093-3*

Voldsund, M. et al., 2018. Techno-economic evaluation of five technologies for CO2 capture from cement production. Presentation at GHGT, Melbourne. *https://www.sintef.no/globalassets/project/cemcap/30-11-18-cemcap/38.-techno-economic-evaluation-of-five-technologies-for-co2capture-from-cement-production.pdf*

Czigler, T., Reiter, S., Schulze, P., Somers, K., 2020. Laying the foundation for zero-carbon cement. Report. McKinsey & Co. *https://www.mckinsey.com/industries/chemicals/our-insights/laying-the-foundation-for-zero-carbon-cement*

NewClimate (2020). Decarbonisation pathways for the EU cement sector: Technology routes and potential ways forward. Report.

https://newclimate.org/2020/12/15/decarbonisation-pathways-for-the-eu-cement-sector/

Chemicals

Saygin, D., Gielen, D.J., Draeck, M., Worrell, E., Patel, M.K., 2014. Assessment of the technical and economic potentials of biomass use for the production of steam, chemicals and polymers. Renewable and Sustainable Energy Reviews 40, 1153–1167. https://doi.org/10.1016/j.rser.2014.07.114

Saygin, D., Gielen, D., 2021. Zero-Emission Pathway for the Global Chemical and Petrochemical Sector. Energies 14, 3772. https://doi.org/10.3390/en14133772

8 Appendix B: E3ME and FTT model description

Overview

E3ME is a computer-based model of the world's economic and energy systems and the environment. It was originally developed through the European Commission's research framework programmes and is now widely used in Europe and beyond for policy assessment, for forecasting and for research purposes. The global version of E3ME provides:

- better geographical coverage
- better feedbacks between individual European countries and other world economies
- better treatment of international trade with bilateral trade between regions
- new technology diffusion sub-modules

This model description provides a short summary of the E3ME model. For further details, please read the full model manual available online from www.e3me.com.

Applications of E3ME

Scenario-based analysis

Although E3ME can be used for forecasting, the model is more commonly used for evaluating the impacts of an input shock through a scenario-based analysis. The shock may be either a change in policy, a change in economic assumptions or another change to a model variable. The analysis can be either forward looking (ex-ante) or evaluating previous developments in an ex-post manner. Scenarios may be used either to assess policy, or to assess sensitivities to key inputs (e.g. international energy prices).

For ex-ante analysis a baseline forecast up to 2050 is required; E3ME is usually calibrated to match a set of projections that are published by the European Commission and the International Energy Agency but alternative projections may be used. The scenarios represent alternative versions of the future based on a different set of inputs. By comparing the outcomes to the baseline (usually in percentage terms), the effects of the change in inputs can be determined.

Price or tax scenarios

Model-based scenario analyses often focus on changes in price because this is easy to quantify and represent in the model structure. Examples include:

- changes in tax rates including direct, indirect, border, energy and environment taxes
- changes in international energy prices

Regulatory impacts

All of the price changes above can be represented in E3ME's framework reasonably well, given the level of disaggregation available. However, it is also possible to assess the effects of regulation, albeit with an assumption about effectiveness and cost. For example, an increase in vehicle fuel-efficiency standards could be assessed in the model with an assumption about how efficient vehicles become, and the cost of these measures. This would be entered into the model as a higher price for cars and a reduction in fuel consumption (all other things being equal). E3ME could then be used to determine:

- secondary effects, for example on fuel suppliers
- rebound effects[55]
- overall macroeconomic impacts

Comparison with CGE models and econometric specification

E3ME is often compared to Computable General Equilibrium (CGE) models. In many ways the modelling approaches are similar; they are used to answer similar questions and use similar inputs and outputs. However, underlying this there are important theoretical differences between the modelling approaches.

In a typical CGE framework, optimal behaviour is assumed, output is determined by supply-side constraints and prices adjust fully so that all the available capacity is used. In E3ME the determination of output comes from a post-Keynesian framework and it is possible to have spare capacity. The model is more demand-driven and it is not assumed that prices always adjust to market clearing levels.

The differences have important practical implications, as they mean that in E3ME regulation and other policy may lead to increases in output if they are able to draw upon spare economic capacity. This is described in more detail in the model manual.

The econometric specification of E3ME gives the model a strong empirical grounding. E3ME uses a system of error correction, allowing short-term dynamic (or transition) outcomes, moving towards a long-term trend. The dynamic specification is important when considering short and medium-term analysis (e.g. up to 2020) and rebound effects[56], which are included as standard in the model's results.

Key strengths of E3ME

In summary the key strengths of E3ME are:

- the close integration of the economy, energy systems and the environment, with two-way linkages between each component
- the detailed sectoral disaggregation in the model's classifications, allowing for the analysis of similarly detailed scenarios
- its global coverage, while still allowing for analysis at the national level for large economies

[55] In the example, the higher fuel efficiency effectively reduces the cost of motoring. In the long-run this is likely to lead to an increase in demand, meaning some of the initial savings are lost. Barker et al (2009) demonstrate that this can be as high as 50% of the original reduction.

[56] Where an initial increase in efficiency reduces demand, but this is negated in the long run as greater efficiency lowers the relative cost and increases consumption. See Barker et al (2009).

- the econometric approach, which provides a strong empirical basis for the model and means it is not reliant on some of the restrictive assumptions common to CGE models
- the econometric specification of the model, making it suitable for short and medium-term assessment, as well as longer-term trends

Limitations of the approach

As with all modelling approaches, E3ME is a simplification of reality and is based on a series of assumptions. Compared to other macroeconomic modelling approaches, the assumptions are relatively non-restrictive as most relationships are determined by the historical data in the model database. This does, however, present its own limitations, for which the model user must be aware:

- The quality of the data used in the modelling is very important. Substantial resources are put into maintaining the E3ME database and filling out gaps in the data. However, particularly in developing countries, there is some uncertainty in results due to the data used.
- Econometric approaches are also sometimes criticised for using the past to explain future trends. In cases where there is large-scale policy change, the 'Lucas Critique' that suggests behaviour might change is also applicable. There is no solution to this argument using any modelling approach (as no one can predict the future) but we must always be aware of the uncertainty in the model results.

The other main limitation to the E3ME approach relates to the dimensions of the model. In general, it is very difficult to go into a level of detail beyond that offered by the model classifications. This means that sub-national analysis is difficult[57] and sub-sectoral analysis is also difficult. Similarly, although usually less relevant, attempting to assess impacts on a monthly or quarterly basis would not be possible.

E3ME basic structure and data

The structure of E3ME is based on the system of national accounts, with further linkages to energy demand and environmental emissions. The labour market is also covered in detail, including both voluntary and involuntary unemployment. In total there are 33 sets of econometrically estimated equations, also including the components of GDP (consumption, investment, international trade), prices, energy demand and materials demand. Each equation set is disaggregated by country and by sector.

E3ME's historical database covers the period 1970-2017 and the model projects forward annually to 2100. The main data sources for European countries are Eurostat and the IEA, supplemented by the OECD's STAN database and other sources where appropriate. For regions outside Europe, additional sources for

[57] If relevant, it may be possible to apply our E3-India or E3-US (currently under development) models to give state-level analysis.

data include the UN, OECD, World Bank, IMF, ILO and national statistics. Gaps in the data are estimated using customised software algorithms.

The main dimensions of the model

The main dimensions of E3ME are:

- 70 countries – all major world economies, the EU28 and candidate countries plus other countries' economies grouped
- 44 or 70 (Europe) industry sectors, based on standard international classifications
- 28 or 43 (Europe) categories of household expenditure
- 23 different users of 12 different fuel types
- 14 types of air-borne emission (where data are available) including the 6 GHG's monitored under the Kyoto Protocol

The countries and sectors covered by the model are listed at the end of this document.

Standard outputs from the model

As a general model of the economy, based on the full structure of the national accounts, E3ME is capable of producing a broad range of economic indicators. In addition there is range of energy and environment indicators. The following list provides a summary of the most common model outputs:

- GDP and the aggregate components of GDP (household expenditure, investment, government expenditure and international trade)
- sectoral output and GVA, prices, trade and competitiveness effects
- international trade by sector, origin and destination
- consumer prices and expenditures
- sectoral employment, unemployment, sectoral wage rates and labour supply
- energy demand, by sector and by fuel, energy prices
- CO_2 emissions by sector and by fuel
- other air-borne emissions
- material demands

This list is by no means exhaustive and the delivered outputs often depend on the requirements of the specific application. In addition to the sectoral dimension mentioned in the list, all indicators are produced at the national and regional level and annually over the period up to 2100.

E3ME as an E3 model

The E3 interactions

Figure 0.1 shows how the three components (modules) of the model - energy, environment and economy - fit together. Each component is shown in its own box. Each data set has been constructed by statistical offices to conform with accounting conventions. Exogenous factors coming from outside the modelling framework are shown on the outside edge of the chart as inputs into each component. For each region's economy the exogenous factors are economic policies (including tax rates, growth in government expenditures, interest rates and exchange rates). For the energy system, the outside factors are the world oil prices and energy policy (including regulation of the energy industries). For the environment component, exogenous factors include policies such as reduction in SO2 emissions by means of end-of-pipe filters from large combustion plants. The linkages between the components of the model are shown explicitly by the arrows that indicate which values are transmitted between components.

The economy module provides measures of economic activity and general price levels to the energy module; the energy module provides measures of emissions of the main air pollutants to the environment module, which in turn can give measures of damage to health and buildings. The energy module provides detailed price levels for energy carriers distinguished in the economy module and the overall price of energy as well as energy use in the economy.

Treatment of international trade

An important part of the modelling concerns international trade. E3ME solves for detailed bilateral trade between regions (similar to a two-tier Armington model). Trade is modelled in three stages:

- econometric estimation of regions' sectoral import demand
- econometric estimation of regions' bilateral imports from each partner
- forming exports from other regions' import demands

Trade volumes are determined by a combination of economic activity indicators, relative prices and technology.

The labour market

Treatment of the labour market is an area that distinguishes E3ME from other macroeconomic models. E3ME includes econometric equation sets for employment, average working hours, wage rates and participation rates. The first three of these are disaggregated by economic sector while participation rates are disaggregated by gender and five-year age band.

The labour force is determined by multiplying labour market participation rates by population. Unemployment (including both voluntary and involuntary unemployment) is determined by taking the difference between the labour force and employment. This is typically a key variable of interest for policy makers.

The role of technology

Technological progress plays an important role in the E3ME model, affecting all three E's: economy, energy and environment. The model's endogenous technical progress indicators (TPIs), a function of R&D and gross investment, appear in nine of E3ME's econometric equation sets including trade, the labour market and prices. Investment and R&D in new technologies also appears in the E3ME's energy and material demand equations to capture energy/resource savings technologies as well as pollution abatement equipment. In addition, E3ME also captures low carbon technologies in the power sector through the FTT power sector model.[58]

FTT: Power Overview

The power sector in E3ME is represented using a novel framework for the dynamic selection and diffusion of innovations, initially developed by J.-F. Mercure (Mercure, 2012), called FTT:Power (Future Technology Transformations for the Power sector). This is the first member of the FTT family of technology diffusion models. It uses a decision-making core for investors wanting to build new electrical capacity, facing several options. The resulting diffusion of competing technologies is constrained by a global database of renewable and non-renewable resources (Mercure & Salas, 2012, 2013). The decision-making core takes place by pairwise levelized cost (LCOE) comparisons, conceptually equivalent to a binary logit model, parameterised by measured technology cost distributions. Costs include reductions originating from learning curves, as well as increasing marginal costs of renewable natural resources (for renewable technologies) using cost-supply curves. The diffusion of technology follows a set of coupled non-linear differential equations, sometimes called 'Lotka-Volterra' or 'replicator dynamics', which represent the better ability of larger or well-established industries to capture the market, and the life expectancy of technologies. Due to learning-by-doing and increasing returns to adoption, it results in path-dependent technology scenarios that arise from electricity sector policies.

FTT: Steel - the steel sector submodel of E3ME

As the newest addition to the FTT suit of models incorporated into E3ME, FTT:steel simulates the take up of technologies with the iron and steel sector. Similar to the other FTT models, it estimates the cost-based preference of investing bodies / entrepreneurs that ultimately choose one technology over another while taking into account sectoral constraints.

It covers 26 technologies, ranging from the present-day dominant design – blast furnaces coupled to basic oxygen furnaces – to several variations (bio-based, inclusion of CCS/U, or a combination of both) of each existing technology (wherever theoretically possible), and completely novel technologies, such as electrolysis and hydrogen flash smelting. The feedbacks of FTT:Steel are investment needs, employment, energy use, emissions, and steel prices. Each of these have further implications on other economic sectors and indicators. This makes the E3ME-FTT framework a suitable tool to analysis a myriad of policies relating to climate change mitigation, energy transition, innovation and much more. Regardless of whether policies are directed at the steel sector or not, the effects can be understood using our inhouse model. A special feature of FTT:Steel is the endogenous calculation of scrap availability, allowing Cambridge Econometrics to analyse questions related to the circular economy from this angle.

FTT: Transport - the transport sector submodel of E3ME

For passenger car transport, which accounts for by far the largest share of transport emissions, FTT:Transport provides a range of policy options. FTT:Transport assesses the types of vehicles that are purchased in three size bands (small, medium and large) and several technology classes (including basic and advanced forms of ICE, hybrid and electric cars). The policy options cover ways of differentiating costs between the different vehicles (either in terms

[58] See Mercure (2012).

of capital costs through variable taxation or fuel/running costs) or regulations on the sales of certain types of vehicles (e.g. phasing out inefficient old cars).

Biofuel mandates can also be imposed. These are modelled as a means of forcing a switch from consumption of motor spirit to consumption of biomass.

E3ME does not include any means for assessing mode switching, however, if the effects of mode switching can be estimated off-model, then the model could then estimate the indirect effects on the wider economy.

FTT: Heat - the heating sector submodel of E3ME

FTT:Heat is a new tool that was developed for European Commission work in 2016/17. Rather than assuming that the energy efficiency happens (e.g. due to public mandate), it provides a range of policy options for heating appliances (e.g. boilers, heat pumps) including subsidies, specific taxes or phase-out of old products. It thus assesses the take-up rates of the different technologies around the world.

The basic philosophy of FTT:Heat is similar to the other FTT models. Technologies diffuse according to how well they are established in the market, which is based on price differentials and other policy stimuli.