CO_2 POINT SOURCE POTENTIAL IN EUROPE

A Frontier Economics analysis for eFuel Alliance & eNG Coalition

02 SEPTEMBER 2025

WWW.FRONTIER-ECONOMICS.COM

CONTENTS

Executive summary

Achieving the European Union's climate neutrality target by 2050 will require a diversified energy mix that includes not only renewable electricity but also significant amounts of **synthetic fuels, in liquid and gaseous forms**. Carbon dioxide (CO_2) is a necessary input for the production of these synthetic fuels.

The European Commission ("EC") has established a regulatory framework for the use of CO_2 sources for fuel production in its Delegated Act 2023/1185. **Eligible sources of CO_2** include biogenic sources[1], as well as CO_2 from industrial sources, which is eligible until the end of 2040 (CO_2 from electricity generation is eligible until 2035) and is required to be subject to an effective carbon pricing system.

This study, commissioned by the eFuel Alliance and the eNG coalition, aims to assess the availability and **potential of large CO_2 point sources** across EU-27 that could supply CO_2 feedstock for the production of synthetic fuels. Furthermore, it explores how the EU's regulatory framework for the use of CO_2 sources for fuel production constrains the availability of CO_2. Focussing on core sectors, the study sheds light on the potentials of different CO_2 point sources now and in 2050, and evaluates how much more synthetic fuels could be produced in the European Union if unavoidable process-related industry emissions were additionally deemed eligible.

CO_2 emissions are categorized into emissions from industrial sources, from power and heat plants using gas or biogenic fuels, and from the production of biomethane, bioliquids and biomass fuels. The emissions are differentiated between process- or energy-related emissions and whether they come from biogenic or fossil sources.

The analysis shows that across large point sources in core sectors there are (as of 2022) approximately **828 $MtCO_2$ in annual emissions**, which could potentially be utilized to produce synthetic fuels under current legislation. In 2050, emissions from these sectors decrease to 661 $MtCO_2$/year, mainly due to fewer emissions from gas power plants (-99 $MtCO_2$/year), refineries (-69 $MtCO_2$/year), and the iron and steel sector (-46 $MtCO_2$/year). CO_2 emissions of biogenic origin, however, could increase by about 50% as parts of the industry as well as power and heat generation facilities are expected to switch from fossil to biogenic fuels. Bioenergy combustion (117 $MtCO_2$/year) and the production of biofuels, bioliquids and biomass fuels (90 $MtCO_2$/year) will constitute the largest sources of biogenic CO_2.

By 2050 the emissions in core sectors could reduce to 661 $MtCO_2$/year. This includes about **368 $MtCO_2$/year of biogenic emissions**, which would be eligible to produce synthetic fuels. This is because the current legislation proscribes the use of any CO_2 emissions from fossil

[1] Other eligible sources are direct air capture, and geological sources, where the CO_2 was previously released naturally. These are not considered in the analysis of this report.

fuels, including process emissions, after 2040.[2] In addition, it is likely that not the entire CO_2 emission potential will be available for capture and utilisation, e.g. due to requirements on the purity of the CO_2 stream, transport constraints or more generally economic viability depending on the locally emitted CO_2 volumes. Accessible carbon could thus make up significantly less than the total emission potential.

In addition to biogenic emissions and a remainder of fossil energy-related emissions in 2050, there will still be a significant amount of **process-related emissions** (approximately 130 $MtCO_2$/year). Expanding eligibility to include those hard-to-abate industrial process emissions, which largely stem from large point sources, could thus add 130 $MtCO_2$/year of emissions for synthetic fuel production. This additional emission volume would potentially allow for generating approximately an additional 36 billion litres[3] of (diesel-equivalent) synthetic fuels in 2050. This compares to estimate of total demand for synthetic fuels of 41 to 84 billion litres in 2050.[4]

The study also assessed the sectoral distribution of emissions, and concludes that in 2050, the largest CO_2 point sources are likely to be found in **industry sectors** like cement and chemicals (energy- and process-related emissions), in power plants (incl. CHP), as well as in biofuel production. To map and describe the development of the eligible CO_2 sources, the study also determined where potential CO_2 sources exist:

- In 2022, we can see that there are a number of **large clusters** of CO_2 emissions. For example, in the region of Western Germany, Netherlands, and Belgium, due to a high density of industrial facilities. Other clusters can be found in Southern Poland and North-Eastern Czech Republic, Northern Italy, North-Eastern Spain and Southern France.
- Large **individual emitters** in 2022 are often facilities from the industry, for example iron and steel facilities in Northern Spain, Southern France or Austria, chemical sites in Belgium, the Netherlands, Germany or Czech Republic or refineries in Poland, Austria or Italy.
- **Regional changes** until 2050 are mainly driven by sector differences in expected sectoral production growth, technological changes and fuel switches. For example, the biogas and -methane sector in Sweden is expected to grow significantly, so that in the long-term a larger share of the emissions eligible for synthetic fuel production could stem from Scandinavia. In contrast, due to switches in production routes and energy sources of the iron and steel sector, the sectors' emission volumes are expected to decline. This results

2 European Commission (2023), „Commission Delegated Regulation (EU) 2023/1185", https://eur-lex.europa.eu/legal-content/ENG/TXT/PDF/?uri=CELEX:32023R1185.

3 Calculation is based 3.6 kg of CO_2 per diesel-equivalent litre of synthetic fuels (Schreiber et al.). This sits within the range of 2.9 to 3.6 kg of CO_2 per litre of synthetic fuels cited by Concawe (Fig 3).

4 The EC Impact 2040 assessment specifies that 147 $MtCO_2$/year could be used for synthetic fuel production in 2050, equivalent to about 41 bn litres of synthetic fuel (at a conversion of 3.6 kg / l). Aurora predicts synthetic fuel demand in Europe as 331 PJ in 2030 and 1,333 PJ in 2050, which translates to 21 and 84 bn litres using LHV fuel density of methanol (15.9 MJ/l, Indico).

in lower emissions in industrial regions, for example in Germany or Austria. The level of process-related emissions is expected to remain stable though.

- By 2050, chemical and cement plants are expected to remain among the **largest point sources**, also due to their process-related emissions. While cement plants can be found in a higher number of regions across Europe, large chemical emitters are concentrated in Germany, Belgium and the Netherlands as well as regions in Northern and Southern France, in the North-East of Spain and in the West of the Czech Republic.

The results of this study can be used for a number of purposes, for example as an input to the development of ramp-up scenarios for the CO_2 and synthetic fuel sectors, as background to the development of regulation and market design and as data for project developers to identify regions with large CO_2 point sources.

1 Context and study objectives

Achieving the European Union's climate neutrality target by 2050 will require a diversified energy mix that includes renewable electricity as well as synthetic fuels.[5] Synthetic fuels can exist in both gaseous and liquid forms and can facilitate the decarbonisation in sectors such as aviation, maritime, road transport, and in certain industrial processes, for which direct electrification is either technically challenging or economically unviable. **Synthetic fuels** can be integrated into existing fuel distribution systems, offering a pragmatic bridge between current infrastructure and future energy needs.[6] If they meet specific criteria, synthetic fuels can be classified as renewable fuels of non-biological origin (RFNBOs).[7]

Synthetic fuels provide a means of storing renewable energy over long periods and transporting it across regions, thereby enhancing energy security and system flexibility. They are therefore well-suited to complement energy scenarios with high shares of intermittent renewable generation, where balancing supply and demand is paramount.

This study, commissioned by the eFuel Alliance and the eNG coalition, aims to assess the availability and potential of **large CO_2 point sources** (where emissions are concentrated) across Europe that could serve as feedstock for the production of synthetic fuels. The analysis focuses on core sectors with significant CO_2 emissions, evaluates their current and future potential and aligns these findings with the regulatory framework established by the European Commission. Ultimately, the aim is to inform policy and investment decisions that support the ramp-up of sustainable fuel production in line with EU climate goals.

1.1 Producing synthetic fuels requires CO_2 as feedstock

The production of synthetic fuels conventionally relies on the chemical synthesis of hydrogen and carbon dioxide (CO_2). In this process, **CO_2 is a production input**, rather than a waste product which is harmful as a potent greenhouse gas when released into the atmosphere. Its availability and sourcing is a key consideration for the scalability of production technologies for synthetic fuels. Identifying suitable CO_2 sources is therefore critical to ensure reliable and sustainable supply chains for synthetic fuel production.

This study focuses on point sources of CO_2 emissions, particularly from **industrial and bioenergetic processes**, where emissions are concentrated as exhaust gases and thus more

---

5 Synthetic fuels are petroleum-like fuels produced from hydrocarbons. An electrolysis process breaks down water into its components of hydrogen and oxygen. The hydrogen is then combined with carbon dioxide and converted into synthetic fuels, which can exist in both gaseous and liquid forms. The electricity for this process can be sourced from renewable energy sources such as solar, wind or hydroelectric power.

6 EC, eFuel Alliance

7 EC, "Renewable fuels of non-biological origin in the European Union" (2022), https://setis.ec.europa.eu/renewable-fuels-non-biological-origin-european-union_en

economically viable for capture.[8] An alternative to this approach is direct air capture (DAC), where CO_2 is directly removed from the atmosphere. While this remains a long-term option, it is not yet available at scale.[9] Consequently, understanding the current and projected distribution of CO_2 sources from eligible sectors is essential for planning future production capacity and the infrastructure for synthetic fuels.

1.2 The Delegated Acts specify what sources of CO_2 are permissible

The European Commission ("EC") has established a regulatory framework for the use of CO_2 sources for fuel production in its Delegated Act 2023/1185[10]. Eligible sources of CO_2 are:

- CO_2 captured from certain **industrial sources**, where the CO_2 has been taken into account upstream in an effective carbon pricing system[11]. CO_2 from these industrial sources is eligible until the end of 2035 if it stems from electricity generation, or otherwise until the end of 2040. The eligible industrial sources are those named in Annex I to Directive 2003/87/EC[12];
- CO_2 captured when producing or combusting **biofuels, bioliquids or biomass fuels,** compliant with Annex V and VI of Directive (EU) 2018/2001[13], and the CO_2 capture did not receive credits for emission savings;
- CO_2 from **direct air capture**;
- CO_2 captured from the combustion of **renewable liquid and gaseous transport fuels of non-biological origin, or recycled carbon fuels**, complying with Article 25(2) and Article 28(5) of Directive (EU) 2018/2001; and
- Captured CO_2 stemming from **geological sources**, which was previously released entirely naturally.

In a recently published paper[14], the eFuel Alliance has described the EU production rules of so-called renewable fuels of non-biological origin (RFNBOs) in detail and further compared

---

8 The analysis depicts the CO_2 volume potentials to produce synthetic fuels, without taking barriers into account (often site-specific), for example stemming from the feasibility of CO_2 capture for CO_2 transport.

9 It is forecasted that direct air capture, will play a more important role in the 2040st and mainly outside of Europe in rural regions. See e.g. Ram et al (2020). Powerfuels in a Renewable Energy World - Global volumes, costs, and trading 2030 to 2050. LUT University and dena, Berlin, https://www.efuel-alliance.eu/fileadmin/Downloads/Global_Alliance_Powerfuels_Study_Powerfuels_in_a_Renewable_Energy_World.pdf

10 European Commission (2023), "Commission Delegated Regulation (EU) 2023/1185", https://eur-lex.europa.eu/legal-content/ENG/TXT/PDF/?uri=CELEX:32023R1185

11 I.e. when such emissions have been covered (e.g. recognized and priced) under a carbon scheme earlier in the process.

12 European Commission (2003),"Directive 2003/87/EC", consolidated version https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02003L0087-20240301

13 European Commission (2018), "Directive (EU) 2018/2001", https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018L2001

14 E-Fuel Alliance (2025), Analysis of the EU, UK, and US Approaches to Regulatory Frameworks for RFNBOs, https://www.efuel-alliance.eu/fileadmin/Downloads/20250618_eFA_Paper_Comparison_Production-Rules_EU-UK-US.pdf

the requirements to other legislations in the United Kingdom (UK) and the United States of America (US). It is concluded that the EU has the strictest rules of RFNBO production. For example, in the US, all potential CO_2 sources are eligible.

2 Methodology

This section sets out our methodology for assessing CO_2 point potentials. First, we selected core sectors which make up the bulk of CO_2 emissions and are expected to remain relevant up until 2050. We estimated emissions today (largely for 2022, enriched with more recent data where possible[15]), as well as potential emissions in 2050. We differentiate between process, energy and biogenic emissions. We then allocated these emissions geographically to specific point sources (e.g. industrial sites, power plants, biomethane plants), or regions.[16]

While we rely on the best available data sources and provide point estimates for CO_2 emission volumes, it is important to acknowledge that there is considerable uncertainty surrounding the actual levels. Data coverage and measurement methodologies vary significantly, which limits precision. In addition, information on different emission types (process-related, energetic, and biogenic emissions) is very limited. As a result, any differentiation between these categories is largely based on estimates and assumptions rather than comprehensive data.

2.1 This study identifies core sectors and assesses today's CO_2 point potentials and estimates 2050 potentials

The analysis focuses on CO_2 point sources in industry, power and heat generation and in the production or combustion of biofuels, bioliquids and biomass fuels. The EC has grouped these CO_2 sources as follows:

- **CO_2 from industrial sources** refers to CO_2 emissions that could be captured from industrial installations. Eligible sectors are listed in Annex I of Directive 2003/87/EC[17], and these emissions are typically covered by the EU Emissions Trading System (ETS). Eligible sectors include for example cement, steel, refineries and **power and heat generation**.
- **The production and the combustion of biofuels, bioliquids and biomass fuels**[18] from sustainable feedstocks are considered carbon-neutral. However, these processes may still generate CO_2, which can be captured and used for synthetic fuel production. For instance, biomethane production involves CO_2 being formed during biogas upgrading. Combustion of these biogas will also entail CO_2 emissions.

15 Given limited data availability 2022 was chosen as a base year, as this year is not unduly influenced by the Covid-19 pandemic. Only biodiesel and bioethanol production volumes are based on 2020 (https://www.ieabioenergy.com/wp-content/uploads/2023/09/IEA-BioenergyT39-Biofuel-News-62-final.pdf)

16 The combustion of sustainable biomass is defined as a biogenic source of CO_2 as feedstock.

17 European Commission (2003),"Directive 2003/87/EC", consolidated version https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX%3A02003L0087-20240301

18 The EC defines biofuels as "liquid transport fuels, such as biodiesel and bioethanol, made from biomass", whereas bioliquids are "liquid fuel for energy purposes other than for transport, including electricity and heating and cooling, produced from biomass".

  - Some of this CO_2 emissions may take place in industrial point sources, for example, if biogenic energy carriers are combusted.

We do not consider:

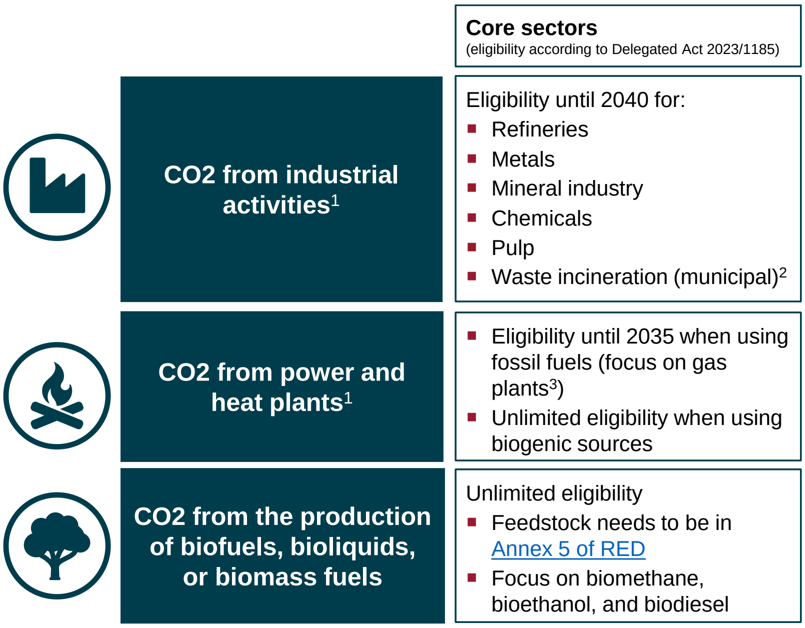
- **Direct air capture**, which in principle is possible anywhere, but is not yet operating at scale, meaning there is high uncertainty about its future locations and application,
- The combustion of **renewable liquid and gaseous transport fuels of non-biological origin, or recycled carbon fuels**, due to the diffuse nature of transport emissions and its high uncertainty about future locations and application, (including the combustion of biofuels),
- **Geological sources** of CO_2, which from today's perspective have limited relevance in the EU-27.

We have categorized the CO_2 point sources into three groups, and amongst these, we selected core sectors to focus on.

- The CO_2 emissions that could be captured from industrial installations (as above) are considered **CO_2 from industrial activities**. We are differentiating these emissions from power and heat plants (next bullet).
- Where biogenic fuels are combusted in power and heat plants, and where power and heat is generated using fossil fuels, these are considered in a third group, "**CO_2 from power and heat plants**".
- The remaining **CO_2 emissions from the production and the combustion of biofuels, bioliquids and biomass fuels** (where not combusted in power and heat plants) makes up the third group.

The core sectors are intended to represent sectors that make up the bulk of CO_2 emissions and are expected to remain relevant to 2050. These are shown in Figure 1.

Figure 1 Grouping of CO_2 point sources



Source: *Frontier Economics*

Note: **The coverage of waste in the EU ETS is limited to the "combustion of fuels in installations for the incineration of municipal waste". To assess the total CO_2 potential we consider all waste, rather than just municipal waste*
[1] Including combustion of biogenic energy carriers

For **industrial activities**, the most important sectors (i.e. those including large point sources of CO_2) include the following. We compare these to the total emissions in the E-PRTR database[19], which lists CO_2 emissions for large facilities in EU-27, to give a sense of scale:

- **Refineries** - mineral oil and gas refineries (112 $MtCO_2$/year, 8% of E-PRTR CO_2 emissions in EU-27 in 2022, covering only large facilities)
- **Metals** – production of pig iron or steel (83 $MtCO_2$/year, 6%)
- **Mineral Industry** – production of cement clinker and/or lime (120 $MtCO_2$/year, 9%)
- **Chemicals** – production of basic organic chemicals (52 $MtCO_2$/year, 4%)
- **Pulp** – production of pulp from timber or similar fibrous materials (55 $MtCO_2$/year, 4%)
- **Waste incineration** – incineration of non-hazardous waste (59 $MtCO_2$/year, 4%)

Regarding **electricity generation** emissions, the E-PRTR contains emissions from large power plants (producing a combined 714 $MtCO_2$/year, 60% of the E-PRTR). In combination, these core sectors cover about 90% of emissions in the European Pollutant Release and Transfer Register (E-PRTR).

19 Industrial Reporting under the Industrial Emissions Directive 2010/75/EU and European Pollutant Release and Transfer Register Regulation (EC) No 166/2006 - ver. 14.0 Mar. 2025 source

In the next step, out of all power plants, we focused only on gas power plants emissions (189 $MtCO_2$/year, 14%).[20] A number of EU countries plan to use gas power plants as dispatchable capacity in 2040 and beyond, for example Greece, Italy and Poland[21]. We excluded coal, oil, and other fossil fuel-based plants from our analysis in 2022, as these are not of interest when looking towards 2050.[22]

Electricity generation includes emissions from the combustion of biofuels, bioliquids and biomass fuels. We estimate this using figures and projections of bioenergy used in the energy sector from the EC 2040 Impact Assessment Report [23] (2024).

For the **production of biofuels, bioliquids and biomass fuels**, we have focused on biogas and biomethane, as well as bioethanol and biodiesel production, which entail the emission of approximately 22 $MtCO_2$/year in 2022.[24] Our research has shown that other smaller biogenic sources like breweries do not produce sufficient amounts of CO_2 to be economically viable for the production of synthetic fuels.

For the sectors described, we have evaluated their emissions in 2022, and potential emissions in 2050. Data sources for this exercise include:

- The **E-PRTR database**[25], which contains facilities with large amounts of CO_2 emissions (> 100,000 tons of CO_2 release/year[26]) in 2022;
- The **EC 2040 Impact Assessment Report**[27] (2024), which estimates present and future CO_2 emissions under current climate targets;
- As well as other supporting sources, shown in Table 1.

20 We do not include coal power plants, or other fossil fuel-based power plants, in the analysis, as there is significant uncertainty about their potential long-term operational activities, for example in combination with CCUS or with biofuels (the extent of the transformation of coal power plants, pace and scale will likely vary significantly by country and region). We estimate that fossil fuel-based plants that are not primarily gas-powered emit 525 $MtCO_2$/year in 2022, or 40% of emissions in the European Pollutant Release and Transfer Register (E-PRTR).

21 Combined and open cycle gas generation is in construction or being commissioned across countries in the EU, see SP Global (2023), https://www.spglobal.com/commodity-insights/en/news-research/latest-news/electric-power/032123-europe-undergoes-modest-revival-in-gas-plant-construction-as-further-coal-closures-loom

22 The resulting emissions, after this filtering step, represent ~51% of the emissions in the E-PRTR.

23 European Commission, Impact Assessment Report (2024), Part 1 and Part 3 (in particular Figures 52, 53, 87, Table 3), accompanying the document Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society

24 We have included individual biogas and biomethane facilities of at least 2,000 m³/h and clusters where facilities are closely located to each other and their total capacity surpasses 2,000 m³/h.

25 Industrial Reporting under the Industrial Emissions Directive 2010/75/EU and European Pollutant Release and Transfer Register Regulation (EC) No 166/2006 - ver. 14.0 Mar. 2025 source

26 100,000 t of CO_2/year, if captured, could support the production of 30 million litres or 300 GWh of e-fuels/year. This would further require an electrolyser with a capacity of 150 MW (assuming 4000 full-load hours, and an efficiency of 50%).

27 European Commission, Impact Assessment Report (2024), Part 1 and Part 3 (in particular Figures 52, 53, 87, Table 3), accompanying the document Europe's 2040 climate target and path to climate neutrality by 2050 building a sustainable, just and prosperous society

Table 1 Main sources for emission estimates

Sector	Subsector	2022 Estimates	2050 Estimates
Industrial activities	Industry (metals, minerals, chemicals)	E-PRTR, EC 2040, Eurostat[28]	EC 2040
	Pulp production	E-PRTR, EC 2040	EC 2040, TYNDP[29], 2022 estimate
	Waste	E-PRTR, Eurostat	EC 2040, Eurostat
	Refineries	E-PRTR	EC 2040, TYNDP
Power and heat plants	Power plants: gas	EEA[30]	EC 2040, TYNDP
	Power plants (incl. CHP): biomass	Eurostat	EC 2040, 2022 estimate
Production of biofuels, bioliquids and biomass fuels	Biogas and biomethane production	European Biogas Association (EBA)[31]	RePower[32], TYNDP
	Bioethanol and biodiesel production[33]	IEA[34]	EC 2040

Source: Frontier Economics

Note: The theoretical potential of biogenic CO_2 from biogas is based on an intensity of ~1.3 $MtCO_2$/bcm based on EBA. This is consistent with a weighted average of different feedstocks ranging from manure (surface water) to mixed waste (https://pmc.ncbi.nlm.nih.gov/articles/PMC7608650). The allocation of CO_2 emissions to CHP plants is based on their respective production capacities.

Using this data, we estimated the total CO_2 emissions across our core sectors. The figures for 2022 are primarily based on the E-PRTR database (actual historical emissions), while the figures for 2050 are primarily based on the EC 2040 Impact Assessment Report (projected emissions).

28 Eurostat data on supply, transformation & consumption of renewables & wastes (nrg_cb_rw), as well as data on Complete Energy Balances (nrg_bal_c)

29 TYNDP 2024, Global Ambition Scenario, https://2024.entsos-tyndp-scenarios.eu/

30 EEA Greenhouse Gas Inventory https://www.eea.europa.eu/en/analysis/publications/annual-european-union-greenhouse-gas-inventory-2025

31 European Biomethane Map, https://www.gie.eu/wp-content/uploads/filr/12557/GIE_EBA_BIO_2025_A0_FULL_252.pdf https://www.europeanbiogas.eu/wp-content/uploads/2022/01/GIE_EBA_BIO_2021_A0_FULL_3D_253_online.pdf

32 EU REPowerEU Plan (2022) source

33 The underlying CO_2 intensity during production of bioethanol and biodiesel is estimated as 0.9 and 1.05 $MtCO_2$/Mtoe respectively. For bioethanol, Schwenk estimates emissions of 0.56 tCO_2/ton produced, converted using 0.64 toe/ton (EC). For biodiesel (FAME), the EEA estimates emissions of 25.17 g CO_2e/MJ, equivalent to 1.05 $MtCO_2$/Mtoe - this refers to GHG emissions from the use of biofuels (excluding ILUC emissions).

34 IEA Bioenergy T39 (2023) Biofuel News 62

In our analysis we capture individual facilities with annual emissions of at least 10,000 tCO_2/year.[35] While that threshold for emissions of individual facilities might be too small to create an economically viable concept for CO_2 capture and e-fuel production, the intention is to capture a large number of facilities, allowing to identify regional clusters of emitters. This could be of interest for regional concepts for CO_2 capture and e-fuel production.

2.2 Emissions were then differentiated by type and geography

2.2.1 Emission types

As part of this work step, emissions were differentiated by type and geography. The emission types are categorized as follows:

- **Biogenic emissions**: These emissions are generated by the combustion or decomposition of organic, non-fossil materials such as biofuels, bioliquids, wood or agricultural waste. They are generally considered carbon-neutral, even if CO_2 is emitted. Energy from biomass can replace fossil energy in most sectors.
- **Energy emissions (from fossil sources)**: Energy emissions occur in basically all industrial sectors and stem from the combustion of (fossil) fuels, usually in order to generate heat or power or both. Since these emissions are tied to the energy carriers, they are generally easier to abate by switching to renewable alternatives. In our study, we only refer to fossil energy emissions. Some thermal power generation based on fossil fuels, likely based on natural gas, will likely remain in place by 2050, for example, to ensure security of supply during periods of low renewable generation.
- **Process emissions**: Process emissions are released during certain industrial or chemical production processes, such as cement or steel production. For example, in cement production the dominant source of process emissions is the calcination of limestone, which is heated in a kiln to produce lime.[36] This reaction releases CO_2 as a byproduct of the chemical process, not from fuel combustion. These emissions are typically more difficult or even impossible to abate because they are inherent to the chemical reactions involved.

Below, we can see which emission types occur in which analysed sector (Figure 2).

---

35 Due to the methodology underlying the E-PRTR dataset industrial facilities in 2022 have a minimum of 100,000 tCO_2/year. Clusters of biogas and biomethane plants have a minimum capacity of 2,000 m^3/year.

36 $CaCO_3 \rightarrow CaO + CO_2$

Figure 2 Distribution of emission types by sector

	Industrial activities[1]	Power and heat plants	Production of biofuels, bioliquids, or biomass fuels
Process emissions	▪ Metals ▪ Mineral industry ▪ Chemicals		
Energy emissions	In all sectors	Focus on gas plants	
Biogenic emissions	In many sectors	From biogenic power used in the energy sector	From production

Source: Frontier Economics. Note that biogenic power refers to biofuels, bioliquids, or biomass fuels combusted for the generation of power and heat.

Note: [1] Including combustion of biogenic energy carriers

To further differentiate the emission types we proceeded as follows:

- First, we distinguished between **fossil and biogenic emissions**.
  - For 2022, the volume of fossil CO_2 emissions was sourced from E-PRTR, while biogenic emissions were usually sourced from Eurostat.[37]
  - For 2050, we were generally able to use data from the EC 2040 Impact Assessment to estimate both fossil and biogenic emissions. We estimated biogas and -methane production volumes using RePower and TYNDP 2024[38]. TYNDP was also used to estimate biogenic emission shares by sector where needed.
- Second, we differentiate fossil emissions between **process and energy emissions** and use the EC 2040 Impact Assessment to determine the respective amounts, see Table 2.

---

37 Source: Eurostat, nrg_bal_c, 2022, data in toe. E.g. for steel ca. 700 ktoe bioenergy used in 2022, i.e. ca. 3 $MtCO_2$. For the waste sector, we assumed that the E-PRTR emissions also included biogenic emissions. The total waste emissions were split into fossil and biogenic based on what share of industrial and municipal waste in the EU-27 is considered renewable (Source: Eurostat, IPRD, nrg_cb_rw, 2022, data in TJ.). For biogas, -methane, -ethanol and -diesel, we used EBA and IEA data to estimate biogenic emissions.

38 ENTSO-E and ENTSO-G (2025), TYNDP 2024 (Global Ambitions Scenario)

Table 2 Process emission shares in different sectors

Sector	Main activity (simplified)	Process emissions as share of total emissions
Metals	Production of pig **iron or steel**	~ 60%
Mineral industry	Production of **cement** clinker/ lime	~ 55%
Chemical industry	Production of basic organic **chemicals**	~ 40%

Source: Frontier Economics based on European Commission (2024), Impact Assessment Report, Part 3, Figures 52, 53

Differentiating process, energy, biogenic emissions – example: Refineries

- Our emission numbers from refineries in **2022** are based on the E-PRTR database (112 $MtCO_2$/year). These were entirely classified as energy emissions – process emissions are not applicable in this sector, and the use of bioenergy in refineries is not widespread yet, so that biogenic refinery emissions are not substantial in 2022[39]
- Emissions estimates for **2050** are based on the EC 2040 Impact Assessment, which estimates that final energy consumption in the refinery sector will, by 2050, shrink to 23% of the amount in 2022. The resulting emission estimate is 43 $MtCO_2$/year. Of this, 12% was considered biogenic emissions (5 $MtCO_2$/year), based on TYNDP emissions in Industry[40], and 88% as energy emissions (38 $MtCO_2$/year).

39 See CaptureMap, https://www.capturemap.no/the-biogenic-CO2-breakdown/

40 TYNDP, Global Ambition Scenario, 2050. Using final demand in the refineries sector by fuel, multiplied by emission factors, we calculated the share of biogenic emissions as 12%

Differentiating process, energy, biogenic emissions – Example: Non-metallic minerals (cement clinker and lime)

Emission estimates for **2022** were based on E-PRTR emissions in this sector (120 $MtCO_2$/year):

- *Biogenic emissions:* Eurostat provides a final consumption of bioenergy estimate of 11 $MtCO_2$/year.[41] This was adjusted to reflect that E-PRTR emissions are only part of the total as they cover large facilities only: based on the ratio of E-PRTR to EC 2040 Impact Assessment emissions (120 $MtCO_2$ vs 163 $MtCO_2$/year, respectively), the estimate was scaled down to 8 $MtCO_2$/year biogenic emissions.
- *Process and energy emissions:* The remaining (fossil) emissions (112 $MtCO_2$/year) were split into process and energy emissions based on the ratio of the EC 2040 Impact Assessment emissions for the sector (55% and 45%, respectively, see Table 2[42]). This calculation yields process emissions of 62 $MtCO_2$/year and energy emissions of 57 $MtCO_2$/year.

In **2050**, our emission estimates were calculated as follows:

- *Biogenic emissions* are based on EC 2040 Impact Assessment estimates.
  - Final bioenergy demand in all of industry (metal, mineral, and chemical industries) is 106 $MtCO_2$/year (24 mtoe).
  - This total then needs to be distributed across the metal, mineral, and chemical industry. This requires relative shares of biogenic emissions in 2050. To approximate these, we take the 2022 energy emissions and apply sector growth rates (both from the EC) to estimate 2050 energy emissions. We use this to approximate the share of biogenic emissions across these three sectors (24% for metals, 41% for non-metallic minerals, and 35% for chemicals). Assuming that biogenic shares behave similarly, we calculate that non-metallic minerals has a share of 41% of the total, or 43 $MtCO_2$/year.
- *Process and energy emissions:* Process (86 $MtCO_2$/year) and energy emission volumes (1 $MtCO_2$/year) are sourced from the EC 2040 Impact Assessment

41 Eurostat lists final consumption of bioenergy as 2.5 mtoe, equivalent to 11 $MtCO_2$/year, based on an emission factor of 4.35 $MtCO_2$/year/mtoe from the IPCC (Emission Factor Database, https://www.ipcc-nggip.iges.or.jp/EFDB/find_ef.php - conversions done with unitjuggler e.g. source)

42 European Commission (2024), Impact Assessment Report, Part 3, Figures 52 and 53

2.2.2 Emission geography

For emissions in 2022, we could identify exact locations based on the E-PRTR data. For 2050, emissions were grouped at NUTS 2 level[43] due to data availability, as well as uncertainty about the precise future location of, for example, industrial production sites. Where we had estimates for precise locations, we allocated them to the respective NUTS 2 region and thereby calculated totals for each NUTS 2 region.

Data sources for this included:

- The **E-PRTR** database, which contains precise geospatial location data;
- The **Global Energy Monitor** database with locations of biomass combustion plants[44] and oil and gas plants[45] (the E-PRTR does not specify fuels used in combustion plants);
- Biogas and -methane production sites were identified using the European Biogas Association's **European Biomethane Map 2022 and 2024**[46], as well as desktop research;
- Bioethanol and -diesel production sites were identified through desk research.

For **2022**, within each sector, emissions were distributed across point sources based on the emissions of those point sources in the E-PRTR, or according to production capacities, depending on data availability. For biogenic emissions from power and heat production, emissions were first split into country totals according to relevant country-level data, and then distributed at NUTS 2 level proportionally to the capacities of individual plants in our data[47].

For **2050**, we distributed sector emissions proportionally to the NUTS 2 emissions of that sector in the E-PRTR in 2022, as the best available proxy. Where we do not have precise historical emission data based on E-PRTR, particularly for biogenic emissions, emissions were again split into country totals according to relevant country-level data[48], and then distributed at NUTS 2 level proportionally to the capacities of individual plants in our data.

Estimates for 2050 were grouped into regions at **NUTS 2 level** to reflect increased uncertainty around precise locations. This assumes that while individual sites may not remain until 2050,

---

43 NUTS (Nomenclature of territorial units for statistics) divide each EU country into levels. NUTS 0 refers to each country (27 units); NUTS 1 refers to major socio-economic regions (92 units – 16 in Germany, equivalent to the States (Länder)), NUTS 2 refers to basic regions (244 units, 38 in Germany, equivalent to the Government regions (Regierungsbezirke).

44 Global Energy Monitor, Global Bioenergy Power Tracker, September 2024 source

45 Global Energy Monitor, Global Oil and Gas Plant Tracker, January 2025 source

46 EBA, European Biomethane Map 2024 source – we extracted data for cities containing plants with a total capacity of more than 2,000 m3/h. These were geocoded using Google Maps data. Further desktop research was conducted to identify additional sites producing biogas, bioethanol, and biodiesel

47 This implicitly assumes that relative country shares will remain stable until 2050.

48 Country-level data was sourced from Eurostat data on supply, transformation & consumption of renewables & wastes (nrg_cb_rw), as well as data on Complete Energy Balances (nrg_bal_c)

future sites are likely to be built near or on existing sites. Uncertainty particularly applies to the following sectors:

- **Refineries**: The output of refineries is expected to be substantially lower in 2050 due to a lower demand for their products, for example liquid fuels. This means it is difficult to predict where remaining refineries will be sited.
- **Power plants (gas)**: There is substantial uncertainty about the future locations of gas plants. With some variation across countries, some gas plants will have been decommissioned by 2050 while other countries plan to build additional gas plants. Both developments render the prediction of future gas plant locations difficult.
- **Iron and Steel and Pulp, Paper & Print**: Many industrial sectors are undergoing a major transformation of their production processes (including production assets) and energy inputs. Combined with a difficult economic (competitive) environment today, the outlook on industrial sites in 2050 is uncertain.
- **Bioethanol and biodiesel production**: The production volume of bioethanol and biodiesel is expected to grow until 2050. New (potentially larger) production sites are expected to emerge, and in this sector particularly, exact locations cannot yet be predicted reliably.

By contrast, today's **production sites** in other sectors will likely remain the major production sites of these sectors by 2050. This applies for example to the production sites of the chemicals, non-metallic minerals and cement industry, where a similar or even higher level of production is required in the future.[49] Similarly, today's sites for waste incineration and biomethane production will likely remain in operation in the coming decades.[50] New sites could cluster near existing sites, for example to exploit existing input supply routes.

49 European Commission (2024), Impact Assessment Report, Part 3, Table 8

50 See https://www.unep.org/resources/global-waste-management-outlook-2024#:~:text=Key%20findings,USD%20108.5%20billion%20per%20year and European Commission (2024), Impact Assessment Report, Part 3, Figure 87

3 Long-term sources of CO_2 feedstock

In this section, we set out our estimates for CO_2 point source potentials in 2022 and 2050. We first present our total estimates, then differentiate the results by sector, country and by location.

3.1 Total CO_2 point source potential in 2022 adds up to 828 $MtCO_2$/year, but could reduce to 661 $MtCO_2$/year by 2050

3.1.1 Point source potential in 2022

Based on our analysis, in 2022 total CO_2 point source potentials in our core sectors add up to about 828 $MtCO_2$/year, shown in Figure 3.

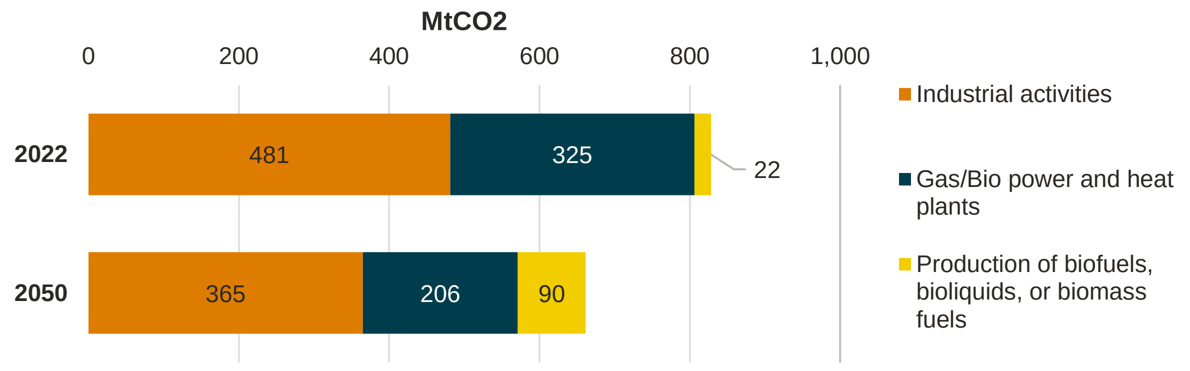
These large point sources are responsible for the vast majority of the emissions in these sectors. The point sources in our primary dataset cover a similar amount of CO_2 emissions as the ETS database[51], and about a third of total EU-27 greenhouse gas emissions.[52] The breakdown into the main activities for 2022 is as follows:

- 58% of our total emissions estimate stem from **industrial activities** (481 $MtCO_2$).
- **Power and heat generation** makes up a further 39% (325 $MtCO_2$), of which slightly more than half comes from large-scale gas power plants, and the other half from bioenergy used in the energy sector.
- The **production of biofuels, bioliquids, or biomass fuels**, makes up a small share.

51 See EU Emissions Trading System (ETS) data viewer https://www.eea.europa.eu/en/analysis/maps-and-charts/emissions-trading-viewer-1-dashboards - verified emissions for 2022 amount to 1,300 $MtCO_2eq$ across all sectors, compared to 1,200 $MtCO_2$/year in the E-PRTR. The smaller number of 828 $MtCO_2$/year in our point source analysis results principally from the exclusion of emissions from coal and oil-based power stations, estimated at 480 $MtCO_2$.

52 See Eurostat, https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20231221-3 which states that EU-27 emissions stood at 3.6 billion tonnes of CO_2eq. While greenhouse gases (GHG) include gases beyond CO_2, but CO_2 represents around 80% of EU GHG emissions in 2021 https://www.europarl.europa.eu/topics/en/article/20180703STO07123/climate-change-in-europe-facts-and-figures

Figure 3 CO_2 point source emission potentials in core sectors

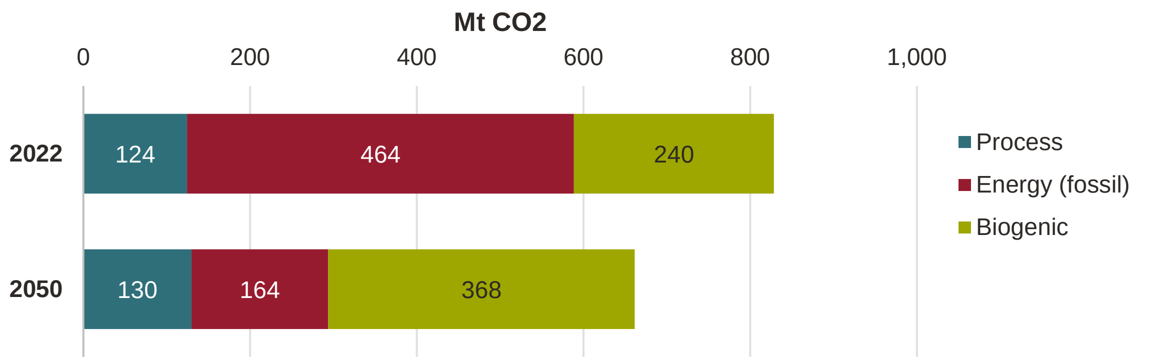


Source: Frontier Economics

We can also consider emissions split by emission type. This is shown in Figure 4.

- **Energy emissions from fossil sources** dominate (464 $MtCO_2$/year). They come primarily from gas power plants (189 $MtCO_2$/year) and refineries (122 $MtCO_2$/year).
- **Biogenic emissions** make up a further 240 $MtCO_2$/year, primarily from bioenergy used in the energy sector (136 $MtCO_2$/year), for example in CHP plants.
- **Process emissions** (124 $MtCO_2$/year) that stem from the metal, mineral and chemical industry. These sectors also generate 114 $MtCO_2$/year of energy emissions.

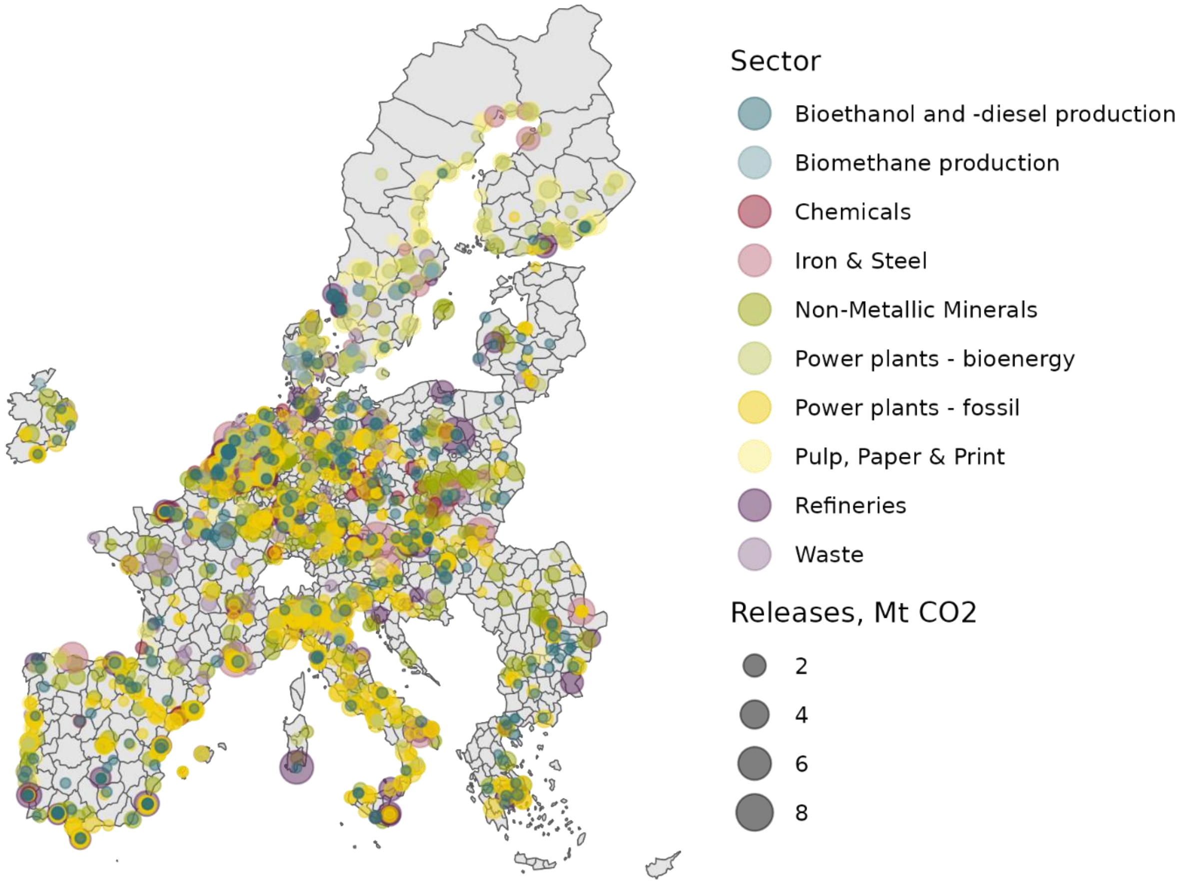
Figure 4 CO_2 point source emission potentials in core sectors, by emission type



Source: Frontier Economics

Germany, Italy, France and Spain are the countries where the most emissions from large point source potentials are located (Figure 5). In Iberia and Scandinavia, we can see that emissions tend to cluster around the coast.

Figure 5 Distribution of 2022 emissions, by sector



Source: *Frontier Economics based on E-PRTR, Global Energy Monitor, European Biogas Association, Eurostat*

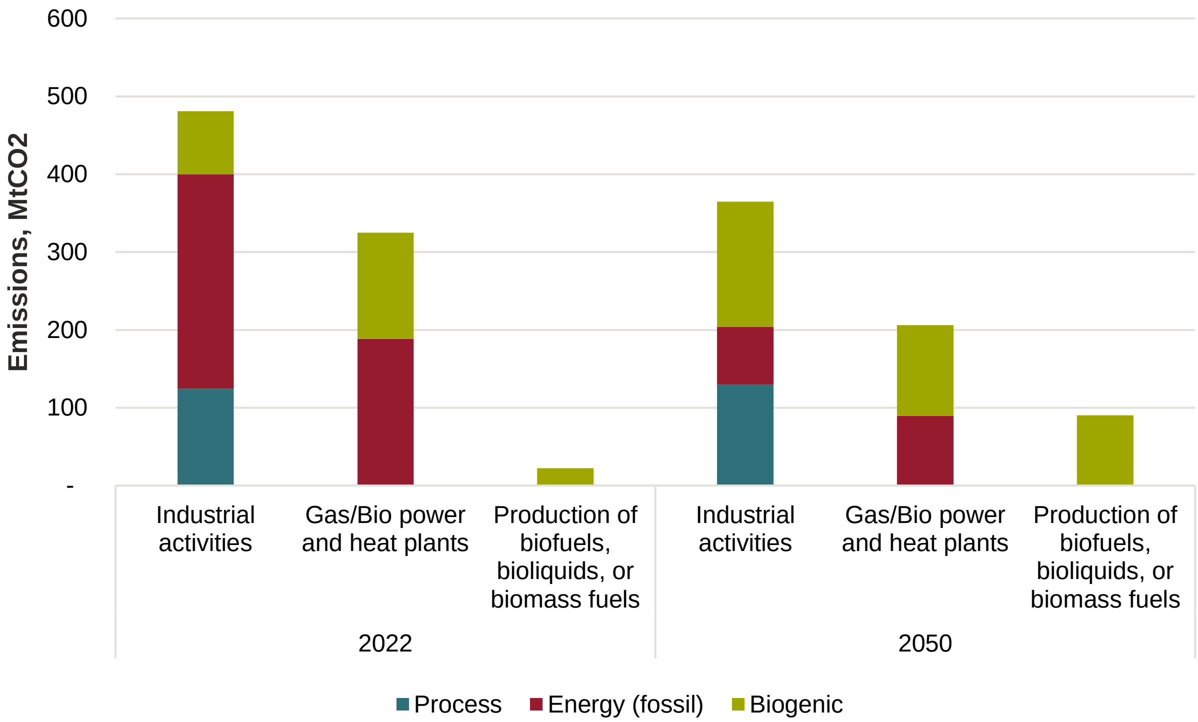
Note: *Locations are primarily based on E-PRTR locations, as well as Global Energy Monitor (GEM) power plants. Emissions from bioenergy in power sector not fully shown on map as no data on locations available (96 $MtCO_2$/year missing).*

3.1.2 Point source potential in 2050

For 2050, emissions are approximated based on EC 2040 Impact Assessment estimates (which includes estimates for 2050), and thus reflect potentials for all sizes of emitters in the EU-27, rather than just large emitters. As a result, sector totals across 2022 and 2050 are not fully comparable. However, because **large facilities** make up a large share of total emissions, figures for 2022 would not be significantly larger if they were calculated for the same scope, and so relevant trends can be identified when comparing the two.

Total point source emissions are expected to decrease to 661 $MtCO_2$/year in 2050. While emissions from the production of biomethane, bioliquids or biomass fuels increase significantly (from 22 $MtCO_2$/year to 90 $MtCO_2$/year), this is outweighed by the reduction of gas power plant emissions and energy emissions from the use of fossil fuels in industrial production.

Figure 6 CO_2 emission potentials, by sector and emission types



Source: Frontier Economics

Note: 2022 estimates based on E-PRTR large point sources, 2050 estimates based on EC 2040 Impact Assessment for the whole of EU-27

There are a few underlying developments: starting with the industry sector, **industrial emissions** in the EU have been decreasing steadily since 1990, and are expected to continue to do so. Total sector emissions are projected to shrink by about 24%, with a shift from energy to biogenic emissions:

- **Fossil energy emissions** decline significantly (-73%). This reduction is particularly driven by shrinking emissions from refineries. Change comes from improvements in energy efficiency and electrification, shrinking demand for raw materials, as well as bio- and e-fuels replacing fossil fuels.
- However, **process emissions**, which are inherent to the chemical reactions involved, are harder to reduce, and in fact increase slightly relative to our 2022 E-PRTR baseline (+4%). Instead, the EC 2040 Impact Assessment predicts a large amount of carbon capture in this sector to reduce net emissions. There is however a shift in which sectors emit process emissions based on differential growth rates and technological change:
  - In the EU-27 **steel sector** (metal industry), production of crude steel is expected to remain flat, relative to 2015. Decarbonisation will happen through an increase of the use of the electric arc furnace (EAF) process, and an expansion of the use of

hydrogen for the reduction of iron ore.[53] Consequently, process emissions in this sector, which are estimated at 43 $MtCO_2$/year in 2022, will shrink to 11 $MtCO_2$/year in 2050 (-75%).

- In **cement and lime** (mineral industry), production is expected to grow by 20%. Process emissions in this sector increases from 62 $MtCO_2$/year to 86 $MtCO_2$/year (+40%[54]).
- In **chemicals**, production is expected to grow by 25%, linked to a doubling in global demand for petrochemicals. Process emissions in this sector increase from 19 $MtCO_2$/year to 33 $MtCO_2$/year (+70%).

Biogenic emissions are projected to double in terms of volume, particularly due to minerals, metals and chemicals industries shifting from the use of fossil to biogenic fuels.

Regarding the emissions from **power and heat plants**, both energy and biogenic emissions are projected to shrink:

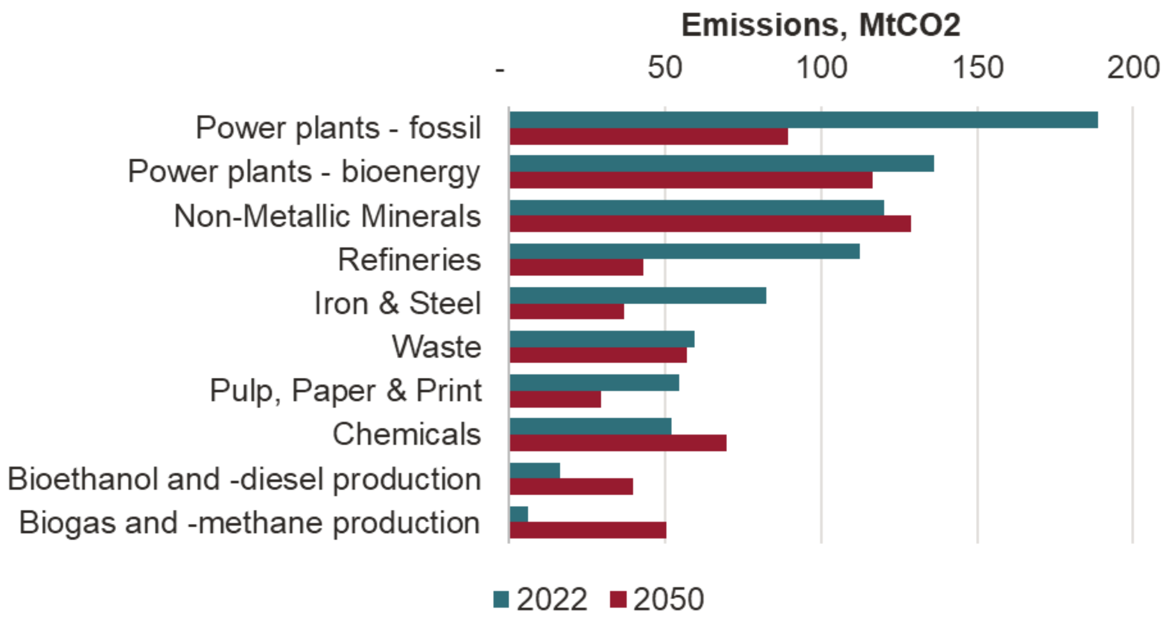
- Gas plant emissions halve, reducing fossil emissions
- Bioenergy used in the energy sector also reduces slightly (with a corresponding reduction in emissions of -14%), as wind and solar generation are increasingly integrated, and correspondingly less bioenergy is used in power production and district heating.

At the same time, the **increased production of biogas, -methane, -ethanol and -diesel** yields an increase of 68 $MtCO_2$/year which can potentially be captured.

53 EC 2040 Impact Assessment

54 The relative change in process emissions is not directly comparable to the change in production, as we are comparing emissions in 2050 for the whole EU-27 to emissions in 2022 for large point sources only

Figure 7 CO_2 emission potentials across core sectors



Source: Frontier Economics

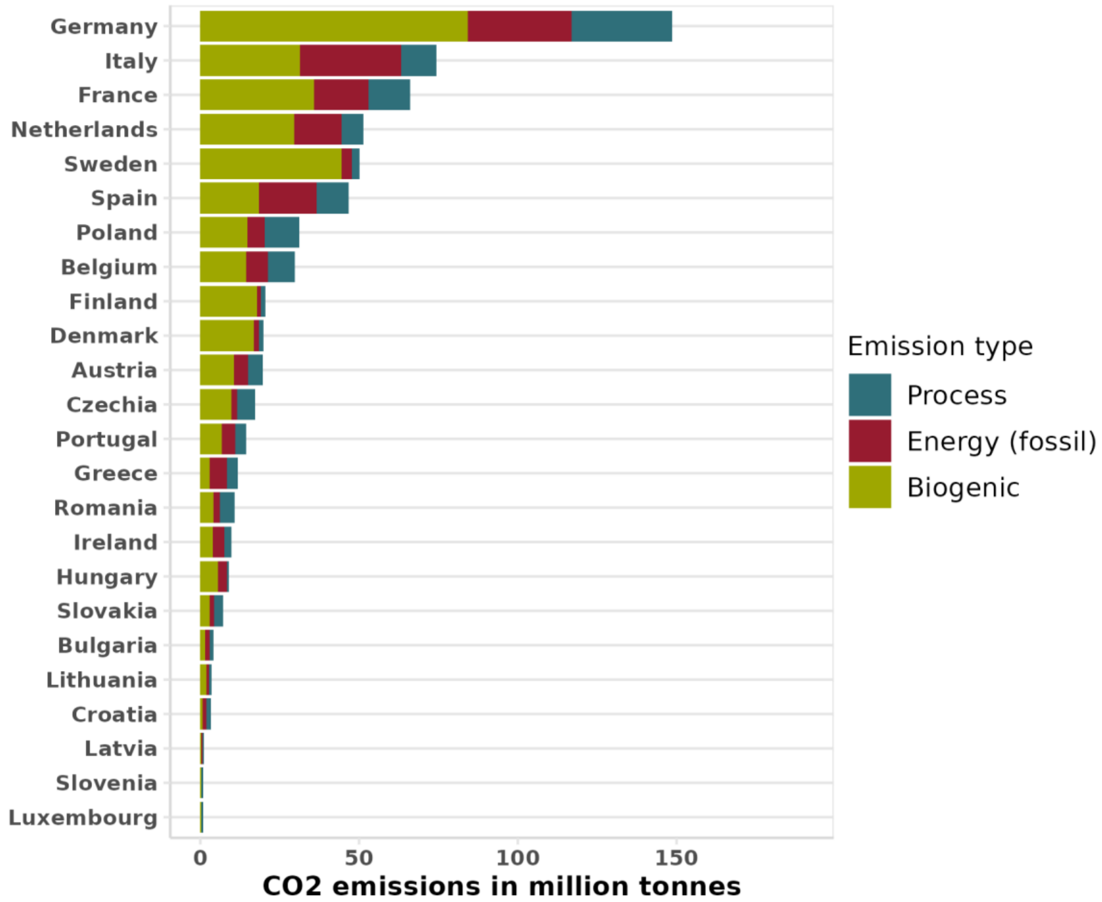
3.2 The largest biogenic CO_2 point source potentials are in Germany and Sweden

Emissions split by emission type are shown for the year 2050 in Figure 8. We can see that some countries produce a large amount of biogenic emissions (e.g. Germany), while others have a very high share of biogenic emission (e.g. Sweden).

- In **Germany**, 35% of emissions in core sectors in 2022 are generated in the metals, minerals and chemicals sector, which generate a lot of process emissions (17% of total emissions). Given these are hard to abate, we project that there is also a large share of these in 2050 (21%). Biogenic emissions in 2022 are large, mostly from the use bioenergy in the energy sector, but they only make up 32% of total German emissions due to the large amount of industrial emissions.
- By comparison, in **Sweden** process-heavy sectors (metals, minerals and chemicals) make up only 14% of total emissions in 2022. The largest sectors in terms of CO_2 emission volumes in 2022 are the pulp and paper industry (50%), followed by biogenic power production (15%), bioenergy-heavy sectors. Additionally, Sweden has the largest biogas and -methane production sector of all EU countries (30% of EU-27 in 2022)[55].

[55] Sector size is estimated based on the location and size of large biogas and -methane plants

Figure 8 Emission potentials in core sectors, by country and type, 2050



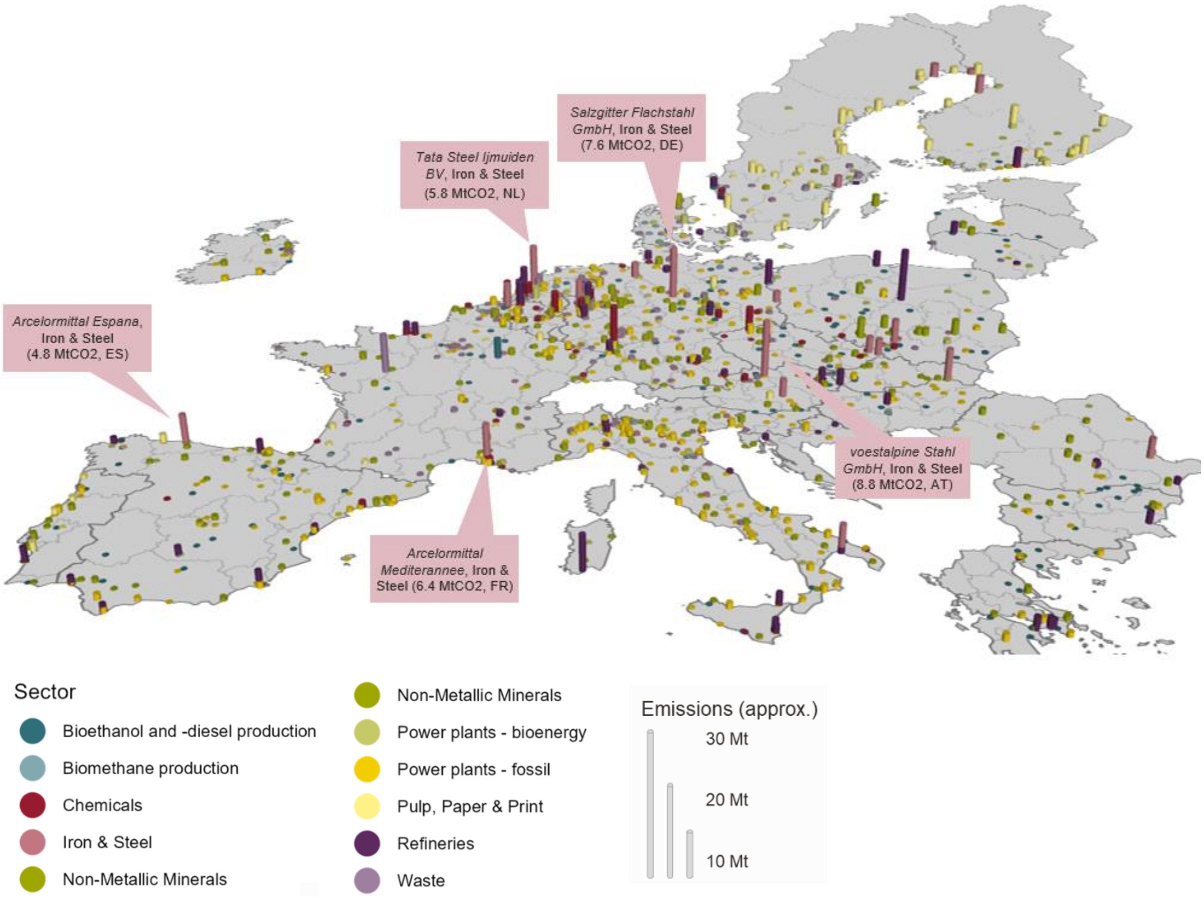
Source: Frontier Economics

3.3 Large emission volumes around the North-West of Continental Europe, and in Iron & Steel sector

We have mapped emission sources geospatially, with taller columns representing larger point sources (see Figure 9). As an example, on the map, large iron and steel point sources are called out with name and CO_2 emissions (in light pink). In 2022, we can see that there are **large clusters** of CO_2 emissions. For example,

- In the region of Western Germany, Netherlands, and Belgium, due to a high density of industrial facilities in this area;
- Other clusters can be found in Southern Poland and North-Eastern Czech Republic, Northern Italy, North-Eastern Spain and Southern France;
- Sweden has the largest biogas and -methane production sector, resulting in larger volumes of biogenic emissions.

Figure 9 Emissions by sector, 2022



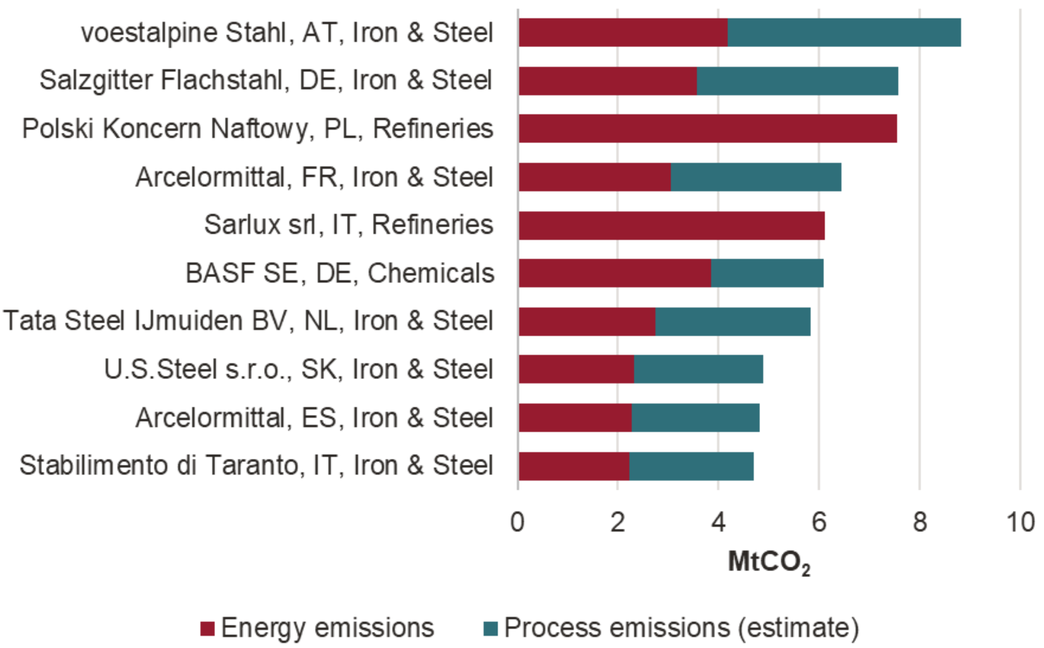
Source: *Frontier Economics based on E-PRTR, Global Energy Monitor, European Biogas Association, Eurostat*

Note: *Locations are primarily based on E-PRTR locations, as well as GEM power plants. Emissions from bioenergy in power sector not fully shown on map as no data on locations available (96 $MtCO_2$/year missing).*

- Large **individual emitters** in 2022 are often facilities from the industry, for example
  - iron and steel facilities in Northern Spain, Southern France or Austria;
  - chemical sites in Belgium, the Netherlands, Germany or Czech Republic;
  - refineries in Poland, Austria or Italy.

The industry facilities with the largest unavoidable **process-related emission** volumes in 2022 are iron and steel production plants. Looking at total emissions, the single largest emitter is the Voestalpine Stahl GmbH in Austria with emissions of 8.8 $MtCO_2$/year according to E-PRTR data (Figure 10). Of these emissions, approximately 4.6 $MtCO_2$/year can be categorized as process-related based on today's production technologies. This amount of process-related CO_2 could be used to produce 1.4 billion litres of synthetic fuels.

Figure 10 Largest industrial CO_2 emissions sites, 2022



Source: Frontier Economics based on E-PRTR, Global Energy Monitor, European Biogas Association, Eurostat

In Germany, which has the **highest total emissions**, we also find the BASF SE chemical park (number 6 in Figure 10). Of about 6 Mt total CO_2 emissions from this facility, approximately 2 Mt are process-related. The largest cement plants in terms of unavoidable process emissions include Górażdże Cement S.A. (approximately 1.5 $MtCO_2$ process emissions in 2022) and Grupa Ożarów S.A. (1.1 $MtCO_2$), both located in Poland.

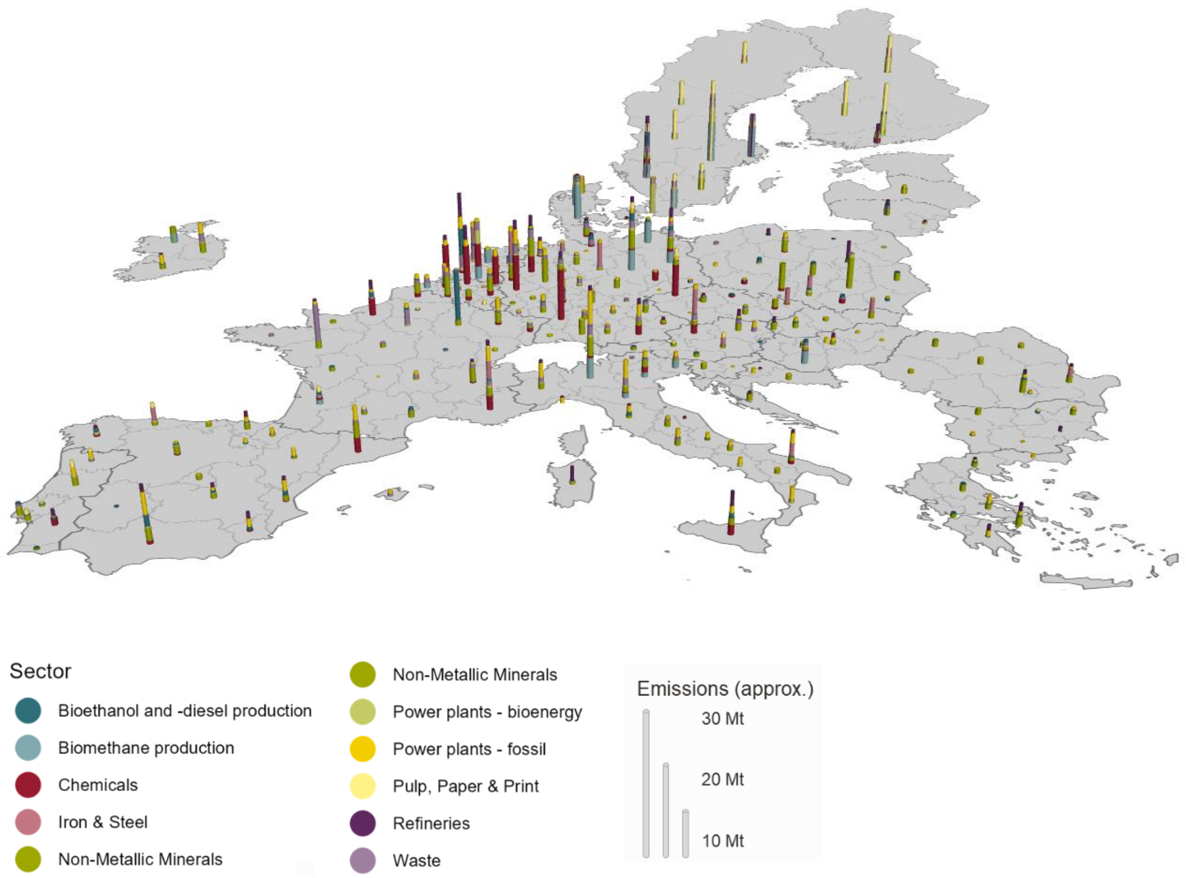
Significant point sources of biogenic emissions in 2022, besides large power plants using biogenic fuels, are in the **pulp and paper industry** (partly due to energy-intensive processes such as pulping) and in **bioethanol and biodiesel production** sectors:[56]

- As per the E-PRTR, sites with large point emissions the in pulp and paper sector include for example Metsä Fibre Oy and Stora Enso Oyj in Finland, Mondi Štětí a.s. in the Czech Republic as well as SCA Östrands and Södra Cell Mönsterås in Sweden.
- One of the largest bioethanol and biodiesel production sites is Cristal Union, located in France.
- Furthermore, individual power plants make use of biofuels (e.g. biomass), including co-firing biofuels to fossil fuels. These include Amer power station in the Netherlands and Avedore power station in Denmark, however there is uncertainty about the amount of bioenergy employed.

56 While the largest amount of biogenic emissions in 2022 in scope of this study comes from the use of bioenergy in the energy sector, some of these emissions will be diffuse.

Regional changes in the distribution of emissions by 2050 are mainly driven by differences in expected **growth rates and technology switches** across the analysed sectors. For example, Sweden already has a high number (and relatively large capacity) of biogas and biomethane production point sources in 2022. This is the sector with the highest expected growth in total CO_2 emissions in our analysis, meaning (biogenic) emissions become weighted more heavily towards Sweden. Conversely, emissions from the iron and steel sector are expected to halve, for example due to technological switches to recycled products or electricity-based production. This means that countries that currently have a high level of emissions from this sector will tend to make up a smaller share of total emissions by 2050.[57] Figure 11 shows the projected distribution of CO_2 emissions in 2050 on NUTS 2 level by sectors.

Figure 11 Emission potentials by sector, NUTS 2, 2050



Source: Frontier Economics based on E-PRTR, Global Energy Monitor, European Biogas Association, Eurostat

Note: Point sources have been grouped by NUTS 2 region. Some CO_2 emissions of biogenic origins from power sector not shown on map, as location data is not complete (83 $MtCO_2$/year missing). Note that there is higher uncertainty about the locations of some sector emissions, see section 2.2.2.

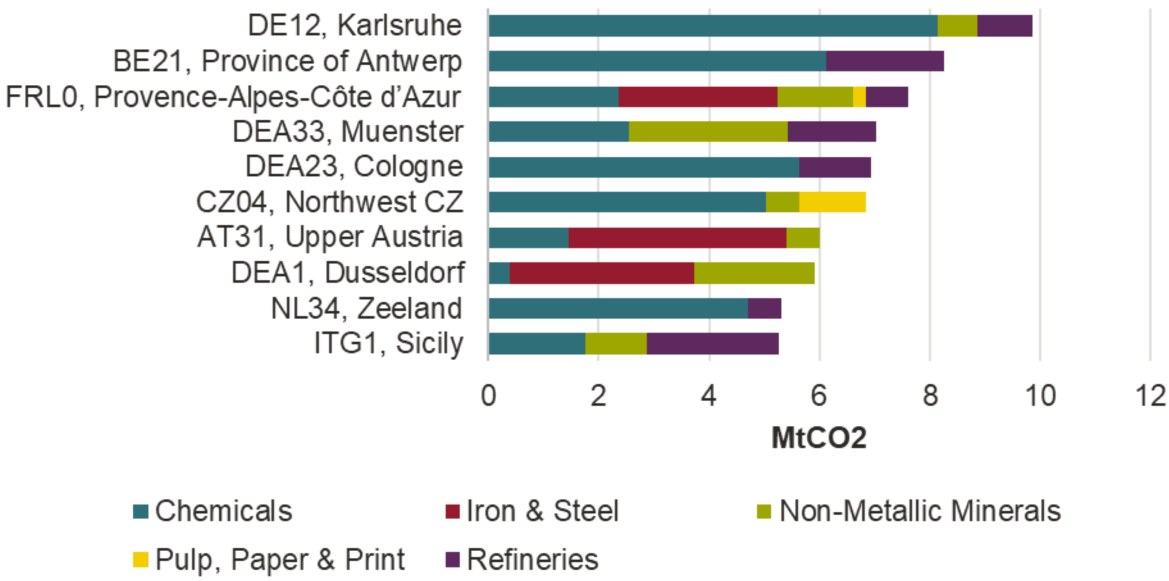
Biogenic emissions from power plants (incl. CHP) that use bioenergy as fuel will likely increase by 2050. It is also expected that the production of biomethane, bioethanol and biodiesel will increase, raising the CO_2 capture potential at these production sites. Further

57 For example, countries with a high share of emissions from the iron & steel sectors in 2022 are Slovakia, Austria, Czechia and Germany. These all make up a smaller share of EU-27 emissions in 2050 than in 2022.

potential large sources for biogenic emissions include the chemical as well as the iron and steel industries, which need to transform their demand for gaseous and liquid fossil fuels and feedstock to be in line with climate targets.

The main industrial facilities with large amounts of unavoidable **process-related emissions** is likely to look very different in 2050. Due to the expected switch in production routes, as well as potential shrinkage of the sector, process-related emissions in the iron and steel sectors will decrease. In chemical and cement plants the main production technologies and processes will not significantly change, so that process emissions will still exist. Chemical and cement plants are therefore expected to remain the largest emitters of process-related emissions in the long-run. While cement plants can be found in a higher number of regions across Europe, large chemical emitters are concentrated in Germany, Belgium and the Netherlands as well as regions in Northern and Southern France, North-Eastern Spain and Western Czech Republic.

Figure 12 Largest industrial CO_2 emission regions (estimate, NUTS 2), 2050



Source: Frontier Economics based on E-PRTR, Global Energy Monitor, European Biogas Association, Eurostat.

Towards 2050, the (NUTS 2) regions with the largest volumes of estimated CO_2 emissions are spread across different countries in Europe (see Figure 12). While some of the sites (e.g. Antwerp, Rhineland, Zeeland) are located in the cluster mentioned above - Netherlands, Belgium and Western Germany - other high-emission regions are located in Southern France, Czechia, Austria and Italy. The chemical industry will likely be a strong determinant for high emission regions.

4 Impact of EU CO_2 regulation on the synthetic fuel production potentials

In this section, we set out how EU regulation affects CO_2 feedstocks for synthetic fuels. Furthermore, we explore how much additional production of synthetic fuels might be possible if the regulation was adjusted in order to include additional sources of CO_2.

The Delegated Acts only permit biogenic sources in the long run

According to the EC's Delegated Act 2023/1185, from 2041 on only biogenic sources of CO_2 are permissible for the production of synthetic fuels. The reasoning is that using carbon from non-sustainable fuels in this manner "is not compatible with a trajectory towards climate neutrality by 2050 as it would entail the continued use of non-sustainable fuels and their related emissions".[58] Based on our analysis, this reduces the potential of large point source CO_2 emissions in 2050 to approximately **368 MtCO_2/year**[59].

In theory, this potential of EU biogenic CO_2 point sources could be used to produce up to **112 billion litres of e-fuels**[60]. This could be sufficient to cover most of the predicted RFNBO demand. However, 112 billion litres of e-fuels are derived from the theoretical CO_2 potential, without taking into account **constraints**, e.g. due to

- Requirements on the purity of the CO_2 stream;
- The need for technically viable capture rates;
- Transport constraints, e.g. for dispersed CO_2 sources; and
- Requirements for CO_2 capture and use to be economically viable, such as the volume of local emissions.

For example transport constraints could be a relevant factor as the results show that biogenic emissions are often dispersed across a large number of point sources in Europe. There are limited regions with stronger concentrations of large volumes biogenic point sources (as e.g. in some parts of Scandinavia). For these reasons the realistic potential of EU biogenic CO_2 from point sources for e-fuel production is likely to be significantly lower than the theoretical potential.

58 Paragraph (5), European Commission (2023), „Commission Delegated Regulation (EU) 2023/1185", https://eur-lex.europa.eu/legal-content/ENG/TXT/PDF/?uri=CELEX:32023R1185

59 Without taking account (often site-specific) constraints, for example stemming from CO_2 capture feasibility or transport.

60 Calculation is based on 3.6 kg of CO_2 per diesel-equivalent litre of e-fuels (Schreiber et al.). This sits within the range of 2.9 to 3.6 kg of CO_2 per litre of e-fuels cited by Concawe, Figure 3.

Expanding permissible CO_2 feedstocks could permit the production of an additional 36 billion litres of synthetic fuels

Across many regions in the EU-27 the results indicate that more **large-scale industrial point sources with (unavoidable) process emissions** are available than comparable large-scale biogenic point sources. At the same time larger CO_2 point sources often exhibit a higher economic feasibility of capturing and using carbon. For these reasons, the inclusion of process-related unavoidable industry sources of CO_2, beyond 2040, could be considered for the RFNBO rules for synthetic fuels production, supporting the EC's strategy on synthetic fuels and gases[61].

If unavoidable emissions sources in industry (process emissions, particularly from the non-metallic minerals industry, i.e. the cement and lime sector, and chemicals) were included, this would raise the full potential to approximately 498 $MtCO_2$/year.[62] That means expanding permissible CO_2 feedstocks to include **process emissions** would add around **130 $MtCO_2$/year** to large volume point source emissions in 2050.[63] This would significantly increase the potential for synthetic fuel production in the EU-27. For illustration: This amount of CO_2 would theoretically (if fully captured and used) allow for an additional production of approximately **36 billion litres of synthetic fuels**. This compares to estimates of total demand for synthetic fuels between 41 and 84 billion litres in 2050.[64]

61 Due to the link between synthetic fuel and hydrogen production this could also support the EU Hydrogen Strategy https://energy.ec.europa.eu/topics/eus-energy-system/hydrogen/key-actions-eu-hydrogen-strategy_en

62 The use of Carbon Removals and Carbon Farming (CRCF) as set out by the European Union is also proscribed (see Carbon Removals and Carbon Farming - European Commission).

63 Ceteris paribus – changing eligibility rules would likely change the emissions profile

64 The EC Impact 2040 assessment specifies that 147 $MtCO_2$/year could be used for e-Fuel production in 2050, equivalent to about 41 bn litres of e-Fuel (at a conversion of 3.6 kg / l). Aurora predicts e-fuels demand in Europe as 331 PJ in 2030 and 1,333 PJ in 2050, which translates to 21 and 84 bn litres using LHV fuel density of methanol (15.9 MJ/l, Indico).

5 Conclusion

In this report, we have set out the potential of CO_2 point sources across Europe that could serve as feedstock for the production of synthetic fuels. Furthermore, the report explores how the EU's regulatory framework for the use of CO_2 sources for fuel production constrains the future availability of CO_2. As investments into carbon capture or RFNBO production usually have a time horizon of more than 15 years, it is important to assess the future development and regulatory eligibility of potential CO_2 point sources. We summarise the findings on the future potential CO_2 point sources in the following.

The analysis shows that across large point sources in core sectors there are (as of 2022) approximately **828 $MtCO_2$ in annual emissions**, which could potentially be utilized to produce synthetic fuels under current legislation. In 2050, emissions from these sectors decrease to 661 $MtCO_2$/year, mainly due to fewer emissions from gas power plants (-99 $MtCO_2$/year), refineries (-69 $MtCO_2$/year), and the iron and steel sector (-46 $MtCO_2$/year). CO_2 emissions of biogenic origin, however, could increase by about 50% as parts of the industry as well as power and heat generation facilities are expected to switch from fossil to biogenic fuels. Bioenergy combustion (117 $MtCO_2$/year) and the production of biofuels, bioliquids and biomass fuels (90 $MtCO_2$/year) will constitute the largest sources of biogenic CO_2.

By 2050 the emissions in core sectors could reduce to 661 $MtCO_2$/year. This includes about **368 $MtCO_2$/year of biogenic emissions**, which would be eligible to produce synthetic fuels. This is because the current legislation proscribes the use of any CO_2 emissions from fossil fuels, including process emissions, after 2040.[65] In addition, it is likely that not the entire CO_2 emission potential will be available for capture and utilisation, e.g. due to requirements on the purity of the CO_2 stream, transport constraints or more generally economic viability depending on the locally emitted CO_2 volumes. Accessible carbon could thus make up significantly less than the total emission potential.

In addition to biogenic emissions and a remainder of fossil energy-related emissions in 2050, there will still be a significant amount of **process-related emissions** (approximately 130 $MtCO_2$/year). Expanding eligibility to include those hard-to-abate industrial process emissions, which largely stem from large point sources, could thus add 130 $MtCO_2$/year of emissions for synthetic fuel production. This additional emission volume would potentially allow for generating approximately an additional 36 billion litres[66] of (diesel-equivalent)

65 European Commission (2023), „Commission Delegated Regulation (EU) 2023/1185", https://eur-lex.europa.eu/legal-content/ENG/TXT/PDF/?uri=CELEX:32023R1185.

66 Calculation is based 3.6 kg of CO_2 per diesel-equivalent litre of synthetic fuels (Schreiber et al.). This sits within the range of 2.9 to 3.6 kg of CO_2 per litre of synthetic fuels cited by Concawe (Fig 3).

synthetic fuels in 2050. This compares to estimate of total demand for synthetic fuels of 41 to 84 billion litres in 2050.[67]

The study also assessed the sectoral distribution of emissions, and concludes that in 2050, the largest CO_2 point sources are likely to be found in **industry sectors** like cement and chemicals (energy- and process-related emissions), in power plants (incl. CHP), as well as in biofuel production. To map and describe the development of the eligible CO_2 sources, the study also determined where potential CO_2 sources exist:

- In 2022, we can see that there are a number of **large clusters** of CO_2 emissions. For example, in the region of Western Germany, Netherlands, and Belgium, due to a high density of industrial facilities. Other clusters can be found in Southern Poland and North-Eastern Czech Republic, Northern Italy, North-Eastern Spain and Southern France.
- Large **individual emitters** in 2022 are often facilities from the industry, for example iron and steel facilities in Northern Spain, Southern France or Austria, chemical sites in Belgium, the Netherlands, Germany or Czech Republic or refineries in Poland, Austria or Italy.
- **Regional changes** until 2050 are mainly driven by sector differences in expected sectoral production growth, technological changes and fuel switches. For example, the biogas and -methane sector in Sweden is expected to grow significantly, so that in the long-term a larger share of the emissions eligible for synthetic fuel production could stem from Scandinavia. In contrast, due to switches in production routes and energy sources of the iron and steel sector, the sectors' emission volumes are expected to decline. This results in lower emissions in industrial regions, for example in Germany or Austria. The level of process-related emissions is expected to remain stable though.
- By 2050, chemical and cement plants are expected to remain among the **largest point sources**, also due to their process-related emissions. While cement plants can be found in a higher number of regions across Europe, large chemical emitters are concentrated in Germany, Belgium and the Netherlands as well as regions in Northern and Southern France, in the North-East of Spain and in the West of the Czech Republic.

In light of the findings relating to the potential and geographic dispersion of CO_2 emissions across Europe, the European Commission will seek to ensure that CO_2 capture and use develops in line with its scenarios and objectives, for example as outlined in its 2040 impact assessment. To support this and the wider contribution of the CO_2 use for synthetic fuels to the European decarbonization, potential accompanying measures and follow-up research include:

- Improve data availability and reporting on CO_2 emissions with differentiation by emission types (process, energetic, biogenic) and for additional sectors outside E-PRTR

[67] The EC Impact 2040 assessment specifies that 147 $MtCO_2$/year could be used for synthetic fuel production in 2050, equivalent to about 41 bn litres of synthetic fuel (at a conversion of 3.6 kg / l). Aurora predicts synthetic fuel demand in Europe as 331 PJ in 2030 and 1,333 PJ in 2050, which translates to 21 and 84 bn litres using LHV fuel density of methanol (15.9 MJ/l, Indico).

- Conducting analyses on the feasible ramp-up scenarios under constraints such as CO_2 purity and transport;
- Establishing adequate frameworks for regulation and market design, in particular in ramp-up phase, and sufficient CO_2 transport infrastructure; and
- Ensuring continuous monitoring of biogenic CO_2 availability to align eligible emissions with the European Union's ambitions for e-fuels development.