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Assessing future energy GHG emission scenarios at regional scale

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Abstract

This feasibility study investigates the utilization of the Integration of EDGAR and POLES (EDGAR-POLES) model to assess future greenhouse gas (GHG) emission scenarios within energy-related sectors, focusing on the impact of alternative energy scenarios options from the POLES model.

With the aim of supporting the objectives of the EU 2050 long-term strategy, the study evaluates the technical feasibility of employing the EDGAR-POLES framework to analyse changes in energy supply, fuel shift dynamics, and the penetration of new technologies.

By narrowing its focus to energy-related sectors, the study aims to provide granular insights into the future trajectories of GHG emissions, facilitating evidence-based decision-making and targeted interventions to mitigate climate change effectively. Through collaboration with stakeholders, the study seeks to contribute to the realization of a sustainable, low-carbon future in line with EU objectives.

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1 Introduction

In the process of mitigating climate change, understanding and effectively addressing greenhouse gas (GHG) emissions at regional levels are imperative. Such localized assessments not only inform targeted interventions but also play a pivotal role in shaping sustainable development strategies. Within this context, the use of advanced methodologies becomes essential.

Sub-national assessments provide a more detailed and localized understanding of GHG emissions within a country. By analysing emissions at regional or local level, it is possible to identify hotspots, trends, and patterns that may not be apparent at the national level. This granularity allows for more targeted and effective policy interventions.

Sub-national assessments enable policymakers to tailor interventions and strategies to address specific regional challenges and opportunities. Different regions may have unique economic structures, energy profiles, and emission sources, necessitating region-specific approaches to emission reduction.

Emissions scenarios at the regional scale for the EU27 typically involve projections or forecasts of greenhouse gas (GHG) emissions within the member states of the European Union. These scenarios aim to provide insights into potential future trajectories of emissions, considering various factors such as economic development, technological advancements, policy interventions, and societal changes.

The energy sector is a primary contributor to GHG emissions. Scenarios assess potential shifts in energy production and consumption, including the adoption of renewable energy sources, changes in fuel mix, energy efficiency improvements, and the deployment of low-carbon technologies.

Achieving a reduction in GHG emissions at the local level necessitates a comprehensive grasp of the ongoing transformation dynamics, the establishment of a clear trajectory, and the formulation of a political action plan to attain the set objectives.

To ensure the EU's progress towards meeting these targets, it's crucial to rely on independent emission inventories, such as the EDGAR (Emissions Database for Global Atmospheric Research) emission inventory. These inventories provide essential tracking mechanisms for monitoring the country's advancement, offering detailed geographical, sectoral, and temporal insights. Independent methods for estimating emissions contribute to our understanding of emission sources. However, these methods can make it challenging for decision making to select the most suitable approaches.

Several literature deals with the comparison or coupling of different approaches to improve and enhance the emissions estimation over time. A large literature also exists on exploiting and comparison of different methods, databases, models and scenarios related to the estimation of greenhouse gas and air pollutant emissions. Among these data sources, we can distinguish approaches as the bottom-up and the top-down, the short-term and the long-term, used to provide policy-relevant insights into global environmental change and sustainable development issues.

The main objective is to enable a comprehensive analysis of policies with a new approach that combines the bottom-up Emissions Database for Global Atmospheric Research (EDGAR) and the recursive partial equilibrium energy model Prospective Outlook on Long-term Energy Systems (POLES).

2 EDGAR database

The Emissions Database for Global Atmospheric Research (EDGAR) is a bottom-up inventory of greenhouse gases (GHGs) and air pollutants, developed and maintained by the Joint Research Centre of the European Commission (https://edgar.jrc.ec.europa.eu/). Renowned for its comprehensive and coherent approach, EDGAR stands at the forefront of emission inventories, boasting completeness and consistency across temporal (spanning from 1970 to present), geographical (covering all countries worldwide), and sectoral (encompassing all Intergovernmental Panel on Climate Change (IPCC) reporting sectors) dimensions. GHG emissions in EDGAR are computed using a uniform methodology based on the IPCC Guidelines (IPCC, 2006; IPCC 2019), ensuring uniformity across all countries.

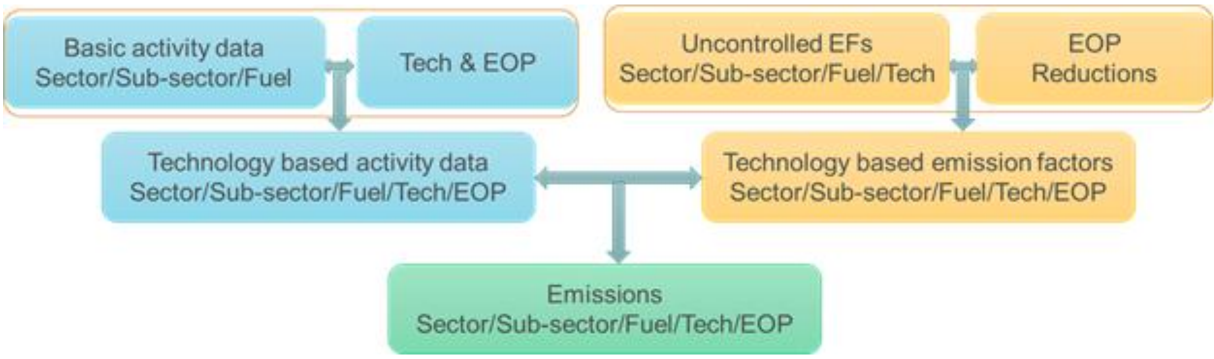
The EDGAR database provides historical emission time series from 1970 to the most recent "t-1" year. EDGAR stands as a worldwide repository delivering assessments of emissions, employing an openly accessible, state-of-the-art approach. It offers emissions data meticulously calculated for over 220 countries globally, drawing from international data sources and a meticulous bottom-up methodology aligned with IPCC guidelines.

Emissions are calculated by gathering data on human activities from international statistics sources such as IEA, FAO, USGS, etc. Default technology-based emission factors from the IPCC and scientific literature, along with updated abatement measures, are applied in accordance with Equation 1:

$$EMi(C,t,x) = \sum j,k \; ADi(C,t) * TECHi,j(C,t) * EOPi,j,k(C,t) * EFi(C,t,x) * (1 - RED)i,j,k(C,t,x) \quad \text{(Eq. 1)}$$

This equation calculates the emissions (EM) from a specific sector (i) within a country (C) for a chemical compound (x) accumulated over a year (t). It incorporates country-specific activity data (AD) to quantify human activity within the sector, the mix of technologies (TECH) used, the mix of end-of-pipe abatement measures (EOP) employed, with each technology (j) having a share (k) of installed abatement measures. Additionally, it considers the uncontrolled emission factor (EF) for each sector and technology, along with the relative reduction (RED) achieved by each abatement measure.

Figure 1. Schematic structure of EDGAR database



Source: JRC, 2024

Emissions are typically calculated across approximately 165 detailed sectors outlined by the Intergovernmental Panel on Climate Change (IPCC), spanning approximately 60 different fuel types. For a comprehensive understanding of the EDGAR emission computation process, detailed descriptions can be found in Janssens-Maenhout et al. (2019), Crippa et al. (2018, 2023), and Oreggioni et al. (2021, 2022). Additionally, an IPCC-based methodology has been utilized to compute GHG emission uncertainty by sector for the EDGAR estimates, as outlined in Solazzo et al. (2021).

Developments regarding the EDGAR-LULUCF GHG emission database are outlined in Crippa et al. (2023).

Country and sector-specific annual GHG emissions are subsequently distributed over the globe with a spatial resolution of 0.1x0.1 degree, employing numerous spatial proxies. These proxies, elaborated upon in Janssens-Maenhout et al. (2019) and Crippa et al. (2021, 2024), encompass a range of emitting sources and are categorized as point sources (e.g., power plants, industrial facilities), area sources (e.g., various settlement layers, crops), and linear sources (e.g., road networks, shipping and air routes, pipelines). Accurate and current information on the location of these emission sources is pivotal to refining the precision and representativeness of the spatial proxies utilized in EDGAR and the subsequent distribution of emission data across space.

Table 1. Main activities included in EDGAR greenhouse gas emission estimation following IPCC categories

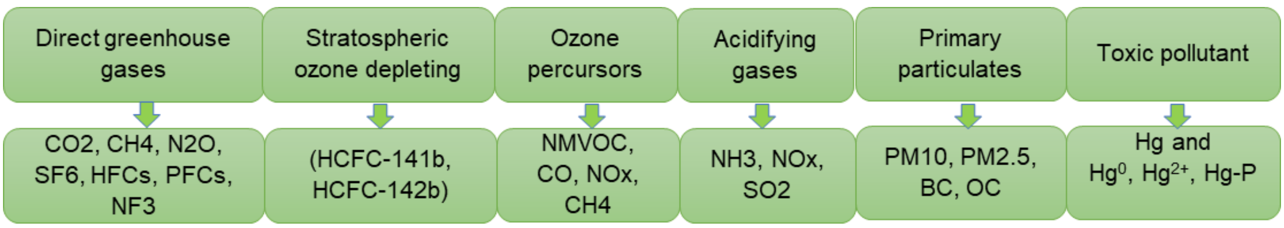
Fossil CO_2	CH_4, N_2O	F-gases	CO_2 LULUCF
Power Industry: power and heat generation plants (public and auto-producers)		**Non-Ferrous Metal** and **Electronics Industry** **Product uses** as substitute for ozone depleting substances	**Forest remaining forest** **Land converted to forest** **Deforestation** **Organic soil** **Fires** **Other:** cropland, grassland and settlements
Other industrial combustion: combustion for industrial manufacturing and fuel production			
Buildings: small scale non-industrial stationary combustion			
Transport: road, non-road, domestic and international aviation, inland waterways and international shipping			
Other sectors: industrial processes, agriculture soils (urea application and lime) and waste	**Other sectors**: agriculture livestock (enteric fermentation, manure management), agriculture soils (fertilisers, lime application, rice cultivation, bread and paper production), field burning of agricultural residues and waste		

Source: Crippa et al., 2023

Table 1 shows the main activities included in EDGAR emissions estimation. EDGAR makes use of the IPCC sectorial classification, and a consistent bottom-up emission calculation methodology is applied to all countries, so that emissions of different countries can be compared, considering their respective levels of detail, uncertainties or data limitations. In particular, for developing countries with less robust and systematic statistical data infrastructures and limited experience in reporting their fossil fuel emissions inventories, EDGAR can provide information and support them in complying with their inventory preparation. Regarding fossil CO_2 emissions, all anthropogenic activities leading to climate relevant emissions are included, except biomass/biofuel combustion (short-cycle carbon) in the power, industry, buildings, transport and agricultural sectors, large-scale biomass burning and land use, land-use change and forestry (LULUCF).

Figure 2 illustrates substances and the schematic view of sectors allocation according to the main processes included in EDGAR. In the following sub-sections, a short description of EDGAR main sectors is provided. In Annex 2 sectors/subsectors, codes and names are provided.

Figure 2. Substances included in EDGAR



Source: JRC, 2024

3 POLES JRC model

POLES is a partial equilibrium energy model designed to comprehensively capture the dynamics of the energy system, spanning from final energy demand, transformation, and power generation to primary supply and energy commodity trade among nations and regions.

At the heart of POLES JRC lies a meticulous representation of energy systems and greenhouse gas (GHG) emissions, enabling the evaluation of different energy types' (fossil fuels, nuclear, renewables) contributions to future energy demands.

Originally developed in 1990 at the University of Grenoble (France), POLES was subsequently transformed into a simulation software by the Joint Research Centre (JRC). The JRC has been actively involved in the model's development and has released the POLES JRC version.

Implemented using the Vensim system dynamics software, the POLES JRC model encompasses a domain spanning 66 regional entities, which includes 12 non-EU regions, the EU27, and 26 non-EU countries, covering detailed regions such as the OECD, G20, and emerging Asia.

The POLES JRC model uses annual historical data to initialise the projections, typically for the period 1980 to the latest data available. The data needed to run projections are those on

- socioeconomic and activity variables (e.g. population, GDP, sectoral value added etc.),
- energy balances (final demand, transformation, supply),
- energy prices and taxes; (iv) energy reserves and resources,
- GHG emissions.

Energy-related emissions refer to GHG emissions where the primary driver is energy production or consumption. They consist in CO_2 emissions from fossil fuel combustion and non-CO_2 emissions from energy-related activities.

Emission factors by fossil fuels (coal, oil, gas) are applied in POLES JRC for CO_2 and non-CO_2 emissions from combustion. For CO_2 emissions from fossil fuel combustion, emission volumes are obtained directly from the use of individual fossil fuels with an emission factor.

Carbon capture and storage (CCS) technology can be developed both in power generation and in industry sectors. Total emissions balances take into account carbon that is captured in CCS (in power plants, synthetic fuel production, hydrogen production and industry) and the uptake of carbon in steelmaking from coking coal. Full energy system in POLES IRC model is shown in the scheme below.

Figure 3. POLES JRC full energy system

Source: JRC, 2024

The POLES JRC model can be used for the

- Assessment of policies related to energy sector,
- GHG emissions abatement strategies,
- Technology dynamics,
- International fuel markets and price feedback.

In addition, it calculates the evolution of GHG emissions: endogenously for the energy-industry sectors and through linkage with specialist models for GHG emissions from agriculture and LULUCF, and air pollution. POLES operates on a yearly time step, allowing integrating recent developments. POLES JRC models energy and emission scenarios allowing the selected scenarios to be developed and policies to be translated into quantitative modelling inputs, by sector and region, by 2050 in a standard configuration and up to 2100 for long-term mitigation strategies.

4 EDGAR-POLES methodology for the energy sector

The mapping methodology for EDGAR-POLES JRC consists of creating a matching matrix for each sector at the finest possible granularity, taking into account limitations that exist on fuels and technologies.

EDGAR database categories for CO_2, CH_4, N_2O and F-gases correspond to the detailed IPCC categories within the sector included in the mapping exercise. In POLES JRC the categories for the estimation of CO_2 emission from combustion also correspond to the IPCC categories. In other sectors and for other substances due to the less detailed structure several categories match the IPCC categories whereas other are aggregated. In case where no match exists (e.g. in power sector the internal combustion and biofuels do not exist in POLES) these are omitted from the matching. Table 2 shows the possible issues and cooperation topics between EDGAR and POLES JRC in combustion process.

Table 2. EDGAR-POLES JRC possible mapping categories for fuel combustion

EDGAR			POLES	
Substance & Category		**Issues & Cooperation**	**Categories**	**Issues & Cooperation**
CO_2 combustion	IPCC	IEA as main data source	CO_2 emissions by sector & fuel	
CO_2 process emissions	IPCC	Possibility to map categories and aggregate emissions accordingly	• Some variables match IPCC categories • Other aggregate several IPCC categories	• Understand methodology of EDGAR • Harmonize POLES Modelling with EDGAR methodology
Non-CO_2 (CH_4, N_2O, F-gases)				

Source: JRC, 2024

In POLES JRC biomass combustion emissions (CO_2BIO) are not accounted as CO_2 emissions in inventories (since they are considered to be CO_2 neutral under a climate perspective). However, an emission factor for biomass combustion is included in order to account for carbon captured when biomass is used in carbon captured and storage (CCS). CCS emissions from biomass combustion are accounted as negative emissions.

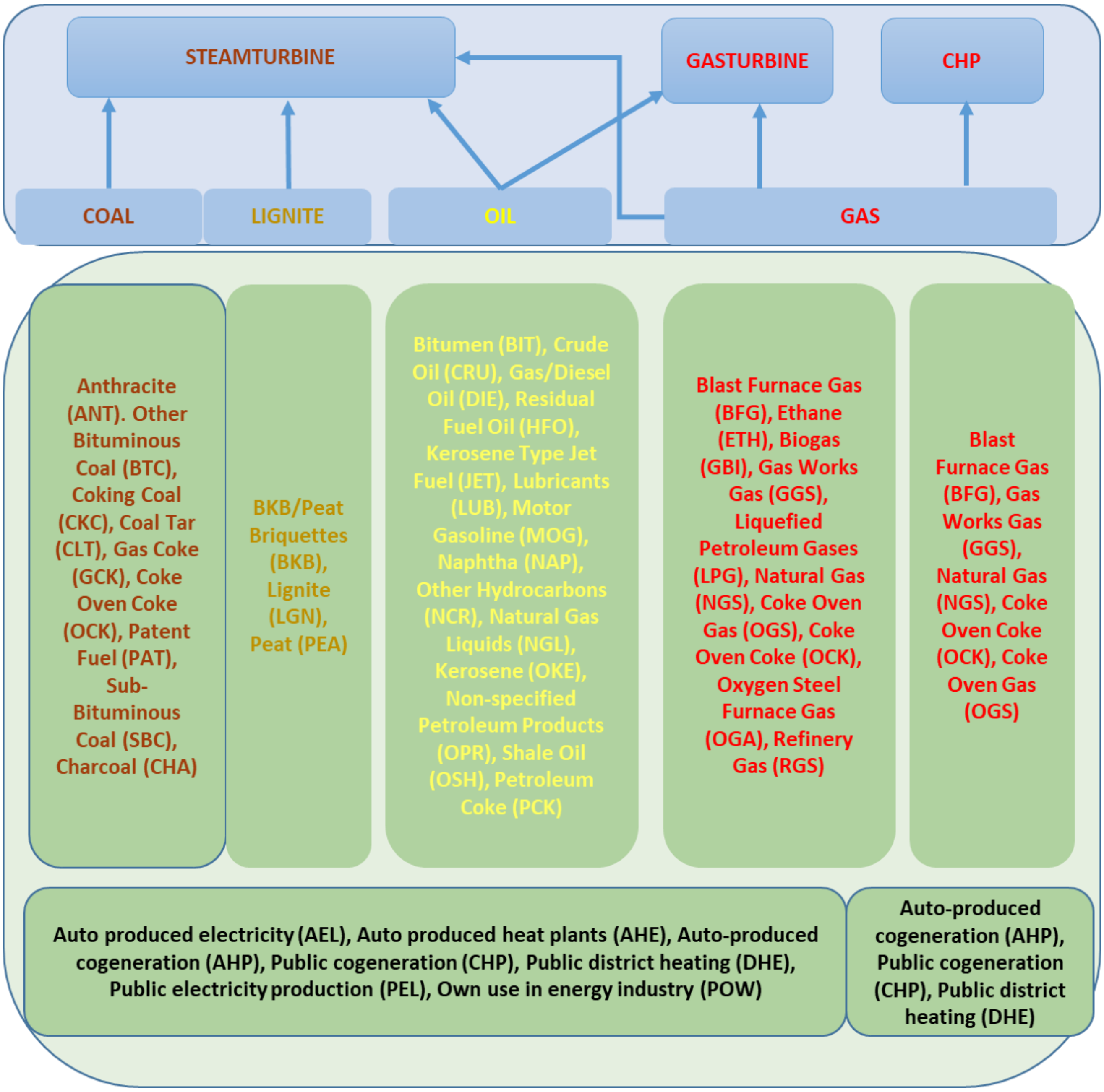
Emissions from the energy sector within the EDGAR database are calculated using data on energy consumption, which are sourced from the International Energy Agency's (IEA) fuel balances. Emission factors applied within energy sector are based on the carbon, nitrogen, and sulphur content of fuels, the type of combustion device used, and any internal or downstream air pollutant removal process.

Within the energy sector, seven distinct sub-sectors are delineated, with definitions aligned with IEA fuel balance criteria. The fuel allocation within the energy sector also adheres to IEA definitions.

- Auto-produced cogeneration
- Public electricity production
- Own use in the energy industry sector
- Public district heating
- Public cogeneration
- Auto-produced electricity
- Auto-produced heat plants

Figure 4 illustrates the mapping between EDGAR and POLES JRC for power and heat sector, based on the fuel types. POLES JRC main fuels are used as basis for this match. It can be seen that several EDGAR fuels are allocated to each POLES JRC fuel, which is then allocated to one or more technologies. In the POLES JRC model, the CHP is applied only to gas fuel.

Figure 4. Matching structure for power sector by technology and fuel type (EDGAR in the bottom panel and-POLES JRC in the top panel).

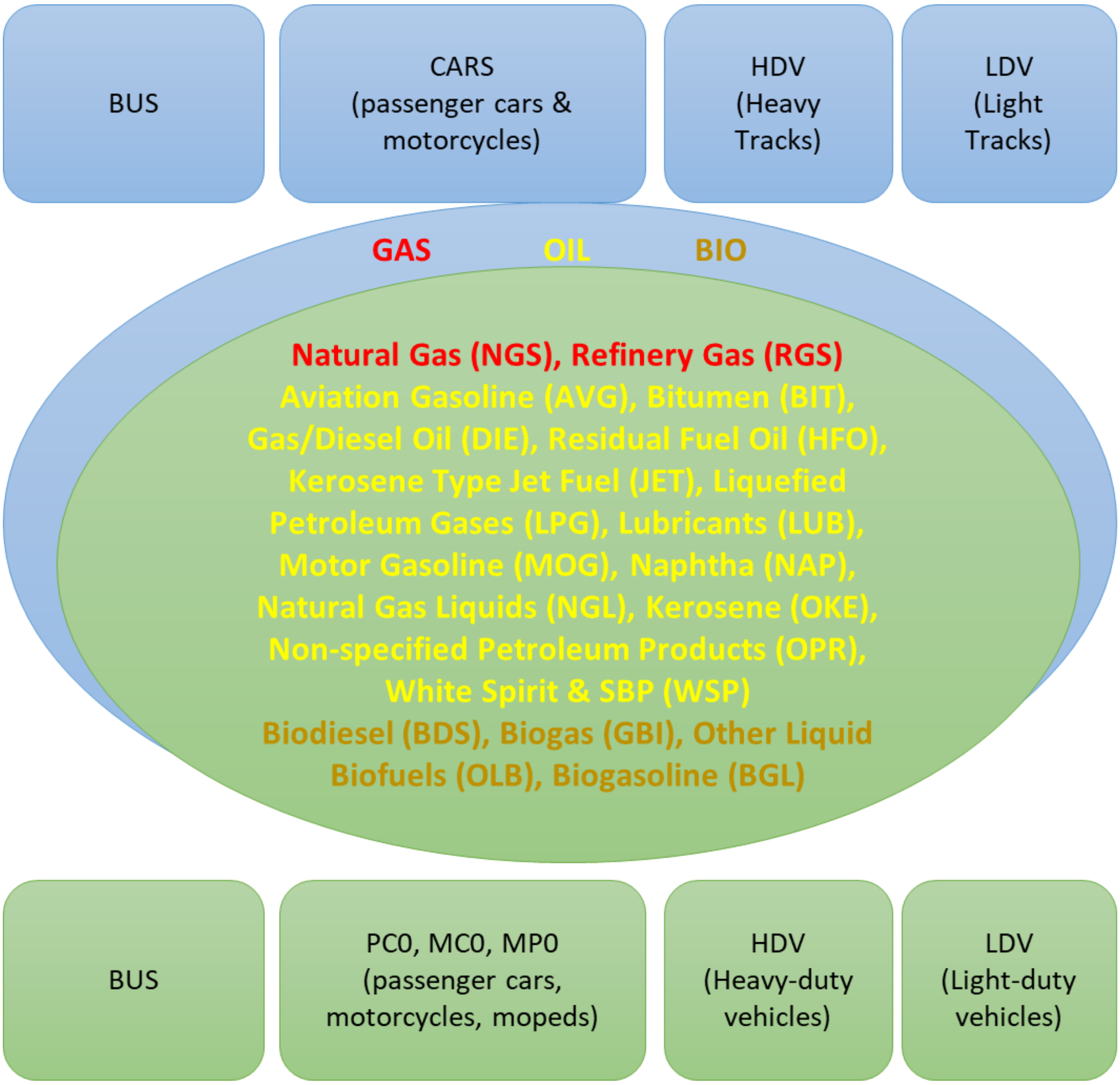


Source: JRC, 2024

In transport sector emissions estimated in EDGAR include road transport and non-road transport (rail, domestic and international aviation, inland waterways, international shipping and other transportation). In the road transport a) driving cycles as urban, rural or highway and b) cold start conditions are not considered.

Activity data on fuel consumption are sourced from the IEA energy balances (IEA, 2022a, 2022b). Statistics on fuel consumption are based on data on fuel sale. Fuels are distributed to different vehicle categories for which different emission standards may exist applying technology penetration rates based on literature review and commercially available data. Emissions are estimated for buses, heavy-duty vehicles, light duty vehicles, passenger cars, motorcycles and mopeds (Lekaki et al., 2024).

Figure 5. Mapping structure for road transport by vehicle and fuel type (EDGAR below- POLES JRC above)



Source: JRC, 2024

Figure 5 illustrates the mapping structure for road transport sector. EDGAR vehicle types as passenger cars, motorcycle and mopeds are aggregated under the POLES JRC cars typology (includes passenger cars and motorcycle POLES JRC categories). The EDGAR-POLES JRC road transport matrix is build based on EDGAR level 4 combination of sector/subsector/fuel/technology.

In POLES JRC, the ranking of in this combination is sector/subsector/technology/fuel. So the mapping is based on the corresponding technologies and fuels. For CH_4 and N_2O mapping will be only at the sector level whereas for air pollutants mapping will reach the sector and fuel level.

The structure of EDGAR and POLES JRC in transport sector is similar. As shown in Table 3 EDGAR applies also abatement measures following the development of regional legislations for the relevant air pollutants as SO_2, NOx, PM_{10} and $PM_{2.5}$. In POLES JRC, six types of vehicle engines are included.

Table 3. EDGAR abatement standards and POLES JRC engine types in road transport sector

EDGAR	POLES JRC
6 EU standards, 3 US standards	6 engine technologies – Conventional, Plug-in hybrid, Full-electric, Hydrogen fuel cell, other fuel cell

Source: JRC, 2024

Table 4. EDGAR-POLES JRC mapping structure for non-road transport by subsector and fuel

POLES subsector	**AIRDOM**	**RAIL**	**NAV**
POLES fuel	OIL, **GAS**, BIO	**COAL**, OIL, **GAS**, BIO	COAL, GAS, OIL, BIO
EDGAR subsector emissions	DAT	RAIL	ILW
EDGAR subsector activity data	Domestic (DAT), Road Surface Wear (RSW)		
EDGAR fuel	**Aviation Gasoline (AVG), Gas/diesel Oil (DIE), Gasoline Type Jet Fuel (GJE), Residual Fuel Oil (HFO), Kerosene Type Jet Fuel (JET), Liquefied Petroleum Gases (LPG), Motor Gasoline (MOG), Kerosene (OKE), Non-specified Petroleum Products (OPR)** **Biogasoline (BGL), Refinery Gas (RGS), Solid Biomass (SBI), White Spirit & SBP (WSP)**	**Anthracite (ANT), BKB/Peat Briquettes (BKB), Other Bituminous Coal (BTC), Coking Coal (CKC), Gas Coke (GCK), Lignite/Brown Coal (LGN), Coke Oven Coke (OCK), Patent Fuel (PAT), Peat product (Briquettes) (PEP), Peat (PEA), Sub-Bituminous Coal (SBC), Industrial Waste (IWS)** **Gas Works Gas (GGS)** **Biodiesel (BDS),** **Gas/Diesel Oil (DIE), Residual Fuel Oil (HFO), Liquefied Petroleum Gases (LPG), Motor Gasoline (MOG), Kerosene (OKE), Lubricants (LUB), Non-specified Petroleum Products (OPR), White Spirit & SBP (WSP), Petroleum Coke (PCK)**	**Other Bituminous Coal (BTC), Coking Coal (CKC), Lignite/Brown Coal (LGN), Coke Oven Coke (OCK), Sub-Bituminous Coal (SBC),** **Gas/Diesel Oil (DIE), Residual Fuel Oil (HFO), Liquefied Petroleum Gases (LPG), Lubricants (LUB), Motor Gasoline (MOG), Kerosene (OKE), Non-specified Petroleum Products (OPR), White Spirit & SBP (WSP),** **Natural Gas (NGS)** **Biodiesel (BDS), Biogasoline (BGL),**

Source: JRC, 2024

The EDGAR-POLES JRC non-road matrix is also built based on EDGAR combination of sector/subsector/fuel/technology. In POLES JRC, three are the main subsectors within non-road transport: Air domestic (AIRDOM), Rail (RAIL) and Navigation (NAV).

In POLES JRC category, AIRDOM represents the aggregation of EDGAR subsectors of Domestic air transport (DAT), while Road surface wear (RSW) is allocated (see Table 4). Other transport ("TNR.PIP" and TNR.OTH" in EDGAR) does not exist in POLES JRC so no mapping is provided.

POLES JRC does not estimate emissions from road surface wear subsector. However, the model can provide the activity data for this subsector, which can be compared with historic EDGAR activity data. POLES JRC will provide the allocation of total value for emissions and activity data for international aviation (IAT) and shipping (SEA).

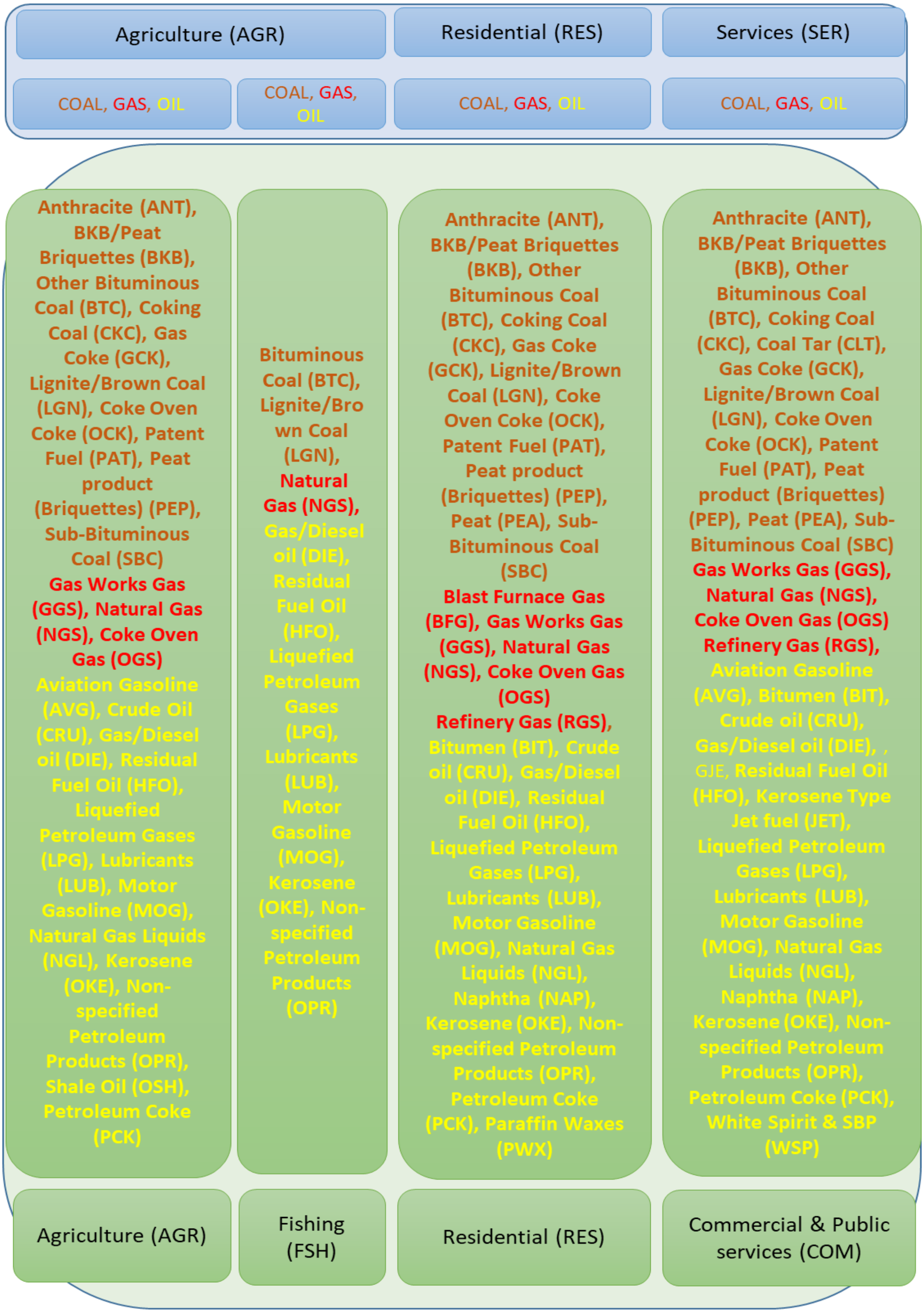
The EDGAR-POLES JRC residential matrix is based on the EDGAR combination of sector/subsector/fuel/technology. Five subsectors (see Figure 6) are included in the EDGAR database for this sector:

- Residential (RES),
- Commercial and public services (COM),
- Agriculture/Forestry (AGR), Fishing (FSH), and
- Other (OTH) not specified (OTH).

POLES JRC on the other side responds with Use of fuels in Agriculture (AGR), Residential (RES) and Services (SER). In this mapping work, the EDGAR codes on Other not specified (OTH) are not assigned to any of POLES JRC codes.

Mapping for "AGR" has been done based on the fuel use. For POLES JRC "RES" and "SER" subsectors the mapping has been done for space heating & cooling (SH) and waste heating & cooking (WH).

Figure 6. Matching structure for residential sector by subsectors/fuel type (EDGAR Error! Bookmark not defined. in the bottom panel and POLES JRC in the top panel)



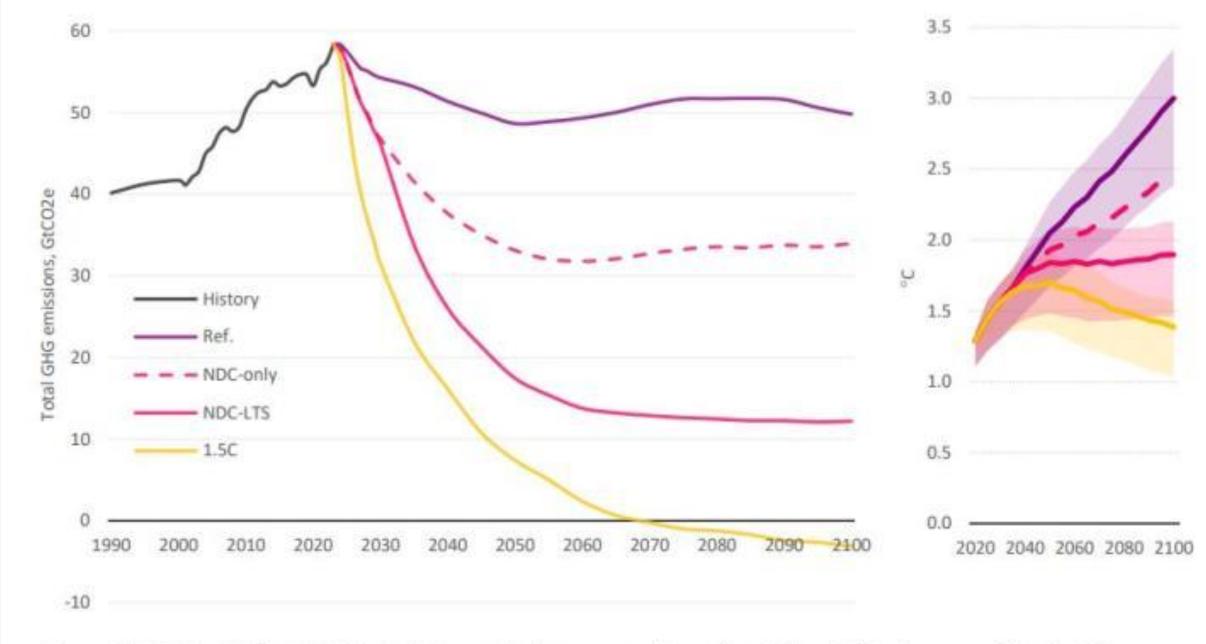
NB. In the EDGAR database, the fuel use in agriculture is included in residential sector and not in agriculture sector.

Source: JRC, 2024

5 Scenarios exploration and harmonisation methodology

The POLES-JRC model provides projections on how the energy system, GHG and air pollutant emissions evolve over years in the Reference, NDC-LTS and 1.5°C scenarios (Keramidas et al., 2023).

Figure 7. Global emissions and global mean temperature change, by scenario



Source: POLES-JRC model; liveMAGICC (probabilistic setting). The temperature lines refer to 67% probability; the ranges refer to the 83% and 17% percentile ranges. The overshoot in the 1.5°C scenario is limited to 1.6°C at median probability and 1.7°C at 67% probability.

Source: GECO 2023

The **Reference scenario** (Current Policies) takes into account the policy and targets framework as by the latest year available (June 2023 for GECO 2023) for energy supply, demand and GHG emissions. Projections of energy system and GHG emissions are based on the combination of these policies and targets with macroeconomic projections related to GDP and population combined with energy prices and technological development estimates from the POLES-JRC model. This combination of factors results in specific projections for the energy system and GHG emissions, which may differ from projections by national and international agencies. This scenario does not account for policies or targets that lack legal backing and concrete action plans.

The **NDC-LTS scenario** incorporates the medium-term policies of Nationally Determined Contributions (NDCs) and the long-term strategies (LTSs) of various countries. It assumes that the targets set in the NDCs, including any conditional goals, are met by their designated years, typically 2030. To achieve these targets, additional carbon pricing and regulatory measures are implemented alongside the existing legislated policies of the Reference Scenario. After 2030, countries pursue their LTS objectives where available; if no LTS has been announced, it is assumed there will be no further decarbonisation efforts, with carbon values remaining at 2030 levels. This scenario also accounts for the net zero targets announced by several countries and includes decarbonisation efforts for international aviation and maritime transport (international bunker fuels).

The **1.5-degree scenario** is formulated to achieve a decarbonisation goal aimed at constraining the global temperature rise to 1.5°C. It was developed based on a global carbon budget spanning from

2020 to 2100 (cumulative net CO_2 emissions) of around 400 Gt CO_2, which corresponds to a 50% likelihood of not surpassing the 1.5°C temperature threshold by 2100. In this scenario, a global carbon price is uniformly implemented across all regions starting immediately (from 2024 in GECO 2023), with a significant increase over time. It does not incorporate bottom-up policy drivers from the NDC-LTS scenario, relying solely on the policy framework of the Reference Scenario. The uniform global carbon price drives emissions reductions efficiently by prioritizing areas with the lowest abatement costs. Financial transfers between countries for mitigation measures are not considered.

Negative emissions technologies, including land use sinks, play a substantial role (21 Gt CO_2/year by 2100), while CO_2 capture technologies gradually become available post-2030 (<5 Gt CO_2/year by 2050). Biomass utilization remains relatively limited (below 200 EJ/year throughout) to ensure sustainability.

The harmonization year between the EDGAR database and the POLES JRC model was set as 2020. Consistency is ensured by calculating a constant offset value for the chosen harmonization year. This offset value, presented either as a ratio or a difference, is then scaled according to the POLES trend or subsequently applied to align all scenario time series. Hierarchical alignment is used to compute the offset for the year 2020, forming the EDGAR-POLES structure. Country/sector emissions totals serve as the starting point to estimate this offset. Several steps are followed for this harmonisation procedure shown in following:

- Calculate the total difference for each country in each sector
- Calculate the differences for each code within each sector and each country
- Create the 2020 EDGAR-POLES using POLES codes
- Calculate the shares of POLES codes in each sector in each country for each year (2020-2050)
- Apply the difference calculated at Step1 to the totals of each year of POLES for 2021-2050 following the POLES trend (this will create a scalable dynamic absolute difference)
- Calculate the absolute contribution of each POLES codes using the shares created in Step4 and the totals created in Step5
- Convert POLES codes to EDGAR codes

Depending on the aggregation of POLES emissions, the harmonisation at the sector/subsector/fuel/technology level (from level 1 to 4) was possible for some of the sectors. Table 5[1] shows at which level the harmonisation is done for each sector and which inventory distribution is applied to the trend 2020-2050.

(1) Refer to the report JRC131423 for the definitions of sectors, subsectors, fuels and technologies

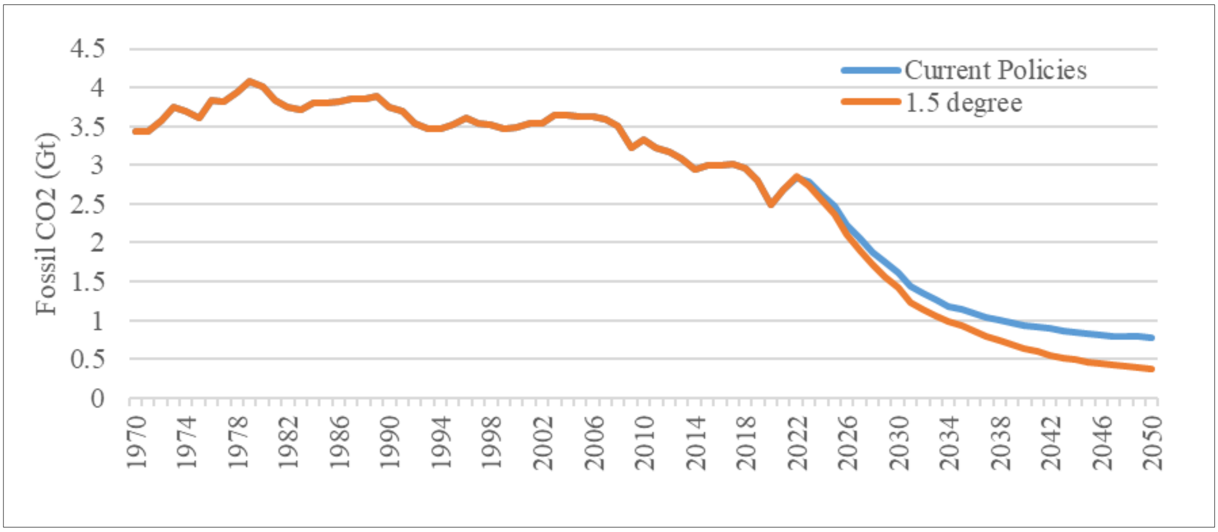
Table 5. Levels of harmonisation between EDGAR and POLES JRC. The level of aggregation is defined as following: Level 1: 'Sector'; Level 2: Sector/Subsector; Level 3: Sector/Subsector/fuel; Level 4: Sector/subsector/fuel/technology.

Sector	Sector description	Level 4	Level 3	Level 2	Level 1
AGS	Agricultural soils				x (POLES N_2O trend & EDGAR distribution)
CHE	Production of chemicals				x (EDGAR distribution)
ENE	Power industry	x (POLES distribution)			
IND	Combustion in manufacturing indus-try		x (POLES distribution)		
IRO	Iron and Steel production				x (EDGAR distribution)
NFE	Non-ferrous metals production				x (EDGAR distribution)
NMM	Non-metallic minerals production				x (EDGAR distribution)
RCO					x (EDGAR distribution)
REF	Refineries		x (POLES) distribution		
SOL	Solvents Use				x (EDGAR distribution)
SWD	Solid Waste Disposal				x (EDGAR distribution)
TNR	Non-road transport		x (POLES) distribution)		
TRF	Transformation Industry				X (TRF.E+REF) trend for TRF.T & EDGAR distribution)
TRO	Road transport	x (POLES distribution)			

Source: JRC, 2024

Figure 8 shows fossil CO_2 emissions in EU27 from EDGAR-POLES, thus using EDGAR CO_2 emissions from 1970 to 2022 and the harmonised dataset after 2022 under two different scenarios (current policies and 1.5 degree target).

Figure 8. Fossil CO2 emissions from EDGAR-POLES under current policies and 1.5-degree scenarios.



Source: JRC, 2024

6 Spatial distribution of projected CO_2 emissions – examples

Figure 9 illustrates the relative change in fossil CO2 emissions in the EU-27 at the NUTS2 regional level, as estimated by the EDGAR-POLES model, comparing two scenarios: current policies (left panels) and the 1.5-degree pathways (right panels).

The emissions are shown for three key years (2030, 2040, and 2050) relative to 1990 levels. NUTS2-level emissions are derived by downscaling the EDGAR-POLES national values, following the methodology described in Crippa et al. (2024).

To better capture the projected emissions at the regional scale, time-dependent spatial proxies have been used, particularly focusing on population dynamics and changes in residential and non-residential built-up areas up to 2030 (Schiavina et al., 2023a, 2023b), as well as the status of power plants up to 2050, using data on planned openings and closures from the Global Coal, Gas and Oil Plant Tracker of the Global Energy Monitor (2022a, 2022b, 2022c)).

Having information on the spatial allocation of future emissions is even more challenging than national emission projections. However, EDGAR is a unique inventory using time varying spatial proxies both for historic and future emissions. However, further improvements and assumptions may be considered and developed taking into account population dynamics, urbanisation processes, industrial delocalisation etc.

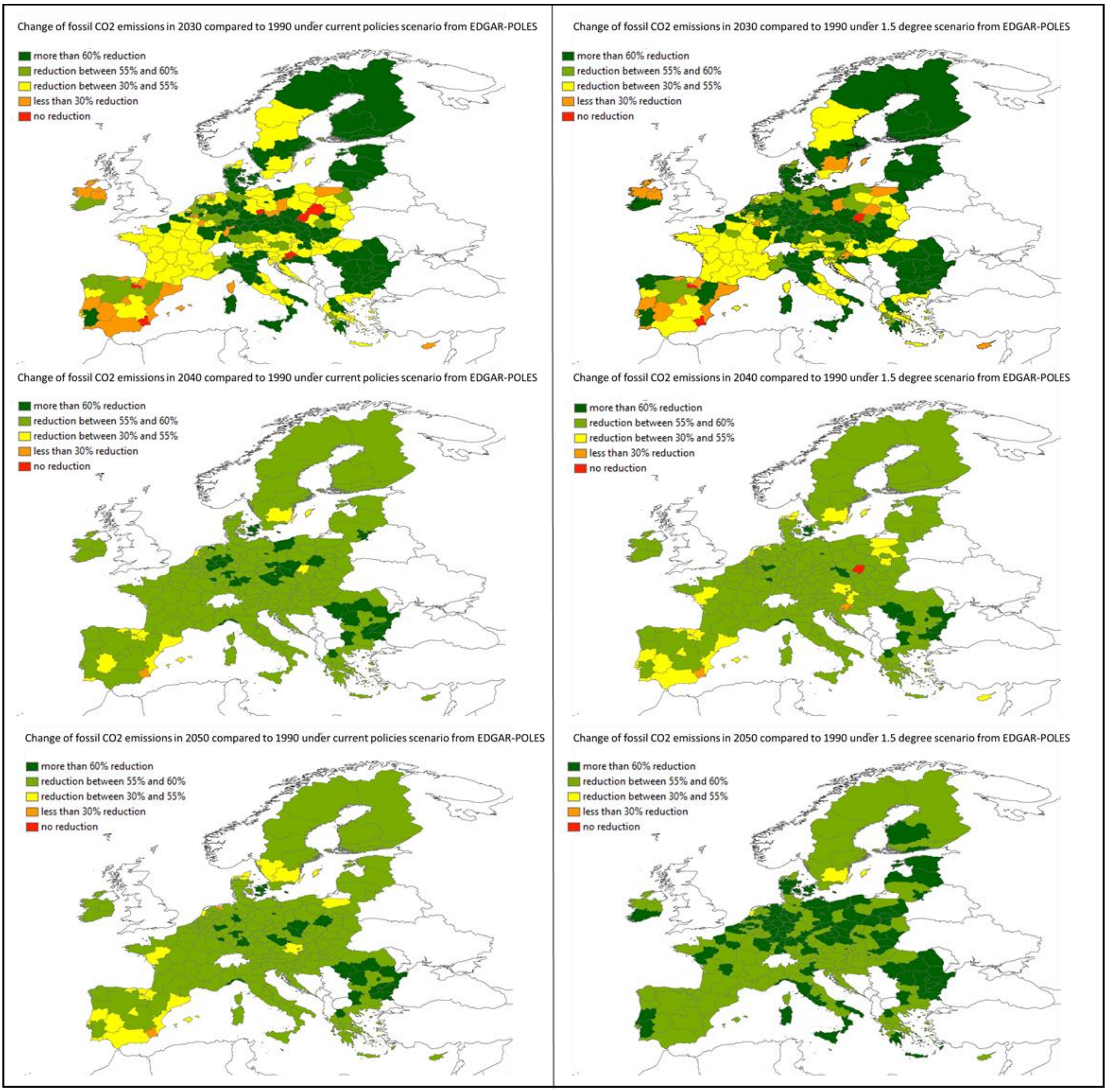
Having information on the spatial allocation of future emissions is even more challenging than national emission projections. Nevertheless, EDGAR stands out as a unique inventory due to its use of time-varying spatial proxies for both historical and future emissions. Despite this, further improvements may be considered and developed, incorporating additional factors such as population dynamics, urbanization trends, and industrial relocations, which could impact the accuracy of future projections.

Under the current policies scenario, 119 out of 237 EU regions are expected to align with the Fit for 55 targets (i.e., a 55% reduction in emissions compared to 1990) by 2030. However, by 2040, only 16 regions are projected to achieve the more ambitious 90% reduction target[2].

In contrast, under the 1.5-degree scenario, 221 regions are on track to meet the 55% reduction target by 2030, and by 2040, 100 regions are anticipated to have reduced their emissions by 90% or more. This highlights the significant differences in regional emission trajectories under the two scenarios.

[2] Note that EU climate targets are set for total GHG emissions and not for fossil CO2 only which are described in the current analysis.

Figure 9. Change of fossil CO_2 emissions in 2030, 2040 and 2050 compared to 1990 at NUTS2 level. Fossil CO_2 emissions are estimated by EDGAR-POLES for the current policies and 1.5 degree scenarios. Green colours represent regions having already achieved the 2030 and/or 2040 EU climate targets (-55% and -90% reduction compared to 1990 levels).



Source: JRC, 2024

7 Discussions on the potentialities and limitations of the EDGAR-POLES approach

The EDGAR database and the POLES JRC model are important tools for understanding and projecting global emissions and energy use. Despite their importance, integrating these models is complicated by differences in mapping granularity, sectoral categorization, and technology representation.

While the integration of EDGAR and POLES JRC presents a promising approach to comprehensive emissions and energy use analysis, significant limitations remain. Addressing these challenges through enhanced mapping strategies and expanded model capabilities will be crucial for improving the accuracy and utility of the combined approach.

Both EDGAR and POLES JRC aim to provide comprehensive insights into energy use and emissions. However, their differences in mapping granularity, sectoral focus, and fuel classification present significant challenges. The analysis presented in this feasibility study identifies key areas of misalignment and proposes potential solutions for improving the consistency and accuracy of the combined approach.

In the energy sector, POLES JRC model employs an energy balance approach focusing on three primary fossil fuels: coal, gas, and oil. These fuels are associated with three main technologies: steam turbine, gas turbine, and combined heat and power. This approach simplifies the alignment with EDGAR. However, the EDGAR database includes a broader range of fuels and subsectors, necessitating considerable aggregation. Additionally, internal combustion technology, which is present in EDGAR, is not represented in the POLES JRC model. Aligning this technology with the gas turbine technology in POLES JRC might seem a reasonable solution, but it does not capture the specific characteristics and emissions profiles of internal combustion engines.

In the transport sector, the mapping process also reveals several challenges. For road transport, the types of vehicles are similar in both EDGAR and POLES JRC, but the aggregation of EDGAR fuels into broader categories such as gas, oil, and biofuels is necessary to match POLES JRC classifications. This aggregation may mask important differences in emissions characteristics between specific fuel types. In the non-road transport sector, EDGAR's subsectors are generally well mapped to their counterparts in POLES JRC. However, a notable issue is the absence of POLES JRC emissions data for road surface wear. Although POLES JRC can provide activity data, this does not fully substitute for the missing emissions data, limiting the ability to comprehensively assess non-road transport emissions.

The residential sector presents further aggregation challenges. EDGAR's detailed subsectors for agriculture and fishing need to be combined to align with the broader agriculture category in POLES JRC. The unspecified subsector in EDGAR does not correspond to any category in POLES JRC, indicating a gap in the model's coverage. Additionally, several fuels listed in EDGAR must be aggregated to match the three primary fuels in POLES JRC, potentially leading to a loss of detailed emissions information and affecting the accuracy of sectoral emissions estimates.

Despite these limitations, there are strengths in the mapping process. For instance, there is a strong alignment of categories, subsectors, and fuels for CO_2 emissions in the power sector. This indicates a reliable basis for integrated analysis in this sector. However, the estimation of methane and nitrous oxide emissions depends on their treatment as residual processes in POLES JRC. While POLES JRC provides total sector values, the lack of detailed granularity remains a concern.

One of the significant contributions of the POLES JRC model is the provision of comprehensive activity data across all EDGAR sectors. Even when emissions data is unavailable, the activity data, which includes the impact of policies reported to the UNFCCC, offers valuable insights. However, mapping of air pollutants is limited to fuel-based and sector-based levels, often not meeting expectations, particularly in the energy sector. This limitation restricts detailed analysis of air pollutant trends and sources.

8 Ideas for future developments of EDGAR projections

Ideas to enhance the EDGAR projections by incorporating data from other sources as the International Energy Agency (IEA), Food and Agriculture Organization (FAO), and Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model from the International Institute for Applied Systems Analysis (IIASA) should be developed. By integrating these diverse data sources, the aim is to improve the granularity, accuracy, and comprehensiveness of the EDGAR projections.

Using multiple reliable international; data sources helps cross-verifying information, reducing uncertainties and improving the reliability of projections. Consistent updates from these sources ensure that EDGAR remains up-to-date with the latest trends and policy impacts.

Incorporating diverse data sources enables EDGAR to cover a broader range of emissions sources and drivers, including technological advancements, agricultural practices, and air pollution interactions. This broader scope allows for more comprehensive analysis and better-informed policy recommendations.

Given that EDGAR projections may be constrained by limited data granularity and sectoral coverage, incorporating data from the sources mentioned above can effectively address these limitations.

The EDGAR structure for energy sector goes in line with the IEA structure of energy balances. Currently an agreement exists between IEA and EDGAR for the provision of energy balances for the estimation of CO_2 emissions. As such, the IEA can provides detailed projections for energy consumption, production, and emissions across various scenarios. The existing alignment of EDGAR sectoral and fuel data with IEA's projections can enhance the accuracy of energy sector forecasts (IEA, 2023). This will involve mapping EDGAR's detailed fuel types and technologies to the IEA's categories, ensuring consistency in data interpretation and projection. The IEA's technology-specific data on energy generation and efficiency can be integrated into EDGAR to improve projections of technological advancements and their impact on emissions.

FAO provides comprehensive data on agricultural production, land use, and emissions, which can be used to refine EDGAR's agricultural projections (FAO, 2018). Integrating FAO data involves mapping agricultural activities and emissions sources between the two datasets, ensuring that all relevant agricultural subsectors are accurately represented in EDGAR. FAO's detailed data on land use changes and livestock emissions can enhance the granularity of EDGAR's projections, providing more accurate estimates of methane and nitrous oxide emissions from agriculture.

The GAINS model provides comprehensive data on air pollutants and greenhouse gases, including their interactions and mitigation scenarios. Integrating GAINS data can enhance EDGAR's projections by providing detailed emission factors and mitigation potential for various pollutants. GAINS IIASA's scenario analysis capabilities can be used to model the impact of different policy measures on emissions, offering a dynamic and responsive projection framework for EDGAR.

However, integrating data from the IEA, FAO, and GAINS IIASA into EDGAR projections presents several challenges, primarily related to data harmonization, consistency, and maintenance. Addressing these challenges requires careful planning and strategic solutions.

One of the main challenges is data harmonization. The different data formats, categorizations, and methodologies used by EDGAR, IEA, FAO, and GAINS can complicate the integration process. For instance, each organization may use different units of measurement, temporal resolutions, and sector definitions.

Another significant challenge is ensuring consistency across the integrated datasets and managing overlapping data. Since each data source may cover similar sectors and emission types, discrepancies and redundancies can arise. Developing a robust framework for cross-referencing and reconciling overlapping data is crucial to address this issue. This framework would prioritize the most accurate and relevant data sources for each sector or emission type, reducing redundancy and ensuring that the integrated dataset remains consistent and reliable. Additionally, careful validation and cross-verification of data can help identify and correct any inconsistencies.

Regularly updating and maintaining the integrated datasets also poses a challenge, requiring significant effort and coordination. Given the dynamic nature of emissions data and the continual updates from sources, as the IEA, FAO, and GAINS, maintaining an up-to-date and accurate database can be time-consuming even that automated data update systems are already in place for EDGAR-IEA and EDGAR-FAO linkages.

In summary, integrating IEA, FAO, and GAINS IIASA data into EDGAR projections offers significant benefits but also presents challenges related to data harmonization, consistency, and maintenance. This approach will enhance the granularity, accuracy, and comprehensiveness of EDGAR projections, providing valuable insights for global emissions management and policy-making.

9 Conclusions

Integrating EDGAR and POLES JRC presents a promising approach to support comprehensive emissions and energy use analysis. However, addressing the identified limitations through enhanced mapping strategies and expanded model capabilities is crucial for improving the accuracy and utility of the combined approach. Further research and development are necessary to refine these tools and ensure they provide reliable insights for policymakers and researchers.

Continuing the development of the EDGAR-POLES JRC platform is important to facilitate the creation and delivery of GHG emission scenario analyses. These analyses will play an important role in considering various policy pathways and assessing their impacts, thereby aiding in the formulation of long-term EU climate targets.

The EDGAR-POLES JRC mapping process demonstrates robust alignment for CO_2 emissions in the power and industry sectors, indicating successful integration areas. However, significant differences in gas utilization, methane and nitrous oxide emissions totals, and air pollutant estimations between EDGAR and POLES JRC highlight areas needing further refinement. The lack of comprehensive data on carbon capture and storage (CCS) and combined technologies in EDGAR also presents challenges, necessitating improved data harmonization and model expansion.

To address these challenges, several strategies can be implemented. Enhanced technology mapping could involve aligning internal combustion technologies in EDGAR with similar technologies in POLES JRC or developing new categories in POLES JRC to reflect the technological diversity in EDGAR. Furthermore, developing a more detailed fuel categorization in POLES JRC would reduce the need for aggregation from EDGAR, preserving data granularity and improving emissions estimates. Additionally, expanding the sectoral coverage in POLES JRC to include currently unassigned EDGAR subsectors would enhance the model's comprehensiveness and accuracy.

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List of abbreviations and definitions

Abbreviations	Definitions
CH_4	methane, greenhouse gas with GWP-100 = 28-30 under IPCC AR5
CO_2	carbon dioxide
EDGAR	Emissions Database for Global Atmospheric Research
F-gases	fluorinated gases
GHG	greenhouse Gas
Gt	gigatonnes (1000 megatonnes = 10^9 metric tonnes) mass of a given (greenhouse gas) substance
GWP-100	Global Warming Potential over a 100-year period
LULUCF	Land Use, Land Use Change and Forestry
N_2O	Nitrous oxide, greenhouse gas with GWP-100 = 265 under IPCC AR5
POLES	Prospective Outlook on Long-term Energy Systems

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Annexes

Annex 1. EDGAR sectors and subsectors codes

Fuel combustion and production	
Energy Industries (ENE)	**Manufactory Industry (IND)**
Auto produced electricity (AEL)	Chemicals (combustion) (CHE)
Auto produced heat plants (AHE)	Construction (combustion) (CON)
Auto-produced cogeneration (AHP)	Food and tobacco (combustion) (FOO)
Public electricity production (PEL)	Iron and steel (combustion) (IRO)
Public district heating (DHE)	Machinery (combustion) (MAC)
Public cogeneration (CHP)	Mining (combustion) (MIN)
	Non-ferrous metals (combustion) (NFE)
Road Transport (TRO)	Non-metallic minerals (combustion) (NMM)
Transport - road (ROA)	Paper, pulp and print (combustion) (PAP)
Evaporation (EVP)	Transport equipment (combustion) (TEQ)
Road surface wear (RSW)	Textiles (combustion) (TEX)
Road vehicle tyre and brake wear (TYR)	Wood and wood products (combustion) (WOO)
Non Road Transport (TNR)	Non-specified industry (IND)
Domestic air transport (DAT)	
Inland water ways (ILW)	**Transformation Industry (TRF)**
Non-specified non-road transport (OTH)	Fuel combustion: Blast Furnaces (EBF)
Pipeline transport (PIP)	Fuel combustion: BKB plants (EBK)
International air transport (IAT)	Fuel combustion: Gasification plants (EBO)
International marine bunkers (SEA)	Fuel combustion: Charcoal production (ECH)
	Fuel combustion: Coke ovens (ECK)
Residential (RCO)	Fuel combustion: Gas works (EGW)
Agriculture/Forestry (AGR)	Fuel combustion: Liquefaction/Regasification plant (ELN)
Commercial & Public service (COM)	Fuel combustion: Coal liquefaction (ELQ)
Fishing (FSH)	Fuel combustion: Energy in coal mines (EMI)
Non-specified (OTH)	Fuel combustion: Non-specified transformation (ENO)
Residential (RCO)	Fuel combustion: Oil & Gas extraction (EOG)
	Fuel combustion: Patent fuel plants (EPA)
Fuel production/transmission (PRO)	Fuel transformation: Blast Furnaces (TBF)
Brown coal production (BRC)	Fuel transformation: BKB plants (TBK)
Gas production, transmission & venting from production (GAS)	Fuel transformation: Blending of natural gas (TBN)
Hard coal production (HDC)	Fuel transformation: Charcoal (TCH)
Oil production transmission, loading, venting & flaring (OIL)	Fuel transformation: Coke ovens (TCK)
	Fuel transformation: Natural gas into oil in (GLT) plant (TGL)
Oil Refineries (REF)	Fuel transformation: Gas works (TGW)
Fuel combustion petroleum refineries (CMB)	Fuel transformation: Coal liquefaction (TQL)
Fuel transformation petroleum refineries (EVA)	Fuel transformation: Distribution losses (TLQ)
	Fuel transformation: Non-specified (TNO)
	Fuel transformation: Patent fuel plants (PAT)
	Fuel transformation: Petrochemical plant (TPE)
Agriculture and Waste	
Agriculture	**Waste/Waste Water handling**
Agricultural soils (AGS)	**Solid waste disposal (SWD)**
Animal waste as fertilizer (AWS)	Solid waste incineration (INC)
Crop residues (CRP)	Solid waste disposed to landfills (LDF)
Histosols (HIS)	Other waste handling (OTH)
Liming (LMN)	**Waste water handling (WWT)**
Nitrogen-fixing crops (NFC)	Domestic waste water (DOM)
Nitrogen fertilizers (NFE)	Industrial waste water (IND)
Rice cultivation (RIC)	
CO_2 from urea fertilization (URE)	
Livestock in pasture	
Agriculture waste burning (AWB)	
Crop residues (CRP)	
Enteric fermentation (ENF)	

Livestock number		
Manure management (MNM)		
Livestock number		
Process emissions during production and application		
Production of chemicals (CHE)		**Production and use of other products PRU)**
Adipic acid production (AAP)		Aerosols (AER)
Ammonia production (AMP)		Accellerators/HEP (ACC)
Bulks chemical production (BLK)		Closed cell foam (CCF)
Calcium carbide production (CLC)		Production, application of CFC (CFC)
Caprolactam production (CLP)		Commercial refrigeration (COM)
Glyoxal production (GXA)		Domestic refrigeration (DOM)
Nitric acid production (NAP)		PFC use in fire extinguishers (FEX)
N-fertilizer production (NFP)		Flat Panel Display production (FPD)
Sulphuric acid production (SAP)		Production, application of HCFC (HFC)
Silicon carbide production (SLC)		PFC use in accelerators/High Energy Physics (HEP)
		Industrial refrigeration (IND)
Production of iron and steel (IRO)		Mobile Air Conditioning (MAC)
Crude steel production (CSP)		Consumption for miscellaneous (MIS)
Ferro Ally production (FEA)		Open cell foam (OCF)
Pigment iron production (PIG)		Electrical equipment manufacturing (OEM)
Sinter production (SNT)		Production and use of other products (OTH)
		Production, application of PFC & HCFC (PFC)
Non energy use of fuels (NEU)		Production PV solar cells (PVP)
Non energy use: Industry (IND)		PFC use in refrigeration (REF)
Non energy use: Tansport (TRA)		Stationary air conditioning (SAC)
Non energy use: Other (OTH)		Semiconductor production (SCO)
		Use in solvents (SOL)
Production of non-ferrous metals (NFE)		Use in sport shoes and other (SPO)
Aluminium production (primary) (ALP)		Transport refrigeration (TRA)
Copper production (primary) (CUP)		Tyres (TYR)
Magnesium production (primary) (MGP)		SF6 consumption unaccounted for elsewhere UAE)
Lead production (primary) (PBP)		GIS Stock emissions from leakage and maintenance (UTL)
Zinc production (primary) (ZNP)		
Molybdenum production (OTH)		
Production of non-metallic minerals (NMM)		
Cement production (CMN)		
Glass production (GLS)		
Lime production (LMN)		
Limestone and Dolomite Use (LMU)		

Source: EDGAR database, 2024

Annex 2. EDGAR fuel codes

Type	Subtype	Fuel name	Code	Carrier group
Solid fuels and products	Hard coal	Anthracite	ANT	Coal
	Hard coal	Other Bituminous Coal	BTC	Bituminous
	Hard coal	Coking Coal	CKC	Bituminous
	Hard coal	Coal Tar	CLT	Coal product (for NEU)
	Hard coal	Gas Coke	GCK	Coal product
	Hard coal	Hard Coal (if no detail)	HDC	Coal
	Hard coal	Coke Oven Coke	OCK	Coal product
	Hard coal	Patent Fuel	PAT	Coal product
	Hard coal	Sub-Bituminous Coal	SBC	Sub-bituminous
	Brown coal	BKB/Peat Briquettes	BKB	Coal product
	Brown coal	Brown Coal (if no detail)	BRC	Brown coal/Peat
	Brown coal	Lignite/Brown Coal	LGN	Brown coal/Peat
	Peat	Peat	PEA	Brown coal/Peat
	Peat	Peat product (Briquettes)	PEP	Brown coal/Peat
	Solid waste	Municipal Waste (non-renew)	MWN	Waste (no biomass)
Oil and oil products	Heavy oils	Bitumen	BIT	Oil product
	Heavy oils	Crude/NGL/Feedstock (if no detail)	CNF	Crude oil subtype
	Heavy oils	Crude Oil	CRU	
	Heavy oils	Gas/Diesel Oil	DIE	
	Heavy oils	Residual Fuel Oil	HFO	
	Heavy oils	Lubricants	LUB	used in NEU
	Heavy oils	Other Hydrocarbons	NCR	
	Heavy oils	Petroleum Coke	PCK	used in NEU
	Heavy oils	Paraffin Waxes	PWX	used in NEU
	Heavy oils	Refinery Feedstock	RFD	Crude oil subtype
	Heavy oils	Orimulsion	ORI	
	Light oils	Additives/Blending Components	ADD	Crude oil subtype
	Light oils	Aviation Gasoline	AVG	
	Light oils	Ethane	ETH	
	Light oils	Gasoline Type Jet Fuel	GJE	
	Light oils	Kerosene Type Jet Fuel	JET	
	Light oils	Liquefied Petroleum Gases (LPG)	LPG	
	Light oils	Motor Gasoline	MOG	
	Light oils	Naphtha	NAP	Used in NEU
	Light oils	Natural Gas Liquids	NGL	Crude oil subtype
	Light oils	Kerosene	OKE	
	Light oils	Non-specified Petroleum Products	OPR	
	Light oils	Shale oil	OSH	Light tight oil
	Light oils	White Spirit & SBP	WSP	Used in NEU
Gaseous fuels and products	Natural gas	Natural Gas	NGS	
	Derived gases	Blast Furnace Gas	BFG	Coal product
	Derived gases	Gas Works Gas	GGS	Coal product
	Derived gases	Elec/Heat Output from Non-spec. Manuf. Gases	MNG	Product of misc. FF
	Derived gases	Coke Oven Gas	OGS	Coal product
	Derived gases	Refinery Gas	RGS	Oil product
	Derived gases	Oxygen Steel Furnace Gas	OGA	
Biomass Fuels (short cycle for CO_2)	Solid biomass	Charcoal	CHA	Wood product
	Solid biomass	Dung	DNG	
	Solid biomass	Industrial Waste	IWS	Waste
	Solid biomass	Municipal Waste (Renew)	MWR	Waste
	Solid biomass	Non-specified Combust. Renewables + Wastes	NSF	
	Solid biomass	Primary Solid Biomass (non-specified)	SBI	
	Solid biomass	Vegetal waste	VWS	
	Solid biomass	Wood	WOD	
	Liquid biomass	Biodiesel	BDS	
	Liquid biomass	Biogasoline	BGL	
	Liquid biomass	Bagasse	BGS	Sugar cane product
	Liquid biomass	Black Liquor	BLI	Pulp product
	Liquid biomass	Liquid Biomass	LBI	Bioethanol, biodiesel
	Liquid biomass	Other Liquid Biofuels	OLB	
	Gaseous biomass	Biogas	GBI	Landfills, WWTP, digester

Source: EDGAR database, 2024

Getting in touch with the EU

In person

All over the European Union there are hundreds of Europe Direct centres. You can find the address of the centre nearest you online (european-union.europa.eu/contact-eu/meet-us_en).

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Finding information about the EU

Online

Information about the European Union in all the official languages of the EU is available on the Europa website (european-union.europa.eu).

EU publications

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EU law and related documents

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EU open data

The portal data.europa.eu provides access to open datasets from the EU institutions, bodies and agencies. These can be downloaded and reused for free, for both commercial and non-commercial purposes. The portal also provides access to a wealth of datasets from European countries.

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