

Carbon footprint of coal-fired power plants in Poland

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Abstract

The use of coal as a primary energy source has significant environmental implications. In recent years, the share of coal and fossil fuels in the energy mix has declined significantly. Nevertheless, the carbon footprint of electricity generation from fossil fuels remains significant. Coal-fired power plants, where energy is generated, should be the next link in the process of calculating the carbon footprint of coal, after coal mines. This article provides an overview of the literature on the carbon footprint of power plants. It aims to analyse and assess the carbon footprint of Polish coal-fired power plants and to present the current state of knowledge on methodologies for calculating it and ways to reduce it. The article uses databases from the International Energy Agency (IEA), the Instytut Fundacji, the National Emission Balancing Centre, the Ministry of Climate and Environment, and the National Power System (KSE) from Polskie Sieci Elektroenergetyczne S.A. The analysis covered actively operating power plants in Poland (as of 2025), including the basic fuel structure, the share of emissions from fuel combustion in total energy emissions, annual emissions and the emissions intensity of fossil fuels and derivatives. The latest available data from 2020-2024 was taken into account. The carbon footprint driving climate change is a reason to take action to reduce it. The article discusses CCS (carbon capture and storage) and its extension, CCUS (Carbon Capture, Utilisation and Storage). The article is the next stage of research on the carbon footprint of various non-renewable and renewable energy sources in Poland and the European Union.

Keywords

carbon footprint, non-renewable energy sources, coal-fired power plants, LCA, Carbon Capture and Storage, Carbon Capture Utilisation



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Introduction

Fossil fuels are the main source of carbon dioxide, the greenhouse gas with the highest emissions (Wang, 2021). A report by the International Energy Agency (IEA, 2021) indicates that coal ranks second after oil in global primary energy demand and maintains a significant role in the global fuel market. Coal is also the primary fuel used for electricity generation in Poland. Data from Eurelectric - The Union of the Electricity Industry indicate that in 2024, as much as 69% of the energy produced came from fossil fuels, including 55% from hard coal and lignite. Compared to 2018, the share of coal in the mix decreased by 22%. This is a significant change, but coal and other fossil fuels still account for the carbon footprint of electricity production (Eurelectric, 2025).

The LCA life cycle assessment indicates that the method of energy production has a significant impact on the size of the carbon footprint. The carbon footprint of coal should be considered from 'cradle to grave'. One stage of carbon footprint analysis (after coal mining and production) involves coal-fired power plants that generate electricity, where coal is transported from the mine. The issue of carbon dioxide emissions from coal-fired power plants has been addressed in the works of Wang et al. (2021), Liu et al. (2023), Guo et al. (2024), Chen et al. (2025) and Liu & Li (2025). Using a first-order Taylor series approximation, Liu & Li (2025) investigated the quantitative impact of various coal composition elements on the carbon dioxide emission factor. The least squares method was used to analyse methods for calculating carbon dioxide emissions from coal-fired power plants (Liu et al., 2023). A linear programming model was used to identify the optimal carbon dioxide emission reduction strategy, taking into account the various stages of power plant production processes (Wang et al., 2021;).

Assessments of the carbon footprint of power plants were carried out in the works of Darich et al. (2017), Rasheed et al. (2021), Sun et al. (2022), Butrym and Panchenko (2023), Wang et al. (2023), Liu et al. (2024), Yousuf et al. (2025) and Sharma (2025). The impact of individual stages, such as the transport of raw materials and materials, energy production and emissions associated with the operation of coal-fired power plants, was studied by Rasheed et al. (2021). Butrym and Panchenko (2023) analysed the carbon footprint associated with electricity production from hard coal and natural gas, taking into account all stages of the life cycle – from the investment phase (power plant construction) through operation (extraction, fuel transport, energy generation and distribution) to the final stage of waste management.

Drożdż et al. (2023) conducted a comparable multi-criteria sustainability assessment of European energy generation systems, incorporating economic, environmental, and social indicators, and found that Eastern European countries face greater challenges due to heavier reliance on fossil fuels than Scandinavian countries. Similar decarbonisation challenges, exacerbated by geopolitical disruption, have been documented for Ukraine's path toward the EU's Green Deal acquis (Kolasinski et al., 2025). At the household level, the transition away from coal-dependent electricity is also shaped by economic and behavioural barriers to renewable energy adoption, as Streimikiene (2022) and Tomczyk (2025) documents for low-income EU populations facing energy poverty.

Carbon footprint calculation methodologies assess the impact of human activity on the environment and include calculating greenhouse gas emissions in accordance with the GHG Protocol (World Resources Institute, 2004; Odeh, N. A., & Cockerill, T. T., 2008). Carbon dioxide emissions can be reduced by applying CCS (carbon capture and storage) technology to coal-fired power plants in order to reduce the impact of emissions on the environment. However, LCA is necessary to assess the effectiveness of these measures (Wolferdsdorf & Meyer, 2017). CCS technology may increase emissions of sulphur oxides (SO(x)) Widder et al. (2011) and particulate matter (PM) Yousuf et al. (2025). In their literature review, Okezie et al. (2025) noted that CO₂ is the main greenhouse gas but has significant potential as a sustainable raw material for chemical production. They showed that it is possible to create useful products while maintaining the principles of sustainable development and proper energy management, which can significantly reduce anthropogenic CO₂ greenhouse gas emissions.

Human activity and its impact on the environment have been an important issue for many years, both locally and globally, first expressed in the United Nations Framework Convention on Climate Change (UNFCCC, 1992), signed on 9 May 1992 in New York. The Convention was signed that year at the Rio de Janeiro Conference, and its aim was to reduce greenhouse gas emissions and limit the risk of negative effects of climate change associated with them. The document supplementing this Convention was the so-called Kyoto Protocol, adopted on 11 December 1997. It set a target to reduce greenhouse gas emissions by at least 5% by 2012 compared to 1990 levels. This document listed emissions of six greenhouse gases: carbon dioxide (CO₂), methane (CH₄), nitrous oxide (N₂O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), sulphur hexafluoride (SF₆), and nitrogen trifluoride (NF₃) (Kyoto Protocol to UNFCCC, 2002). On 21 December 2015, during the 21st United Nations Framework Convention on Climate Change (COP21) in Paris, the Paris Agreement was adopted to limit global warming, i.e., keeping the increase in global average temperature below 1.5°C (The Paris Protocol, 2015). The agreement between the signatories expressed concern for the environment and people affected by progressive climate change. Currently, the 27 Member States of the European Union have signed the European Green Deal (2019), a continuation of previous declarations that aims to reduce greenhouse gas emissions by at least 55% by 2030 compared to 1990 levels. It is also worth mentioning the 17 goals of the UN Sustainable Development Goals (SDGs) adopted by the member states in a General Assembly resolution on 25 September 2015 in New York. Goal

13 of this agenda refers to urgent climate action to mitigate climate change and adapt to its effects (UNIC Warsaw, 2016).

Greenhouse gas emissions are inventoried in CO₂ equivalents. This equivalent corresponds to 1 megagram of carbon dioxide (1 Mg) or the amount of another greenhouse gas multiplied by the global warming potential specified in Decision 18/CMA.1 (Glasgow Climate Change Conference, 2021). In Poland, total national greenhouse gas emissions in 2022 amounted to 380.51 million tonnes of CO₂ equivalent and decreased by 34.3% compared to 1988 (KOBIZE, 2024). In 2023, according to data from the Central Statistical Office, Poland was the fifth largest emitter of greenhouse gases in the European Union, and our share of global emissions was 0.69% (GUS, 2024). The share of individual greenhouse gases in total global emissions, data for emissions in the EU (European Environment Agency, 2024), by pollutant, calculated as a share of total emissions converted to CO₂ in 2022, was: 80.6% for CO₂, 12.1% for CH₄, 53% for N₂O, and 20% for fluorinated greenhouse gases.

The article aims to determine the carbon footprint of a coal-fired power plant and to present the current state of knowledge on methodologies for calculating and reducing this footprint.

Carbon footprint calculation methodology

The Kyoto Protocol lists greenhouse gases that contribute to global warming. To determine how a given entity's greenhouse gas emissions affect the environment, a methodology for calculating the carbon footprint has been developed. Its size allows quantification of the pollutants emitted into the environment and, thus, the impact of a given entity or organisation on the climate. Because this is a problem for every country, measures have been taken for years to reduce emissions while monitoring and reporting the effects of climate change caused by these emissions.

Increased public awareness of the environmental impact of manufacturing and consuming products has led to greater interest in developing methods to reduce this impact. One technique developed for this purpose is life cycle assessment (LCA). ISO (the International Organisation for Standardisation) is a global federation of national standardisation bodies (ISO member bodies), which for many years has been developing standards such as: Environmental management – Life cycle assessment – Principles and framework (ISO 14040:2006); Environmental management – Life cycle assessment – Requirements and guidelines (14044:2006) as a family of standards for life cycle assessment (LCA), Environmental management – Life cycle assessment – Illustrative examples on how to apply ISO 14044 to goal and scope definition and inventory analysis (ISO/TR 14049:2012) and Greenhouse gases – Carbon footprint of products – Requirements and guidelines for quantification (14067:2018).

The carbon footprint is defined as the total greenhouse gas emissions generated throughout a product's entire life cycle (LCA). Scientific research has long examined methods to reduce carbon dioxide emissions from coal-fired power plants. Zhang et al. (2009) and Lee et al. (2020) reviewed LCA studies for coal-fired power plants with carbon dioxide capture and storage. They pointed out that conducting an LCA is a prerequisite for assessing the effectiveness of introducing CCS into coal-fired power plants in order to reduce the environmental impact of emissions. Another important issue is the study of the environmental costs of coal-fired power plant operations (Li et al., 2021). Life cycle assessment (LCA) as a key tool for quantifying the environmental impact of coal-fired power plants has also been addressed in the works of Odeh et al. (2008), Wang et al. (2018), Chai et al. (2018), Kemp and Lim (2020), Tarannum et al. (2020), Li et al. (2020), Sun et al. (2022), Haran et al. (2023), Liu et al. (2024), Yan et al. (2025), Butrym and Panchenko (2023), Batista et al. (2025), and Yousuf et al. (2025). Batista et al. (2025) pointed to the use of LCA to analyse and quantify the environmental impact of coal-fired power plants, which contribute significantly to global greenhouse gas emissions and air pollution. Haran et al. (2023) used a process-based LCA model to assess the energy, carbon, and water footprints of an operating coal-fired power plant's life cycle. Yousuf et al. (2025) conducted a comprehensive life cycle assessment (LCA) of an ultra-supercritical coal-fired power plant (USC CFPP).

The sustainability of energy system transformation as part of decarbonisation involves the modernisation of existing coal-fired power plants (He et al., 2024). In their research, they focused on the potential of electric heaters and thermal energy storage technology using molten salt-based heat transfer fluids to upgrade coal-fired condensing power plants (CFPP) for grid-side energy storage systems (ESS).

Lyulyov et al. (2026) provide a broader cross-country perspective on the pace of the energy transition, finding that renewable energy penetration converges faster across EU member states than carbon emission reduction itself, highlighting persistent structural divergence in decarbonisation outcomes.

The study by Rasheed et al. (2021) assessed the impact of stages such as material and coal transport and coal-fired power plant operation. LCA was used as a tool to determine the environmental footprint of electricity production in a modern supercritical coal-fired power plant. Butrym and Panchenko (2023) calculated the carbon footprint associated with electricity production from hard coal and natural gas, taking into account the entire process – from power plant construction, through fuel extraction and transport, energy production and distribution, to the management of waste generated during its production. Sherwood et al. (2020) drew attention to the scale of

emissions from coal transport. Analysing IEA (2023) data, they noted that coal basins are characterised by high emission intensity and that, in their view, transport emissions are comparable to power plant operating emissions. The environmental impact throughout the life cycle of a coal-fired power plant was examined in Jung et al. (2022). Based on actual data, a model using LCA data was constructed. Statistical tools were used to analyse changes in the environmental impact of coal-fired power plants in the context of changing exploration factors.

Yan et al. (2025) calculated emissions based on coal combustion activity and LCA, analysing the correlation between key factors affecting the carbon balance, such as coal consumption and efficiency. They emphasised the importance of prioritising high-calorific coal and modernising generation units to reduce emissions. Analyses of the relationship between electricity production and carbon footprint, taking into account primary fossil fuel consumption and associated greenhouse gas emissions, were carried out by Kemp and Lim (2020). Malode et al. (2023) conducted a life cycle assessment (LCA) to assess the environmental impact of coal-fired power plants equipped with various emission-reduction technologies. The system boundaries included processes related to raw material extraction, transport, power plant operation, and electricity transmission losses, assumed for a functional unit of 1 kWh. The life cycle assessment (LCA) was conducted within cradle-to-gate boundaries, and environmental impact indicators were assessed using the ReCiPe2016 LCIA method (Huijbregts et al., 2017). The system boundaries for coal-based energy generation and production for life cycle assessment are presented in Spath, P. L., Mann, M. K., & Kerr, D. R. (1999) and Sharma, M.M. (2025). Fig. 1 presents a general life cycle assessment diagram for a coal-fired power plant, accounting for energy, raw materials, materials, and emissions.

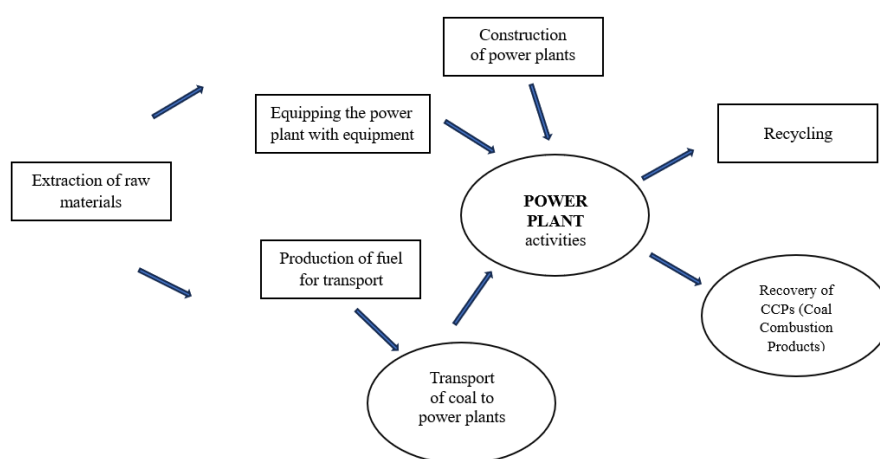


Fig. 1. General LCA diagram(*) of a coal-fired power plant.

Source: own elaboration based on (Sharma, 2025)

(*) The ellipse shape means the assessment considers energy use, materials, and emissions. Whereas the rectangle includes energy, raw materials, and emissions.

The assessment of an entity's impact on the environment, known in the literature as the concept of carbon footprint, is reflected in the Kyoto Protocol on climate change (2002). The categorisation of emission scopes has been formalised in the Greenhouse Gas Protocol (World Resources Institute, 2004) and in the corporate accounting and reporting standard developed by the World Business Council for Sustainable Development in collaboration with the World Resources Institute. A key element in quantifying greenhouse gas emissions is converting them to carbon dioxide equivalents (CO₂e), which allows comparability and aggregation of the impact of individual gases. For this purpose, so-called global warming potential factors are used (for example, for CH₄ – 25, N₂O – 298). Emissions for a specific greenhouse gas are the product of this coefficient and the amount of its emissions.

Greenhouse gas emissions from fuel combustion in the energy industry (used for the production of electricity and heat) depend largely on the type of fuel used. The fuels with the highest emission factors (i.e. those that emit the largest amounts of greenhouse gases during combustion) are the so-called solid fossil fuels (i.e. all types of hard coal and lignite, as well as coal products such as coke). For facilities such as power plants burning fossil fuels and coal products and their derivatives (hard coal, lignite, coke oven gas, or blast furnace gas), emissions can be considered a carbon footprint. However, it only accounts for the fuel emission factor and is not

calculated for the product's entire life cycle in accordance with LCA methodology. Information on fuel emission intensity in 2023 is illustrated in Fig. 2.

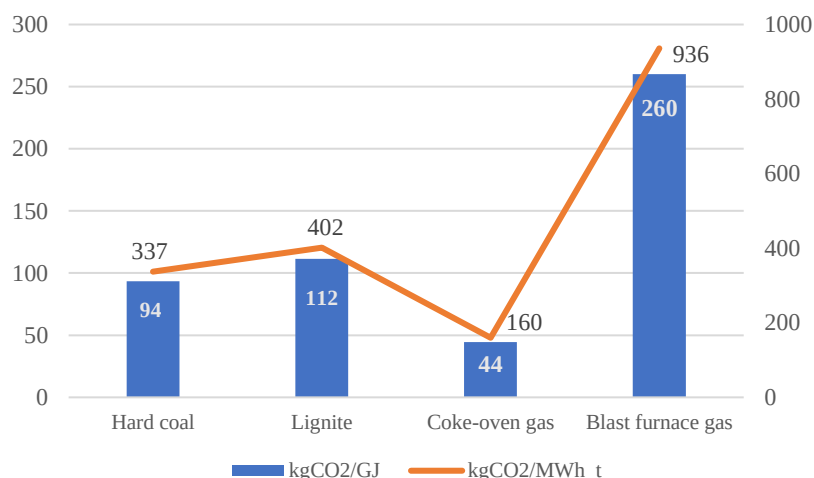


Fig. 2. Emissions() of fossil fuels and derivatives (emission factors)**

Source: own elaboration based on data from Przedlacki et al. (2024)

(**) The basis for the emissions intensity of generation and SRMC is the net electricity generation efficiency.

As sufficiently detailed data are not available, the efficiency values for individual technology groups – as well as the technologies themselves and the classification of units – were determined by Instrat based on a comparison of various sources and expert knowledge as part of a project to model energy system development paths.4

Analysis of power plants in Poland with particular emphasis on coal-fired power plants

The objects of analysis are power plants burning fossil fuels, coal products, and their derivatives. The data for the analysis come from the National Centre for Emissions Balancing and Management of the Institute of Environmental Protection – National Research Institute (KOBIZE, 2024) and from the database of thermal power plants and combined heat and power plants in Poland from the energy.instrat.pl project (Przedlacki et al., 2024), implemented with support from the European Climate Foundation, and from the Energy Market Agency's data on environmental pollutant emissions and emission indicators in the commercial energy sector (Emitor, 2024).

According to Instrat data, Poland had 65 actively operating power plants in 2024 (Przedlacki et al., 2024). Their characteristics in terms of gross available electrical capacity and gross installed electrical capacity, broken down by type: power plant (20 facilities), industrial CHP (5 facilities), independent CHP (6 facilities) and CHP (34 facilities), are presented in Fig. 3. In the case of the most numerous facilities, power plants, the maximum capacity is approx. 5100 [MW_e], and in the case of CHP, approx. 900 [MW_e].

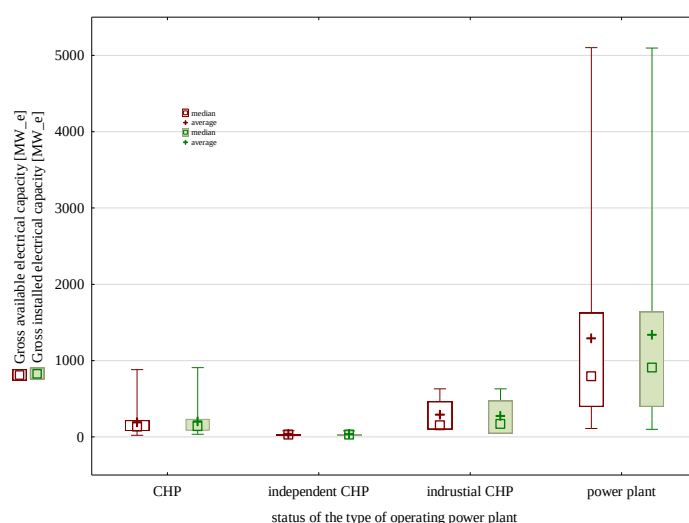


Fig. 3. Distribution of values: gross available electrical capacity and gross installed electrical capacity [MW_e] for types of operating power plants

Source: own elaboration based on data from Przedlacki et al. (2024)

The primary fuel type used in active power plants was analysed (Figs. 4-5). These were: natural gas, lignite, hard coal, coke oven gas, blast furnace gas and biomass.

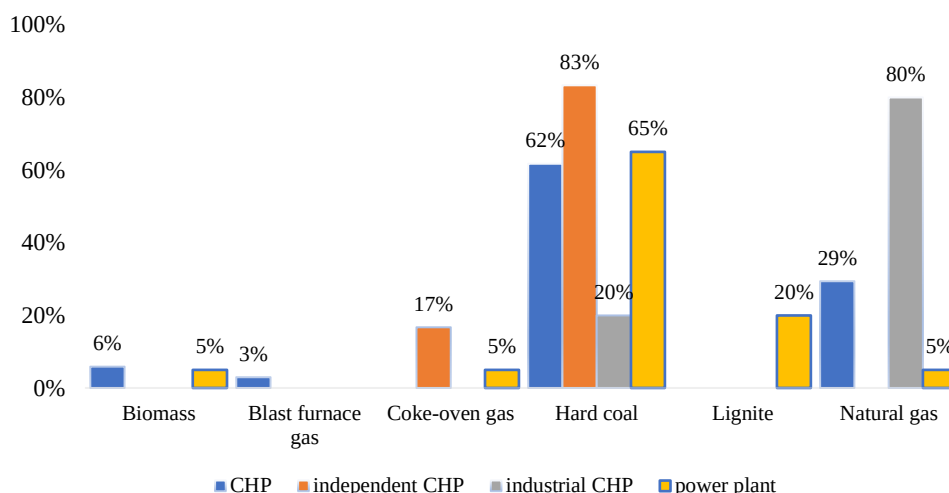


Fig. 4. Structure of the primary fuel used by type of power plant in operation.
Source: own elaboration based on data from Przedlacki et al. (2024)

In power plants, hard coal is the primary fuel for 65% of facilities; in CHP, 62%; in industrial CHP, only 20%; and in independent CHP, as many as 83%. Lignite is used as the primary fuel only in power plants, where 20% of these facilities use it. Considering the overall structure of primary fuel use in operating power plants (Fig. 3), hard coal is used in 62% of facilities.

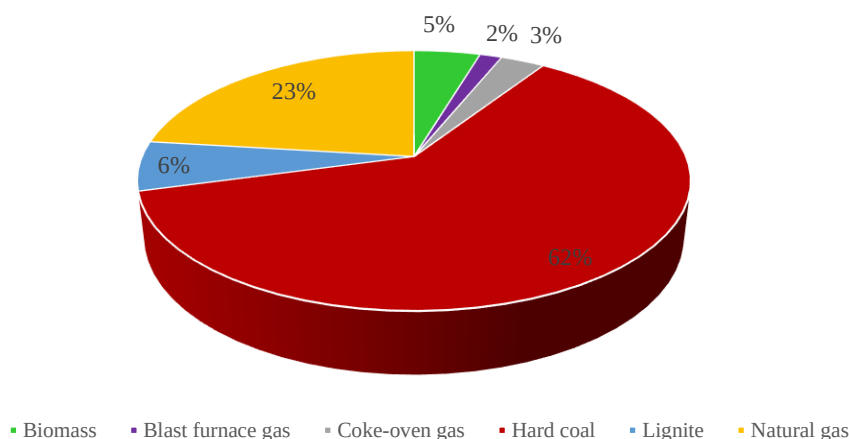


Fig. 5. Structure of the basic fuel used in operating power plants
Source: own elaboration based on data from Przedlacki et al. (2024)

Carbon footprint and other emissions in coal-fired power plants

Anthropogenic emissions of pollutants into the atmosphere are associated with burning fossil fuels for energy. Tokarski & Tajduś (2024) discussed the most important challenges facing the Polish energy sector until 2040. One of them is the reduction of greenhouse gas emissions. The largest share of energy emissions (according to data from the KOBIZE Emissions Inventory Report (2024)) comes from burning fuels to produce or convert energy. For emissions of pollutants such as SO₂ [Mg] and CO[Mg] in 2020-2022, this was over 95%, and for NO_x [Mg], approx. 84% of total energy emissions (Fig. 6).

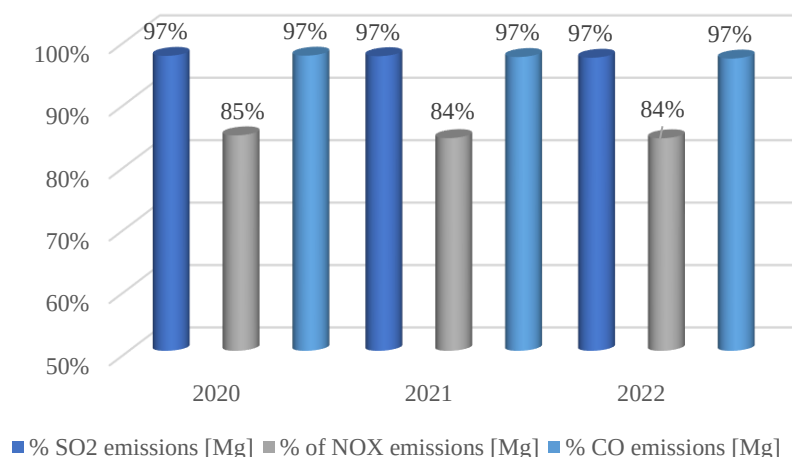


Fig. 6. Share of emissions from fuel combustion in total energy emissions.
Source: own elaboration based on data from KOBIZE (2024)

Fig. 7a- b shows the distribution of SO₂[Mg], NO_x[Mg] and CO [Mg] emissions in 2022 by type of power plant.

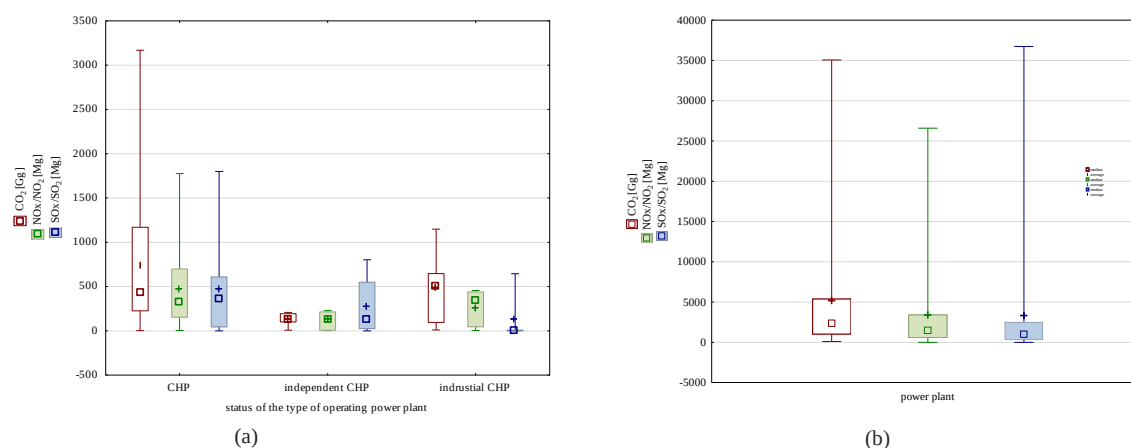


Fig. 7a- b. Distribution of annual emissions for types of operating power plants
Source: own elaboration based on data from Przedlacki et al. (2024)

The highest levels of CO₂[Mg], NO_x[Mg] and SO₂[Mg] emissions in 2022 for the examined groups of facilities were recorded in power plants and CHP facilities. This is because these facilities make up the largest share of active power plants. The combustion of fossil fuels for energy purposes implies high emissions for energy obtained from coal.

Commercial energy is energy intended for production and distribution to individual users (consumers), businesses, and public institutions (Tokarski, 2022). Tajduś & Tokarski (2020) discuss the prospects for hard coal and lignite mining in Poland through 2040 and compare them with projected demand for coal in Polish power plants and combined heat and power plants. An analysis of 2020-2024 data from reports by the National Power Grid (PSE, 2022; PSE, 2024) indicates that energy production from commercial power plants operating on hard coal and lignite accounts for a significant share of total electricity production. In 2020, it accounted for 63% (including 46% for hard coal), in 2022 for 55% (41%) (PSE, 2022), and in 2024 for 44% (33%) (PSE, 2024).

The Ministry of Climate and Environment publishes data on environmental pollutant emissions and emission indicators for commercial energy production (Emitor, 2024), i.e. commercial power plants and combined heat and power plants in Poland. The available data for 2020-2022 cover emissions of SO₂ [Mg], NO_x [Mg], CO [Mg], CO₂ [Gg], and CH₄ [Mg]. Taking into account only emissions included in the carbon footprint for carbon dioxide, the following indicators of the structure of the total carbon footprint of a coal-fired power plant (Fig. 8) in 2020-2022 were obtained. Fig. 8 shows that hard coal-fired power plants and combined heat and power plants accounted for 49% of the total footprint in those years, while lignite-fired power plants accounted for approximately 30%. The remaining approx. 21% is the footprint of gas-fired combined heat and power plants,

biomass and biogas power plants, and combined heat and power plants. Thus, of all energy sources used in power plants, coal generates the largest carbon footprint (Sharoma, 2025).

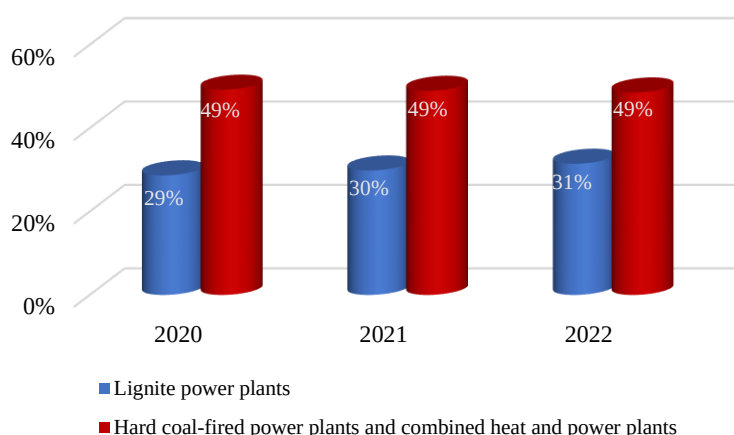


Fig. 8. Percentage share of the coal footprint of lignite-fired power plants, hard coal-fired power plants and combined heat and power plants in 2020-2022.

Source: own elaboration based on data from (Emitor, 2024)

Carbon dioxide emissions associated with energy production account for the majority of global greenhouse gas emissions (Lee, 2020; Tian, 2025). The use of fuel cells can significantly reduce these emissions (Yang et al., 2022). Tetteh et al. (2021) reviewed the literature on carbon dioxide emission reduction technologies to reduce the carbon footprint. Because coal-fired power plants generate a large share of these emissions, CCS technologies are necessary to reduce their negative effects on the climate. Many studies point to the use of coal gasification methods and carbon dioxide capture and storage technologies as a way to significantly reduce the carbon footprint: Wang et al. (2017), Liu et al. (2018), Urych and Smolinski (2019), Koteras et al. (2020), Tarannum et al. (2020), Zheng et al. (2020), Ekanayaka et al. (2020), Kumar et al. (2020), Tramošljika et al. (2021), Jadhawar et al. (2021), Erans et al. (2022), Feng et al. (2022), Urych et al. (2022), Xie et al. (2025), Ali & Gamil (2025), Sharoma (2025). Li et al. (2022), Śliwińska et al. (2022), and Li et al. (2025) also describe a technology combining CCS and CCU (Carbon Capture and Utilisation), known as CCUS (Carbon Capture Utilisation and Storage).

Bandilla (2020) discussed CCS technology aimed at reducing anthropogenic CO₂ emissions by separating CO₂ at large point sources, such as fossil fuel-fired power plants, and storing it long term in deep geological formations. This analysis focuses on: CO₂ capture, transport of captured gas to designated storage sites, and geological injection. In their study, Osman et al. (2021) assessed carbon dioxide capture technologies, such as pre-combustion, post-combustion, and oxy-fuel combustion. They analysed the current achievements in the field of carbon dioxide capture, storage and utilisation, comparing absorption methods with separation techniques.

Tarannum et al. (2020) investigated the benefits of CO₂ capture by assessing the life cycle of a power plant using fossil fuels such as coal and natural gas. They examined greenhouse gas emissions and found that CO₂ capture installations can reduce CO₂ emissions in supercritical (SCPC) and subcritical (Sub-PC) coal-fired power plants by more than 80%. Wang et al. (2017) and Ekanayaka et al. (2020) reviewed post-combustion CO₂ capture technologies. Liu et al. (2018) and Feng et al. (2022) studied CO₂ capture, considering it one of the most effective methods for reducing emissions. The authors analysed the impact of various cooling methods on water consumption in a coal-fired power plant integrated with an amine-based CO₂ capture system, in three operating modes: with power reduction; with constant power output and constant CO₂ capture; and with constant power output and constant CO₂ capture rate. The conclusions indicate that integrating the CCS system reduces water consumption, as some water vapour is directed to the reboiler, reducing the amount of steam entering the condenser.

Ali & Gamil (2025) analysed the impact of CCS technology on coal-based electricity generation pathways in line with sustainable development principles. The study aimed to develop a set of comparative indicators to assess sustainability throughout the life cycle of coal-based power generation (CBPG) integrated with CCS technology. Petrescu et al. (2017) conducted an environmental assessment of supercritical (SC) coal dust processes with carbon capture and storage (CCS) after combustion.

Tramošljika et al. (2021). The thermal efficiency of the planned A-USC units was estimated at 50% gross and 47.6% net. Compared to subcritical units, net efficiency is 8% higher, and CO₂ emissions are 16.5% lower. The energy requirements of CCS units have a significant impact on power plant efficiency and energy production, with

CO₂ emissions per unit of energy produced still calculated at 700 kg CO₂/MWh. Integrating CCS with A-USC can reduce CO₂ emissions by 90% to as low as 70 kg CO₂/MWh.

Feng et al. (2021) discussed underground gas-to-power (UGCC), which, together with CCS, is considered an environmentally beneficial approach to clean coal utilisation. Using LCA methodology, they conducted a comprehensive assessment of the impact of coal-fired power plants integrated with CO₂ capture and storage technology (UGCC with CCS) and conventional UGCC plants without CCS. They compared the results with the performance and environmental indicators of integrated surface gasification (IGCC), accounting for the full range of emissions and resource consumption throughout the operating cycle.

AirPure (Martinho et al., 2025) is an innovative technology that aims to increase the efficiency of traditional absorption systems at low carbon dioxide concentrations. This technology uses a micro-mixing device in the CO₂ hydrate production process, offering promising opportunities for efficient capture and transport of carbon dioxide under moderate conditions. To identify potential benefits and trade-offs and support the design of technological processes, this study assesses the environmental performance of a modernised power plant producing CO₂ hydrate slurry. A life cycle assessment (LCA) of the supply of 1 MWh of electricity to the grid from coal and gas power plants is being carried out both with and without the implementation of AirPure technology. For coal-fired power plants, considering different operational contexts, including alternative transport options, emissions can be reduced by 82–90% CO₂ equivalent over the entire life cycle (Martinho et al., 2025).

Life cycle assessment (LCA) is used to evaluate power plants fuelled by mixed fuels, including coal, waste, and biomass (Bennett et al., 2023). Determining the optimal share of individual fuels makes it possible to achieve net zero emissions, defined as a balance between greenhouse gas emissions and their absorption by the natural environment or CO₂ capture technologies. The principles, methods and cost estimates for achieving net-zero carbon dioxide emissions are described by Ju et al. (2025). An alternative to CCS is biological carbon dioxide capture (Onyeaka et al., 2021). Microalgae research not only enables CO₂ sequestration but also its conversion into biomass, which can be used as a carbon source for producing lipids or bioenergy. According to Onyeaka et al. (2021), this method is another tool for minimising the carbon footprint.

Li et al. (2022) described the use of carbon capture, utilisation and storage (CCUS) technology in coal-fired power plants (CFPPs), noting that it can significantly reduce carbon dioxide emissions. They also emphasised that coal-fired power plants (CFPPs) play a key role as a primary source of power in the electricity system, while also being a major source of CO₂ emissions across various sectors of the economy (IEA, 2020).

Reducing CO₂ emissions from the coal-fired power sector is crucial to achieving carbon neutrality (Gao et al., 2022). Research indicates that carbon capture, utilisation and storage (CCUS) technologies are considered a key solution for reducing these emissions in the energy sector (Li et al., 2025). In this study, they integrated an optimisation model for matching sources and sinks with a levelised cost of energy (LCOE) analysis to quantitatively assess, for the first time on a national scale, the impact of changes in energy generation hours on emission reduction costs and the spatial distribution of CCU installations for coal-fired power plants (CFPP) at the level of individual generating units. Karmaker et al. (2020) proposed a mathematical model of parameters related to the emissions of gases listed in the GHG Protocol. Using HOMER (Hybrid Optimisation of Multiple Energy Resources) software, they analysed GHG emissions from fossil fuel power plants.

Another interesting issue concerning carbon dioxide capture was raised in a paper by Moore et al. (2022). They assessed the contribution of implementing the Calcium Looping (CaL) process for CO₂ capture as a tool for achieving greenhouse gas emission reduction targets. Using multi-criteria linear programming methods, they assessed the system's links in terms of energy, environmental, and economic aspects. The minimisation criterion focused on greenhouse gas emissions and energy consumption for energy purposes, while the maximisation criterion focused on gross domestic product. Two scenarios were considered, with and without the use of the CaL process. The results for the scenario using the CaL process in coal-fired power plants showed an improvement in environmental impact, but the reduction was not significant.

A coal-fired power plant's efficiency determines its environmental impact, measured by its carbon footprint. Higher efficiency reduces fuel demand, which reduces emissions associated with extraction, transport, and, above all, combustion. According to data from the database of power plants and combined heat and power plants in Poland from the Energy.instrat.pl project (Przedlacki et al., 2024), at the end of 2023, the average efficiency was 30% (min. 27%, max. 48%).

Emissions not included in the carbon footprint

Analysis of available pollutant emissions based on data from the Ministry of Climate and Environment for commercial energy production (Emitor, 2024), the National Centre for Emissions Balancing and Management (KOBIZE, 2024) and the database from the energy.instrat.pl project (Instrat, 2024) also show that gases not classified as greenhouse gases are subject to research. As mentioned, the inventory covers emissions of the following compounds: SO₂ [Mg], NO_x [Mg], CO [Mg], CO₂ [Gg], CH₄ [Mg], but also fly ash [Mg], cadmium [kg], lead [kg] and mercury [kg] Odeh et al., 2008; Widder et al., 2011; and Kim et al., 2023.

Odeh et al. (2008) analysed the full life cycle emissions of three types of fossil fuel-based power plants: supercritical coal-fired power plant (super-PC), natural gas combined cycle (NGCC) and integrated coal gasification combined cycle (IGCC), both with and without CCS technology. The results indicate that although CCS reduces greenhouse gas potential, it can increase emissions of other air pollutants, such as NO(x) and NH₃, which can increase eutrophication and acidification.

Widder et al. (2011) raised the issue of widely implementing CCS technology in new and existing coal-fired power plants in relation to the need to reduce greenhouse gas emissions. However, they noted that achieving sustainable energy production also entails emissions of nitrogen oxides (NO(x)), sulphur oxides (SO(x)) and particulate matter (PM), which is as important an environmental issue for coal-fired power plants as greenhouse gas emissions. Yousuf et al. (2025) noted that transporting imported coal increases particulate matter emissions, which increases the potential risk to human health. Another study by Kim et al. (2023) proposed quantifying SO₂ emission rates using three aerial sampling studies over a coal-fired power plant, using the mass balance method and the Gaussian plume method. The results showed that the Gaussian plume method offered significantly better accuracy than the mass balance method. Kobos et al. (2010) assessed the potential to increase the scale of carbon dioxide (CO₂) storage in salt formations by developing an assessment model using a national database and modelling tool. They highlighted the potential to use complete data on brine formation wells that meet criteria for working depth, salinity, and geological formation intersection.

Asfur et al. (2021) studied the power plant performance parameter of heating rate. This relates to fuel economy, which implies reduced CO₂, SO₂, CH₄, N₂O, and Hg emissions. The power plant heating rate was modelled using an artificial neural network and machine learning. Maruyama et al. (2020) used computational modelling to optimise the study of the impact of carbon dioxide recovery on energy consumption. Post-combustion CO₂ capture using pressure swing adsorption (PSA) was studied for flue gases from cement plants, coal-fired power plants and gas-fired power plants, using four adsorbents. Modelling showed that reducing CO₂ recovery from 90% to 70% significantly increases efficiency while keeping energy consumption moderate. Akinola et al. (2022) described adsorption-based post-combustion carbon dioxide capture as a promising technology for reducing emissions from conventional power plants, highlighting the ease of regenerating adsorbents compared with solvent-based methods.

Zhang et al. (2009) emphasised that although CCS is one of the key technologies for reducing greenhouse gas emissions from coal-fired power plants, it should be remembered that the use of coal not only contributes to global climate change, but also causes other significant environmental effects, such as acidification, eutrophication and the depletion of non-renewable resources. A broader concept than the carbon footprint is the environmental footprint. Defining the concept of the environmental footprint has made it possible to develop a tool for assessing the impact of an entity's activities on the environment. Anthropogenic impact on the environment is understood more broadly as direct and indirect emissions to air, soil, and water; the consumption of non-renewable or limited water resources; and the degradation of biodiversity and forest resources. The concept of carbon footprint is therefore included in the concept of environmental footprint. However, the most commonly used methodology for assessing the environmental impact of anthropogenic activity is the carbon footprint.

Conclusions

Solutions aimed at decarbonising the economy and, consequently, reducing the carbon footprint are in line with the idea of sustainable development. The transition to renewable energy sources in the energy sector is a process that is changing the structure of the energy mix. The amount of emissions from the combustion of fuels used in the production of electricity and heat depends on the type of fuel used. Fossil fuels have the highest greenhouse gas emission factors. Electricity and heat production from fossil fuels contribute to environmental degradation through water eutrophication, soil acidification, depletion of non-renewable resources, and adverse climate change. Carbon footprint assessment, one method for calculating environmental footprint, is also carried out in entities in the mining and energy industries, which are responsible for the highest emissions throughout the entire life cycle of their products. This article covers power plants that use coal and its derivatives as fuel. Analysis of available data indicates that they account for a large share of the emissions driving global warming. For many years, research and analysis have focused not only on monitoring emissions, but also on finding solutions to reduce them.

A review of the literature shows that numerous studies are being conducted to find solutions to reduce greenhouse gas emissions. Many scientific studies point to measures to prevent the release of carbon dioxide (CCS) into the atmosphere through capture and storage, or capture, utilisation, and storage (CCUS).

It should be remembered that the mining and energy industries are pillars of the Polish economy, and every household consumes the energy they produce. Reducing emissions from coal-based energy is linked to the need to care for the environment for future generations. This refers to the problem of quantifying emissions, with particular emphasis on greenhouse gas (GHG) emissions that contribute to the carbon footprint. Coal-fired power plants that produce electricity and the associated pollutant emissions contribute significantly to the carbon footprint. This is one stage in the formation of coal's carbon footprint, as described in this article. Renewable

energy sources also generate a carbon footprint, but it is significantly smaller than that of non-renewable sources. Subsequent publications will refer to issues related to this topic.

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