Environmental protection - greenhouse gas emissions from electricity production in Poland

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Abstract. The analysis of greenhouse gas emissions from the production of electricity in the so-called conventional coal based thermal power plant was carried out. The aim of the paper is to prove the legitimacy of using electricity in transport in the context of environmental protection, especially against greenhouse gas emissions. Emission factors were calculated on the basis of current and original data from the national generation plant. These indices, calculated per 1 Mg of extracted and transported raw material and 1 kWh of produced electricity, are related to net production of electricity and heat and direct emission of carbon dioxide and other greenhouse gases in the assumed life cycle of the product (energy). The life cycle includes direct and indirect emissions related to the demand for various forms of energy and materials during: hard coal mining, coal enrichment processes, transport of coal by rail from the mine to the power plant, preparation of raw material for the technological process, as well as the basic process of burning raw material and obtaining electricity. The emission of greenhouse gases during the production of 1 kWh of electricity from hard coal amounts 0.9379 kg CO₂.

1. Introduction

Civilization development requires increased energy supplies and advancement of broadly understood transport infrastructure. The transport sector is one of the key factors determining, among others, the competitiveness of a given country on the international market. Transport is an integral part of every society [1]. The progressive evolution of transport infrastructure degrades the natural environment, mainly due to the use of natural resources, i.e. coal or oil and significant landscape modification. What is important, conventional fuels based on hydrocarbons are considered to be quickly depleting [2]. Negative environmental effects of the use of crude oil and petroleum derivatives are mainly related to greenhouse gas emissions (GHG) [3]. The challenge for EU Member States is to reduce GHG emissions from the transport sector [4]. Protection and improvement of the condition of atmospheric air is one of the subject of the area of interest of the European Commission. For several years, efforts to reduce GHG emissions have been intensified in EU countries. In 2017, EU greenhouse gas emissions decreased by 22% in comparison to 1990. Such a reduction is partly a result of an effort taken to achieve the assumed reduction of 20% by 2020. The transport sector (including international aviation) was the second largest source of GHG emissions, 25% in 2017. In 2019, transport is responsible for nearly 30% of total EU GHG emissions, of which road transport accounts for as much as 72% [5]. The European Community has deputed itself the target of reducing these emissions by 60% by 2050, making it somewhat independent from oil [6]. Dependence of the European economy on imported oil is a difficult area. That is why it is so important to develop and implement new solutions for transportation. In 2013, the European Commission issued a Communication from the Commission to the European Parliament, the Council, the European Economic and Social Committee and the Committee of the Regions “Clean Power for Transport: A European alternative fuels strategy”. The aim was to define a policy framework for steering the technological development and investment of alternative fuels [7]. In March 2017, the Polish Ministry of Energy, referring to European requirements and Directive 2014/94/EC, published a document and appointed a task force for the "Electromobility Development Programme". [8]. The main...
task of the team was, among others, to prepare and develop a concept for the application of the electromobility. The Polish Act on Electromobility and Alternative Fuels aims to stimulate the development and application of electro-solutions in the transport sector by assigning the legal framework for the development of infrastructure for charging electric cars and refueling alternative fuel. The Act provides for the construction of a refueling or charging network, especially in urban and densely populated areas, which will allow the usage of such vehicles without concerns about a possible shortage of fuel.

The use of electric vehicles in Poland is a certain paradox. Cars of this type are powered by electricity from the power grid which in Poland is still burdened with significant greenhouse gas emissions [9]. In consequence, electric vehicles indirectly emit pollutants or noise. Although the discussed technologies are well known and used in transport for years, but in Poland they still remain at the development stage and are perceived as uneconomical and harmful to the environment, especially when the domestic energy mix is based on hard coal and lignite. Additionally, the development of electro-mobility in Poland is hampered by the lack of a sufficient number of vehicle charging points. According to the European Alternative Fuels Observatory [10], by mid-2019, approximately 158,000 charging points for BEV (battery electric vehicle) and PHEV (plug-in hybrid electric vehicle) electric vehicles were in operation throughout the European Union, of which approximately 132,000 are points of power up to 22 kW (normal charge), and another 24,000 are points of power above 22 kW (fast charge). There are currently 949 charging points, 580 normal charge and 349 fast charge points in Poland. Compared to Germany, where there are about 29,000 charging stations for BEV and PHEV vehicles, Poland is unattractive from the point of view of electric vehicle users.

The domestic power industry in Poland operates mainly on the basis of so-called conventional thermal power plants also known as condensing power plants, where the fuel is hard coal or lignite. Having the real and actual data from an electric energy generating plant in Poland, in this paper we presented the analysis and calculation of the total GHG emission for the production of 1 kWh of hard coal and convert its value according to the amount of electric energy necessary to power an electric car. For example, according to the Allgemeiner Deutscher Automobil-Club (ADAC), the electric Hyundai Ioniq consumes about 14.7 kWh per 100 km [11].

2. Methodology

GHG analysis covers direct and indirect emissions related to the demand for various forms of energy and materials during hard coal mining, coal enrichment processes, transport of coal by rail from the mine to the power plant, preparation of raw material for the technological process as well as the basic process of burning raw material and obtaining electric energy. Such a range of analysis is called "from cradle to gate".

2.1. Conversion unit

In the GHG emission analysis, the conversion unit was defined as the generation of 1 kWh of electricity from hard coal, obtained through its combustion in a condensing power plant. During the extraction of the raw material and its transport, the unit of 1 Mg of coal was adopted, which corresponded to the data obtained from the coal mine and the Polish State Railways carrier, and these values were later transformed into the obtained kWh, with the knowledge of raw material input to the boiler.
2.2. Inventory of data for analysis

2.2.1. Production and enrichment of coal raw material

When choosing a model hard coal mine aspects like the type of coal, the level of production and the applied mechanical processing technology were taken into account as representative for the purposes of determining the energy consumption indicators as well as CO₂ emissions related to coal mining. Table 1 presents the characteristics of the raw material which is dedicated for power plants. The amount and structure of electricity and heat consumption in the mine are presented in Tables 2 and 3. Annual coal production in the mine under analysis amounts 4 368 547 Mg.

Table 1. Characteristics of hard coal

| Term             | Symbol | Unit | Operating condition | Dry condition |
|------------------|--------|------|---------------------|---------------|
| Coal             | C      | %    | 47.8                | 59.1          |
| Hydrogen         | H      | %    | 3.6                 | 4.4           |
| Nitrogen         | N      | %    | 0.8                 | 1.0           |
| Total sulphur    | S<sub>t</sub> | % | 1.8            | 2.3           |
| Oxygen           | O      | %    | 9.4                 | 11.6          |
| Moisture         | W<sub>t</sub> | % | 19.1               | 0.0           |
| Ash              | A      | %    | 17.5                | 21.7          |
| Calorific value  | Q<sub>i</sub> | kJ/kg | 18 851           | 23 879        |
| Combustion heat  | Q<sub>s</sub> | kJ/kg | 20 134           | 24 875        |

Table 2. Electricity consumption in a hard coal mine

| Electricity consumption [MWh], including: | [MWh]          |
|-----------------------------------------|----------------|
| total down                              | 107 189.539    |
| hoisting machinery                      | 15 134.380     |
| ventilators                             | 14 049.620     |
| mechanical processing                   | 15 694.520     |
| other consumptions                      | 6 876.590      |
| total                                     | 158 944.649    |

Table 3. Consumption of heat energy in a hard coal mine

| Total consumption [GJ], including: | [GJ]          |
|------------------------------------|---------------|
| heating of shafts                  | 20 454.00     |
| space heating                      | 104 924.37    |
| water preparation                   | 27 194.31     |
| total                                     | 152 572.68    |
The index of electricity consumption for producing 1 Mg of hard coal is 36.3839 kWh, while the corresponding index of heat consumption is 34.925 GJ. Assuming that electricity comes from the Polish power industry, for which the emission factor per 1 kWh of electricity produced is 0.82 kg CO$_2$/kWh [12], and the corresponding factor for the production of heat energy of 101.13 kg CO$_2$/GJ, the GHG emission associated with the production of 1 Mg of coal in the conditions of the investigated coal mine amounts 33.367 kg CO$_2$/Mg.

2.2.2. Coal transporting to power plant

To determine the energy consumption index for the coal transport part the data contained in the PKP Report [13] were used. It was assumed that the value of the unit electricity consumption index for railway transport of 1 Mg of coal at a distance of 1 km is 0.0789 kWh/(Mg/km). Based on this index, and taking into account the emission from the production of 1 kWh in Polish conditions and the distance between the extraction and combustion plants (78 km), the unit CO$_2$ emission index associated with the transport of hard coal was calculated as 5.04 kg CO$_2$/Mg.

2.2.3. Electricity production

The technological solution of the OP-650 boiler manufactured by RAFAKO company was adopted for the analysis of the emission of electricity generation. The power plant under analysis is a condensing block thermal power plant with a closed cooling water system. There are 8 power units in operation, 225 MW each. All units are equipped with a wet flue gas desulphurization system. The calculations included the distribution and amount of electricity consumption for the basic processes including preparing the raw material for combustion and auxiliary processes in the energy production process, i.e.: grinding coal in mills, dedusting exhaust fumes in an electrostatic precipitator and flue gas desulphurization by wet method (water solution of limestone meal). On the basis of data from power plant controlling system, boiler characteristics, boiler load and resulting coal consumption, the flue gas stream and composition of flue gases discharged through the chimney were determined. The following GHG streams were distinguished: CO$_2$ and N$_2$O. These values were related to 1 kWh of electricity produced and expressed in carbon dioxide equivalent, using GWP according to the latest, fifth report of the GHG Protocol [14]. To calculate the CO$_2$ emission, a unit emission index in Polish conditions was adopted: 0.82 kg CO$_2$/kWh of electricity [12]. The unit generating electricity may operate at different load levels and for the purpose of the GHG analysis for electricity production the value of 60% (minimum) of the nominal power was assumed. On the basis of the analyses of the process of electricity generation from hard coal, the total GHG emission of the process was calculated. This figure included: indirect emissions during coal extraction and enrichment; indirect emissions during coal transport to power plants; indirect emissions related to the operation of auxiliary equipment in power plants and direct emission of CO$_2$ and N$_2$O in the process of hard coal combustion (flue gases). GHG emissions from the production of 1 kWh of electricity from hard coal (60% of the boiler power) amounted to 0.9379 kg CO$_2$. Analyzing the structure of GHG emission from energy production, it can be concluded that the largest share in the total GHG emission is generated by coal combustion in power plants, i.e. direct emission.

3. Conclusions

The amount of GHG emissions during the production of electricity from hard coal in the following work differs from the value reported by the IPCC, by approximately 12%. One of the reasons for this is that emissions from nitrogen oxides with high GWP values are included in the balance sheet. Direct CO$_2$ emissions, as reported by the IPCC, underestimate the environmental impact of producing 1 kWh in terms of greenhouse gas emissions. This is because the IPCC does not take into account direct emissions of other GHGs. It also does not include indirect emissions related to energy consumption and indirect and possible direct emissions (e.g. methane mines) in the processes of coal extraction and transport to power plants, as well as in the processes carried out at power plants. The paper presents the results of
GHG emission analysis of one of the processes of energy-chemical processing of coal in Polish conditions. The applied methodology of the analysis, based on the life cycle, allowed to determine the emission of direct and indirect greenhouse gases of the considered process of coal combustion in order to obtain electricity. Detailed analysis of the above mentioned emissions was carried out within the limits “from the cradle to the gate”, i.e. from the moment of extraction of the raw material necessary for the process, through its transport to the basic technology. The GHG analysis performed in this paper is not strictly LCA analysis, however, an attempt was made to identify with the highest accuracy all indirect and direct GHG emissions in the assumed life cycle, based on actual data and process balances of electricity production in a coal-fired power plant. The analysis of GHG emissions from electricity production in Poland seems to be important in the context of ongoing discussions on electromobility. For countries such as Poland, where power generation is based on coal and lignite, GHG emissions from power generation for transport will be burdened with relatively high emission values associated with the generation of electricity and/or heat necessary for the entire process (from extraction to combustion). Additionally, to the basket of emissions should be added those resulting from the production of dedicated vehicles and their operation. As already mentioned, Hyundai Ioniq consumes 14.7 kWh for every 100 km driven, which, according to this analysis, gives GHG the production of electricity about 14 kg of emitted carbon dioxide. Therefore, in countries with a similar economic and raw material situation to Poland, calling electricity “zero-emission fuel”, as well as transport based on it, is a considerable abuse. It is in a some sense the allocation of emissions as they are in fact have an effect on the vicinity of power stations and the cars powered by this “fuel” locally relieve the congested streets of large cities.

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