WELL-TO-WHEEL CO_2 EMISSION OF ELECTRIC VEHICLE IN POLAND

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Abstract

The total CO2 emission of electric vehicle depends on a renewable energy share in an energy market of given country. At the moment, this share is significant only in a few European countries (Denmark, Germany, Scandinavian countries) having large number of water, solar and wind power plants. Additionally, France may be considered as a country possessing low-emission electric energy, because around 90% of this energy is generated by a nuclear power plants. In order to compare the greenhouse gas emission from an electric vehicle with combustion powered cars well-to-wheel (WtW) methodology may be applied. The well-to-wheel emission estimates the total CO2 which is required to generate a given power measured on vehicle wheels including generating, transferring and processing losses. The magnitude of WtW varies from 0g/km in the case of a vehicle charged directly by a solar or wind powered charging point to 200 g/km in the case of charging form public grid powered by old coal power plants.

For the Polish energy market the share of renewable energy sources is negligible (below 10%), moreover majority of a power plants uses coal to generate electricity. However, according to the EU strategy this share should be doubled until 2020. Additionally, it is considered building of a nuclear power plant, which results in further reduction of CO2 from energetic industry.

In this article WtW CO2 emission of electric driven vehicle charged from the public grid was analyzed for Polish conditions at present and various growth scenario as well. Moreover, an actual energy market structure as well as growth perspectives were reviewed.

Keywords: *CO2 emission, electric vehicle, well-to-wheel emission, air pollution, renewable energy sources*

1. Introduction

In recent years, intensive activities aimed at popularization of clean transport are carried out in many countries. One way to achieve these goals is the use of electric drive in vehicles. The volume of the total greenhouse gas emissions produced by a car very strongly depends on the share of renewables in the grid, from which the traction batteries are charged. In order to reduce harmful emissions from the energy industry the works are conducted, sometimes enforced by legal regulations, on new types of renewable energy sources (RES) in the form of hydro, solar or wind power plants. In the following part this paper analyzes the impact of the share of RES in energy production on the total CO_2 emissions coming from the electric vehicle.

The first signal to begin intensive work on reducing greenhouse gas emissions, including CO_2 emissions of anthropogenic origin - although even in this matter the opinion of experts is not clear

[1] - were the results of temperature measurement, which in recent decades show a strong upward trend (Fig. 1) [2]. Since the late nineteenth century the average temperature on Earth's surface began to grow rapidly (compared to the years 1951 to 1980 the increase was about 0.8°C). It is believed that the cause of this situation is the rapid development of industry and the increase of burning fossil fuels. This leads to increased greenhouse gas emissions, and as a result to uncontrolled growth of air pollution. Maintaining such a trend may soon lead to serious climate changes, involving the continuous increase in the average air temperature causing melting of glaciers and raising ocean levels. There is also a likely increase in extreme weather events, especially the occurrence of heat waves, droughts and heavy precipitation [3]. Burning fossil fuels has also led to the formation of acid rain. As a result of greenhouse gases such as sulfur dioxide - SO_2 and nitrogen oxide - NO, which react with water in the atmosphere to form sulfuric acid (H_2SO_4) and nitric acid (HNO3), respectively. Acid rain causes the reduction of pH of water and soil [4]. Acidification of the soil results in slowing absorption of nutrients by plants, and also inhibit the growth of microorganisms. In order to prevent from that events the action on a global scale were undertaken. As a result of agreement reached in Kyoto in 1997 (the agreement came into force in 2005), many countries undertook to control and reduce greenhouse gas emissions (Fig. 2).

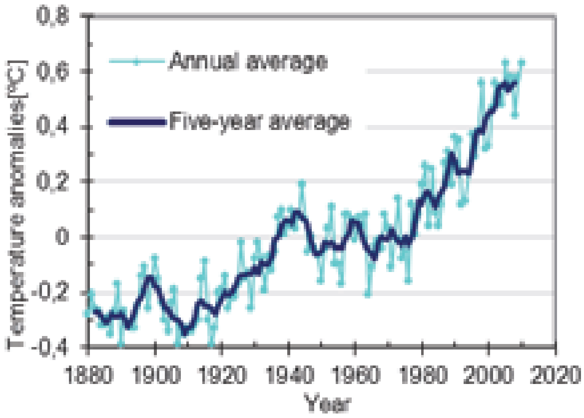

Fig. 1. Global temperature changes in recent years, the anomalies relative to the average temperature in the years 1951-1980 [6]

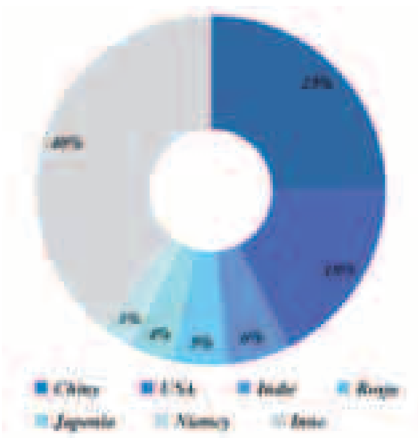

Fig. 2. CO_2 emissions by different countries [19]

As a result of many economic, political and environmental conditions the European Parliament gradually introduces regulations aimed at promoting and developing environmentally friendly technologies. One of the main currents of these activities is to reduce the emissions of CO2 and harmful substances into the atmosphere. Below are examples of acts that are directly or indirectly related to the issue of renewable energy sources in transport.

Emissions standards define the acceptable levels of pollutants such as carbon monoxide, hydrocarbons, non-methane hydrocarbons, nitrogen oxides, particulate matter, generated by vehicles per kilometer. Overview of the requirements contained in new editions of the standards is presented in Tab. 1 and 2 for cars with spark ignition and diesel engines, respectively. More and more stringent requirements are forcing manufacturers to use the newer technologies in propulsion systems such as exhaust gas recirculation valve, or a particle filter. One possible limitation of emissions of harmful substances is the use of hybrid or electric drive, which can use the energy derived from RES.

In addition to regulations on pollution emissions, the European Commission also conducts legislative work aimed at reducing CO2 emissions from transport. The strategy developed by the EC assumes the use of electric propulsion [2] in cars next to alternative fuels such as liquid biofuels and gaseous fuels. Energy storage in the case of the electric drive can be fuel cells or batteries. Specific standards include a cut in the average specific CO2 emissions (ASE) for cars to the level of 130 g/km in 2015 and 95g/km in 2020 [8], while for light-duty vehicles to 175 g/km in

Tab. 1. The emission values for cars and light commercial vehicles with spark-ignition engine

	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
CO (g/km)	2.72	2.20	2.30	1.00	1.00	1.00
HC (g/km)	-	-	0.20	0.10	0.10	0.10
NO_x (g/km)	-	-	0.15	0.08	0.06	0.06
HC + NO_x (g/km)	0.97	0.5	-	-	-	-
Particles (g/km)	-	-	-	-	0.005*	0.005*
Valid from	07/1992	01/1996	01/2000	01/2005	09/2009	08/2014

** applicable for vehicles with direct injection*

Tab. 2. The emission values for cars and light commercial vehicles with compression ignition engine

	Euro I	Euro II	Euro III	Euro IV	Euro V	Euro VI
CO (g/km)	3.16	1.00	0.64	0.50	0.50	0.50
HC (g/km)	-	0.15	0.06	0.05	0.05	0.09
NO_x (g/km)	-	0.55	0.50	0.25	0.18	0.08
HC + NO_x (g/km)	1.13	0.70*	0.56	0.30	0.23	0.17
Particles (g/km)	0.14	0.08	0.05	0.025	0.005	0.005
Valid from	07/1992	01/1996	01/2000	01/2005	09/2009	08/2014

** for vehicles with compression-ignition and direct injection the limit for emissions of hydrocarbons and nitrogen oxides is 0.9g/km and for particles is 0.10g/km until 30.09.1999*

2017 and 147 g/km in 2020 [7]. ASE is defined as the average specific CO2 emissions of all new cars of a given manufacturer. An important issue in terms of low-emission vehicles, including also electric ones, is the introduction of the super-credit definition in the regulations [6, 7], which is defined as a new car with its specific CO2 emissions below 50g/km. In the calculations concerning ASE the super-credits are calculated as a multiple of the type of car, but in subsequent years, the coefficient decreases to 1. This action is highly stimulating the manufacturers to market the electric or hybrid vehicles (because only these can meet the requirements for super-credits) because, especially in the early years, even single models, with a multiplier equal to 3.5 strongly affect the calculated ASE value.

2. The share of individual energy sources in the market

The country's energy structure is primarily determined by the amount of owned natural resources and the possibility of their exploitation. The current Polish energy economy is thus based on more than 80% of energy generation from coal (Fig. 3). Other raw materials - natural gas and oil are present in small quantities and do not meet the national demand hence the need to import these materials from abroad. One of the objectives of the European Union within the overall environmental commitments is to reduce greenhouse gas emissions by 20% compared to 1990. This fact obliges Poland to significantly change the structure of energy - to reduce the share of energy from coal in favor of renewable energy sources and nuclear energy. Energy acquisition in the European Union is more or less spread evenly on each of the primary energy sources (Fig. 4).

According to the assumed development strategy, the share of RES in total energy production for the EU's countries in 2020 should rise to about 20% [9]. At present, there is a great differentiation among the individual countries (Fig. 5), with an average of about 10%. The largest share of RES of 50% has been received in Sweden, which was the objective to achieve in 2020, and this result was obtained in 2009.

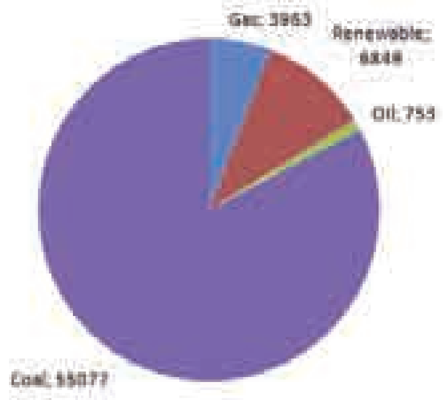

Fig. 3. Primary energy in Poland coming from various sources, 2010, [000's] ton [8]

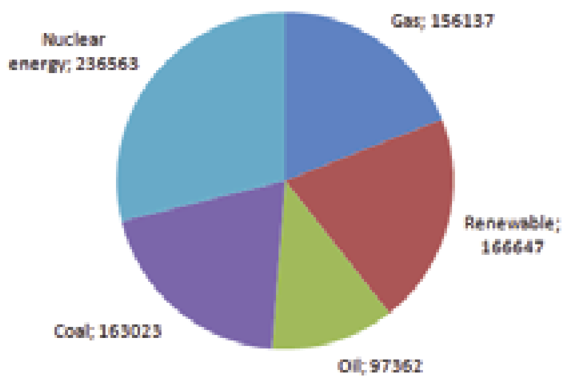

Fig. 4. Primary energy in the European Union coming from various sources, 2010, [000's] ton [8]

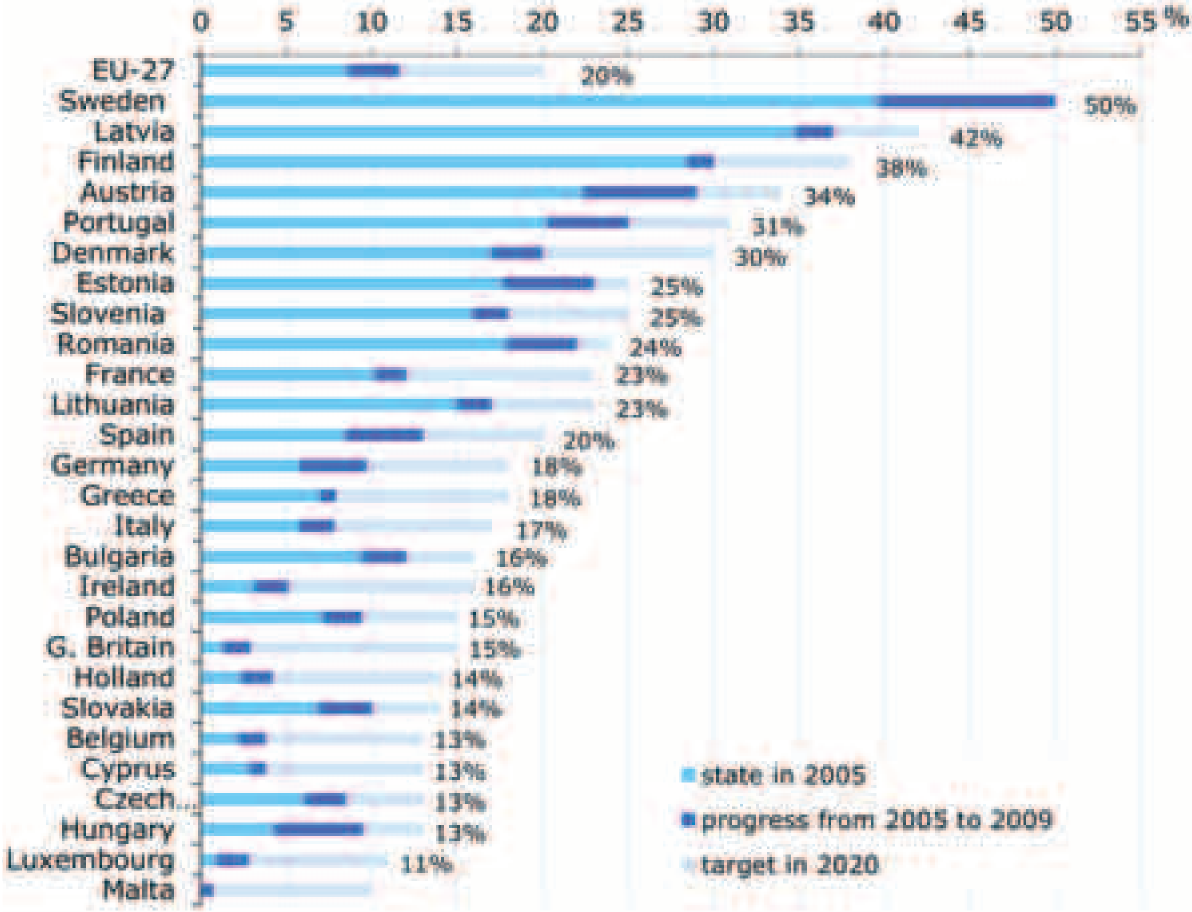

Fig. 5. The share of RES in final energy [10]

As compared to the others, Poland is a country with a small share of RES in total production, both as regards the current state (9%) and the plans (15%). Electrical energy is extracted primarily from burning fossil fuels which mean additional CO2 emissions. As a result, the WtW emission of the vehicle charged in Poland is comparable to the internal combustion engine powered vehicles. The situation may be improved by the planned construction of nuclear power plants, which are not included in the RES, but also do not emit greenhouse gases during the production of electricity

3. Total emissions of CO_2

The energy stored in the traction batteries used in the electric propulsion system of a vehicle must be supplemented as far as depletion by charging from the power grid. During the production of electricity CO2 is emitted to the atmosphere, the volume of which depends on the structure of the given power system. Thus, it is possible for the electric car, as in the case of vehicles with internal combustion engines, to determine the total emissions of CO2 per km (WtW), which depends on the type of the power station supplying a given grid, transmission and distribution losses and efficiency of the propulsion system [11].

Table 3 presents the results of tests carried out by van Vliet [12] concerning the total CO2 emissions from the cars of the compact class fitted with different types of drive. The emission ranges shown in Tab. 3 for the cars powered by electricity from the grid (PHEV and BPEV) mean the values obtainable depending on the type of the power plant from which the current used for charging becomes. For the electric car BPEVWM 2015 the total emission amounts to 0 g/km in the case of the energy from renewable sources of energy, and 47 g/km for the energy from a gas power plant and 139 g/km with the use of energy from old-type coal plants [11].

Tab. 3. The total CO_2 emissions of a compact car, depending on drive configuration [12]

Drive configuration*	Fuel	Total emission, [g/km]
SZC	Diesel	156±5
SZI	Petrol	163±6
Parallel hybrid	Petrol	129±4
SHEV central engine	Petrol	108±21
SHEV motors in the wheels	Petrol	93±20
PHEV CM 2010	Electric energy/petrol	25-151
PHEVWM in the future	Electric energy/petrol	22-129
BPEVCM 2010	Electric energy	0-166
BPEVCM 2015	Electric energy	0-163
BPEVWM 2015	Electric energy	0-139
BPEVWM in the future	Electric energy	0-136

**) SZC - compression-ignition engine; SZI - spark-ignition engine, SHEV - serial hybrid drive; PHEV CM - "plug-in" hybrid drive with the central engine, PHEVWM- "plug-in" hybrid drive with motors in the wheels, BPEVCM - electric drive with a central motor, BPEVWM - electric drive with motors in the wheels*

The total CO2 emissions can be divided into Well-to-Tank emission (WtT) and Tank-to-Wheel (TtW) emission. In the calculations the following assumptions were made regarding the efficiency of power plants:

– renewable sources do not emit CO_2 at power generation,
– gas-fired power plants, in accordance with the recent EU's directives have an efficiency of 52.5% [13], while the efficiency associated with the coal extraction, compression and transport amounts to 90% [14, 15],
– annual average efficiency of coal-fired power plants is 44.2% [13], and the efficiency associated with the production and transport is equal to 98% [14, 15].

The WtT value can be determined on the basis of CO2 emissions of a particular type of power station WtTsource and losses resulting from the efficiency ηgenerator and fuel transport ηtransport as:

$$WtT = WtT_{source} / \eta_{generator} / \eta_{transport\_fuel} / \eta_{grid} / n_{charge\text{-}discharge}. \quad (1)$$

The efficiency of the power grid does not depend on the primary fuel used and is 86% [13]. After delivery to the point of charging the electricity is stored in the batteries of the vehicle (charging) and then absorbed by the drive system (discharging) with a specified efficiency, which can be taken as 92% [11]. Electric drive allows you to convert energy from the battery to mechanical energy at the wheels of the vehicle. The nominal efficiency of the three-phase induction motor (ηengine), the most commonly used in electric vehicles, is 92% [16]. The DC/AC converters are used for motor control, which efficiency (ηconverter) declared by the manufacturers is 97% [16, 17]. The losses in the mechanical part of the vehicle propulsion system (ηmechanical) are equal to about 2%.

The value of TtW efficiency can be determined from the following relation:

$$\eta TtW = \eta engine / \eta converter / \eta mechanical. \quad (2)$$

The value of electric energy, taking into account the TtW losses, absorbed by the electric vehicle moving in a standardized cycle ECE-UEDC [18] to pass 1km amounts to 180 Wh/km [11]. The forecast of fuel consumption for electricity production in Poland prepared by the Ministry of Economy [19] is presented in Tab. 4 and Fig. 6 (scenario 1). It assumes the construction of nuclear power plants and increase in the renewable energy's share in total production.

The authors suggested two additional scenarios for the energy market development in Poland:

– Scenario 2 (Fig. 7), aims to reduce consumption of coal, nuclear power development at the level assumed by the Ministry of Economy for Scenario 1 and a significant increase in the share of renewable energy in total production. The values were selected in such a way to enable the comparison of the total CO_2 emissions of the electric vehicle charged from the public grid, estimated based on equation (1) and (2), with the requirements of the EU for internal combustion engine powered vehicles,
– Scenario 3 (Fig. 8), implies a departure from the planned nuclear power plants and maintaining the development pace of the energy based on renewable sources. A gap in energy production due to a lack of nuclear power plants will be filled by coal-fired plants.

Tab. 4. Fuel consumption for electricity generation [ktoe] [19]

	2006	2010	2015	2020	2025	2030
Hard coal	25084	20665	18897	17722	16327	18331
Brown coal	12517	11091	12036	9266	11095	9615
Natural gas	961	970	1094	1623	2114	2473
Petroleum products	533	591	732	791	806	837
Nuclear energy	0	0	0	2515	5030	7546
Renewable energy	703	1461	2912	5128	5995	6212
Waste	144	154	162	168	185	201
Total	39942	34932	35833	37213	41552	45215

4. Summary

Based on the analysis of three different scenarios for the energy market development in Poland (Fig. 9) the following conclusions can be drawn concerning the total CO2 emissions:

– at present, the WtW value for an electric car is at the level of 180 g/km,
– development of low-carbon energy based on nuclear power plants and renewables, according to the strategy adopted by the Ministry of Economy, shall allow for a gradual reduction of WtW emission for an electric vehicle. According to the analyzes carried out in 2030, the WtW value determined on the basis of scenario 1 shall amount to ca. 130 g/km, which is more than implied by the EU legislation for passenger cars powered by combustion engines (95 g/km),
– achieving the WtW emissions for an electric-powered car at 95 g/km requires limiting the contribution of coal-fired power plants and increasing the share of renewable energy to about 30% of total production,
– stopping the program of the nuclear power station construction will stop the decline in WtW emissions on the level of 160 g/km, which far exceeds the standards required for passenger cars with a combustion engine.

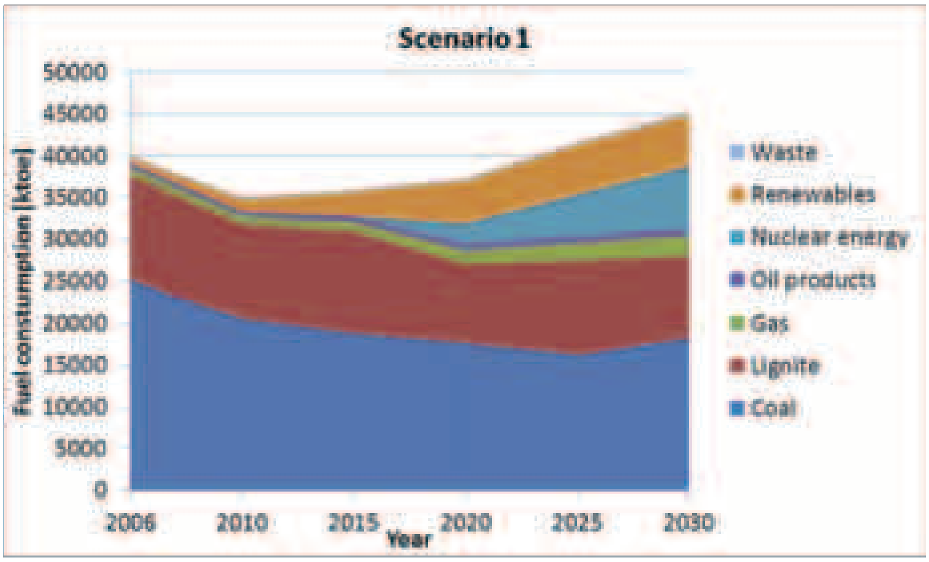

Fig. 6. Fuel consumption for electricity production [19]

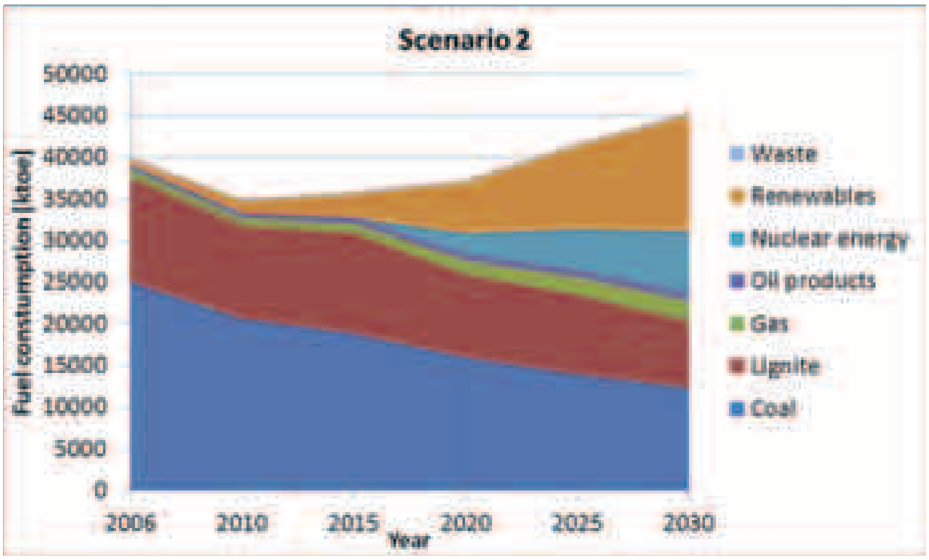

Fig. 7. Fuel consumption for electricity generation, taking into account CO2 emissions of electric vehicle

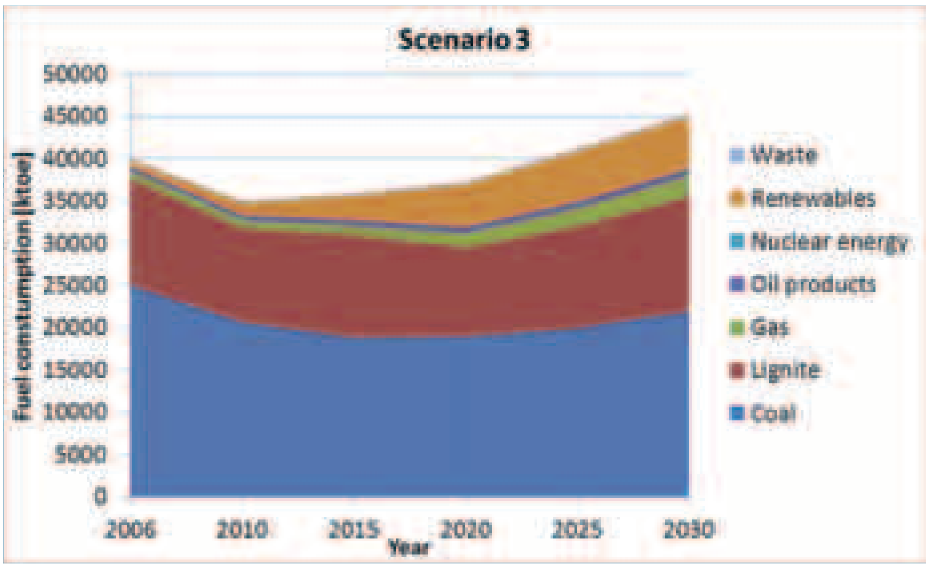

Fig. 8. Fuel consumption for electricity production in the event of failure to build nuclear power plants

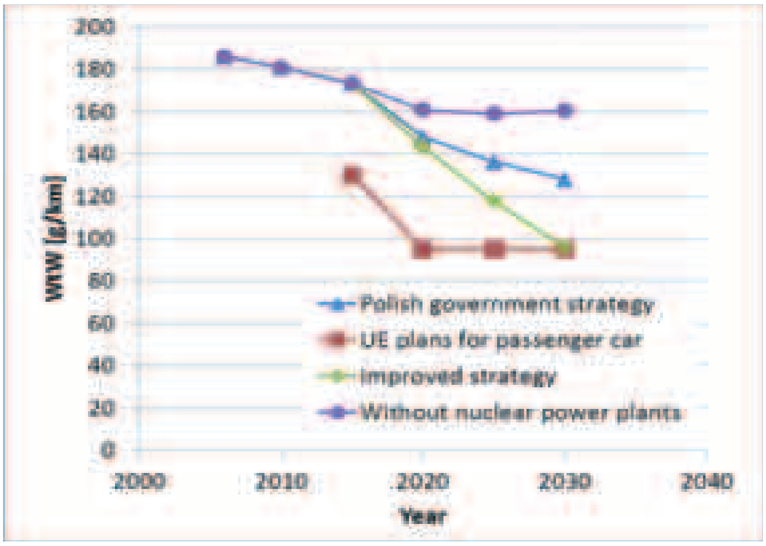

Fig. 9. Changes in the total CO2 emissions of electric vehicle for the different scenarios of the energy market development in Poland

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