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ESTIMATING ENVIRONMENTAL BENEFITS RESULTING FROM THE JUSTIFICATION FOR THE IMPLEMENTATION OF HYDROGEN TECHNOLOGY IN THE ROAD TRANSPORT IN POLAND

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Abstract

Taking into account the depletion of crude oil resources, as well as progressive climate changes, requires both in the short and the long term a radical restructuring of the EU's transport system. Among the measures designed to ensure attaining objectives of transport policy there are, among the others, proposals such as: gradual phasing-out of the conventionally-powered cars from the cities by the 2050 and transferring in the same time horizon, 50% of passenger transport over medium distances and the freight one over long distances, from the roads over to other modes of transport.

New technologies for vehicles and traffic management will be the key to decreasing pollutants emissions form transport.

The method of estimating environmental benefits resulting from the expected development of hydrogen technology in the road transport in Poland. The results of the adopted scenario of the expert forecast by the 2050 of the development of the fleet of cars equipped with hydrogen supplied fuel cells diving along the Polish roads, forecasts of the mileages of these vehicles. Predicted consumption of petroleum originated fuels by the vehicles being replaced by electric vehicles equipped with fuel cells. Estimating the emissions of pollutants by the said car fleet. The costs not incurred, related to the air pollution by gases and dust emitted from combustion engines of cars and buses as a result of the development of hydrogen technology in Poland in the selected forecast years, calculated based on the rates in force in Poland. These costs estimated based on the indicators published by the European Commission.

Keywords: *road transport, hydrogen technology, future development, environmental benefits*

1. Introduction

For over 20 years in various countries of the world there we has been research carried out and then performance tests with the use of hydrogen to power electric cars fuel cells. The result is the creation, by the 2015, of fewer than 80 public stations refuelling hydrogen car tanks. In the heart of Berlin, for example, at a distance of about 100 km from the Polish border, there are four such stations. There is subsequent hydrogen refuelling stations planned to be built. In Europe, by the 2020, their number is expected to exceed 50, of which nearly half will be located in Germany. Naturally, the development of the fleet of electric cars with fuel cells is preceded by the construction of adequate hydrogen fuel refuelling infrastructure.

Poland, having accepted relevant EU recommendations on ensuring the accessibility, on its territory, primarily along the main transport routes, to the hydrogen-refuelling infrastructure, will be incorporated in the forthcoming years in the transport system using modern technology, which the hydrogen technology is. It will be a long-term process, probably dependent on the financial considerations when it comes to investing in the said infrastructure. From this infrastructure will benefit both Polish hydrogen cars users, including urban bus transport companies, as well as hydrogen cars users from other countries visiting Poland.

The expected development and the gradual implementation in Poland of the innovative technology that the electric cars equipped with fuel cells supplied with hydrogen are in transport,

can undoubtedly bring environmental effect, helping to limit growth and reduce the physical size of the pollution emitted from the engines of the conventional car fleet. In addition, to this issue is devoted this article.

2. Subject matter and research methodology

The economic effects arising as a result of replacing vehicles with internal combustion engines, with hydrogen vehicles, will result from the avoided (in this case) pollutants emissions from the vehicles running on petroleum fuels and from the applicable fee rates for gases or dust introduced into the air. Hence, it is important to adopt certain assumptions, in this case the expert assumptions regarding the future development of the fuel cells cars fleet in Poland and the intensity of their use.

The adopted, selected assumptions for the forecast concerning the cars fleet, using hydrogen fuel in the years 2025 - 2050 (replacing the cars feet with a conventional propulsion) [2] are given in Table 1.

Tab. 1. A scenario assuming the number of vehicles with engines running on petroleum fuels replaced by hydrogen-fuelled vehicles in Poland in the years 2025-2050 [2]

Year/Listing/	Unit	2025	2030	2040	2050
1	2	3	4	5	6
passenger cars	no	1000	15000	600000	2000000
buses	no	10	100	500	1000
passenger cars transiting Poland or heading for Poland	no/year	10000	60000	100000	300000
in this: transiting	no/year	4000	24000	40000	120000
heading for Poland	no/year	6000	36000	60000	180000

Making appropriate estimates, it was established by experts that:

- in the first periods of the forecast the passenger cars with fuel cells will be operated primarily in fleets, hence their average annual mileages will be relatively high (around 25 thousand km/year),
- the buses with fuel cells will primarily be operated in urban centres and their average annual mileage in the coming years will amount to approximately 50 thousand km/year,
- among the cars coming to Poland after 2020, 40% will be the cars transiting through Poland with an average mileage in both directions of 1500 km, and 60% the cars for which Poland will be the country of destination, with an average mileage (travelling in both directions: arrival and departure) of 500 kilometres.

The electricity for hydrogen production will come from renewable energy sources. It is assumed that in Poland is will mainly be produced by the electrolysis of water. The hydrogen, according to the opinion of one of the main energy operators on the Polish market, would represent storage of the energy obtained from the surplus electricity at a time when the demand of the economy, including households, is the smallest.

The current average operational petrol consumption per 100 km of the statistical passenger car in Poland is estimated at 8 dm^3/100 km [8]. For years, of the said forecast the decline of this value is assumed [8]. Average operational consumption of diesel oil per 100 km was assumed, for example, by a city bus (according to the manufacturer of the Solaris Urbino 18.75 m articulated bus) at 57 dm^3/100 km [1], [3]. Average operational consumption of diesel oil per 100 km of bus over 3.5 Mg GTW in the forecast years should increase [8].

3. Research results and discussion

Under the adopted assumptions, replacing part of the cars fleet equipped with an engines running on petroleum fuels with the electric cars with fuel cells would allow a reduction in the

consumption of these fuels in 2025 by about 1900 Mg (84 TJ of energy), respectively, in 2030 about 15.4 Gg (676 TJ, in 2040 by about 423 Gg (18600 TJ), in 2050 about 1.394 Gg (61300 TJ) (Tab. 2).

The calculated weight of emissions according to the type of pollutant from the engines of passenger cars, buses and passenger cars transiting through Poland or driving to Poland, is a product of the weight of fuel consumed and the corresponding average energy indicators of the pollutants emissions (Tab. 3).

The average energy indicators of the key pollutants' emission from internal combustion engines per unit of fuel energy were adopted based on the data published by the National Centre for Emissions Balancing and Management (KOBiZE) [4] [5]. The indicators were adopted for the passenger cars equipped with catalytic converters in the low-emission gasoline engines, and in the case of buses of more than 3.5 Mg GTW the indicators assumed were for the engines of the new generation with exhausts catalytic converter. Since the forecast values of the pollutants emissions indicators for the country were not available, it was decided to adopt for the entire forecast period the indicators published by KOBiZE.

Tab. 2. Estimated consumption of petroleum fuels by motor vehicles replaced by electric vehicles equipped with fuel cells

Consumption of petroleum fuels	Unit	**2025**	**2030**	**2040**	**2050**
in this: **passenger cars**	thousand dm^3	1725	14400	558000	1860000
buses	thousand dm^3	230	2890	14500	29000
passenger cars transiting Poland or heading for Poland	thousand dm^3	621	3456	5580	16740
Consumption of petroleum fuels	Unit	**2025**	**2030**	**2040**	**2050**
in this: **passenger cars**	Mg	1259	10512	407340	1357800
buses	Mg	188	2370	11890	23780
passenger cars transiting Poland or heading for Poland	Mg	453	2523	4073	12220
Total	Mg	1901	15405	423303	1393800
Consumption of petroleum fuels	Unit	**2025**	**2030**	**2040**	**2050**
in this: **passenger cars**	TJ	55	463	17923	59743
buses	TJ	8	103	515	1030
passenger cars transiting Poland or heading for Poland	TJ	20	111	179	538
Total	TJ	84	676	18617	61311

Source: own calculations based on the data from Tab. 1, [3], [8].

Tab. 3. Estimated weight of the pollutants emission from the vehicles expected to be replaced by the electric cars with fuel cells by the year 2050. [Mg]

Year/Emission	**2025**	**2030**	**2040**	**2050**
1	2	3	4	5
carbon dioxide	5895	47838	1310457	4313732
methane	0.6	4.4	128.7	426.0
nitrous oxide	0.2	1.9	55.0	182.2
carbon monoxide	138	1055	32973	109721
nitrogen oxides	22.1	186	4669	15248
aliphatic hydrocarbons and their derivatives	5.7	45	1292	4270
cyclic hydrocarbons, aromatic and their derivatives	2.4	19.3	554	1830
total particulate matter	0.2	2.5	14.9	33.6

Source: own calculations based on the data from Tab. 2, [4].

This reduction in the consumption of petroleum-based fuels by the road transport replaced by electric vehicles equipped with fuel cells would in effect result in:

- in 2025, a reduction in carbon dioxide emissions by 5.89 Gg, methane by 0.6 Mg, nitrous oxide by 0.2 Mg, carbon monoxide by 138 Mg, nitrogen oxides by 22 Mg, non-methane volatile organic compounds by 8.1 Mg , total particulate matter by 0.2 Mg;

- in 2030, the reduction in carbon dioxide emissions by 47.8 Gg, methane by 4.4 Mg, nitrous oxide by 1.9 Mg, carbon monoxide by 1055 Mg, nitrogen oxides by 186 Mg, non-methane volatile organic compounds by 65 Mg, total particulate matter by 2.5 Mg;
- in 2040 the reduction in carbon dioxide emissions by 1310 Gg, methane by 129 Mg, nitrous oxide by 55 Mg, carbon monoxide by 33 Gg, nitrogen oxides by 4.67 Gg, non-methane volatile organic compounds by 1.85 Gg, total particulate matter by 15 Mg;
- in 2050, the reducing in carbon dioxide emissions by 4314 Gg, methane by 426 Mg, nitrous oxide by 182 Mg carbon monoxide by 109.7 Gg, nitrogen oxides by 15.2 Gg, non-methane volatile organic compounds by 6.1 Gg, total particulate matter by 33.6 Mg.

The average fee rates for the pollutants emission as the result of the combustion of motor fuels were adopted based on the regulations in force in Poland [6] (Tab. 4).

Tab. 4. The charge rates for gases or particulate matter introduced into the air in force in Poland in 2015. [PLN/kg]

Type of the pollutant	The unit of the rate [PLN/kg]
Carbon dioxide	0.00029
Methane	0.00029
Carbon monoxide	0.11
Nitrogen oxides (expressed as nitrogen dioxide)	0.53
Aliphatic hydrocarbons and their derivatives	0.11
Cyclic hydrocarbons, aromatics and their derivatives	1.44
Particulate matter from the fuel combustion	0.35

Source: [6]

In the case of nitrous oxide emission, it was assumed that the charges rate for gases or particulate matter introduced into the air is equivalent to the rates for the emission of nitrogen oxides.

In the case of the emission of non-methane volatile organic compounds (NMVOC), the rates applied were those related to the emission of aliphatic hydrocarbons and their derivatives, and the rates for the emission of cyclic hydrocarbons, aromatic and their derivatives on the assumption that the proportions of their emissions (in the NMVOC emission) are similar to the share of these components in motor fuels. Thus, it was assumed that in the NMVOC emission, the aliphatic hydrocarbons and their derivatives constitute 70%, the cyclic hydrocarbons, aromatic, and their derivatives account for 30%.

In the absence of other grounds for the assumptions, the rates set for 2015 have also been adopted for the forecast years.

Not incurred costs related to the air pollution by gases and particulate matter emitted from combustion engines of cars and buses as a result of the development of hydrogen technology in Poland by the 2025, estimated in accordance with applicable in Poland in 2015 charges for gases and particulate matter introduced into the air were determined to be at about 33 thousand PLN, in 2030 about 263 thousand PLN, in 2040 at about 7.5 million PLN, and in 2050 at about 24.6 million PLN (in 2015 prices) (Tab. 5).

Setting by the governmental bodies new, higher than those currently in force in Poland, individual fees for gases or particulate matter introduced into the air, which would apply to vehicles with internal combustion engine, would represent a policy tool for promoting the use of alternative fuels in road transport contributing to the development of modern, environmentally friendly transport technologies.

For comparisons sake, the costs related to air pollution by the exhausts emitted from internal combustion engines of cars and buses, estimated based on the indicators published by the European Commission, have been calculated [7]. The indicators taken into account refer to:

- passenger cars with petrol engines with a displacement volume of 1.4 - 2.0 dm^3, meeting the Euro 6 pollutants emission standards requirements:

Tab. 5. Estimated (acc. to the rates applicable in Poland) costs of air pollution by the pollutants emission from automotive internal combustion engines (avoided because of the development of hydrogen technology) in Poland by the 2050. [Thousand PLN]

Year/Emission	2025	2030	2040	2050
1	2	3	4	5
carbon dioxide	1.7	13.9	380.0	1251.0
methane	0.0	0.0	0.0	0.1
nitrous oxide	0.1	1.0	29.1	96.6
carbon monoxide	15.2	116.0	3627.0	12069.3
nitrogen oxides	11.7	98.5	2475.0	8081.5
aliphatic hydrocarbons and their derivatives	0.6	5.0	142.1	469.7
cyclic hydrocarbons, aromatic and their derivatives	3.5	27.8	797.4	2635.0
total particulate matter	0.1	0.9	5.2	11.8
Total avoided costs	32.9	263.1	7455.8	24615.0

Source: own calculations based on the data from Tab. 3 and 4

- in the city traffic: 0.4 Eurocent/ veh-km,
- in the suburban traffic, rural one and on motorways: 0.1 Eurocents/veh-km.
- city buses with engines running on Diesel fuel, with a maximum weight exceeding 18.0 Mg, meeting the Euro 6 pollutants emission standards requirements, in the city traffic: 2.0 Eurocent/veh-km.

The share of urban mileages in the total passenger cars' mileages in Poland is estimated at 40% [8]. It was assumed that this share would be retained in the forecast period.

For simplicity sake, it was assumed that the traffic of vehicles transiting the Polish territory and those heading for Poland, would take place mainly on the extra urban roads.

Potential cost reduction of air pollution by gases and particulate matter emitted from automobile engines resulting from the development of hydrogen technology in Poland would be higher in their estimations based on appropriate unit costs operating in other countries, and adopting the current mid-European value would amount in 2025 to - 308 thousand PLN (72 thousand €), in the year 2030 - 2772 thousand PLN (649 thousand €), in 2040 - 87.1 million PLN (€ 20.4 million), in 2050 - 287 million PLN (€ 67.3 million) (Tab. 6).

The estimates of the said costs related to the emission of pollutants from internal combustion engines according to the rates of the European Commission are more than 10 times higher than those are resulting from calculations based on the current rates in Poland for gases or particulate matter emitted into the air.

This clearly indicates the importance of the development of innovative technologies in transport, which is the use of electricity generated in the fuel cells powered by hydrogen, fitted to vehicles, and the political tools supporting the development, that remain at the discretion of the public administration.

4. Conclusions

1 As a result of replacing vehicles with internal combustion engine with hydrogen fuel cells vehicles, the environmental effects will result from the avoided (in this case) pollutants emission from vehicles powered by petroleum fuels.

2 It is assumed that the electricity to produce hydrogen will come from renewable energy sources. In Poland, it will mainly be produced by the water electrolysis. The hydrogen would be a storage of energy from the surplus electricity at a time when the demand of the economy, including households, is the smallest.

3 With the forecasting assumptions, replacing part of the fleet of cars equipped with an petroleum fuels powered engine, by fuel cells electric cars would allow a reduction in the consumption of these fuels in the year 2030 by approx. 15.4 Gg (676 TJ) and in 2050 by approx. 1394 Gg (61300 TJ).

Tab. 6. Estimated (acc. to the rates of the European Commission) costs of the air pollution (avoided as a result of the development of hydrogen technology) in Poland by the 2050

Year/Listing/	Unit	2025	2030	2040	2050
1	2	3	4	5	6
Passenger cars	thousand €	55	495	19800	66000
In this: in the city traffic	thousand €	40	360	14400	48000
In the extra urban traffic	thousand €	15	135	5400	18000
Buses	thousand €	8	100	500	1000
Passenger cars transiting Poland or heading for Poland	thousand €	9	54	90	270
In total	thousand €	72	649	20390	67270
Passenger cars	thousand PLN	235	2114	84564	281879
In this: in the city traffic	thousand PLN	171	1538	61501	205003
In the extra urban traffic	thousand PLN	64	577	23063	76876
Buses	thousand PLN	34	427	2135	4271
Passenger cars transiting Poland or heading for Poland	thousand PLN	38	231	384	1153
In total	thousand PLN	308	2772	87084	287303

Source: own calculations based on the data from Tab. 1 [7], [8].

4 Reduced consumption of petroleum fuels by the road transport replaced by electric fuel cells equipped vehicles would bring in effectively:
   a in 2030, reduction of the carbon dioxide emission by 47.8 Gg, methane by 4.4 Mg, nitrous oxide by 1.9 Mg, carbon monoxide by 1055 Mg, nitrogen oxides by 186 Mg, non-methane volatile organic compounds by 65 Mg, total particulate matter by 2.5 Mg;
   b in 2050, reduction of the carbon dioxide emission by 4314 Gg, methane by 426 Mg, nitrous oxide by 182 Mg carbon monoxide by 109.7 Gg, nitrogen oxides by 15.2 Gg, non-methane volatile organic compounds by 6.1 Gg, total particulate matter by 33.6 Mg.

5 The avoided costs related to the air pollution by gases and particulate matter emitted from combustion engines of cars and buses as a result of the development of hydrogen technology in Poland, estimated based on the charges existing in Poland in 2015 for the gases and particulate matter introduced into the air, would amount, by the 2030 to about 263 thousand PLN, in 2050 at about 24.6 million PLN (in the 2015 prices).

6 The estimates of these costs related to the emission of pollutants from internal combustion engines according to the rates of the European Commission are more than 10 times higher than those are resulting from the calculations based on the current rates in Poland for gases or particulate matter emitted.

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