POLITYKA ENERGETYCZNA – ENERGY POLICY JOURNAL

2023 ✦ Volume 26 ✦ Issue 3 ✦ 171–186

DOI: 10.33223/epj/171324

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An evaluation of the potential of the conversion of passenger cars powered by conventional fuels into electric vehicles

ABSTRACT: The aim of this article is to assess the potential of converting gasoline-powered passenger cars into electric vehicles in Poland. Based on the available literature data, the vehicle structure was classified using the following criteria: vehicle age, engine capacity, car segment, type of fuel used, and curb weight. The average fuel and electric energy consumption values per vehicle before and after conversion were determined using specially developed statistical models. The conversion and operation costs of a conventionally fueled vehicle and an electric vehicle (after conversion) were estimated using a stochastic simulation model employing probability density distributions of vehicle parameters and the Monte Carlo method. Vehicle parameters were estimated to reflect the real structure of passenger cars in Poland. The estimated costs of converting a gasoline-powered vehicle to an electric vehicle (including the purchase and installation of an electric motor and battery) and its subsequent operating costs enabled the assessment of the economic efficiency of the car conversion process. The potential for converting gasoline-powered cars to electric vehicles was estimated by comparing the operating costs of the vehicle before and after conversion, taking into

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account the costs of the conversion itself. The potential of the studied conversion process amounted to 535,000 vehicles, which would generate an annual electricity demand of 1,746.36 GWh with electricity prices of 0.6 PLN/kWh. The conversion is economically viable mainly in passenger cars with a spark engine (more than 90% of cases).

Keywords: electromobility, conversion, ICE vehicles, Monte Carlo, economic efficiency

Introduction

The introduction of energy-climate packages such as EC 2019 and EC 2021 has imposed regulatory frameworks on European Union member states, including Poland, to regulate the level of harmful emissions released into the atmosphere. As a result, citizens of the European Union seek increasingly innovative and eco-friendly solutions in each developing sector of the economy, aimed at reducing the amount of harmful pollutants emitted into the atmosphere. A trend of the reduction or complete replacement of high-emission pollution sources with so-called "clean" sources is observable. One of the main national sources of pollution, alongside industry and the household sector, is the road-transport sector (mainly emissions from exhaust pipes). Therefore, a series of actions are being taken to support eco-friendly solutions in this area. The continuous increase in the number of vehicles in the country, especially in large urban agglomerations, is the cause of a constant rise in pollution emissions. This is why many cities are introducing Clean Transport Zones (CTZs). According to the EIT Urban Mobility Report (2022), the number of CTZs in Europe has increased by 40% in the last three years and will continue to grow as regulations on vehicle access to cities are enforced. The driver of this growth is the European Green Deal (EC 2019), which is aimed at incentivizing the transition to less emission-intensive vehicles. The electric vehicle market is benefiting from this. The European Parliament has set a target that by 2025, electric vehicles will constitute 15%, and by 2030 – 30% of all cars sold (Dornoff et al. 2021).

With the increasing environmental awareness of society and the promotion of environmentally friendly approaches, as well as rising fossil fuel prices, many users are viewing the idea of electromobility more favorably. The incentive to purchase an electric vehicle is the possibility of receiving a subsidy from the Low-Emission Transport Fund. However, some consumers still hesitate due to the high prices – an electric vehicle can cost even twice as much as its conventional counterpart, which is why the growth of the market is not as fast as projected a few years ago. Besides the high purchase price of electric vehicles, the second most significant reason for this situation is the limited availability. It is already known that the above-mentioned assumptions regarding the share of electric vehicle sales will not be achieved.

According to calculations (ACEA 2023), countries (including Poland) with a GDP per capita less than the equivalent of 78,000 PLN have electric vehicle sales levels that are well below 1% of the total market. In this situation, the only way to achieve the set goals for emission reduction seems to be the significantly cheaper conversion of vehicles powered by internal combustion engines to electric-powered vehicles, which will reduce the use of conventional fuels, the main cause of emissions in road transport. Converting a gasoline-powered vehicle to an electric vehicle is a potential transitional solution that will accelerate the widespread adoption of electric vehicles. It will increase the social acceptance of electric vehicles and the pace of the development of electric vehicle charging infrastructure.

Currently, the annual number of passenger cars being converted to electric vehicles is several dozen units.

The aim of the study is to estimate the potential for converting gasoline or diesel-powered passenger cars to electric vehicles and to prepare a forecast of the electricity demand for powering the converted cars.

The article consists of the following parts: it begins with an introduction, which provides an overview of the topic. The next section presents the factors favorable for the conversion of vehicles and those limiting such conversions as well as a brief description of the conversion process. Subsequent sections include a literature review, a description of the mathematical model, a presentation of the analysis results, and their interpretation. The study concludes with a summary and a list of references.

1. The conversion of internal-combustion-engine vehicles to electric vehicles

The premises for converting an internal combustion engine vehicle to an electric vehicle includes the following aspects: environmental benefits associated with the lack of pollutant emissions, quieter operation, higher driving comfort due to the constant torque of the electric motor and the elimination of the gearbox, lower operating and maintenance costs, extension of the vehicle’s service life, reduced likelihood of breakdowns due to fewer mechanical components, various privileges for electric vehicle users such as free parking and access to bus lanes. An important advantage is also the possibility of bringing back into use ICE vehicles that have been taken out of operation by replacing the internal combustion engine with an electric alternative.

The conversion of internal combustion engine vehicles to electric vehicles is also favored by legal regulations mandating an increase in the share of electric vehicles in the Polish market, the rising prices of liquid fuels, user preferences, and the corporate policies of companies aiming for a higher proportion of electric vehicles in their vehicle fleets due to prestige and alignment with the sustainable development trend.

The barriers limiting the potential of converting internal combustion engine vehicles to electric vehicles stem from various factors, such as the limited range of the vehicle after conversion (as much as 67% of people indicate this as a barrier when choosing an electric car), long charging time, high initial investment costs required for the vehicle conversion, unfamiliarity and novelty of the solution, as well as emotional attachment to the internal combustion engine. Some users are also concerned about durability and potential battery replacement. Another argument working against electromobility is the infrastructure. By the end of the first quarter of 2023, there were 2,699 publicly accessible charging stations (5,305 charging points) in Poland (RP 2023). There is particular shortage of fast-charging points, which currently make up only thirty percent of all stations. Charging stations are just starting to emerge, and the construction of additional points necessitates increasing the available power of the energy grid and expanding it with additional cable lines, transformer stations, and connectors.

The conversion process involves removing unnecessary elements from ICE vehicles, including the engine, fuel tank, exhaust system, radiator, and fuel lines. It also includes connecting the electric motor to the gearbox and mounting it in the engine compartment, along with modifications to or replacement of the frame to hold the electric motor in place. Since an electric vehicle does not require a carburetor, a controller for speed and acceleration regulation needs to be installed. The installation of batteries, due to their size and weight, requires structural changes to the chassis to ensure stability of mounting, proper vehicle balance, and minimal vibration frequency during vehicle movement.

In the subsequent steps of the conversion process, the motor and batteries are connected to the controller, and the lighting and other electrical systems of the vehicle are connected to maintain their functions, such as the cabin heating system, which can utilize the existing air conditioner compressor or an electric heater. As most gasoline-powered vehicles are equipped with hydraulic power steering, it needs to be replaced with an electric hydraulic pump after conversion. Additionally, it is advisable to install a regenerative braking system, which allows recycling energy back to the battery pack. One of the final stages of the conversion is installing a charging port in the vehicle.

2. Literature review

Research on the operation of cars and their conversion has been analyzed in many publications, and this topic is useful and relevant. Furthermore, the analysis of scientific literature indicates that the topic of vehicle conversion mostly focuses on optimization, but the studies primarily address narrow areas and specific elements. Moreover, they are conducted at the experimental level.

Vražić (2014) and his colleagues conducted a conversion of ICE to EV and evaluated its costs and benefits, taking into account fuel prices, maintenance costs, battery life, etc. Kaleg (2015) and his team conducted research on optimizing the conversion of ICE vehicles to EV, with consideration to the range of the vehicle after conversion, the maximum speed and the cost efficiency.

Embrandiri et al. (2011) performed a prototype conversion of a Malaysian city car, the Perodua Kancil, and conducted tests on it. Aggarwal and Chawla (2021) conducted similar work in their article, where they discussed the main components used for vehicle conversion and provided a detailed description of their layout. Using information obtained from interviews and primary research, Kondev et al. (2023) performed a total cost of ownership assessment for electric vehicles compared to gasoline-powered vehicles and converted vehicles in Kyrgyzstan. The authors found that under current conditions, electric vehicles may have a lower total cost of ownership compared to similar converted vehicles.

An article by Hoeft (2021) presents research results on the concept of a business model for converting internal combustion engine vehicles to electric vehicles, with particular attention to customer needs and public opinion. The implications of the business model highlight how a company can configure and integrate ICE to EV conversion with existing market structures.

An important aspect of the studied problem is addressed in a paper by Wu et al. (2015) which focuses on estimating the total cost of ownership of converted cars to assess the overall cost for consumers. The authors concentrate on specific vehicle classes, drivetrain technologies, and usage scenarios, building a probabilistic simulation model. Their results indicate that the comparative cost-effectiveness would depend on the distances traveled and the size of the vehicles.

In an article by Hagman et al. (2016), it is indicated that awareness and recognition of factors such as the total cost of ownership will be more significant in the future than they currently are.

Zhang et al. (2014) suggests that to promote electric vehicles, governments should introduce a broader range of policies, such as financial incentives, technological support or charging infrastructure.

The assessment of the potential for converting internal combustion engine vehicles to electric vehicles has only been addressed by Wu (2015) and his team so far, making this issue relatively new in the context of the electromobility industry. Previous research on Polish conditions has focused on analyzing the economic benefits resulting from switching a car from traditional (gasoline or diesel) to electric (Majchrzak et al. 2021).

In the article, the authors utilized their expertise in assessing the potential in the road transport sector, gained through research on the development of the alternative fuel market in Poland, primarily focusing on CNG (Orzechowska and Kryzia 2015). The methods developed during these studies were employed in this work to assess the potential for converting internal combustion engine vehicles to electric vehicles.

3. Research method

In Poland, the vast majority of passenger cars are equipped with internal combustion engines using either spark ignition or compression ignition. These engines are fueled by liquid fuels, mainly gasoline and diesel. Users considering the conversion of such a vehicle to electric propulsion must take costs into account. The decision to convert a combustion engine vehicle to electric should be based on an economic analysis, where a key factor is the energy consumption of the vehicle and the ratio of the price of electricity to the price of fuel. The total cost of ownership depends on the specifications of the vehicle, usage patterns, and road conditions during both summer and winter periods (Siłka 1994; Lorenc 2012; Ubysz 2008; Żywica 2012; Guoet al. 2022; Sendek-Matysiak i Grysa 2021; Palmer et al. 2018; Desreveaux et al. 2020).

The potential for converting passenger cars with internal combustion engines to electric vehicles in Poland was estimated based on a conducted simulation using a proprietary model of the consumption of liquid motor fuels, including gasoline, diesel and electricity, for powering passenger cars. The model, using empirical probability density distributions of explanatory variables established during the analysis of the passenger car market in Poland, enables the simulating of parameter values characterizing a hypothetical vehicle. For this vehicle, fuel consumption per one hundred kilometers driven is calculated using econometric models, utilizing data declared by vehicle owners and manufacturers (www.autocentrum.pl/spalanie). A full description of the models used is presented in the work (Kryzia et al. 2015). The model assumes that vehicles can be powered by gasoline or diesel. The analysis omits other forms of powering passenger cars, such as LPG, CNG, LNG, and hydrogen. This is justified by the low share of vehicles powered by such fuels in the passenger car market and the significant uncertainty regarding the development of such vehicles.

In the developed models, the stochastic explanatory variables characterizing the hypothetical vehicle are as follows:

- type of fuel used,
- vehicle's curb weight,
- engine displacement,
- age of the vehicle,
- vehicle segment to which it belongs.

Table 1 presents the descriptive statistics of probability density distributions for parameters characterizing passenger cars. Based on randomly drawn parameter values for a hypothetical passenger car, fuel consumption was estimated using statistical models. The choice of fuel in the model is random, with one of two options (diesel or gasoline) being randomly drawn based on the probability density distribution prepared from available statistics on the number of registered passenger cars in Poland with diesel and spark ignition engines. Additionally, it was assumed that engine displacement is stochastic and varies from 0.8 to 4.2 liters. The age of the vehicle is also a random variable and can range from zero to thirty-one years. All vehicles with an age exceeding thirty years were classified as thirty-one-year-old vehicles. They were described with a single probability value, as reliable data for such vehicles was lacking, and this assumption did not significantly affect the results, given that vehicles over thirty years old are considered for scrapping, and conversion is not economically feasible. The vehicle's service life is calculated as the difference between the maximum lifespan of the vehicle and its current age. The curb weight, as a stochastic variable, can range from 660 to 2,180 kg. The model assumes that the hypothetical vehicle can belong to one of eight auto segments: 1 – smallest cars, 2 – small

Table 1. Descriptive statistics for personal users in Poland

Tabela 1. Statystyki opisowe dla próbki populacji samochodów osobowych w Polsce

Parameter	Unit	Average	Median	Value min.	Value max.	Deviation standard	Coefficient of variation	Skewness	Kurtosis
Vehicle's curb weight	kg	1,546	1,540	780	2,675	257.4	0.167	0.597	1.405
Engine displacement	dm^3	1.53	1.48	0.8	4.2	0.54	0.35	1.69	7.50
Age of the vehicle	year	15.92	15	0	31	3.92	0.53	0.29	2.23
Vehicle segment to which it belongs	–	3.61	3	1	8	1.68	0.46	0.47	2.19

Source: authors' own work.

cars, 3 – lower middle class, 4 – middle class, 5 – vans, 6 – small SUVs, 7 – upper middle class, 8 – large SUVs. Luxury and sports cars were excluded from the analysis under the assumption that such vehicles would not be converted to electric vehicles. Probability density distributions for the specified parameters were established based on data obtained from the CEPIK (Central Register of Vehicles and Drivers) database and PZPM (Polish Association of the Automotive Industry) reports. Through the Monte Carlo simulation, sets of parameter values characterizing the vehicles were obtained for a hypothetical dataset of passenger cars (consisting of 19,660 elements), representing the currently existing structure of passenger cars in Poland. To ensure that the combination of parameter values corresponds to real-world scenarios, correlation coefficients characterizing relationships between parameters were considered in the model. The values of the adopted correlation coefficients are presented in Tables 2 and 3.

To estimate the operating costs, knowledge of fuel consumption per hundred kilometers (calculated based on statistical models described by Formulas 1 and 2 in the form of first-degree

Table 2. Correlation coefficients for explanatory variables in the case of passenger cars with spark ignition engines

Tabela 2. Wartości współczynników korelacji dla zmiennych objaśniających w przypadku samochodów osobowych z silnikiem iskrowym

Itemization	Engine displacement	Vehicle's curb weight	Vehicle segment to which it belongs
Engine displacement	1.00	0.87	0.73
Vehicle's curb weight	0.87	1.00	0.78
Vehicle segment to which it belongs	0.73	0.78	1.00

Source: authors' own work.

TABLE 3. Correlation coefficients for explanatory variables in the case of passenger cars with compression ignition engines

TABELA 3. Wartości współczynników korelacji dla zmiennych objaśniających w przypadku samochodów osobowych z silnikiem wysokoprężnym

Itemization	Engine displacement	Vehicle's curb weight	Vehicle segment to which it belongs
Engine displacement	1.00	0.83	0.72
Vehicle's curb weight	0.83	1.00	0.84
Vehicle segment to which it belongs	0.72	0.84	1.00

Source: authors' own work

polynomials), fuel prices, and the average annual mileage of the vehicle is necessary. Due to significant uncertainty, it was assumed that fuel prices are constant and equal to 6.50 PLN/dm^3 for gasoline and 6.25 PLN/dm^3 for diesel. The average annual mileage of the vehicle in kilometers depends on the type of fuel and the automotive segment to which the vehicle belongs. Table 4 presents the assumed average annual mileage values used in the analysis.

$$S_g = 0.1117 \cdot A_s - 0.0269 \cdot R_p + 2.4642 \cdot P_s + 0.0013 \cdot M_w + 56.0856 \tag{1}$$

$$S_d = 0.2864 \cdot A_s - 0.0084 \cdot R_p + 1.1688 \cdot P_s + 0.0019 \cdot M_w + 16.1199 \tag{2}$$

where:

S_g – gasoline consumption value per hundred kilometers [dm^3/100km],
S_d – diesel fuel consumption value per hundred kilometers [dm^3/100km],
A_s – vehicle autosegment,
R_p – year of production commencement,
P_s – engine displacement [dm^3],
M_w– vehicle curb weight [kg].

The adjusted coefficient of determination R2, which is a measure of model fit, has values of 0.813 for vehicles powered by diesel fuel and 0.869 for vehicles powered by gasoline, indicating that the statistical models explain the variation in the dependent variables (fuel consumption) well.

The mass of the electric motor and equipment to be used in the conversion process is assumed to be constant at 75 kg for all converted vehicles. The vehicle's weight after conversion increases within the range of 10% to 33%. Vehicle weight is an important factor as it affects energy efficiency. An increase in weight results in higher energy consumption. The size of the battery pack not only influences the vehicle's weight but also its range. The probability density

TABLE 4. Average annual mileage values for passenger cars by automotive segment and fuel type [km/year]

TABELA 4. Średnie roczna wartości przebiegów samochodów osobowych według autosegmentu i rodzaju paliwa [km/rok]

Vehicle segment	Smallest cars	Small cars	Lower middle class	Middle class	Vans	Small SUVs	Higher class	Large SUVs
Average annual mileage of a vehicle powered by diesel fuel.	12 000	12 000	20 500	20 800	20 800	22 000	23 100	21 600
Average annual mileage of a vehicle powered by gasoline	10 000	10 000	13 800	16 000	16 000	14 500	17 200	16 700

Source: authors' own work.

distribution for this parameter was prepared based on comparing the curb weight of conventional gasoline-powered cars and their electric counterparts with comparable engine power performance. The increase in vehicle weight is limited by chassis design parameters and the vehicle's allowable total weight. The mass of the components removed from the vehicle during the conversion process (engine, exhaust, fuel tank, etc.) is described by mathematical Formula 3, which was derived from collected empirical data.

$$m_u = 97.07 \cdot e^{0.3389 \cdot P_s} \tag{3}$$

where:

m_u – mass of removed elements from the internal combustion engine vehicle [kg],
P_s – engine displacement [dm^3].

The mass of the battery pack (m_b) was determined based on the difference between the vehicle's mass after conversion and before conversion, minus the mass of removed elements from the internal combustion engine vehicle, plus the mass of the electric motor and its accessories.

Based on the mass of the battery pack installed in the converted vehicle, the maximum amount of energy stored in the battery pack is determined according to the equation:

$$K_b = 0.2355 \cdot m_b^{0.8709} \tag{4}$$

where:

K_b – the maximum amount of energy stored in the battery pack [kWh];
m_b – the mass of the battery pack [kg].

The cost of conversion depends on the battery pack capacity, the number of electric motors, and the necessary modifications to the structure of the vehicle. The cost of converting a car is calculated according to the formula:

$$N = 1756.58 \cdot K_b + 40143.83 \tag{5}$$

where:

N – conversion costs of the vehicle [PLN],
K_b – the maximum amount of energy stored in the battery pack [kWh].

As indicated by the above formula, labor and motor costs along with accessories are the same for each vehicle and amount to 40,143.83 PLN.

The amount of electrical energy consumed by the vehicle after conversion was determined based on the fuel consumption of the vehicle before conversion, taking into account the change in vehicle mass due to the conversion. Formulas 6 and 7, which describe this relationship, were derived based on the analysis of gasoline-powered passenger cars and their electric counterparts with comparable engine power. It was assumed that the converted electric vehicle would not be as efficient as a vehicle that was originally designed as electric, thus the vehicle's efficiency after conversion is equal to 90% of the efficiency of a factory-designed electric vehicle.

$$E_g = \frac{1.0173 \cdot S_g + 9.7931}{0.9} \tag{6}$$

$$E_d = \frac{1.0173 \cdot S_d + 12.8330}{0.9} \tag{7}$$

where:

E_g – the value of electrical energy consumption by the car after conversion from a vehicle originally powered by gasoline [kWh/100km],
E_d – the value of electrical energy consumption by the car after conversion from a vehicle originally powered by diesel [kWh/100km],
S_g – the value of gasoline consumption per one hundred kilometers [dm^3/100km],
S_d – the value of diesel consumption per one hundred kilometers [dm^3/100km].

Due to wear and tear, it was assumed that the replacement of battery packs must occur after covering 100,000 kilometers. The costs of replacing battery packs depend on the year when such a replacement would be necessary, considering the effect of decreasing battery prices with technological progress and increased production scale. This effect is described by a learning curve, which takes the form:

$$p_b = 1.0397 \cdot e^{-0.068 \cdot t} \tag{8}$$

where:

p_b – the rate of change in battery pack prices after t years,
t – the number of years.

The unit price of battery packs capable of storing 1 kWh of electrical energy for the current year was set at 1400 PLN.

To illustrate the dependency of the potential conversion of internal combustion engine vehicles to electric vehicles on the electricity price, various scenarios of electricity prices were analyzed. The values were varied with a step of 0.1 in the range of from 0.1 to 1 PLN/kWh. Currently, the electricity price for households hovers around 1 PLN/kWh. A lower electricity price may result from the utilization of self-generated energy sources, such as photovoltaic cells.

The analysis utilized Monte Carlo simulation based on the conditional sampling of probability density models constructed from empirical data. These variables comprised combinations of features of the analyzed passenger vehicles. For each hypothetical vehicle, the conversion cost and operating expenses were determined from the conversion date until the vehicle reached thirty-one years of age. The operating costs did not include expenses for traveling to charging stations, inspection costs, and the time spent on charging the vehicle. Additionally, the analysis did not account for the fact that some vehicle owners may choose not to convert their internal combustion engine vehicles to electric vehicles, even if it would be economically viable. This is due to the discomfort associated with using electric vehicles, including limited range, long charging times, and the limited number of refueling stations.

For such constructed model, a simulation was conducted by randomly selecting 19 669 hypothetical vehicles (1 per thousand of all passenger cars in Poland). For each hypothetical vehicle, the total operating costs of a conventionally fueled vehicle (gasoline or diesel) throughout its entire lifecycle were determined, as well as the conversion and operating costs for the electric conversion variant. These values were compared against each other. If the total cost for the converted vehicle was lower than the total cost for the conventionally fueled vehicle, the annual level of electric energy consumption for that vehicle was recorded. The total electric energy consumption calculated in the manner described above for all simulated vehicles was multiplied by one thousand, resulting in the annual potential electric energy consumption in Poland by passenger cars subjected to conversion and previously utilizing gasoline or diesel for fueling.

The Monte Carlo simulation was conducted using the Crystal Ball v.11 software by Oracle.

4. Results

Based on the conducted simulation studies, the potential for converting passenger cars in Poland and the annual energy consumption by these vehicles were estimated. The value of this potential depends on the price of electric energy. Table 5 presents the potential demand for electric energy to power converted passenger cars depending on the price of electric energy.

Conversion is economically viable mainly in passenger cars with a spark ignition engine (over 90% of cases). As the electricity prices increase, the average engine displacement value

TABLE 5. Potential for converting internal combustion engine passenger cars to electric vehicles depending on the price of electric energy

TABELA 5. Potencjał konwersji samochodów osobowych z silnikiem spalinowym na pojazdy elektryczne w zależności od ceny energii elektrycznej

Parameter	Unit	Value									
Electric energy price	PLN/kWh	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1
Number of cars for conversion	in thousands of units	2,048	1,747	1,301	1,003	749	535	388	286	220	146
Annual electric energy consumption	GWh/year	6,460.99	5,576.04	4,160.46	3,216.90	2,403.64	1,746.36	1,344.89	965.77	748.67	495.58

Source: authors' own work.

increases for vehicles in which the conversion is cost-effective – from around 1.78 dm^3 in the case of a price of 0.1 PLN/kWh for spark ignition engine vehicles to around 2.02 dm^3 in the case of a price of 1 PLN/kWh. The same trend applies to compression ignition engine vehicles, where the average engine displacement is approximately 2.17 dm^3 at a price of 0.1 PLN/kWh, and at a price of 1 PLN/kWh, it increases to 2.48 dm^3. The age of the vehicle also affects the viability of conversion. The higher the electricity price, the lower the age of the vehicle for which the conversion is cost-effective. At an electricity price of 0.1 PLN/kWh, it is not cost-effective to convert vehicles older than eighteen years. In the case of an electricity price of 1 PLN/kWh, over 80% of the vehicles for which the conversion is cost-effective are new vehicles. The simulation results indicate that the conversion of larger vehicles belonging to the class of higher middle class and large SUVs is the most cost-effective – 19.2% of vehicles belong to these auto segments (at an electricity price of 0.6 PLN/kWh). The conversion of the smallest and small vehicles is the least effective – 0.5% of vehicles belong to these auto segments (at an electricity price of 0.6 PLN/kWh).

Summary

The conducted simulation allowed us to conclude that the price of electricity is crucial for the economic efficiency of converting passenger cars powered by liquid fuels to electric vehicles. The conducted research provides several conclusions:

1. At the price of electricity equal to 0.6 PLN/kWh, the conversion of passenger cars in Poland is economically justified for a small percentage of vehicles (2.72%).
2. The low share of converted electric vehicles in the structure of passenger cars in Poland may result from a lack of economic awareness regarding the use of such vehicles and concerns related to comfort issues, such as limited range, a small number of charging stations, and high initial conversion costs.
3. Conversion most frequently achieves positive economic effects when it occurs in vehicles with gasoline engines characterized by high fuel consumption and not older than sixteen years. Conversion is especially justified for large SUV-type premium passenger cars (for which the purchase of an electric equivalent is significantly more expensive) owned by users with their own source of electricity, such as a photovoltaic installation, which generates surplus energy that can be utilized.

Future research works, as a continuation of the presented studies, will encompass the following topics:

- Assessing the change in the potential for converting gasoline-powered cars to electric vehicles over time.
- Consideration of the variability of fuel prices and its impact on the change in the conversion potential.

- Incorporating learning curves into the model regarding the reduction of vehicle conversion costs.
- Evaluating the potential for converting passenger cars in Poland, taking into account competition from electric vehicles offered by automotive companies.

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Ocena potencjału konwersji samochodów osobowych zasilanych paliwami konwencjonalnymi na pojazdy elektryczne

Streszczenie

Celem artykułu jest ocena potencjału konwersji samochodów osobowych napędzanych silnikiem spalinowym na samochody elektryczne w Polsce. Na podstawie dostępnych danych literaturowych scharakteryzowano strukturę pojazdów za pomocą następujących kryteriów: wiek pojazdu, pojemność silnika, autosegment, rodzaj stosowanego paliwa, masa własna. Średnie zużycie paliwa i energii elektrycznej przez pojazd przed i po konwersji zostało określone na podstawie specjalnie opracowanych modeli statystycznych. Koszty konwersji i eksploatacji pojazdu zasilanego paliwem konwencjonalnym oraz energią elektryczną (po konwersji pojazdu) oszacowano na podstawie stochastycznego modelu symulacyjnego wykorzystującego rozkłady gęstości prawdopodobieństwa parametrów pojazdów oraz metodę Monte Carlo. Parametry pojazdów estymowano tak, aby otrzymany zbiór pojazdów odzwierciedlał rzeczywistą strukturę samochodów osobowych w Polsce. Oszacowane koszty konwersji pojazdu spalinowego na elektryczny (zakup i montaż silnika elektrycznego i baterii akumulatorów) oraz jego późniejszej koszty eksploatacji umożliwiły ocenę efektywności ekonomicznej procesu konwersji samochodu. Potencjał konwersji samochodów spalinowych na elektryczne został oszacowany poprzez porównanie kosztów eksploatacji pojazdu przed konwersją i kosztów eksploatacji pojazdu po konwersji z uwzględnieniem kosztów jej przeprowadzenia. Potencjał badanego procesu konwersji wyniósł 535 tysięcy sztuk pojazdów, co wygeneruje roczne zapotrzebowanie na energię elektryczną na poziomie 1746,36 GWh przy cenie energii elektrycznej na poziomie 0,6 zł/kWh. Konwersja jest ekonomicznie opłacalna głównie w samochodach osobowych z silnikiem iskrowym (ponad 90% przypadków).

Słowa kluczowe: elektromobilność, konwersja, samochody spalinowe, Monte Carlo, efektywność ekonomiczna