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Assessment of selected environmental and economic factors for the development of electro-mobility in Poland

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Abstract

Electromobility is now widely recognized as a remedy for the growing level of greenhouse gas emissions from the transport sector. The result of this approach is the agreement of the European Commission with the member states regarding the achievement of CO_2-free emission of the new fleet of passenger cars by 2035 through the use of battery electric vehicles. However, it should be emphasized that currently, not every country in the European Union has electricity sources with low CO_2 emission (Proposal for a REGULATION… (EU) 2019/631), which in fact can contribute to a lower environmental effect than expected. The amount of environmental impact of a battery electric vehicle depends mainly on the type of energy mix of the country in which it is used. In view of the above, the first scientific objective of the article is a comparative assessment of environmental impact, using the LCA (Life Cycle Assessment), the phase of use of passenger cars with conventional drive in relation to battery electric vehicles consuming electricity from the power grid in Poland and in Italy. The results of the LCA analysis, phases of BEV use in Poland indicate a higher level of environmental impact in relation to ICE due to the generation of electricity, for the most part from hard coal. Nevertheless, in Poland, as in other EU countries, an electromobility support system is being implemented. The successful implementation of electromobility depends on the environmental awareness of BEV users. The scientific cognitive aspect of the BEV purchase decisions of the Polish society is carried out using a survey questionnaire with the use of a non-random selection of the research sample (convenient selection). The aim of this cross-sectional survey was to confront the results of the environmental impact of the BEV use phase with the knowledge of the Polish society, as well as to learn about purchasing factors (future and current users). The results of the survey questionnaire demonstrate the low level of knowledge of the Polish society on the impact of the BEV use phase in Poland. This can be the result of media coverage in which BEV is presented as ecological transport. The aim of the article is not to depreciate the environmental performance of BEVs, but to draw attention to the fact that, to a large extent, the environmental impact of the BEV use phase depends on the place of use (country), and precisely the type of energy mix of a particular country. The literature on the subject lacks the confrontation of the results of scientific research in the field of environmental impact assessment of the BEV use phase with the knowledge of the public on this subject. The research results can be used by decision makers to properly target the support for the development of electromobility in Poland, consisting primarily in increasing

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the availability of infrastructure for charging BEV and changing the energy mix to energy sources with a lower environmental impact.

Keywords Electromobility · Development determinants · Environmental factor · Economic factors · Data analysis · LCA methods · Questionnaire research

Abbreviations

BEV	Battery electric vehicle
ICE	Internal combustion engine
PHEV	Plug-in hybrid electric vehicle
MHEV	Mild hybrid electric vehicle
EREV	Extended range electric vehicle
HEV	Hybrid electric vehicle
FCEV	Fuel cell electric vehicles
LCA	Life cycle assessment
TCO	Total cost of ownership
G1	Group of respondents as BEV users
G2	Group of respondents as potential buyers of BEV

Introduction

Transport is an integral part of the world economy. Due to the scale of the phenomenon, it is responsible for high greenhouse gas emissions, which globally amount to 17% (*Distribution of greenhouse gas emissions worldwide in* 2018). Although transport needs are secondary human needs, the resignation from transport, despite the large amount of pollution generated, is not taken into consideration. The only solution to this situation is to take up the challenge of minimizing the impact of transport on the environment using all available techniques and instruments (Ayoko et al. 2004).

The pressure of transport on the environment involves not only emissions of pollutants into the atmosphere as a result of the combustion of traditional fuels, but also emissions of pollutants to soil, water and noise. One of the suggested solutions that have a significant impact on reducing the pressure of transport on the environment in the European Union is electromobility.

Battery electric vehicles are not an innovative solution of this century, they have been known since the beginning of the last century (Helmers 2009). However, due to the increased interest in internal combustion cars, battery electric vehicles have lost their importance. The reason for this was, among other things, the fact that at the beginning of the last century there was a lack of infrastructure to support electric vehicles and the battery electric vehicle was much heavier than internal combustion cars due to the weight of the batteries.

Electromobility is to be a remedy for the growing needs of the society around the world, mainly related to passenger transport, but there are also plans for freight transport. An important aspect of this solution is the fact that battery electric vehicles do not emit practically any pollutants into the atmosphere at the place of their use. The noise level of BEVs is also much lower. All pollution is generated where electricity is generated, while the amount of pollution depends on how it was produced.

Battery electric vehicles are not an invention of the twenty-first century, yet they are not popular in most countries among individual users, if only because of their higher price. A number of countries around the world use many instruments to encourage the purchase and use of these cars. The instruments used to encourage the purchase of these cars vary from country to country and also bring different effects (Cansino et al. 2018).

The electromobility initiative in the European Union was a consequence of the provisions of *Europe 2020 strategy: Strategy for smart, sustainable and inclusive growth* from 2010 and the *Commission's White Paper* from 2011 entitled *Roadmap to a Single European Transport Area–striving to achieve a competitive and resource-efficient transport system.* The latter document postulates a 60% reduction in greenhouse gas emissions from transport by 2050 compared to 1990 levels. In August 2019, Directive (EU) 2019/1161 of the European Parliament and of the Council of June 20, 2019 entered into force amending Directive 2009/33/EC of the European Parliament on the promotion of clean and energy-efficient road transport vehicles, which aims to stimulate the market for low- and zero-emission and energy-efficient motor vehicles, thus accelerating the EU's transition to low-emission mobility. Implementing Directive 2019/1161, Poland introduced, through *the Act of 2 December 2021 amending the Act on electromobility and alternative fuels and certain other acts* (Journal of Laws, item 2269), the obligation for contracting authorities to ensure minimum target levels for the share of low- and zero-emission road vehicles for the transport of passengers and cargo (categories M and N) in the total number of vehicles covered by the above-threshold public contracts for the supply of vehicles and selected transport services. The principles of operation and development of electromobility in Poland are regulated by the above Act on electromobility and alternative fuels and are based on the strategic assumptions set out in the Transport Development Strategy until 2020 (*Transport Development Strategy until 2020*, 2013) and the Electromobility Development Plan in Poland (*Electromobility Development Plan in Poland "Energy for the future").* The goal of the Electromobility Development Plan in Poland is to increase electric vehicle users to 1 million by 2025. In Poland, currently, PHEV is also included in the statistics as an electric vehicle, despite the fact that this type of vehicle cannot be counted on for co-financing from the electromobility development system. At the end of September 2022, there were 54 795 "electric" passenger cars registered in Poland, of which 27 595 PHEV and 27 200 BEV (*Electromobility Meter*). The statistics of electric vehicles also include mopeds and electric motorcycles 14 967, hybrid cars and vans 419 222[1] and electric buses 770 (data as of July 2022) (*The number of electric cars in Poland is increasing—Wzrost liczy aut elektrycznych w Polsce).* In Poland, the Polish Alternative Fuels Association was also established, which monitors the process of legislative changes in the field of electromobility, organizes meetings and internal debates on the necessary changes in the law and their scope, initiates activities and develops materials regarding the proposed changes. One of the projects of the Polish Alternative Fuels Association is the "White Book of Electromobility", the aim of which is to eliminate barriers hindering the development of electromobility and zero-emission transport in Poland.

The first objective of the article was to assess the impact of the BEV use phase on the environment and to confront the obtained results with the state of knowledge of the Polish society on the environmental performance of the BEV used in Poland. The energy mix in Poland, which is used to drive BEVs, is mainly based on the combustion of solid fossil fuels, hence ambiguous results in the environmental assessment of the BEV use phase can

[1] The number of cars given in the statistics does not break down into the type of car with a hybrid drive (HEV, PHEV, MHEV).

be expected. The second objective was to identify the knowledge of the Polish society on the impact of the BEV use phase in Poland. The third objective of the article was also to learn about the factors determining the purchase of BEV by the Polish society. Due to the low popularity of this car in Poland, potential BEV users were also included in the questionnaire. The cognitive aspect of the factors determining the purchase of BEV is important because currently the European society has an alternative in the form of ICE, PHEV, EREV, HEV or FCEV, but only until 2035, in accordance with the agreement of the European Parliament and EU member states. Possible adjustments to the plans to implement electromobility in Poland, resulting from the above study, can contribute to accelerating this process (Proposal for a REGULATION… (EU) 2019/631).

The following representative research hypotheses were adopted for the cross-sectional study of the Polish society:

H1 The state of knowledge of the Polish society about the environmental impact of battery electric vehicles is low.

H2 The implementation of electromobility in Poland should be closely related to the development of infrastructure for charging battery electric vehicles.

The article consists of six chapters, the second chapter presents an overview of the literature in the field of electromobility, the electromobility support system in Poland is described, and the system of subsidies that potential BEV users can benefit from is presented. A SWOT analysis of the most common vehicles using electricity was made. The third chapter presents the research methodology, a comparative LCA analysis of the ICE and BEV use phases was conducted, and the results of cross-sectional studies using a survey questionnaire were presented, thanks to which the level of knowledge of the Polish society on the environmental impact of BEVs and the decision-making factors of the society when purchasing this type of cars was determined. Chapters four and five are the results and discussion, respectively. In the last, sixth chapter, conclusions from the research are presented.

Literature review

Electric vehicles according to (UNECE 2016; Helmers and Marx 2012; Zerfaß, 2018; Derollepot et al. 2014; Stark et al. 2018; Propfe et al. 2012; Un-Noor et al. 2017; Camacho and Mihet-Popa 2016) are divided into five categories: electric drive is the only source of energy converted into mechanical energy (1), electric drive coexists with traditional combustion drive (2), electric vehicle with extended range (3), hybrid electric vehicle (4) and electric vehicle with fuel cells (5).

1. BEV *(Battery Electric Vehicle)* are classic electric vehicles powered by one or more electric motors, charged from a socket (with a special cable and plug), pantograph or inductively.

2. PHEV *(Plug-in Hybrid Electric Vehicle)* are *plug-in* hybrid vehicles; equipped as standard with two types of drive: internal combustion and one or more electric motors. Plug-in hybrids differ from regular hybrids in that they are rechargeable. Thanks to this, they allow covering longer distances (at certain speeds) without the need to start the

combustion engine. Both types of vehicles can be equipped with a braking energy recovery system, which is stored in batteries.

3. EREV (*Extended Range Electric Vehicle*) has an auxiliary power unit (in most cases a small internal combustion engine) that increases the driving range of the EREV. Small internal combustion engines drive an electric generator that powers the electric batteries and the electric motor with electricity.

4. HEV (*Hybrid Electric Vehicle*) is a type of vehicle that combines a driveline with a conventional internal combustion engine (ICE) with an electric driveline (hybrid vehicle drive). The presence of an electric drive system is aimed at achieving greater fuel economy and better performance.

5. MHEV (Mild Hybrid Electric Vehicle): in this solution, the combustion engine is supported by a low-power electric motor, most often integrated with the alternator and starter. Mild hybrid supports the combustion engine especially when accelerating or idling.

6. FCEV (*Fuel Cell Electric Vehicles*) generates electricity to power the engine using oxygen from the air and compressed hydrogen gas. Electricity generated from fuel cells goes to an electric motor, which converts electric energy into mechanical energy. The excess of energy is stored in storage systems such as batteries or supercapacitors.

Three types of the above cars can be found on the roads in Poland (BEV, PHEV, HEV). In order to organize the strengths and weaknesses as well as opportunities and threats in the context of their application in Polish conditions, they were subjected to SWOT analysis (Tables 1, 2 and 3).

Based on the SWOT analysis (Tables 1, 2 and 3) of the BEV, PHEV and HEV phases of use in Polish conditions, it is not possible to clearly indicate the optimal solution. However, it should be noted that due to long delays in the renovation of the national power grids in Poland, the additional grid load resulting from the need to charge BEVs and PHEVs may disrupt their proper operation (Zajkowski et al. 2016). Suttakul et al. (2022) made an economic assessment (total cost of ownership (TCO), including residual cost) of ICE, BEV, PHEV and HEV. According to the results, HEVs and PHEVs provide approximately 10% lower TCO than ICEs and BEVs in the absence of government incentives. Furthermore, during the period of operation for 15 years, HEV is the most favourable, for which the TCO is the lowest compared to other vehicles (Suttakul et al. 2022). However, according to the Electric Cars report: Calculating the Total Cost of Ownership for Consumers, the TCO for small and medium cars (for which the public incentive system is included) and the 10-year useful life is in favour of BEV compared to PHEV, ICE, HEV, FCEV (Electric Cars: Calculating the Total Cost of Ownership for Consumers 2021). In the 10-year period, the report included three owners of the analysed cars, the lowest TCO value, as mentioned earlier, is generated by small and medium BEVs for each of the three subsequent car owners. Large BEV cars generate high costs for the first five years of use (respectively for the first and subsequent, second owners of the vehicle) and lower costs (compared to ICE, HEV, FCEV) over the next five years (from the 5th to the 10th year of use). The lowest TCO for large cars after the fourth year of use (i.e. for the second and third user) is generated by PHEV (Electric Cars: Calculating the Total Cost of Ownership for Consumers 2021). The above analysis can slightly differ depending on the country of use of the cars.

These cars (BEV, PHEV, EREV, MEV, HEV, FCEV) use mainly batteries to store electricity. These are car components that are important in terms of its range (the distance it can cover) and affecting the price of electric cars. Despite the fact that the battery production technology has significantly changed from lead-acid, through nickel-metal-hydride (Ni-MH), to the currently used lithium-ion, battery electric vehicles, in the opinion of customers, do not provide the possibility of covering a sufficient distance (Un-Noor et al.

Table 1 SWOT BEV analysis

Strengths:	*Weaknesses*:
• Possibility to reduce operating costs by charging at home;	• Much higher purchase cost (approx. 30%) than ICE;
• Low noise level;	• Increasing the burden on the environment as a result of charging the car with the Polish energy mix;
• High efficiency of converting electrical energy into mechanical energy;	• Low consumer awareness of the negative impact of the Polish energy mix on the environment;
• Lower BEV vs ICE maintenance costs;	• Increasing the demand for energy from the already heavily loaded power grid;
• No problem with the need to manage used engine oils;	• Increased emission of pollutants at the place of energy production;
• No emissions to the atmosphere at the place of use	• Poorly developed vehicle charging infrastructure;
	• The total efficiency of electric drive systems, taking into account the stage of electricity generation in a coal-fired power plant, drops to the value of about 0.15–0.25;
	• Short range
Opportunities:	*Threats*:
• Development of vehicle charging infrastructure;	• Effect different from the intended one—increasing atmospheric pollution;
• Possibility of charging vehicles from renewable energy sources;	• Power grid overload;
• Eliminate the risk of soil contamination from leaky engines	• The need to periodically replace the battery in the car and subject it to recycling processes;
	• Rare metals are used in the production of car batteries;
	• The high price of energy reduces the economic benefits of using a car;
	• Possibility of energy shortages in Polish power grids

2017; Kampker et al. 2013; Betram and Bongard 2014). The distance that battery electric vehicles can cover may seemingly be a less important issue if the charging time of the batteries was much shorter. Electric vehicles can be charged with AC or DC power and various voltage levels. Higher voltage levels provide faster charging, but the charging speed is influenced by another variable such as the ambient temperature. The average charging time in winter (compared to summer) is almost doubled and amounts to 35 min, while in summer, at higher ambient temperatures, the average time is 20 min (Aziz and Oda 2017).

It is widely recognized that battery electric vehicles (BEV) can reduce greenhouse gas emissions and the total emission of air pollutants compared to conventionally driven cars (Helmers and Marx 2012; Ortar and Ryghaug 2019). However, an important aspect influencing the reduction of pollutant emissions to the atmosphere is the share of individual fuels in the energy mix and the percentage share of renewable energy (Ortar and Ryghaug 2019). Electric vehicles operating in regions where the energy mix is dominated by coal (Chinese regions and the three US Central West states) may increase total pollutant emissions or offer a limited reduction of these pollutants (Huo et al. 2015).

Table 2 SWOT PHEV analysis

Strengths:	Weaknesses:
• Possibility to reduce operating costs by charging at home;	• Increasing the burden on the environment as a result of charging the car with the Polish energy mix;
• Long range when using both types of drive;	• Low consumer awareness of the negative impact of the Polish energy mix on the environment;
• Fewer "sensitive" components (such as: starter motor, alternator, clutch, V-belt);	• Poorly developed infrastructure for charging vehicles
• Longer service life of braking system components (brake discs, brake pads)	• Higher emissions of pollutants at the point of energy production when charging from the grid;
	• The total efficiency of electric drive systems, taking into account the stage of electricity generation in a coal-fired power plant, drops to the value of about 0.15–0.25;
	• There is often less trunk capacity;
	• Rare metals are used in the production of car batteries;
	• Increased energy demand
Opportunities:	*Threats*:
• Development of vehicle charging infrastructure;	• In the case of charging from the mains, the effect is different from the intended one—increasing atmospheric pollution;
• Possibility of charging vehicles from renewable energy sources;	• Power grid overload;
• Cleaner environment due to reduced atmospheric pollution (in case of urban driving);	• The need to periodically replace the battery in the car and subject it to recycling processes;
• Less waste (less brake system wear)	• The high price of electricity when charging from the network reduces the economic benefits of using a car;
	• Possibility of energy shortages in the Polish power grid

Table 3 SWOT HEV analysis

Strengths:	*Weaknesses*:
•Lower level of emissions to the atmosphere compared to ICE during use in built-up areas;	•Higher purchase cost of most HEV compared to ICE;
•Fewer "sensitive" components (such as: starter motor, alternator, clutch, V-belt);	•There is often less trunk capacity;
•Longer service life of braking system components (brake discs, brake pads)	•The greater weight of the car;
	•Often there is a smaller fuel tank capacity
Opportunities:	*Threats*:
•A cleaner environment due to reduced atmospheric pollution (in the case of urban driving);	•The need to periodically replace the battery in the car and subject it to recycling processes;
•Little hedging against fuel price volatility;	•Rare metals are used in the production of car batteries;
•Less waste (less brake system wear)	•A smaller trunk volume may influence the purchasing decisions of customers

Huo et al. (2015) also note that the use of battery electric vehicles, charged from the grid, where electricity is primarily generated from coal, has the potential benefit of reducing pollutant emissions in congested cities. Of course, pollution from coal-dominated energy production is high, but it is emitted beyond the boundaries of crowded cities. Moving pollutant emissions from one place to another is not the way to solve the problem of greenhouse gas emissions globally, but as noted, it has a significant impact on reducing emissions locally in cities (Huo et al. 2015).

The environmental impact of battery electric vehicles (BEV) also depends on the geographic parameters of the place where they are used. Energy consumption is affected by the use of heating and/or cooling due to local climatic conditions (Egedea et al. 2015). In a case study, Egedea et al. (2015) analysed three scenarios by LCA, making them dependent on: the specificity of the user's driving, terrain morphology, climatic conditions, duration of use and the weight of the car (heavy steel and light aluminium structures were analysed). On the basis of the obtained results, it is not possible to state unequivocally which car is a better choice for the environment: light (aluminium) or heavy (steel).

Helmers et al. (2020) performed an LCA analysis of a passenger car from cradle to grave, examining various types of propulsion fuels. It has also been noted that there is a high environmental impact during the production of batteries (Li-Ion cells) due to the consumption of large amounts of electricity. Modelling results suggest that the production of energy from renewable energy sources significantly reduces the environmental impact of battery electric vehicles (Helmers et al. 2020).

The Plan for the Development of Electromobility in Poland was adopted by the Council of Ministers on March 16, 2017. The plan is to be implemented in the years 2017–2025. Another stage in the implementation of the electric transport development policy is the *“Act on electromobility and alternative fuels”* passed by the Sejm on January 11, 2018. The act mainly concerns the principles of selling the electric vehicle charging service, according to which entities on the alternative fuel market are to operate, regulations concerning informing consumers about the infrastructure enabling the use of electric vehicles and instruments supporting the development of electric transport. The legislator also included numerous incentives for battery electric vehicle users, including (*Ustawa o elektromobilności i paliwach alternatywnych*):

- The abolition of excise duty on battery electric vehicles and hydrogen-powered cars (*Ustawa* o *podatku akcyzowym*),
- Free entry to the clean transport zone (no such zones were designated in Polish cities as of March 30, 2022),
- Exemption from parking fees in paid parking zones on public roads,
- In the period until 31 December 2028, zero-emission buses of the public collective transport operator providing public utility transport are exempt from tolls on national roads,
- Until January 1, 2026, battery electric vehicles can run on bus lanes,
- Increased depreciation charges for enterprises using battery electric vehicles.

An important element of support for the electromobility system in Poland is the system of subsidies for battery electric vehicles called “My electrician”, which provides for the possibility of co-financing zero-emission vehicles of the following categories:

- M1[2]: the amount of co-financing up to PLN 18750[3] (the possibility of increasing the amount of co-financing to PLN 27000 in the case of declaring the average annual mileage over 15,000 km), the maximum purchase price of the vehicle is PLN 225000;
- M2, M3, N1[1]: co-financing amount up to 20% of eligible costs, but not more than PLN 50000 (possibility of increasing the co-financing amount to 30% of eligible costs, but not more than PLN 70000 in the case of declaring an average annual mileage over 20,000 km);
- L1e-L7e[1]: co-financing up to 30% of eligible costs, but not more than PLN 4000.

The program budget has been set at PLN 500 000 000 for non-returnable forms of financing. The implementation period is planned for the years 2021–2026, including the period of concluding contracts until December 31, 2025 and the period of spending the funds until June 30, 2026.

The electromobility support system in Poland is implemented in many aspects, but each of them ultimately has an economic dimension. The aim of the support system is to reduce the emission of pollutants from transport, in "My electrician" program it is stated that the purpose is: *to avoid air pollutant emissions by co-financing projects aimed at reducing the consumption of emission fuels in transport—supporting the purchase/leasing of zero-emission vehicles.* In the context of such a goal, the question arises whether the electricity used to power battery electric vehicles is actually devoid of emissions to the atmosphere? The originator of the "My electrician" program does not mention the difference resulting from zero emission, but only at the place of use, in relation to the increased emissivity (increased energy demand) at the place of electricity production. In the third part of the article, a study will be conducted to present the results of the research with the use of LCA analysis, which tries to answer the above question.

Taking into account the above variables, the scientific cognitive aspect is important, which factors currently determine to the greatest extent the willingness to buy a BEV. The surveys conducted so far in Poland have focused primarily on: the importance of public incentives to buy BEVs (Thiel et al. 2012), the likelihood of buying BEVs (Thiel et al. 2012; New Mobility Barometer 2019/2020), the reasons for the lack of interest in buying BEVs (Thiel et al. 2012; New Mobility Barometer 2019/2020), operating costs of BEV vs ICE vehicles (Lewicki et al. 2021), limited BEV range (Lewicki et al. 2021), lower popularity of ICE (New Mobility Barometer 2019/2020) and socio-economic factors that can be used to predict consumer buying behaviour (Sobiech-Grabka et al. 2022). In the literature, there are also studies referring to scientific research taking into account the impact of cultural conditions on BEV purchasing decisions (Novotny et al. 2022).

This article refers in the survey to the above elements, due to the nature of the issue, for the success of the implementation of the electromobility system, but the study also includes the identification of the state of knowledge about the environmental impact of the BEV use phase. How important this aspect is in the Polish reality was presented in the study by Łuszczyk et al. (2021). In this article, ecological, economic, social and technical difficulties as well as controversies related to the use of electric cars in Poland were indicated, using statistical analysis for this purpose. From the point of view of ecological difficulties, they pointed to the high share of hard coal in electricity production, reaching over 76%. With regard to economic and technical conditions, they noted the need to transform

[2] Symbol in accordance with Directive 2007/46/EC.

[3] 1 EUR≈4.60 PLN.

the entire energy system into a more efficient and effective system of public incentives for potential BEV buyers. To a large extent, this article illustrates the difficult situation in the effective implementation of electromobility in Poland's economic conditions.

In view of the above, there is some scientific space that has not been included in scientific articles so far and concerns the state of knowledge of the Polish society on the environmental impact of the BEV use phase. The successful implementation of electromobility also depends on the knowledge that potential beneficiaries of the support system have, and how they perceive electromobility can largely contribute to its success or failure. Therefore, in the article, a questionnaire study was carried out to identify the knowledge of Polish society, among the others, on: the impact of electromobility on the environment, purchasing decisions, knowledge of the program co-financing the purchase of a battery electric vehicle.

Life Cycle Assessment (LCA) is a widely used technique to assess the environmental impact of various areas of anthropogenic human activity (Piwowar and Dzikuć, 2017; Dzikuć, 2015; Paragahawewa et al. 2009; Ingrao et al. 2021). The life cycle assessment methodology is standardized and has been repeatedly described in the literature on the subject (Dylewski and Adamczyk 2012; Goedkoop et al. 2016).

In the literature on the subject (Brennan and Barder 2016), attention is drawn to the two times higher level of environmental impact in the production phase of BEV as compared to ICE. The above report assesses the environmental impact in the use phase over a period of 20 years, where ultimately the environmental impact of BEV is approximately 20% lower than ICE.

Methodology

Conceptual assumptions of the research

Life cycle analysis (LCA) in classical terms takes into account the entire product cycle. That is, from the process of obtaining raw materials to the "death" of the product. It is often referred to as "from cradle to grave" analysis, however, the term "from cradle to cradle" has recently been adopted, which is important in recycling end-of-life products and then using recycled raw materials to produce new products–circular closed economy. It should be noted here that the LCA analysis, depending on the purpose of the research, may assess a single product, two or more products and may evaluate:

- The entire product life cycle,
- A selected part of the life cycle (e.g. only the production process),
- Unit process.

The LCA analysis, in accordance with the ISO 14040 and 14044 standards, consists of four phases (PN-EN ISO 14040:2009/A1:2021-03; PN-EN ISO 14044:2009/A2:2021-03):

Phase I: Definition of the goal and scope;

Phase II: Analysis of the collection;

Phase III: Impact assessment;

Phase IV: Interpretation.

LCA analysis is supported by commercial computer programs such as: OneClic, GaBi, Umberto, SimaPro, Athena, etc., in which various assessment methods can be used. The use of a specific method is often conditioned by the purpose of the analysis and the unit in which the result of the LCA analysis is to be expressed.

The purpose of the LCA analysis is to make a comparative assessment of the environmental impact of the use phase of BEV and ICE cars depending on the place of their use. The functional unit is the amount of energy used to travel 100 km of a road section for three types of cars (BEV, ICE diesel, ICE petrol). According to the authors Brennan and Barder (2016), an important aspect in the use phase of BEV is the type of energy mix of the country in which the car is used. Hence, the assumed boundaries of the LCA analysis system include the phases of electricity and fuel production and the phases of use of these energy carriers. The following are left beyond the boundaries of the product system: maintenance, service infrastructure, car production, etc. due to the previously conducted research (Brennan and Barder 2016) and the purpose of this study, where the dependent variable is the energy mix of the country in which BEV is used. The environmental impact of the wear of vehicle tires, which does not depend on the type of vehicle, was also not taken into account when comparing BEV and ICE.

An on-line questionnaire was used to conduct the research on the state of knowledge of the Polish society. The survey was distributed using: messengers, social networks and by e-mail. The survey was aimed at a random adult representative sample.[4] The survey questionnaire was carried out using a non-random selection of the research sample (convenient selection). The questionnaire-survey with closed questions was posted online from November 2021 to March 2022. The questions in the questionnaire-survey were divided into two groups. The first group of questions (G1) was aimed at current BEV users, the second group of questions (G2) was aimed at potential future BEV users. The common part for both groups (G1 and G2) was the respondent's particulars. The following hypotheses were adopted for the implementation of the study:

H1: The state of knowledge of the Polish society about the environmental impact of battery electric vehicles is low.

The environmental impact of BEV, in the use phase, depends primarily on the type of energy mix in a particular country. Electromobility is a kind of novelty on the automotive market, which is presented in the media as an environmentally friendly solution for transport. The knowledge of the Polish society on the environmental impact of using BEV is an important factor that may contribute to the popularization of electromobility.

H2: The implementation of electromobility in Poland should be closely related to the development of infrastructure for charging battery electric vehicles.

The use of BEV depends on the availability of the charging infrastructure for these vehicles. Potential users of these cars should have adequate access to these chargers in order to be able to use them freely not only within their place of residence but also during further journeys. The availability of chargers for BEV is also perceived as an important element in popularizing electromobility. 472 respondents from all over Poland took part in the survey, of which 14.3% did not complete the survey. 413[5] respondents completed the survey. The main research goal was to identify the knowledge of the Polish society about the environmental impact of BEV usage.

[4] In Poland, an adult is a person who is 18 years of age or older. After reaching the age of 18, he/she acquires the right to take the exam to obtain a license to drive M1 and other motor vehicles.

[5] It is a representative sample of Polish residents.

Scheme of the analysis with a description

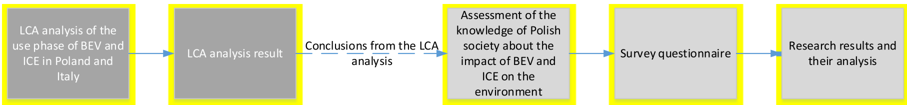
Due to the implementation of two research objectives, a specific concept of their implementation was adopted, which is presented in Scheme 1. An important cognitive aspect (implementation of the first objective) is the identification of the impact of BEV and ICE on the environment, using the LCA analysis, depending on the place of their use. Based on the obtained results of the LCA analysis and their interpretation, an attempt was made to assess the state of knowledge of the Polish society on the impact of the BEV use phase on the environment in conjunction with the identification of their decision-making factors when purchasing BEVs.

The analysis used the SimaPro program and the ReCiPe method, which is a universal method used in the literature on the subject (Dylewski and Adamczyk 2021; Dekker et al. 2020). Compact cars (segment C) were analysed. It was assumed that air emissions from the combustion of liquid fuels (diesel and gasoline) are consistent with (Merker and Teichmann 2014; Lv et al. 2022). The environmental impact assessment of the fuel production phase was performed with the use of the Ecoinvent 3.0 database.

An important aspect influencing the environmental impact of battery electric vehicles is the type of energy mix used by their users in a particular country. The advantage of fossil fuels in the energy mix is an important element contributing to the increased emission of greenhouse gases to the atmosphere (Dzikuć et al. 2020).

In Poland, hard coal is the predominant fuel used to produce electricity. For comparison, the energy mix in Poland and Italy is presented in Table 4. The choice of the Italian energy mix was due to a high level of compliance as to the types of energy carriers (only their percentage differs) used for energy production, and above all the lack of nuclear energy in both cases. The comparative analysis of the Polish and Italian energy mix was aimed at finding justification in the positive media coverage of the environmental performance of the BEV use phase.

For the analysis, it was assumed that BEV consumes 19.5 kWh, and ICE consumes 7.8 dm^3 of gasoline and 6.0 dm^3 of diesel over a distance of 100 km. The results of the LCA analysis are summarized in Table 5.



Scheme 1 Research concept

Table 4 Electricity generation by fuel in 2020 [TWh]

	Poland	Italy
Renewables	25.6	70.3
Hydroelectricity	2.1	46.7
Nuclear	–	–
Coal	111.0	16.7
Natural gas	16.7	136.2
Oil	1.7	9.7
Other	1.1	3.1

Source: Statistical Review of World Energy, 70th edition, 2021

Table 5 Results of the LCA analysis for BEV and ICE in the field of production of energy carriers and emission of pollutants as a result of burning liquid fuels per 100 km [Pt]

Vehicle type	ICE-Gasoline	ICE-Diesel	BEV used in Itali	BEV used in Poland
LCA analysis result	2.95	1.75	1.56	**5.43**

Bold value indicates the highest impact on the environment

Source: own study based on (Merker and Teichmann 2014; Lv et al. 2022Ecoinvent database)

Table 6 The cost of using vehicles depending on the functional unit of 100 km [PLN]

Vehicle type	ICE-Gasoline 95[a]	ICE-Diesel[5]	BEV (public chargers)[b]	BEV (household charging)[6]
Cost of use in Poland	53.51	48.28	39.05	15.60
Cost of use in Italy	61.62	52.68	44.85	18.40

[a]Average data from November 2022

[b]Average data from October 2022

Using a battery electric vehicle (BEV) in Poland is not ecologically effective (see Table 5). This is due to the high share of fossil fuels (coal) in the energy mix, as found by Huo et al. (2015). Despite the fact that in Italy there is no nuclear energy production in the energy mix, the use of BEV is less harmful to the environment. In the further part of the article, the knowledge of the Polish society about the impact of BEV on the environment and potential purchase decisions of future users of these cars was assessed, which is important in the context of the development of electromobility.

Vehicle use costs (per functional unit) are by far the lowest for household BEV charging (see Table 6). The difference in the cost of using a vehicle charged in generally available car chargers and ICE—Diesel is not large. In the current economic situation, it can be expected that the prices of energy carriers will undergo further fluctuations. The prices of energy for charging BEV from public chargers differ significantly depending on the subscription, the amount of energy consumed and the supplier. The statement uses the averaging of values, therefore the difference in the cost of using ICE—Diesel and BEV, currently, is small.

Survey research

Analysis of selected results of the questionnaire-survey in the G1 group (BEV users)

A questionnaire was used to carry out this part of the research. Due to the implementation of the research objectives (second and third) and the verification of research hypotheses H1 and H2, which are part of the scope of research in the social sciences, the survey technique was chosen. The research covered the adult population in Poland, which potentially has the right to drive vehicles and is a potential user or will be a BEV user. The conducted survey was anonymous, unsupervised, online, with the use of a non-random selection of the research sample (convenient selection). The questionnaire included filtering questions that divided the respondents into two different groups (G1: current BEV users) and (G2:

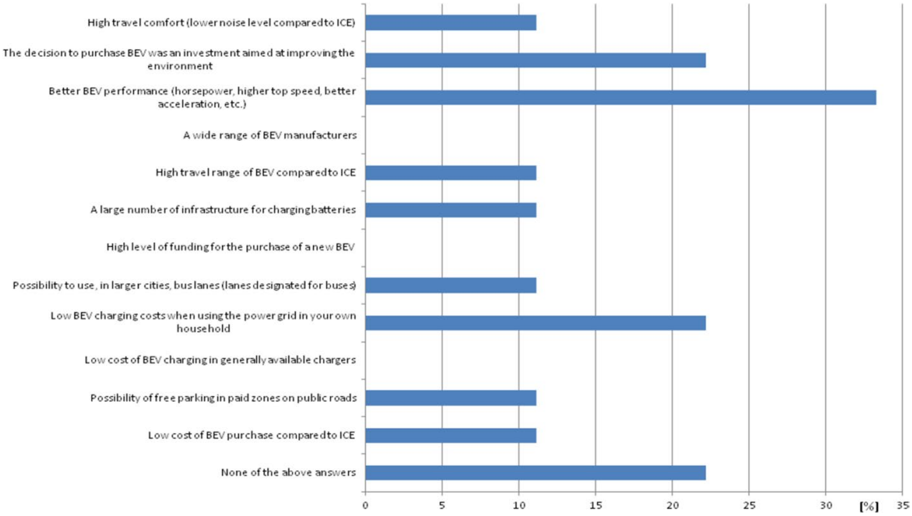
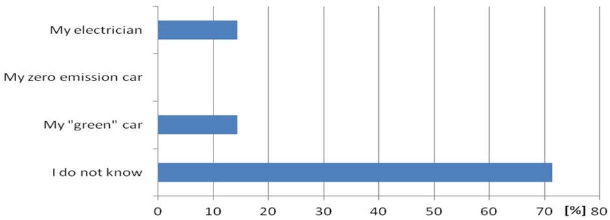


Fig. 1 Answers to the question: what influenced your decision to buy an electric car? (multiple choice question)

Fig. 2 Answers to the question: do you know the current name of the program co-financing the purchase of electric cars in Poland? (multiple choice question)



potential future BEV users). 9 respondents (BEV users) took part in this research group, which is a kind of confirmation of the small number of BEV used in Poland. In December 2021, 18,795 BEVs were registered (*Ile kosztuje ładowanie EV na publicznych stacjach AC i DC w Polsce?*). The first question asked by this group (G1) of respondents concerned BEV purchasing decisions (Fig. 1). Nowadays, from the economic point of view, the used car increasingly determines the social status (Chen et al. 2017). From the point of view of technical characteristics, cars are differentiated in terms of, among other things, the parameters achieved: top speed, horsepower, acceleration. The respondents indicated this aspect as the most important. The important information is that the users justified the purchase of BEV in the context of pro-ecological investment (22%). Respondents also indicated that one of the BEV purchasing decisions was the low operating costs of the car when using power grids from their own household for charging. It should be noted here that in Poland there are also sporadically available, in large cities, in parking lots of shopping centres, free chargers.

The next question in the G1 group (see Fig. 2) concerned the knowledge about the program co-financing the purchase of a new BEV. 71.4% of respondents could not indicate the correct name of this program, despite the fact that at the time of the research, the subsidy program for the purchase of a new BEV was already in operation. However, it should be noticed that due to the Covid-19 epidemic, the implementation of this program in Poland

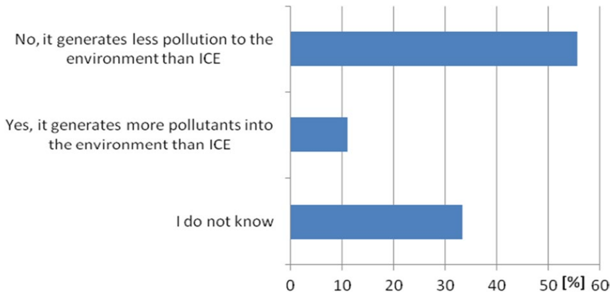


Fig. 3 Responses to the question: In your opinion, does the use of a battery electric vehicle generate a greater burden on the environment in relation to an internal combustion vehicle? (multiple choice question)

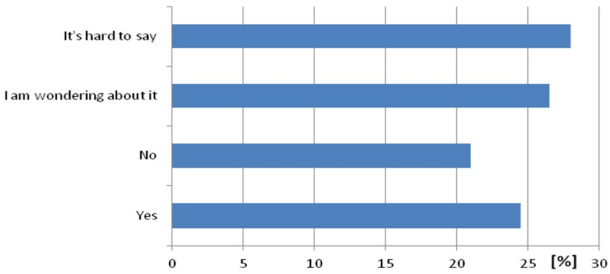


Fig. 4 Answers to the question: do you consider purchasing a battery electric vehicle in the future? (multiple choice question)

has been significantly delayed. Some current BEV users concluded purchase agreements in accordance with the previously agreed date for the implementation of the subsidy system, but as a result of the delay of this program, they did not take advantage of the possibility of co-financing the purchase of BEV.

Another single choice question concerned the comparison between BEV and ICE, which of these cars generates a greater burden on the environment (see Fig. 3). Information on the negative environmental impact of battery electric vehicles used in Poland is not displayed by the media. The media message about BEV is very positive, no attention is paid to the negative environmental impact of the energy mix in Poland, which is used in these cars. The positive information on the lower environmental impact of the BEV use phase is based on the results of studies conducted in Western Europe (Kucukvar et al. 2022). Therefore, the respondents (55.6%) replied that BEV emits less pollutants into the environment.

Below is an overview of the survey results for respondents who do not currently own BEV, but some are considering buying.

Analysis of selected results of the questionnaire-survey in the G2 group (potential BEV users)

The research group (G2) of potential BEV users is a much larger group of respondents, amounting to 404 people. The first question was about future purchasing decisions.

The distribution of the answers given in this question (Fig. 4) is almost identical. The purchase of BEV is considered by more than half of the respondents (answer: "Yes" and "I am wondering about it"). The largest group are respondents who are not sure about buying BEV.

The next question, multiple choice (see Fig. 5), gives an idea of the expectations of potential future BEV users. The cost of buying BEV in each category (with comparable equipment) of a car in Poland is higher than conventional ICE. Despite the introduction of

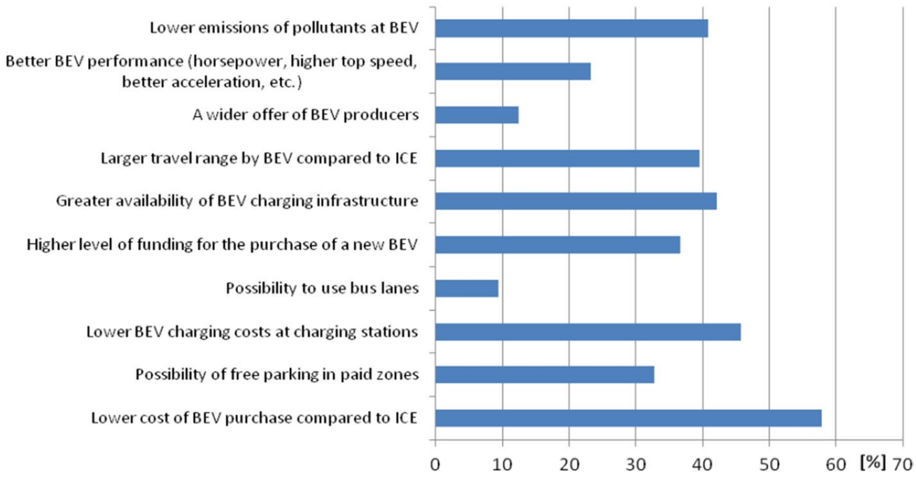


Fig. 5 Responses to the question: What could induce you to buy a battery electric vehicle? (multiple choice question)

a co-financing program for the purchase of a new car in Poland, respondents indicate the price as the most important problem in buying BEV. Another aspect affecting the BEV price is the fact that the aftermarket availability of BEV is very limited. Kucukvar et al. (2022) note that there is no system of subsidizing the purchase of new BEV and tax incentives in Finland, and the BEV sales market is developing well (*Number of electric cars is on the rise*).

The cost of BEV charging at public stations in Poland is high (relative to the average earnings in the country[6]) and varies depending on the subscription, the amount of energy consumed and the supplier from PLN 0.77 to 2.46 PLN/kWh for an AC charger. The cost of BEV charging with direct current ranges from 1.07 to 3.50 PLN/kWh (*Ile kosztuje ładowanie EV na publicznych stacjach AC i DC w Polsce?*). The cost of traveling 100 km by BEV in relation to ICE in Poland slightly differs in favour of the former, assuming that BEV is charged from generally available chargers.

Adequate market saturation with BEV charging infrastructure should encourage potential customers to buy this car. In Poland, as of December 2021, 1,932 electric vehicle charging stations were available (AC 1345, DC 587), with free AC chargers predominating, with the charging time of smaller BEV being about 3 h. The number of BEV chargers is low compared to other western countries (e.g. Italy (Electric Vehicles in Italy 2022)), however, it should also be noticed that when traveling on expressways, along the entire length of newly constructed roads, it may be difficult to charge BEV at Travel Service Areas (MOPs). An example is the S3 (E65) road from the north to the south of the country, where there are currently only a few BEV charging stations on a 478 km stretch of road. A sufficiently large number of DC fast chargers may also have an impact on minimizing the significance of the BEV disadvantage—shorter travel ranges. The expectations of future BEV users confirm positively the assumed research *hypothesis H2*.

In this question, the knowledge of BEV's environmental impact was initially verified. It is interesting that as many as 40.8% of the respondents (165 people) indicated

[6] The average monthly salary in January 2022 was PLN 6,064.24.

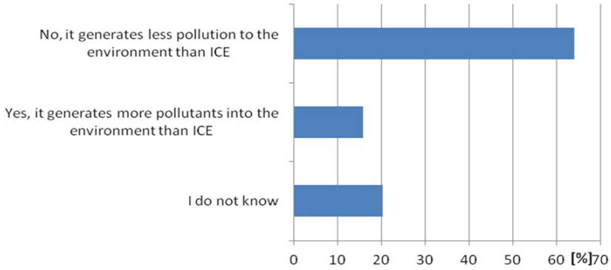


Fig. 6 Answers to the question: in your opinion, does the use of a battery electric vehicle generate a greater burden on the environment in relation to an internal combustion vehicle? (multiple choice question)

the expectations of reducing emissions of pollutants in relation to BEV (see Fig. 5). The answer chosen by the respondents contradicts the assumed research *hypothesis H1*.

However, in the next question, the above-mentioned answers of the respondents were verified.

In this question (as in the G1 group), the respondents were asked to compare the generated BEV load in relation to the ICE (Fig. 6). As in the G1 group, the respondents answered in line with the media coverage that does not take into account the type of energy mix of the country where BEV is used. They found that BEV generates less pollution to the environment (63.9%). Which verifies positively the assumed research hypothesis H1.

Results

The LCA analysis studies were carried out in one phase of the vehicle life cycle, in the use phase. The first objective of these studies was not to assess the environmental impact of the entire life cycle of these vehicles, but to demonstrate that to a large extent it is the use phase, and in particular the place of use of vehicles, that has a significant impact on the environment. The places of use should be seen as the country and the type of energy mix that is used to produce electricity. Cars in the C segment were used for the analysis, due to their greatest popularity in Poland (46.1% market share). It was assumed that air emissions from the combustion of liquid fuels (diesel and gasoline) are consistent with the data in the publications of Merker, Teichmann (2014) and Lv et al. (2022). The ReCiPe method and the SimaPro computer program together with the Ecoinvent 3.0 (*Ecoinvent database v3.0.*) were used to assess the environmental impact. It should be noted that if cars from a different segment are accepted, the environmental rating values will be different, which is directly related to the amount of fuel consumed and emissions to the atmosphere related to the combustion of this fuel. The reproducibility of LCA results also depends on the use of the same assessment method.

The petrol and diesel production processes for ICE were adopted on the basis of the Ecoinvent 3.0 database, which is almost identical throughout the European Union, which is consistent with the description in this database. In view of the above, it was assumed that the environmental impact of the fuel production process does not depend on the place (country) of production in the European Union. Fuel consumption was assumed to be average for cars in the C segment. Comparison of the results of the LCA BEVs used in different countries was limited to Italy.

The choice of the Italian energy mix was due to a high level of compliance as to the types of energy carriers (only their percentage differs) used for energy production, and above all the lack of nuclear energy in both cases.

Based on the results of the LCA analysis of BEVs and ICEs (fuel and diesel) used in Poland, it can be concluded that BEVs have a greater impact on the environment. The increased environmental impact is due to the high percentage of hard coal used in electricity generation in Poland. In an earlier study, Huo et al. (2015) came to the same conclusion for BEVs operated in the Chinese regions and three US Midwestern states.

The economic costs of the use phase (in terms of a functional unit—100 km) are given in average values. The cost of charging BEV in public chargers is at a high level of volatility and depends on the amount of energy consumed, the service provider and the subscription purchased. It can be expected that as the number of BEV charging infrastructure and the number of service providers increases, the costs will decrease in relative terms. In the initial phase of implementing electromobility, in the case of poorly developed infrastructure for charging BEVs, the cost of energy is high (Levy et al. 2020). Nevertheless, the costs of using BEVs (in terms of a functional unit), regardless of the country, are at a lower level than the use of conventional ICEs. It is most economical to charge BEVs from household electrical outlets.

In the surveys, due to the low popularity of BEV in Poland at the time of their conduct (November 2021-March 2022), a decision was made to choose the form of the survey, which was anonymous, unsupervised, online, using a non-random selection of the research sample (convenient selection). The results of the survey are similar to the surveys carried out in Poland, which referred to the cognitive aspect of decision-making factors of BEV purchase (Lewicki et al. 2021) and (New Mobility Barometer 2019/2020). Polish consumers expressed the opinion that they expect from BEVs: lower purchase price, lower charging costs, more publicly available chargers and greater range.

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Discussion

The first objective of the article was to assess the environmental impact of the BEV use phase. This goal was achieved through an LCA analysis of the energy mix in Poland and Italy. The results of the study of the size of the environmental impact of energy production in Poland justified the conduct of scientific research in the Polish society, in the form of surveys, on the negative environmental impact of the BEVs use phase. The questionnaire of the survey contained not only questions relating to the state of knowledge of the Polish society on the environmental impact generated by BEVs during their use (implementation of the second objective and verification of the *H1 hypothesis*). The questionnaire included questions about the factors influencing the purchase decisions of these vehicles. By asking these questions, the third goal was achieved and the *H2 hypothesis* was verified, where respondents expressed their concerns about the unsatisfactory number of infrastructure for charging BEVs.

The negative environmental impact of the energy mix in Poland applies not only to the use phase of BEV, but to the entire energy economy that uses this energy. The obtained research results should be a significant signal to decision-makers that the implementation of electromobility in Poland (and in countries with a similar energy mix) will not solve the problem of high emissivity in transport. It can be stated that it will increase emissions from electricity generation sites. With the current energy mix in Poland, replacing ICE vehicles with BEVs even increases the burden on the environment, unlike in Italy. The only positive aspect will be the reduced emissions at the place of use of BEV. The above study did not refer to other positive aspects related to the use of BEV, such as the reduction of noise emissions in relation to ICE.

The difference in the price of electric and internal combustion cars in the initial period of electromobility development, which we currently face, is high. The government subsidies from the "My electrician" program allow significantly reducing these differences and helping the customer choose a BEV, and in particular to become a product more affordable for people with fewer purchasing possibilities. In Poland, where only 30% of new passenger cars are purchased by individual customers, and more than a million used cars (ICE) are imported each year, the surcharges may not contribute to the sharp increase in sales of battery electric vehicles. Subsidies are also planned for companies, while no subsidies for lessors are foreseen, which will certainly greatly reduce the interest of potential corporate clients.

Any support in the form of a system of subsidies to a new BEV is an important factor in increasing sales, but it only works during the period of operation of this system. On the other hand, the permanent trend is built through long-term benefits—lower failure rate, affordable electricity prices, low loss of value, or the ability to drive battery electric vehicles in low-emission zones in cities. In Poland, it is assumed that clean transport zones will be established in larger cities in 2022. The first city in Poland where the introduction of a clean transport zone is planned is Kraków, the zone will be in force from July 1, 2024 (Brzeziński 2022).

It should be noticed, however, that in the coming years, the share of coal in the energy mix in Poland will decrease and it is only a matter of time before BEVs generate a lower environmental burden than ICE, similarly to Italy.

It is worth noting that in Poland the number of installations of photovoltaic panels is increasing. Assuming the most optimistic scenario, that every BEV user is also a PV plant user, such a scenario would be most desirable. Of course, this does not mean that the emissions in the use phase of BEV would be zero, which is related to the use time of BEV (time of day) and its charging time (usually afternoon or night time).

The knowledge of the Polish society about the impact of BEV use on the environment (one can have such an impression) is based on the media message, in which the position is presented that BEV is a pro-ecological transport solution. The research on the awareness and ecological behaviour of the inhabitants of Poland (Jednotematyczne badanie świadomości i zachowań ekologicznych mieszkańców Polski—zmiany klimatu 2020) obtained results which indicate that as many as 87% of the inhabitants of Poland express the need to reduce greenhouse gas emissions in all areas of the economy and the related low-emission transformation. However, despite such high ecological awareness of the Polish society, previous studies did not link the aspect of BEV use with the need to provide energy with a high degree of emission to charge this vehicle. As previously mentioned, electromobility in Poland is at an early stage of implementation. The small number of generally available chargers does not encourage potential users to buy BEV. A passenger car in Poland is used as a vehicle for commuting to work, picking up and dropping off children from school, shopping, going on a trip or on vacation. Due to the necessity to meet these needs for passenger car users in Poland, they are looking for a universal car. The car that they will be able to use for both near and far travels. In the event of limited (insufficient) availability of the BEV charging installation, they will not decide to purchase such a vehicle.

Conclusions

In the context of the assumptions of the Electromobility Development Plan, which assumes an increase in electric vehicle users to 1 million by 2025, and the results of the LCA analysis of the use phase of BEVs in Poland, it can be concluded that the expected effect of reducing the pressure on the environment will not be achieved. The primary goal of electromobility is to reduce the pressure of transport on the environment, already in 2015. Huo et al. (2015) pointed to the impossibility of achieving this goal in the case of an energy mix using coal as the primary source of electricity. Guided by the goal of reducing the pressure of transport on the environment in Poland, decision-makers should not primarily focus their attention on achieving the expected number of electric vehicles in use (1 million) by 2025, but should make decisions aimed at reducing the share of coal in the energy mix. If this approach is not implemented in Poland, the environmental effect will be lower than intended. The lack of knowledge of the Polish society about the negative impact of the BEV use phase on the environment may now multiply the effect of transport pressure on the environment. Therefore, the implementation of the first objective, the second objective and the verification of the *H1 hypothesis* were so important for the conducted research.

In principle, the electromobility system in Poland is implemented in a less effective way than in other EU countries, not only due to the type of energy mix, but above all due to the lack of investment in the modernization of power grids. As noted by Baraniak et al. (2020) distribution system operators should be prepared for a gradual increase in the number of battery electric vehicles and should be ready to incur investment costs for the construction and modernization of their networks. In the absence of investment in power grids and a high level of simultaneous charging of BEVs in one power circuit in urban areas, the voltage quality can deteriorate (Baraniak et al. 2020). With regard to this conclusion and the concerns of users of (current and future) BEVs, which were expressed in the survey questionnaire, regarding the small number of publicly available chargers, the success of the implementation of the electromobility system seems to be at least at risk. The survey research was also aimed at achieving the third objective and verifying the *H2 hypothesis*.

An additional threat in the implementation of electromobility is the geopolitical situation, which significantly affects the increase in prices of energy carriers. However, the increase in prices does not only concern electricity carriers, but also gasoline and diesel, which reach record prices in the world. This economic situation, unexpected by consumers, can be seen as an opportunity to change habits as to the use of individual means of transport in favour of collective transport, due to high costs. On the other hand, if there was a change in consumer habits, the reduction of pressure on the transport environment would not be the result of the implementation of electromobility.

The research is of a primary nature, in the opinion of the authors, it is necessary to repeat this research in the future, not only due to the cognitive nature of changes in the knowledge of Polish society about the impact of the BEV use phase on the environment, but also due to the current and future investments of the Polish state in low-emission electricity production.

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Data availability The data underlying this article are available in the article and in its online supplementary material.

Declarations

Conflict of interest All authors declare that they have no conflict of interest.

Ethical Approval Not applicable.

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