POLISH JOURNAL OF
TECHNICAL ISSUE 1(25), 2025
ISSN 2956-770X
DOI: 10.37660/PJTI.2025.25.1.3

Analysis of the Development of Electromobility Over the Years

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Summary: The technology of electric cars has been known worldwide since the 19th century. During the Industrial Revolution that took place then, electric vehicles did not achieve significant success. However, at the end of the 20th century, with enormous technological progress, the technology experienced a resurgence, giving it a chance to establish itself in the passenger car market. In recent years, electromobility has continued to develop, and interest in the technology is growing among car users, as indicated by recent sales reports. Manufacturers are presenting increasingly better solutions, which are expected to lead to the electrification of the automotive sector on a large scale in the near future. However, it is necessary to meet the challenges not only related to the vehicles themselves but also to everything that is essential for their use.

Key words: BEV, electrification, EV world market, technological progress, electromobility in Poland, sustainability

1. Introduction

The history of electric cars is full of innovations, challenges, and successes, reaching back to the early 19th century. At that time, Ányos Jedlik turned his attention to design the first car powered by an electric motor. Four years later, in 1832, Robert Anderson built the first electric vehicle, powered by non-rechargeable batteries, laying the foundation for today's electromobility. Unfortunately, the second half of the 20th century was a period of stagnation for electromobility, mainly due to the dominance of oil and internal combustion engines. Over the past 100 years, several periods of increased interest in electric vehicles (EVs) have emerged, driven by policy to address resource constraints related to fossil fuels, primarily during World War II to save fuel prioritized for the military, and during the 70s, due to the oil crisis. From the 90s onward, the curbing of emissions – at first mainly related to local air quality and later carbon emissions affecting climate change – has been the main political motivator [1]. Year by year, more efforts are being made to integrate electromobility into everyday life. As the world strives to reduce greenhouse gas emissions and decrease dependency on fossil fuels, electric vehicles are gaining importance as an alternative to traditional internal combustion vehicles. In Poland, one of the largest countries in the European Union, the current situation is striving to align with legislative developments aimed at electrification and promoting sustainable transport. Researchers predict that by 2040 the number of electric cars worldwide will have reached around five hundred million [2].

2. The Beginnings of Electric Car Technology

Nowadays, the topic of electric cars is frequently discussed in the context of environmental care and recent development trends. This issue is particularly relevant to the member states of the European Union, which, under the "Fit for 55" program, will ban the production of new internal combustion engine cars starting in 2035. This places electric car technology before a significant challenge: to introduce a large number of vehicles to the market within just over 10 years while improving their efficiency and addressing the teething problems of new designs. However, although

currently regarded as a recent development, electric car technology was actually the precursor to the internal combustion engine technology known today. In fact, the first cars created by human were electric cars. The first mentions of these vehicles date back to around 1830, when initial experiments with these machines were conducted. Research was conducted in Hungary, the Netherlands, and the United States [3]. At the beginning, they were prototypes of vehicles hard to be called cars. Around 1890 the first electric vehicle resembling a car was successfully constructed [8]. It turned out that was achieved in many places worldwide within a short period. As various sources report (different people are considered the inventors of the first electric vehicle, depending on the country of origin of the article), those responsible for these projects were: William Morrison (1890), Gustave Pierre Trouvé (1881), Thomas Parker (1895), Andreas Flocken (1888). It is important to acknowledge that all the aforementioned inventors were trailblazers in the development of electric vehicles. After the introduction of electric cars to the market, which found applications in many areas of contemporary life, the "golden era" of electric cars began. For several years, these cars enjoyed great popularity. The models of that time had a range of about 40 km and a top speed of around 17 km/h. Cities started creating taxi networks in the centers; according to unofficial data, by around 1910, there were about 60 electric taxis in New York City [3]. Unfortunately, as quickly as this interest grew, competition appeared on the market in the form of internal combustion and steam engines [3]. This led to the "car war" between manufacturers of different technologies. Newspapers began to feature various advertisements encouraging people to buy their vehicles (Fig. 1).

Fig. 1. A page from a local USA newspaper [4]

With each new manufacturer entering the market with technology other than electric, the electric car industry fared increasingly worse. Although those were the beginnings of the Industrial Revolution, made possible by Edison's discoveries, most machine users were ordinary people who either did not have access to electricity or had limited access. Thus, after the initial success of electric cars, a period of decline followed. They were displaced due to a lack of infrastructure (which, to some extent, remains an issue today). This is a known problem that electric cars have once failed to overcome. Another problem was the lead-acid battery technology itself, which required maintenance every few days (replacing plates, cleaning, and adding electrolyte), and due to the significant weight of the batteries, this became burdensome [5]. Electric vehicles faded into obscurity until the end of the 20th century when work on the concept of electric-powered vehicles was resumed. In the 1960s and 1970s, a turning point occurred in the transportation industry. Conventional fuels, such as gasoline and oil, were widely used in various fields of technology at the time. Increased demand led to increased supply, which resulted in higher prices per barrel of oil, which was predominantly extracted from Arab states at that time [6]. The multiple increases in price sparked the idea of finding a cheaper alternative that would, above all, reduce emissions of pollutants. Thus, the existing concept of electric vehicles was revisited. While still in the testing phase, electric cars of that era could reach speeds of around 55 km/h, and their range was approximately 55 km [3]. Although this did not make them strong competitors to the internal combustion cars of the time, it provided hope that with technological advancement, they could rival widely used vehicles. In terms of technological development, it was the introduction of new batteries that slowly improved the technical parameters of these vehicles. In the 1990s, nickel-metal hydride batteries were developed, which, compared to the previous lead-acid models, featured higher energy density. Over time, the GM Impact 1990/EV1 (Fig. 2) model was developed. That was a groundbreaking prototype car designed by General Motors [3], [6]. The described model, in its version from 1996, had a range exceeding 200 km and could accelerate to nearly 130 km/h, achieving 0 to 100 km/h in about 8 seconds. It was a definite showcase of how quickly these cars could accelerate.

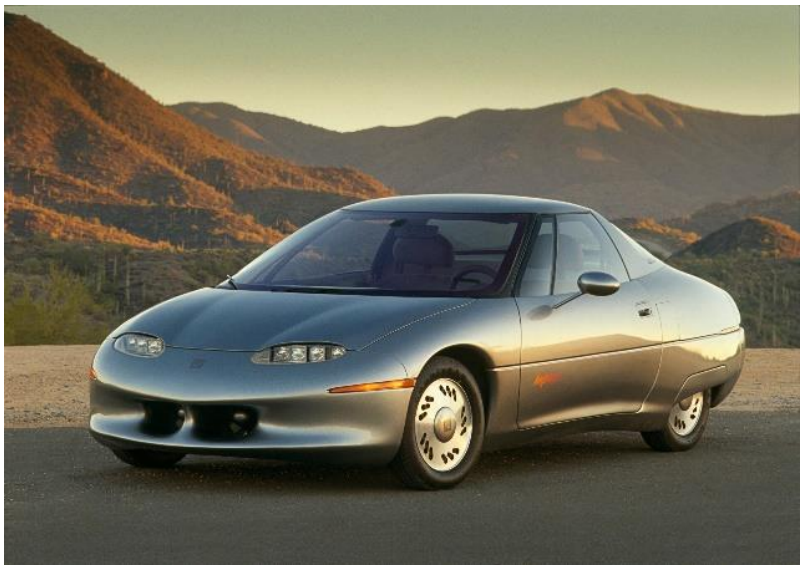

Fig. 2. GM EV1 [7]

Despite the fact that this model did not attract much interest many companies began working on their own prototypes. Numerous engineers worked on developing technology that would prove useful over time. Ultimately, in 2003, GM ceased production of these cars [8]. Shortly thereafter, the Energy Department began its activities, supporting efforts to improve the efficiency of electric vehicles and facilitating the development of this field. At some point, while working on electric cars and reviewing various available technologies, an alternative to existing solutions began to be sought. Two options emerged during this time. Some manufacturers opted to create hybrid solutions, while others chose to develop fully electric cars using lithium-ion batteries, which had been known since the 1970s [3]. Since their introduction in 1991, Sony's Li-ion batteries have been widely used in automobiles, smartphones, and laptop computers [2]. Compared to standard lead–acid batteries, they are three times more efficient and last up to 20 years. If a vehicle is equipped with a lithium-ion battery, it provides an advantage of extra capacity for storing a lot of power and is not cumbersome in facilitating the vehicle to move with less energy [9].

Toyota excelled in hybrid solutions. At the turn of the 20th and 21st centuries the Prius model was released, which, in addition to an internal combustion engine, also featured an electric motor with nickel-metal hydride batteries. The electric vehicle industry also saw the emergence of solutions such as plug-in hybrids. Significant examples of this trend were the Chevrolet Volt and the Nissan Leaf (which later became available in a fully electric version). Pioneers in fully electric vehicle technology were Tesla Motors and Venturi Automobiles. Using these batteries, the companies aimed to create electric sports cars that not only offered impressive performance but also significantly improved range on a single charge. This led to the creation of the Tesla Roadster which debuted in 2008 (Fig. 3). The model had a range exceeding 350 km, a top speed of about 200 km/h, and accelerated from 0 to 100 km/h in under 4 seconds [30]. Over time, Tesla became a leader in electric vehicle technology, in part thanks to support from the Energy Department [6].

Fig. 3. 2008 Tesla Roadster [10]

The company's growth was so rapid that Tesla repaid a loan it had obtained for its operations within 3 years, even though the repayment period was set for 12 years. In the following years, the company earned the title of the largest employer in the automotive industry [3].

3. Current State of the Market and Technology

Over the past few years, many electric car models from various manufacturers have been designed and brought to market. They can be divided into two categories: first-generation vehicles, produced up to around 2015, which have lower power and range, and second-generation vehicles, produced between 2015 and 2020, which feature better technical specifications (Fig. 4). Additionally, vehicles are categorized into BEV (Battery Electric Vehicle) and PHEV (Plug-in Hybrid Electric Vehicle), with FCEV (Fuel Cell Electric Vehicle) emerging around 2020.

Fig. 4. Examples of first- and second-generation electric cars [11]

After 2020, a development trend for electric vehicles emerged among most car manufacturers. This was due to a significant reduction in the production costs of lithium-ion batteries. In general, global sales of electric vehicles in 2020 exceeded expectations and are constantly on the rise. In addition, Europe announced an extra 200 GWh of projected capacity in 2020, a number that will rapidly rise in 2021 up to 600 GWh for electric vehicles and lithium-ion batteries. Thus, understanding Li-ion batteries, as well as multiple design and implementation trends, is even more important [9]. The electric vehicle market saw the permanent addition of brands such as KIA with its EV model, Hyundai with the IONIQ series, Porsche Taycan and Audi e-tron GT. In addition to these well-known large-scale companies, electric vehicle production is also undertaken by lesser-known European firms, such as BAIC Beijing and BYD. Figure 5 shows the sales data for 2022 for several global automotive companies.

Manufacturer	BEV	FCEV	PHEV	Total
BYD	1,572,983	0	1,441,709	3,014,692
Tesla Inc.	1,811,088	0		1,811,088
VW Group	758,210	0	252,053	1,010,263
GM	641,162	0	18,792	659,954
Stellantis	348,422	48	305,968	654,438
Geely Auto Group	420,480	0	178,965	599,445
BMW Group	378,722	151	184,048	562,921
Hyundai Motor	418,632	4,868	128,703	552,203
GAC	499,495	0	25,006	524,501
Mercedes-Benz Group	244,149	0	160,916	405,065
Changan Automobile Group	219,163	0	175,290	394,453
Li Auto (CHJ Automotive)	0	0	376,038	376,038
R-N-M Alliance	288,049	0	56,659	344,708
Other	314,717	0	14,789	329,506
SAIC	292,032	0	32,004	324,539
Geely-Volvo Car Group	170,372	0	150,463	320,835
Great Wall Motors	106,753	0	163,646	270,399
Toyota Motor Corp.	104,380	3,834	122,374	230,588
Dongfeng Motor	115,580	0	74,505	190,085
Ford	120,566	0	69,257	189,823

Fig. 5. Sales data for the largest brands in 2022 [12]

Figure 6 shows graphs depicting the share of electric vehicles in new car sales from 2010 to 2023 for the world, the European Union, the United States and Poland.

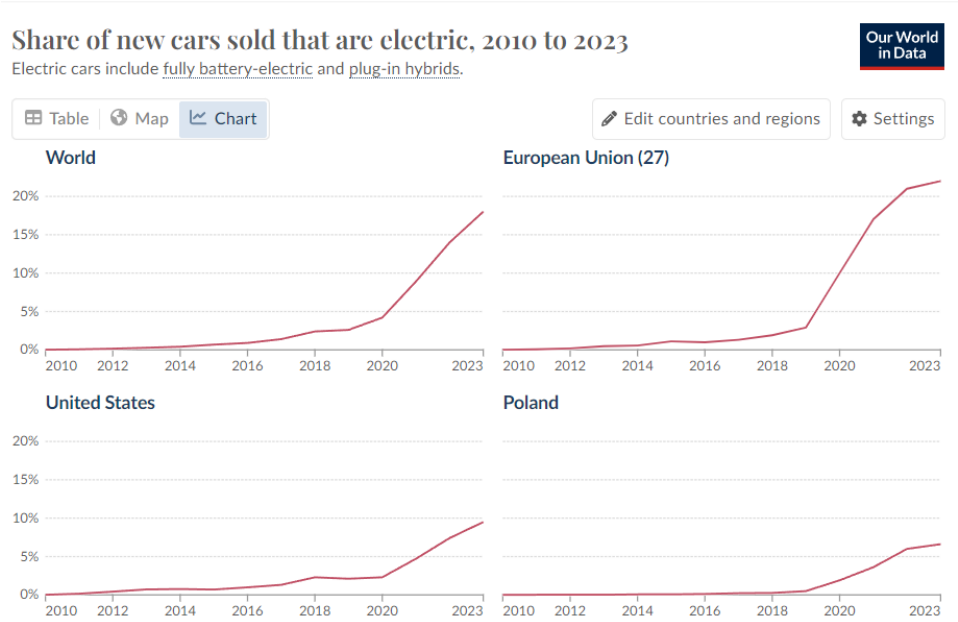

Fig. 6. Percentage of electric vehicles sold relative to all vehicles sold in the listed regions [13]

In 2024, the ACEA report was released, showing how the number of registered electric vehicles changes year over year in various countries. Below (tab. 1) is a comparison of Poland with the largest markets in Europe [14], [15]:

Table 1. Number of registered EVs in various countries.

Country	Number of registered EVs	Change year-on-year
Germany	22 474	+23,9%
UK	20 935	+21%
France	20 017	+36,8%
Belgium	9 995	+75,5%
Poland	1 120	+4%

A 4% increase compared to January of the previous year is certainly an encouraging indicator for the continued growth of the EV industry. However, when looking at the number of units (around 1,000), the situation still appears concerning. Considering that approximately 47,000 cars were registered last year [16] and only slightly over 1,000 of them were electric, the statistic does not look as promising. While the increase in sales is encouraging, there is a need for significantly higher sales of electric vehicles if the goal for the coming years is to reduce emissions.

Table 2 presents models and their technical specifications that are among the best-selling in the electric vehicle market (selected models in their base versions but with the most powerful available engine).

Table 2. Models and Technical Specifications of Best-Selling Electric Cars

Hyundai IONIQ 5 [31]		
	Technical specifications [17]:	
	Engine power [HP/kW]	325/239
	0-100 km/h time [s]	5.1
	Battery capacity [kWh]	77
	Range [km]	454
Tesla model Y [18]		
	Technical specifications [19]:	
	Engine power [HP/kW]	534/393
	0-100 km/h time [s]	3.7
	Battery capacity [kWh]	80
	Range [km]	460

Nissan Leaf [20]		
	Technical specifications [21]:	
	Engine power [HP/kW]	217/160
	0-100 km/h time [s]	6.9
	Battery capacity [kWh]	59
	Range [km]	340
Volkswagen ID.4 [22]		
	Technical specifications [23]:	
	Engine power [HP/kW]	340/250
	0-100 km/h time [s]	5.4
	Battery capacity [kWh]	82
	Range [km]	465
BYD Qin EV [24]		
	Technical specifications [25]:	
	Engine power [HP/kW]	134/100
	0-100 km/h time [s]	-
	Battery capacity [kWh]	48
	Range [km]	420

4. Future Development Prospects

Seeking new solutions in the electric vehicle industry, manufacturers have set several goals to be achieved over the coming years. Primarily, it is essential to continuously improve battery technology, both in terms of vehicle range and minimizing environmental impact. This also applies to the servicing, recycling, and disposal processes of energy storage systems. Along with advancements in battery technology, the development of charging infrastructure and technology should progress as well. In many European countries, including Poland, there is still an insufficient number of charging stations, and the time required to charge a vehicle often forces users to spend more time at the station than they would like. Another aspect is the cost of these vehicles. Despite the fact that the purchase price of electric vehicles is higher, when considering the internal combustion engine edition of the same vehicle model, the EV sales volume has experienced a significant growth, especially in the last years**Błąd! Nie można odnaleźć źródła odwołania.**. Chinese manufacturers have demonstrated that such a car, when converted to Polish zloty, can cost

as little as approximately 60,000 to 70,000 PLN [25]. This is a low price for a new vehicle in this technology. Of course, larger European companies still maintain higher prices (although there is a noticeable decline, prices remain somewhat inflated), but it is likely only a matter of time before the actions of the Chinese market will force similar moves in Europe. Even Elon Musk has recently reduced the price of most of Tesla's car models by 2,000 dollars compared to the previous year [26]. Electromobility opens new opportunities for the use of personal vehicles in various aspects of road traffic, especially when it comes to autonomous driving. Fully autonomous vehicles are going to face significant challenges. First, emerging technology and business models remain an issue. Technicians are working hard to develop commercially available autonomous vehicles, but future roles and business models are unclear. It depends if these vehicles will be utilized for delivery services, personal ownership, or shared mobility solutions. Second, robust regulation and legal frameworks are essential for the continuous evolution of autonomous driving technology. These frameworks help companies address legal challenges and gain public trust. Third, changes in insurance are necessary as autonomous vehicles create complex insurance challenges. Insurers cannot fully and reasonably evaluate the risks associated with autonomous vehicles and need new products for owners, passengers, and operators. Lastly, investment in infrastructure is crucial. Improved infrastructure ensures autonomous vehicles can accurately read road information and maintain full data service coverage to prevent going "offline" [27].

5. Electromobility in the Polish Market

In recent years, there has been a dynamic growth in the electric vehicle market, in Poland as well. This is supported by both the increasing consumer interest in electric technologies and the benefits of their use, as well as a range of government initiatives aimed at promoting electromobility, such as the "Mój Elektryk" program. According to data from the Electromobility Counter (Fig. 7), launched by the Polish Chamber of Commerce for Automotive Industry and Polish Alternative Fuels Association, by the end of December 2023, there were 98,348 electric passenger cars on Polish roads, with 51,211 of these being fully electric vehicles. Compared to 2022, the number of BEVs (Battery Electric Vehicles) increased by 52%.

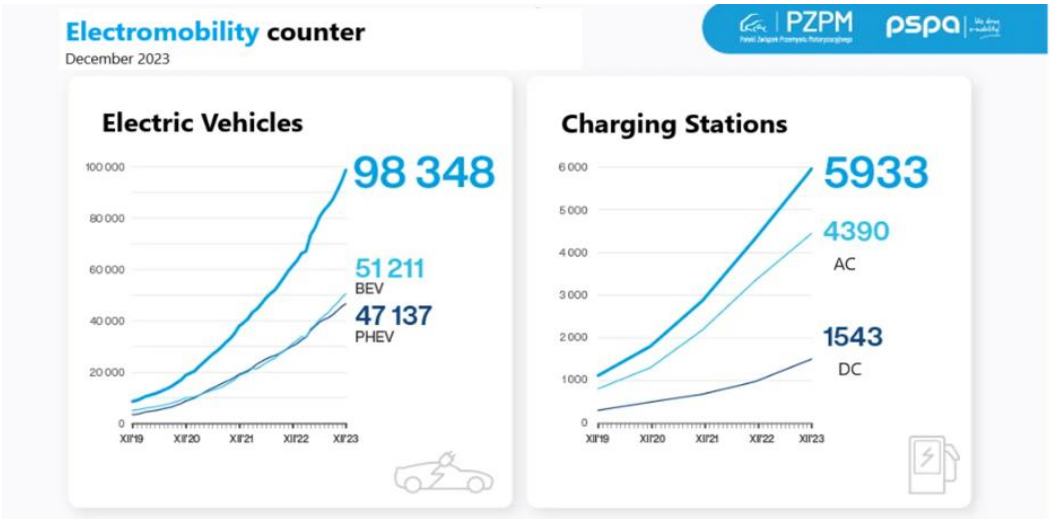

Fig. 7. Number of electric vehicles on polish roads in December 2023 [28]

Despite the dynamic growth of the electric vehicle market in Poland, there are still challenges to address in the pursuit of increasing the number of electric cars. The most noticeable issue is the state of the charging infrastructure. Although the number of charging stations is increasing, it remains insufficient in many regions of the country, especially in rural areas, which poses a problem for longer journeys. This is particularly important considering that the actual range of these vehicles can differ from the manufacturer's claims. Another aspect is the cost of purchasing an electric vehicle. Despite the availability of subsidies, the price of an electric car remains high compared to its internal combustion engine counterpart. Once Poland overcomes these challenges, the potential of electromobility can be fully realized.

6. Conclusions

Like many innovations, electric vehicles have undergone periods of both advancement and decline. Today, we can observe preparations for both the technology and infrastructure needed to introduce a large number of electric vehicles to the market. An extremely helpful element in this regard is the global strategy for sustainable development, which aims to reduce harmful emissions and decrease reliance on fossil fuels. Electromobility, like any other field, faces its challenges. Insufficient charging infrastructure, higher costs of electric vehicles, limited range, and long charging times are major barriers between electric vehicles and potential users. However, the prospects for development are promising. Poland is taking significant steps towards this change; the government supports consumers purchasing electric vehicles through subsidies, and public education in this field plays a significant role. As a result, electric vehicles are becoming more common and accessible. The future of electric vehicles looks positive with advancements in battery technology, charging infrastructure, and supportive policies. Battery prices are expected to drop significantly, making EVs more affordable and convenient for consumers. Switching to EVs can help reduce reliance on fossil fuels and combat climate change and incorporating them into smart city programs can improve efficiency. As the market grows, we can expect new models with improved driving ranges and faster charging times, potentially including self-driving EVs [27].

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