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Battery Electric Multiple Units (BEMU) as an alternative to railway line electrification

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In response to the European Union's policy requiring member states to take action aimed at reducing the negative impact of human activity on the natural environment, one of the key areas of focus is rail transport. This article presents the current level of railway line electrification in EU member states. Battery Electric Multiple Units (BEMU) are introduced as a potential alternative to full railway electrification, with particular emphasis on modern designs being implemented or tested in Europe. Additionally, as a historical curiosity, an example of such a vehicle operating in the early 20th century is presented. The vehicles described in the article may serve as an alternative to the old and worn-out diesel-powered rolling stock currently in use in Poland.

1. Introduction

As we enter the third decade of the 21st century, the countries of the European Union are looking for new solutions and technologies that will promote development and ecology in the transportation sector. The basic document setting the pillars for new thinking on the European transport area of the future is the White Paper on the Roadmap to a Single European Transport Area – Towards a Competitive and Resource-Efficient Transport System, issued in 2011 [4]. The paper, issued by the European Commission, outlines a number of issues that should be analyzed in depth and outlines the strategy that will be implemented. One of the biggest challenges facing the European community is the reduction of greenhouse gas emissions, with the goal of limiting temperature increases to a maximum of 2ºC and slowing climate change. An overarching goal of reducing emissions from 80% to 95% in 2050 compared to 1990 levels has been defined. [4] In addition, the European Commission identified the need to invest in new vehicle and traffic management technologies, which are key to lowering transportation emissions in the European Union and globally.

The response to the plan outlined in the White Paper [4] is the policy of the European Union through which, the modernization and transformation of the economies of the member countries to achieve climate neutrality has begun. Between 1990 and 2018, the European community reduced greenhouse gas emissions by 23%, while its economy grew by 61% [10]. However, the policies in place, which were implemented in the second decade of the 21st century, provide only a 60 percent reduction in greenhouse gas emissions by 2050.The achievements to date and the actions carried out have not and are unlikely to bring the expected long-term benefits. In addition, the Paris Agreement, ratified by 181 countries, requires strong and rapid global action to reduce greenhouse gas emissions [11]. On the basis of past experience and concluded international agreements, it has been decided to accelerate the processes involved in achieving climate neutrality by 2050. One intermediate step is to reduce greenhouse gas emissions by at least 50%, and potentially up to 55% in 2030 from 1990 levels.

It should be pointed out that transportation accounts for a quarter of the EU's greenhouse gas emissions, and this figure continues to rise [10]. The goal of climate

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neutrality can only be achieved if emissions in the transport sector are reduced by 90% by 2050 [10].

The European transport system should be sustainable, so that each branch of the economic sector is used in the most efficient way and places as little burden on the environment as possible. One of the pillars of the EU's approach must be the immediate popularization of low-emission vehicles, zero-emission vehicles and renewable and low-carbon fuels for road, water, air and rail transport [12].

Rail belongs to the low-carbon form of transportation whether we are dealing with passenger or freight transportation. At the present time, rail vehicles operating on the routes rely primarily on overhead power or derive their energy from chemical carriers. The enacted climate policy of limiting, or basically excluding, the use of diesel engines poses a number of challenges for European Union countries. The main problem to be solved is finding alternative options for powering rail vehicles. The two main ways to move away from engines based on oil-based energy are to electrify rail lines or to replace rail traction vehicles with machines that use alternative energy sources.

2. Progress of Electrification in European countries

One solution is the targeted electrification of all rail lines and the adaptation of all rail vehicles to draw electricity from the road network. Electrification is a key component of modernizing rail networks, reducing the negative environmental impact of rail transportation and making it a more favorable mode of transportation compared to road and other modes of transport heavily dependent on fossil fuels.

With the presented path forward in mind, it is important to look at the data presented on the website of the statistical office of the European Union (Eurostat) [7].

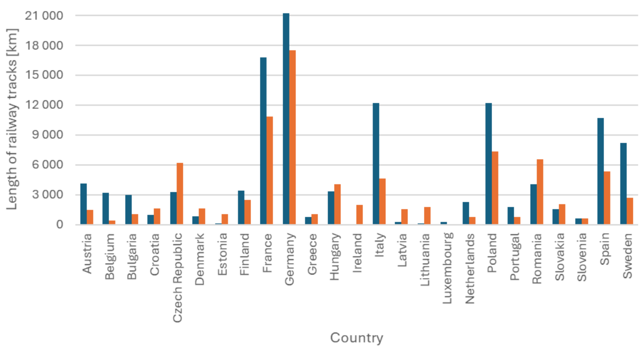

Fig. 1. Comparison of the length of electrified (blue) and non-electrified (red) lines in each European Union country in 2023

Analyzing the data presented in the chart above, it should be noted that the total length of electrified lines in the European Union is greater than the length of non-electrified lines. In the European Union countries with the most developed railroad infrastructure, electrified lines constitute the majority, e.g. Italy, Germany, France, Spain or Poland, while in countries with less developed iron routes, e.g. Denmark, Latvia or Lithuania, non-electrified lines constitute the majority. The data depicted are quite general, so it is necessary to analyze the level of electrification in individual European Union countries, relying on resources made available on the website of the statistical office of the European Union (Eurostat) [7].

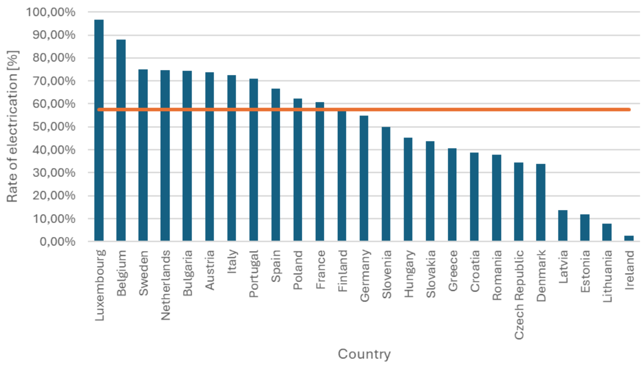

Fig. 2. Level of electrification of railroad lines in European Union countries in 2023

Taking the data to further analysis, it is necessary to look at the level of electrification in each country, taking as a criterion the electrification rate, which is the quotient between the length of electrified lines and the total length of railroad lines in a given country. The red line shown in Chart #2. indicates the average electrification rate in European Union countries, which is 57.45%. The countries with the highest electrification rate are Luxembourg and Belgium. However, it should be pointed out that the railroad infrastructures in the countries with the highest electrification rates are not very extensive. The total length of railroad lines in Luxembourg is about 271 km, and in Belgium approximately 3630 km. In contrast, the countries with the most extensive rail infrastructure, namely France and Germany, have only slightly more than half of their lines electrified, 61% and 55% respectively. It is worth mentioning that this is not the rule. Analyzing the summary, it can be seen that countries that have an expanded rail infrastructure usually boast a fairly high level of electrification. An example of this is Sweden, which has about 10,906 kilometers of railroad lines with an electrification rate of about 75%. Similarly, the Italians, whose total length of rail lines is about 16,830 kilometers with a ratio of approximately 73%. As for Poland, at the current moment the electrification rate is about 63% with a total infrastructure length of about 19,540 kilometers. A country oscillating close to the average is Finland, whose electrification rate is about 58%. Below the average are countries with less developed rail infrastructure. Exceptions to this rule are Germany (electrification rate of 55% with a railroad length of about 38,700 km), Romania (electrification rate of 38% with a railroad length of about 10,600) and the Czech Republic, whose total railroad length is about 9,520 km, with an electrification rate of about 35%. The countries with the lowest electrification rates are Estonia (electrification rate of 12% with a rail line length of about 1171 km), Lithuania (electrification rate of 8% with a rail line length of about 1924 km) and Ireland (electrification rate of 3% with a rail line length of about 2045 km).

Considering the level of electrification of railroad lines in the various countries of the European Union, it is necessary to consider the current state of electrification and look at the dynamics of change in this regard based on data posted on the website of the statistical office of the European Union (Eurostat) [7].

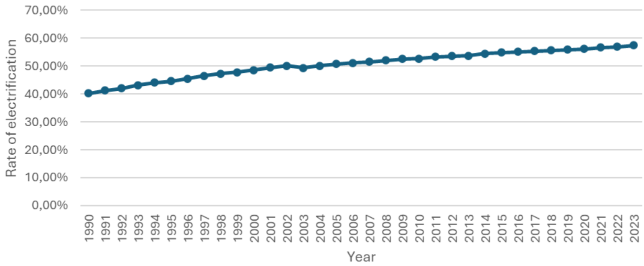

Fig. 3. Summary level of rail electrification in European countries (now in the European Union) from 1990 to 2023

A tool that can help in assessing the progress of electrification of rail routes is the electrification index used earlier. In this case, it will be the ratio of electrified sections to the total length of railroads within the countries currently in the European Union. The data adopted for the analysis goes back to 1990, when the European Union did not yet exist; however, for the sake of a broader analysis, data from before the establishment of this international institution was taken into account. In 1990, the average rate of rail electrification in future European Union member countries was about 40%. By 2023, this percentage had risen to about 57%. It is worth pointing out that throughout the 33-year period the rate has been rising practically all the time. It is possible to note a slight weakening of the trend in 2002–2003. According to information on the website of the statistical office of the European Union (Eurostat), the length of electrified railroad lines in the member countries of the European Union reached 115,000 km, an increase of 31% compared to 1990, when it was 88,000 km [6].

It should be taken into account that the total length of railroad lines has decreased by 7.5% since 1990, when it was about 218,600 km. Decreases in the length of rail routes were recorded in Poland, Latvia, France and Germany. The decline in the declared lengths of railroads in the countries concerned may also have had an impact on raising the electrification rate. However, it is worth pointing out that the rail network has increased significantly in Spain, Estonia and the Netherlands, partly due to the construction of dedicated high-speed lines [6].

The above electrification progress does not warrant the conclusion that all railroads in Europe will be electrified by 2050. Moreover, it should be noted that not all rail lines can be retrofitted with a running network for purely economic reasons or terrain constraints. First of all, electrification of rail lines requires the construction of new infrastructure in various geographic locations in mountains or swamps, among others. In addition, there are limitations associated with already existing parts of the infrastructure, such as narrow tunnels or viaducts. It’s worth mentioning that the costs of retrofitting a rail line with power infrastructure do not end with the investment itself. These types of rail lines must undergo constant maintenance activities that keep the infrastructure up to standard. This generates additional costs for low-traffic lines and makes them unprofitable. Taking the above arguments into account, it should be pointed out that the electrification process cannot be the only solution for reducing the use of internal combustion engines in rail vehicles.

3. Rolling stock of individual European Union countries

The structure of the fleet in each country varies depending on the level of electrification, so it is necessary to look at the available fleet in each country and determine what proportion of vehicles use internal combustion engines.

Using data included on the website of the statistical office of the European Union (Eurostat) [7], a chart was drawn up showing the number of electric and combustion vehicles in each country of the European Union.

Analyzing the data presented in the chart, we can identify two groups to be studied. The first set is made up of countries that have released full data, i.e. the number of electric locomotives, diesel locomotives and electric, diesel multiple units. The second set is made up of countries that have made available only the number of locomotives. The second group includes: Finland, Germany, Italy, the Netherlands, Poland and Slovakia.

In the first group, the number of vehicles with a power system based on internal combustion engines accounts for almost 34% of the declared fleet. This is about 11,550 vehicles.

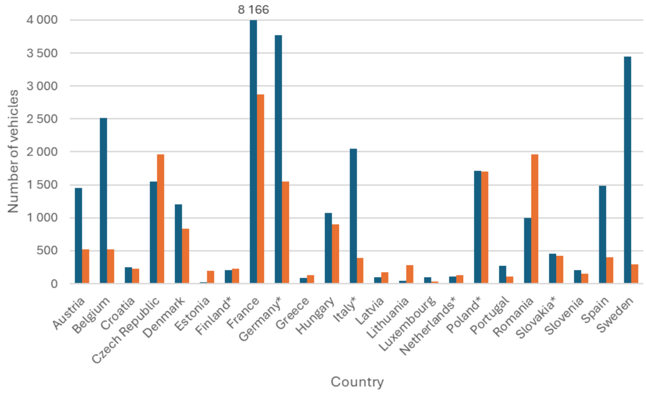

Fig. 4. Summary of electric (blue) and diesel (red) vehicles in European countries in 2023. Countries marked with "*" only have data on locomotives

The highest percentage of electric vehicles has: Sweden, Belgium and Spain. The share of machines based on electric propulsion exceeds 80%. In contrast, the Baltic States, Romania and the Czech Republic are dominated by internal combustion vehicles. Estonia has the lowest percentage of electric vehicles.

The second group, based only on locomotive data, is divided into two subsets. The elements of the first subset are countries with a high share of electric vehicles in the rolling stock, while the second set groups together countries in which the percentage of electric vehicles fluctuates around 50%. The first group includes Germany and Italy. Italy has more than 80% electric vehicles among locomotives. The second set includes: Finland, the Netherlands, Poland and Slovakia. The Netherlands has the smallest pool of electric machines in relation to its declared fleet. It is worth mentioning that the average level of electric machines in the declared fleet is about 65%. However, it should be pointed out that 4411 vehicles are still based on the use of fossil fuel combustion.

Analyzing the above statistics, it should be pointed out that the number of rail vehicles based on low- or zero-emission systems is too small to meet demand and requirements. Displacing diesel engines by 2050 from use in the rail industry from the point of view of the information presented will be a difficult challenge. The policy of moving away from traditional power systems based on fossil fuels and the development and introduction of modern propulsion systems, was also indicated in the European Parliament's resolution of December 13, 2022 on an action plan for the development of long-distance and cross-border rail passenger services [13] where it was emphasized that rail vehicles based on hydrogen technology and battery-powered rail vehicles could be a promising means of transportation.

4. Battery-electric traction units (BEMU)

The examples cited in the European Parliament's resolution can provide a basis for exploring and implementing new designs. However, it should be pointed out that the use of batteries as the only power source for a vehicle reduces its flexibility and range.

The answer, to the above basic limitations of battery power supply and providing an alternative to diesel traction units in passenger traffic, is a hybrid rail vehicle, which can use energy drawn from the catenary network or energy sources built on board in the form of batteries. The machine outlined above is referred to as a battery-electric multiple unit (BEMU) [2].The main advantage of these vehicles is that they do not use fossil fuels such as diesel, do not emit exhaust fumes and do not require the railroad to have expensive infrastructure in the form of catenary over certain distances. The disadvantages are the weight of the batteries, which adds to the weight of the vehicle, and the vehicle range associated with the battery capacity, which is about 200 kilometers.

The solution in the form of the BEMU, increases the flexibility of electric vehicles based primarily on drawing energy from the overhead line. Such a solution allows the vehicle to travel through a non-electrified section.

An additional advantage is the ability to store the energy produced during electrodynamic braking in case there is no possibility of recuperating energy into the overhead line, and the only solution in this situation is to expel energy in resistors.

A graph showing the level of charge (SOC) of the energy storage reservoirs during vehicle operation is shown in the following graphic.

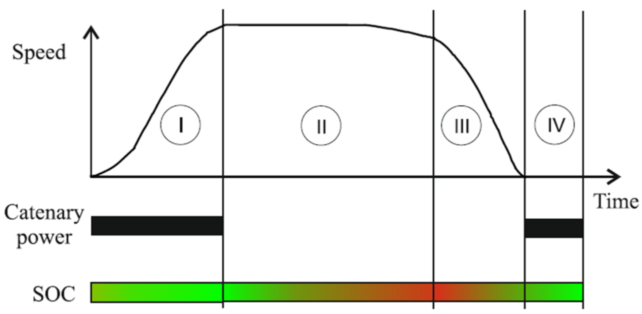

Fig. 5. Control strategy of onboard battery: (I) rolling and battery charging under catenary; (II) rolling in non-electrified sections; (III) battery charging through regenerative braking; (IV) fast-charging at stations with a pantograph [5]

Battery-electric multiple units (BEMUs) are becoming an increasingly considered solution by carriers, so leading companies in the rail industry, in response to market interest, have already prepared machines based on power supply from the catenary as well as from built-in batteries on board the vehicle.

5. Description of selected battery-powered and battery-networked vehicles

Stadler FLIRT Akku

The FLIRT Akku battery-grid traction unit from Swiss rail vehicle manufacturer Stadler is a development of the FLIRT electric traction unit concept. FLIRT is a platform that is widely known to European passenger carriers. With the development of this platform, the FLIRT Akku is a lightweight, single-level vehicle using aluminum alloys in its construction. The vehicle's design allows for a modular construction of the vehicle in the range of two to four members. The manufacturer of the vehicle allows individual configuration of the vehicle, tailored to the needs of the customer. The BEMU concept of the FLIRT Akku type also makes it possible to ride in multiple traction with all-electric vehicles of one- and two-story construction. The vehicle, according to the manufacturer's declaration, can travel at a maximum speed of 160 km/h. The declared range of the vehicle in battery driving mode is 150 km, while the charging time using pantograph charging is 15 min [9, 10].

Figure 6 shows a view of a two-member battery-network trainset of the FLIRT Akku type manufactured for the carrier Deutsche Bahn AG.

Fig. 6. General view of a BEMU of the FLIRT Akku type manufactured by Stadler for the carrier Deutsche Bahn AG [8]

Table 1. The basic data of a battery-network traction unit of the FLIRT Akku type configured for the German carrier Deutsche Bahn AG

No.	Parameter	Value
1.	Type	FLIRT Akku BEMU 2-4/8
2.	Rail spacing	1435 mm
3.	Supply voltage	15 kV/16.7 Hz
4.	Axle arrangement	Bo'Bo'2'2'
5.	Number of seats	172
6.	Vehicle width	2820 mm
7.	Vehicle height	4275 mm
8.	Vehicle length	55,5 m
9.	Wheelbase of the truck	2700 mm
10.	Max speed.	140 km/h

Figure 7 shows the energy transmission in the vehicle.

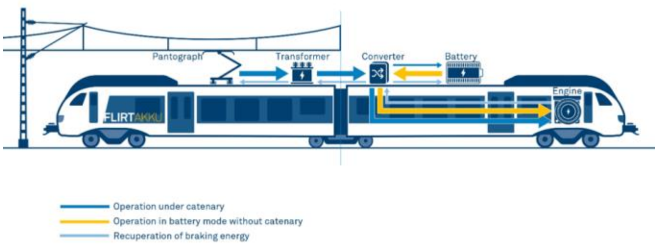

Fig. 7. Energy flow in a battery-grid traction unit of the FLIRT Akku 1 type [8]

FLIRT Akku allows the vehicle to drive by drawing energy from the catenary network. When driving in this mode, it is possible to charge the batteries at the same time, which greatly improves the use of the vehicle on railroad lines that are partially electrified. In addition, the FILTR Akku-type BEMU allows the recuperation of electricity, which can be used to charge the batteries or return it to the grid to reduce the cost of trips.

The vehicle holds the world record officially confirmed by the Guinness Book of World Records for the longest trip – over 224 kilometers – by a battery train in battery mode. The record was set in December 2021 on the Berlin-Gesundbrunnen – Warnemünde route in Germany.

Siemens The Mireo Plus B

The Mireo Plus B battery-grid traction unit, which is manufactured by Siemens Mobility, comes from the Mireo family of traction units presented by the manufacturer in 2016. The vehicle manufacturer declares the possibility of any vehicle configuration according to the individual needs of the customer. The Mireo Plus B-type BEMU is produced in two variants – a two-unit and a three-unit. The driving range of the vehicle using battery power is up to 80 km for the two-unit variant and up to 120 km for the three-unit variant. The vehicle reaches a maximum speed of 140 km/h in both mains-powered and battery-powered driving modes [13].

Fig. 8. Siemens The Mireo Plus B in the colors of Westerland [3]

Table 2. The basic data of the Mireo Plus B battery-grid traction unit [13]

No.	Parameter	Value
1.	Type	Mireo Plus B
2.	Rail spacing	1435 mm
3.	Supply voltage	15 kV/25 kV
4.	Axle arrangement	Bo‘ 2 Bo‘ (two-unit), Bo‘ 2‘ 2‘ Bo‘ (three-unit)
5.	Number of seats	120 (two-unit), 160 (three-unit)
6.	Maximum speed	140 km/h
7.	Vehicle entry height	600/800 mm
8.	Vehicle length	47 m (two-unit), 63 m (three-unit)
9.	Power	1700 kW
10.	Range	from 80 to 120 km

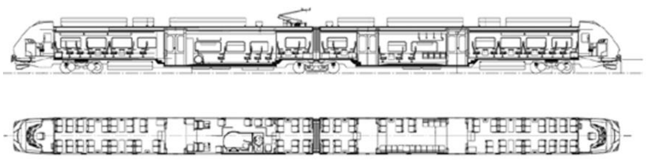

Fig. 9. Layout of Siemens The Mireo Plus B vehicle in two-body configurations [13]

Hitachi Masaccio

The Masaccio trainset platform manufactured by Hitachi Rail comes in three different power options:

– fully battery-powered
– battery-network power, in which the battery power acts as a commuter module
– battery-grid power, in which the vehicle can travel on electrified rail lines using mains power, on non-electrified lines through the use of a diesel engine, and during station stops and starts from stations using battery power.

The vehicle can travel at speeds from 144 to 162 km/h achieving a range of up to 150 km on a single charge. Charging of the Masaccio battery trainset is carried out from the catenary using a single pantograph while driving or two pantographs, the use of which is possible at the vehicle’s terminal station. The declared charging time for the vehicle is about 10 minutes at 15 kV AC and 80 A current. The BEMU Masaccio comes in a three-car option and a four-car option [2].

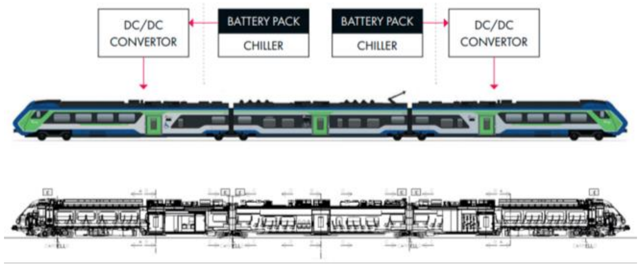

Fig. 10. Distribution of the Hitachi Rail Masaccio vehicle [2]

PESA Bydgoszcz S.A. REGIO 160 BEMU

The new REGIO 160 platform represents a family of rail vehicles for suburban and regional passenger transport. Trainsets from the REGIO 160 platform can develop speeds of up to 160 km/h, depending on configuration and power supply. As the manufacturer declares, the vehicles can be fully battery-powered or battery-grid hybrid [15, 16]. As part of the PESA 2025+ strategy, PESA has presented a concept for a modular REGIO 160 platform, featuring vehicles:

- single-deck
  – REGIO 160 standard – vehicle based on intermediate Jacobs bogies, shorter, one- or two-door sections
  – REGIO 160 XL – vehicle based on two classic bogies, providing better weight distribution and greater capacity
- double-deckers
  – REGIO 160 XXL d-deck – a concept based on a mix of single and double-deck members
  – REGIO 160 EMU d-deck – the entire vehicle is double-deck including the drive section
  – REGIO 160 push-pull.

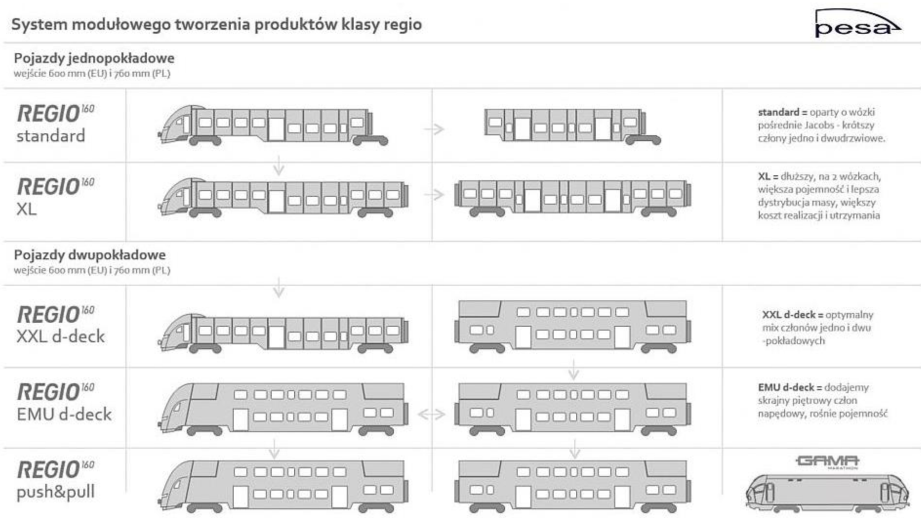

Fig. 11. Modular concept of the REGIO 160 platform presented by PESA Bydgoszcz S.A. [16]

Alstom X'trapolis

Figure 12 shows a visualization of the X'Trapolis vehicle to be produced for Irish Rail. The vehicle is expected to have a range of about 80 km in battery-driven mode with the ability to recharge in about 20 minutes using special super chargers. The manufacturer is also working on the possibility of charging the batteries from the catenary while stationary [1, 14].

Fig. 12. Visualization of BEMU type X'Trapolis made by ALSTOM for Irish Rail carrier. [1, 14]

Škoda Transportation – RegioPanter BEMU

The presented concept of the RegioPanter BEMU-type traction unit made by Škoda Transportation shows the interest of Europe's largest rolling stock manufacturers in producing mains-battery powered vehicles. This vehicle will be able to operate railroad lines that are partially electrified [17, 18]. Figure 13 shows the RegioPanter BEMU vehicle.

Fig. 13. RegioPanter BEMU manufactured by Škoda Transportation [17]

Table 3. Basic technical parameters of the RegioPanter BEMU

No.	Parameter	Value
1.	Type	RegioPanter BEMU
2.	Rail spacing	1435 mm
3.	Power	4×340 kW
4.	Number of passengers	323
5.	Maximum speed	160 km/h
6.	Vehicle height	4260 mm
7.	Vehicle length	52 900 mm
8.	Vehicle width	2820 mm
9.	Driving range in battery mode	to 80 km
10.	Number of bicycles/carriages	9/4

Table 3 shows the basic technical parameters of the RegioPanter BEMU vehicle made available by its manufacturer.

"Wittfeld" type battery unit

Between 1908 and 1913, battery trains were built on behalf of the Prussian railroads KPEV. The original order was for 57 units of newly developed battery vehicles, which was realized by three factories within two years (1908-1909). A further 114 units were produced between 1910 and 1914. KPEV commissioned the vehicles because of the rapid development of railroads, which involved the construction of railroads in areas running through economically undeveloped parts of the country that did not have transportation needs with a view to arousing them and causing economic growth from the excluded areas of Prussia at the time. For this reason, it was uneconomic to operate traditional train sets consisting of steam locomotives and a few passenger cars, and it was necessary to develop a design to provide economically viable service on such rail routes.

Fig. 14. Battery cart of the "Wittfeld" type [20]

Table 4. Basic technical parameters of Wittfeld

No.	Parameter	Value
1.	Type	Wittfeld
2.	Axle arrangement	2A+A2 (firstly 57 pcs, 1A+A1)
3.	Overall length	25,610–25,650 mm
4.	Wheelbase	1500 + 7650 mm
5.	Service weight	53.2–68.3 t
6.	Maximum speed	60 km/h
7.	Range	100–300 km
8.	Number of seats	82/90
9.	Battery battery voltage	350 V DC
10.	Number and power of motors	2×59/66 kW
11.	Type of batteries	lead-acid
12.	Weight of the batteries	17–25.5 t
13.	Charging time (nomin.)	2.5–3 h

The "Wittfeld" battery units were able to travel at 60 km/h with a range of 100, 130, 180 and even 300 km. Such a long range was achieved by using batteries with capacities of 368, 443, 562 and 921/1088 Ah, respectively. Charging the batteries with stationary rectifiers took from 2 to 3 h. Achieving such performance was achieved by minimizing as much as possible the weight of the vehicles, which ranged from 53.2 to 68.3 t, depending on the battery capacities used, and minimizing the need for electricity while the vehicle was running, for example, by installing heating with briquette stoves inserted under the seats [9].

6. Summary

In accordance with the climate policy adopted by the European Union Parliament, it is necessary to take measures to bring member countries closer to achieving climate neutrality. The statistics presented relating to the level of electrification of railroad lines in the European Union member states show that about 43% of the lines are not electrified. These lines are mainly served by diesel-powered vehicles, the average age of which in Poland is about 42 years for diesel locomotives and about 16 years for diesel multiple units [21]. Thus, it is necessary to introduce rolling stock changes and replace the old rolling stock with a new one that can operate non-electrified lines as low-emission as possible. One solution is for carriers to purchase plug-in or battery-powered vehicles. This approach is in line with the climate policy adopted by the EU and confirms the increasing awareness of citizens regarding environmental protection. The range of mains- or battery-powered vehicles presented in the article shows that rolling stock manufacturers are prepared to offer customers low-emission passenger transport vehicles.

Nomenclature

BEMU Battery Electric Multiple Unit

SOC state of charge

Bibliography

[1] Alstom to supply 18 additional X'trapolis battery-electric trains for Irish Rail. https://www.alstom.com/press-releases-news/2022/12/alstom-supply-18-additional-xtrapolis-battery-electric-trains-irish-rail (accessed on 30.04.2025).

[2] Battery Commuter Train Technical Specification. https://www.hitachirail.com/products-and-solutions/battery-powered-trains/battery-commuter-trains/battery-commuter-train-technical-specification/ (accessed on 30.04.2025).

[3] Battery trains from Siemens Mobility for the Westerwald. https://press.siemens.com/global/en/pressrelease/battery-trains-siemens-mobility-westerwald (accessed on 30.04. 2025).

[4] Biała Księga. Plan utworzenia jednolitego europejskiego obszaru transportu – dążenie do osiągnięcia konkurencyjnego i zasobooszczędnego systemu transportu (in Polish). https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=celex:52011DC0144 (accessed on 30.04.2025).

[5] Del Pizzo A, Fedele E, Iannuzzi D. Onboard energy storage in rail transport: review of real applications and techno-economic assessments, IET Electrical Systems in Transportation. 2021;11:279-309. https://doi.org/10.1049/els2.12026

[6] Eurostat. Electrified railway lines increased by 31% since 1990. https://ec.europa.eu/eurostat/web/products-eurostat-news/w/ddn-20240313-1 (accessed on 30.04.2025).

[7] Eurostat. Locomotives and railcars by source of energy. https://ec.europa.eu/eurostat/databrowser/view/rail_eq_locon/default/table?lang=en&category=rail.rail_eq (accessed on 30.04.2025). https://doi.org/10.2908/RAIL_EQ_LOCON

[8] FLIRT Akku: continues where the overhead line ends. https://www.stadlerrail.com/en/solutions/rolling-stock/mainline-flirt-akku (accessed on 30.04.2025).

[9] Jerczyński M. Nasz Portret: Zespół akumulatorowy typu „Wittfeld" (in Polish). Świat Kolei. Magazyn sympatyków komunikacji szynowej Parowozik. Wydanie 3, 1995.

[10] Komunikat Komisji do Parlamentu Europejskiego, Rady Europejskiej, Rady, Komitetu Ekonomiczno-Społecznego i Komitetu Regionów. Europejski Zielony Ład (in Polish). https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=COM:2019:640:FIN (accessed on 30.04.2025).

[11] Komunikat Komisji do Parlamentu Europejskiego, Rady Europejskiej, Rady, Europejskiego Komitetu Ekonomiczno-Społecznego, Komitetu Regionów i Europejskiego Banku Inwestycyjnego. Czysta planeta dla wszystkich. Europejska długoterminowa wizja strategiczna dobrze prosperującej, nowoczesnej, konkurencyjnej i neutralnej dla klimatu gospodarki (in Polish). https://eur-lex.europa.eu/legal-content/PL/TXT/?uri=CELEX:52018DC0773 (accessed on 30.04.2025).

[12] Komunikat Komisji do Parlamentu Europejskiego, Rady, Komitetu Ekonomiczno-Społecznego i Komitetu Regionów. Strategia na rzecz zrównoważonej i inteligentnej mobilności – europejski transport na drodze ku przyszłości (in Polish). https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=CELEX:52020DC0789 (accessed on 30.04.2025).

[13] Mireo Plus – a powerful train becomes even more powerful. https://www.mobility.siemens.com/global/en/portfolio/rolling-stock/commuter-and-regional-trains/mireo/mireo-plus.html (accessed on 30.04.2025).

[14] New fleet for the DART. https://www.modernrailways.com/article/new-fleet-dart?fbclid=IwAR0pXi--_UPp3_cihOmrfwU4SurjnA1AOqzPPyFS895dcGFisV0PDNqT5z8 (accessed on 30.04.2025).

[15] Pesa pokazała nową strategię 2025+ Rynek Kolejowy. Tabor i Technika (in Polish). https://www.rynek-kolejowy.pl/wiadomosci/pesa-pokazala-nowa-strategie-2025-103526.html (accessed on 30.04.2025).

[16] Półpiętrusy i hybrydy w nowej ofercie Pesy Regio160 Rynek Kolejowy. Tabor i Technika (in Polish). https://rynek-kolejowy.bm5.pl/wiadomosci/-polpietrusy-i-hybrydy-w-nowej-ofercie-pesy-regio160-103539.html (accessed on 30.04.2025).
[17] Project for a RegioPanter BEMU. https://www.railvolution.net/news/project-for-a-regiopanter-bemu (accessed on 30.04.2025).
[18] Regiopanter BEMU. https://www.skodagroup.com/reference/regiopanter-battery-unit (accessed on 30.04.2025).
[19] Rezolucja Parlamentu Europejskiego z dnia 13 grudnia 2022 r. w sprawie planu działania na rzecz rozwoju dalekobieżnych i transgranicznych kolejowych przewozów pasażerskich (2022/2022(INI)) (in Polish). https://eur-lex.europa.eu/legal-content/PL/ALL/?uri=CELEX:52022IP0437 (accessed on 30.04.2025).
[20] Terczyński P. Atlas lokomotyw elektrycznych (in Polish). Wydawnictwo KOLPRESS. Poznań 2017.
[21] Tabor kolejowy przewoźników pasażerskich (in Polish). https://dane.utk.gov.pl/sts/tabor/tabor-pasazerski/20878,Tabor-kolejowy-przewoznikow-pasazerskich.html (accessed on 30.04.2025).