IBIMA Publishing
Communications of International Proceedings
https://ibimapublishing.com/p-articles/46MGT/2025/4649125/
Vol. 2025 (30), Article ID 4649125

Development of Truck Electrification On Selected TEN-T Network Routes In Poland*

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* Presented at the 46th IBIMA International Conference, 26-27 November 2025, Ronda, Spain

Abstract

Despite the considerable advancement of various technologies based on broadly defined digitalization, the electrification of trucks remains an unpopular area, especially in terms of implementing new charging points. This is undoubtedly an area where crucial decisions are being made regarding actions to reduce exhaust emissions, which are crucial from the perspective of climate change. Therefore, the electrification of trucks, related to aspects of transport tasks and the transport of large loads using electric heavy-duty vehicles, depends on the deployment of charging points, which are part of the alternative fuel infrastructure.
With this in mind, and in particular the observed research gap in this area, it was deemed appropriate to identify the problem of truck electromobility in the area of overland freight transport on the TEN-T network on Poland's leading routes. Based on this, the main goal of the research was defined: to analyze and forecast the infrastructure needs for electric truck transport along the A1 and A2 motorways in Poland. In this article, the research process involved analyzing the general and detailed locations of electric vehicle charging points based on field surveys and inventory data as well as data from spatial information systems. The spatial data processing and interpolation analyses were performed using ArcGIS tools, which are specialized tools for analyzing data related to electromobility. For a more comprehensive depiction of the phenomenon, the Inverse Distance Weighting method was used to present the results in cartographic form, which enabled the presentation of the results both as a heat map showing the forecasted concentration of charging points for trucks in Poland.

Keywords: truck electrification, truck charging points, TEN-T network.

Introduction

When beginning an analysis focused on the development of road transport, it is undoubtedly worth mentioning what a transport network is. Generally speaking, it is a collection of numerous transport elements that enable the transport of passengers or the relatively smooth reloading of cargo to reach a desired destination [1]. The transport network includes, among other things, transport routes, i.e., roads, as well as the required rail, air, and port infrastructure that secures intermodal transport [2]. One of the most important transport networks in Europe is the Trans-European Transport Networks (TEN-T), established in 1996 in connection with European Parliament Decision No. 1692/96 [3, 4]. The transport network was included in the so-called White Paper in the section related to the plan to create a single European transport area [5, 6, 7].

The assumptions related to the trans-European transport network focus on improving communication, reducing transport costs, and minimizing the negative impact of freight transport on the environment [8]. It is worth noting that Decision No. 1692/96 also takes into account the reduction of road accidents, as the TEN-T network is intended to be safe for users [9]. To illustrate the scope of the project, the TEN-T network comprises several hundred transport routes throughout the European Union. These are primarily road routes connecting all member

Cite this Article as: Dariusz KLOSKOWSKI, Vol. 2025 (30) "Development of Truck Electrification On Selected TEN-T Network Routes In Poland " Communications of International Proceedings, Vol. 2025 (30), Article ID 4649125, https://doi.org/10.5171/2025.4649125

states. The TEN-T also includes European airports, sea and river ports, transshipment ports, logistics centers, and railway stations [10, 11, 12].

The scope of the entire project involves connecting over 95,000 railways and road networks, 13,000 waterways, 330 land and water-land transshipment terminals, and 130 airports, enabling the efficient transport of goods and people. Importantly, all these elements must be effectively connected with each other [13] (Fig. 1.).

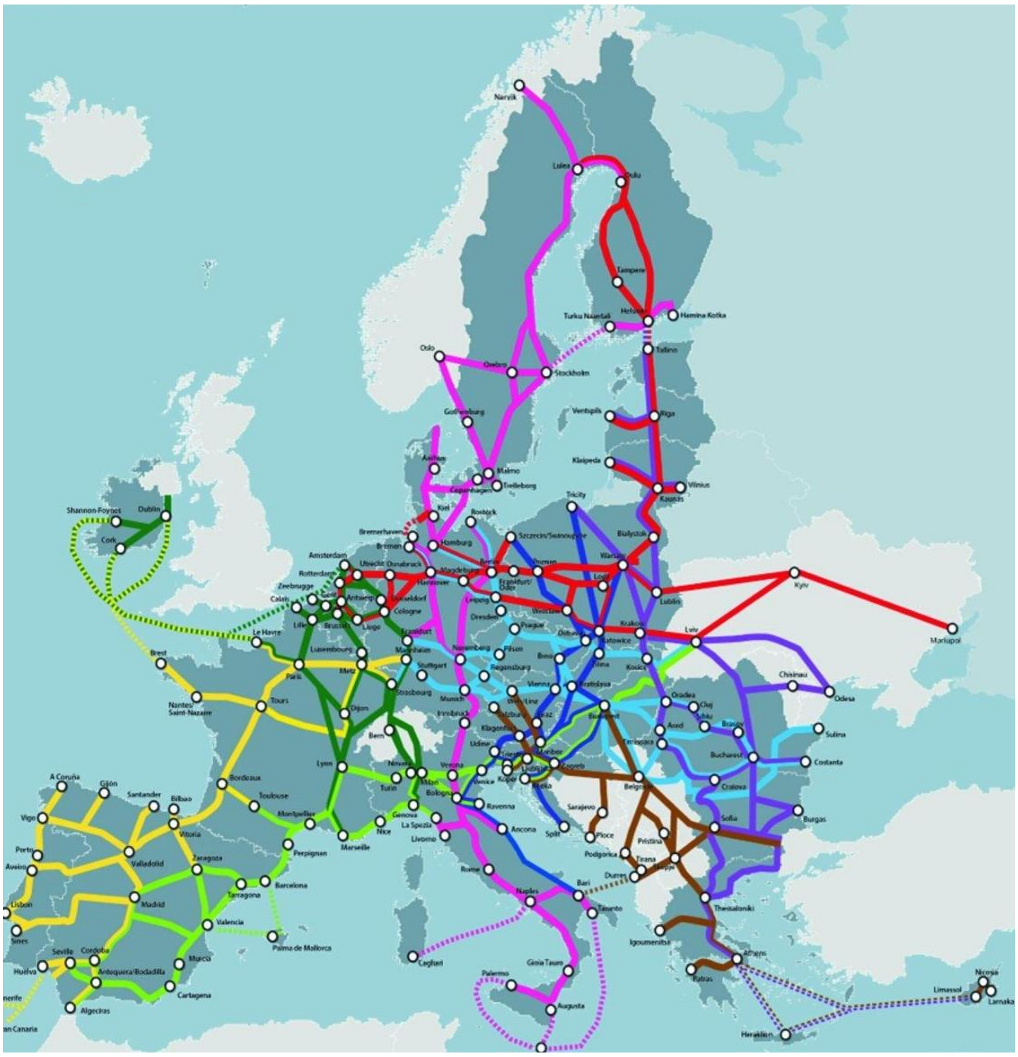

Figure 1: Development of the TEN-T road network
Source: www.gov.pl/web/infrastruktura/transeuropejska-siec-transportowa--ten-t.

Analyzing the development of roads in the TEN-T network in Poland, it is mainly related to the main communication routes, namely the transport corridor: Baltic Sea – Adriatic Sea and the corridor: Baltic Sea – North Sea [14, 15, 16, 17]. The first of them is the route between Poland and Italy, covering over 7,800 kilometers of roads. This network in Poland includes, among others, the A1 motorway running from Gdańsk to Katowice and the road between Szczecin and Wrocław. It also includes railway infrastructure (Fig. 2.).

Figure 2: Transport corridor: Baltic Sea-Adriatic Sea, Baltic Sea-Aegean Sea and Baltic Sea-Black Sea

Source: www.gov.pl/web/gddkia/drogi-krajowe-w-sieci-ten-t-i-korytarzach-miedzynarodowych.

The second corridor connects Poland and Germany with the countries of the Scandinavian Peninsula and runs through the Baltic countries (Lithuania, Latvia, Estonia). This route is part of the New Silk Road. In total, it comprises 6,000 kilometers of railway tracks, 4,100 kilometers of roadways, and 2,100 kilometers of inland waterways. This route connects Poznań with Warsaw via the A2 motorway (Fig. 3.).

Figure 3. Transport corridor: North Sea-Baltic Sea and North Sea-Black Sea and North Sea-Aegean Sea

Source: www.gov.pl/web/gddkia/drogi-krajowe-w-sieci-ten-t-i-korytarzach-miedzynarodowych.

The Polish part of the TEN-T network consists mainly of expressways and motorways. It is worth emphasizing that thanks to the expansion of this program, the transport infrastructure in the country has significantly developed. It is worth noting that, in addition to its advantages and opportunities, the TEN-T network also poses a challenge for transport companies. The European Union requires reducing the negative impact of transport on the environment [18, 19]. This involves finding alternative sources of vehicle power, expanding and investing in electrification infrastructure, and purchasing modern trucks that meet all exhaust gas standards [20, 21, 22]. Due to this fact, which is still a niche issue and a clear gap in the literature in this area, it was decided to conduct research and forecast solutions for heavy transport in Poland.

Research materials and methods

Considering the specific nature of electromobility in truck transport on the TEN-T network in Poland, it is undoubtedly clear that it stems, on the one hand, from regional development strategies and, on the other, from the directions of supply chain development in the European Union [23]. At every level of development, the concept of cargo flow is part of the development of the road network, which determines the successful delivery of cargo on time [24]. This also stems from the fundamental maxim of sustainable development, which underpins the construction of every business: "think globally and act locally." This is not a new trend in road transport in the broad sense, but after the crisis caused by the SARS-CoV-2 virus, it has gained significant importance. This is primarily to promote various forms of development, including the development towards electromobility, which in this case involves the transport of larger loads [25].

This focus promotes areas that have not previously received much attention on the roadmap. This was, of course, necessitated in part by the country's highly urbanized landscape. The accumulation of cargo within a single transport hub created development opportunities in other locations, alleviating truck traffic congestion. It's also arguable that, in a sense, the accumulation of road traffic at key hubs provided an opportunity to change the direction of road transport development, promoting other routes and regions.

Considering the transport of cargo by road using electric trucks, it can be concluded that this is not a standard task [26, 27, 28]. This also applies to research in this area, where a clear gap in the literature is visible. With this in mind, this article addresses the implementation of climate and energy policy goals, including, among others, the reduction of greenhouse gas emissions. This essentially involves a location analysis of available electromobility infrastructure, highlighting charging points that constitute an infrastructural element of heavy transport on the TEN-T network routes [29, 30, 31].

As part of the preliminary work related to the analyzed research subject, the issue of electromobility in the area of land freight transport on the TEN-T network in Poland's leading directions was explored through a study of the relevant literature, including scientific publications. The main objective was then formulated: to analyze and forecast the infrastructure needs for electric truck transport along the A1 and A2 motorways in Poland. The study's analysis was divided into two parts. The first, general part, focused on presenting an analysis of truck electrification, taking into account the benefits and limitations resulting from technology, infrastructure, and transport economics. Road infrastructure was given particular importance in the energy transition process, in accordance with the AFIR regulation [32]. The study considered it appropriate to determine the general and specific locations of electric vehicle charging points as the main development determinants in the context of electromobility. Organizing the research material proved quite difficult due to the categorization of charging stations, which differ significantly in their functions. The analysis was based on our own field surveys and inventories, literature on the subject, databases of spatial information systems for individual monitored areas, planning documents, and data from industry websites. Based on this data, 4,200 data points were collected on the locations of fast electric vehicle charging points. Next, 390 Service Areas (MOPs) were selected, where 98 charging points were verified, which, due to their extensive infrastructure, could serve as stations for servicing electric trucks. The above data was input into ArcGIS software, which was used to process them in a GIS format (Fig. 4.).

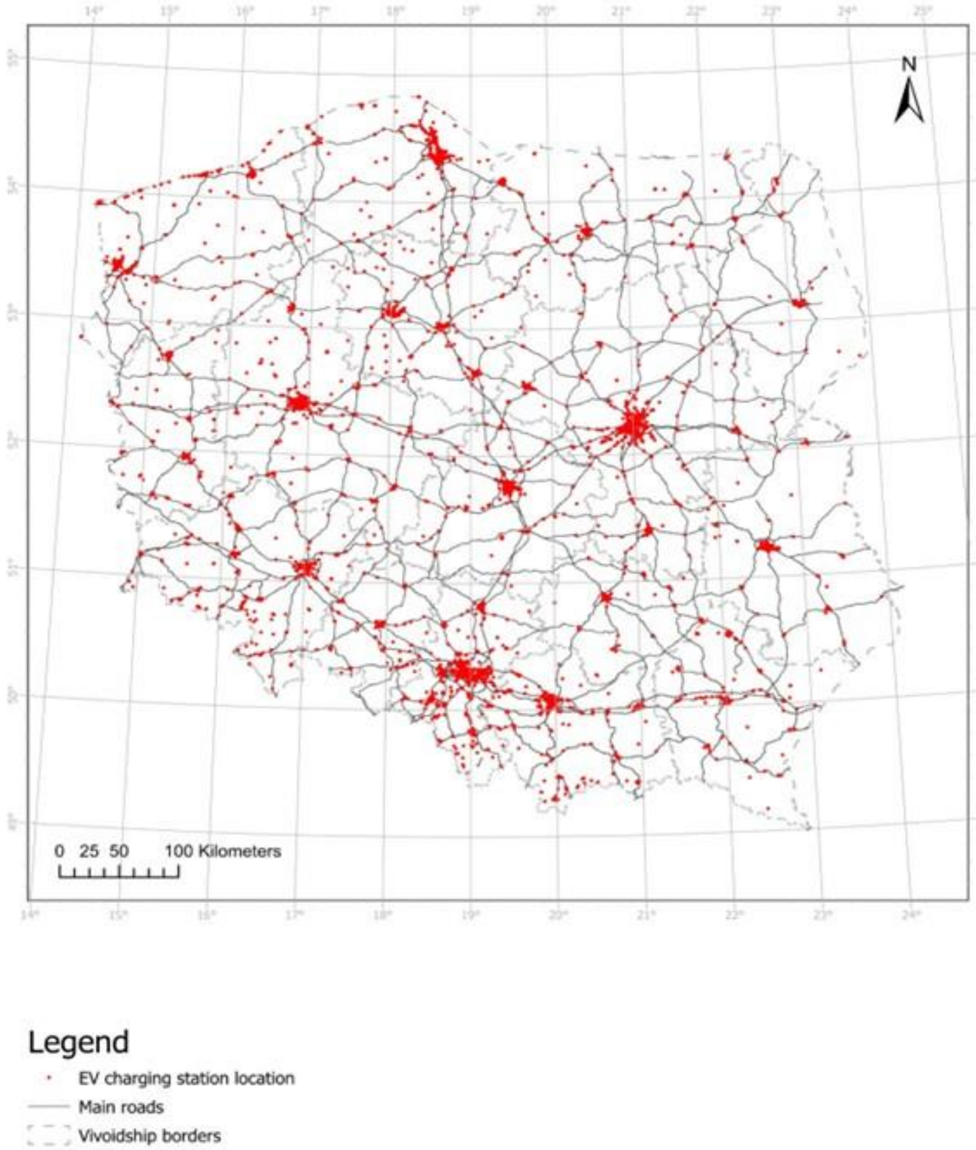

Figure 4: Location of charging points on TEN-T routes in Poland

Source: own study.

To demonstrate the spatial interpolation of the truck charging point density forecast, a hypothesis was used, which was specified as follows: the spatial autocorrelation of truck charging points is related to the directionality of the main chains in the TEN-T system. The movement of cargo on the A1 and A2 routes is the main determinant for making key decisions regarding the implementation of charging points. The above analysis employed the spline method with barriers [33, 34, 35], whereby areas inactive in terms of implementing truck charging points were additionally excluded from the interpolation. This method, for estimating values, uses a mathematical function that minimizes the overall surface curvature, resulting in a smooth surface that passes through the starting points. Generally, this method can be considered analogous to the so-called "bending a sheet of rubber" to pass through known points while minimizing the surface curvature. The projected saturation of stations on the generated A1 and A2 routes was determined by generating polygon centroids representing established heavy goods vehicle charging points. Based on the resulting layer, a heatmap interpolation was performed, based on the proximity and density of charging points in the TEN-T supply chain.

Development of truck electrification on selected TEN-T routes in Poland

Considering the development of road transport in land freight transport in the European Union, it can be noted that despite numerous initiatives for modal shifts and the development of intermodal transport, the share of road freight transport remains at the highest level [36]. This is accompanied by high costs in transport prices, but it can also be noted that road accidents, problems with air pollutant emissions, increased noise, and degradation of land and road infrastructure remain high [37, 38, 39]. At the same time, the capital-intensive linear infrastructure of road transport and the increasing number of companies force a change in transport orientation related to the introduction of more electric vehicles on the roads [40]. This is not only due to the temporary trend of using electric cars, but also necessitated by the situation related to climate warming and environmental protection [41].

From a social perspective, the growing demand for passenger and freight transport is of particular importance, resulting from ongoing globalization, including the free flow of supply chains within EU agreements. Available analyses indicate that the intensification of urban development, the expansion of metropolitan areas, and suburbanization are forcing changes related to the transition to other, alternative modes of transport or to other vehicle power sources [42, 43]. This is related to the ongoing implementation of the EU Alternative Fuels Infrastructure Regulation (AFIR) and the pursuit of the goals of the European Green Deal and the Fit for 55 package [44]. According to Polish government data, by 2030, 166 charging stations for heavy goods vehicles should be operational on the core TEN-T network in Poland, while currently only several dozen are in operation, necessitating continuous expansion. It should be noted that only some of the existing MOPs have access to sufficient connection power, and in many locations, new stations will need to be built. The AFIR requirements for heavy goods vehicle charging infrastructure in the TEN-T network are presented in the table below (Tab.1.).

Table 1. AFIR requirements for heavy goods vehicle charging infrastructure in the TEN-T network

Network TEN-T	2025	2027	2030
Core Network	15% network, 1400 kW, 1 punkt ≥350 kW, distance ≤120 km	50% network, 2800 kW, 2 punkty ≥350kW, ≤120 km	100% network, 3600 kW at least 2 points ≥ kW; distance ≤60 km

Źródło: www.gov.pl/web/gddkia/zalozenia-afir-jak-unijne-rozporzadzenie-wplynie-na-rozwoj-elektromobilnosci-w-polsce.

Effective dimensioning of charging infrastructure on TEN-T network corridors requires estimating the average daily truck traffic. As shown by the available scenarios for the share of electric trucks in total truck traffic, traffic increases of 5%, 25%, and 50% are assumed, assuming a three-year growth period. Since AFIR does not impose a fixed share of electric HGVs in 2030, these scenarios are model-based and consistent with the methodology used by the European Environment Agency, ICCT (International Council on Clean Transportation) [45]. In principle, the main criterion for converting existing charging stations into truck charging points results from the requirements for implementing peak power on the indicated TEN-T network roads. The required peak power values on the A1 and A2 motorways of the TEN-T network are presented below (Table 2).

Table 2. Required peak power on A1 and A2

Scenario	A1: E- daily (MWh)	A1: P- required (MW)	A2: E- daily (MWh)	A2: P- required (MW)
5%	125,3	**83,53**	117,5	**78,33**
25%	625,6	**417,07**	587,9	**391,93**
50%	1 251,2	**834,13**	1 175,9	**783,93**

Źródło: www.gov.pl/web/gddkia/zalozenia-afir-jak-unijne-rozporzadzenie-wplynie-na-rozwoj-elektromobilnosci-w-polsce.

These figures reflect the optimal scenario, which assumes 239 charging stations on the A1 and 224 on the A2, assuming a 5% increase; 1,192 on the A1 and 1,120 on the A2, assuming a 25% increase; and 2,384 on the A1 and 2,240 on the A2, assuming a 50% increase. This result should be considered the minimum number of charging points, taking into account the assumptions of the AFIR regulation, which stipulates the availability of infrastructure for trucks every 60 km. With this in mind, and taking into account the diagnosed number of MOPs on the A1 and A2 motorways, interpolation estimates were made using the inverse distance weighting (IDW) method [46], which revealed the saturation of the number of stations generated based on the heat map (Fig. 5).

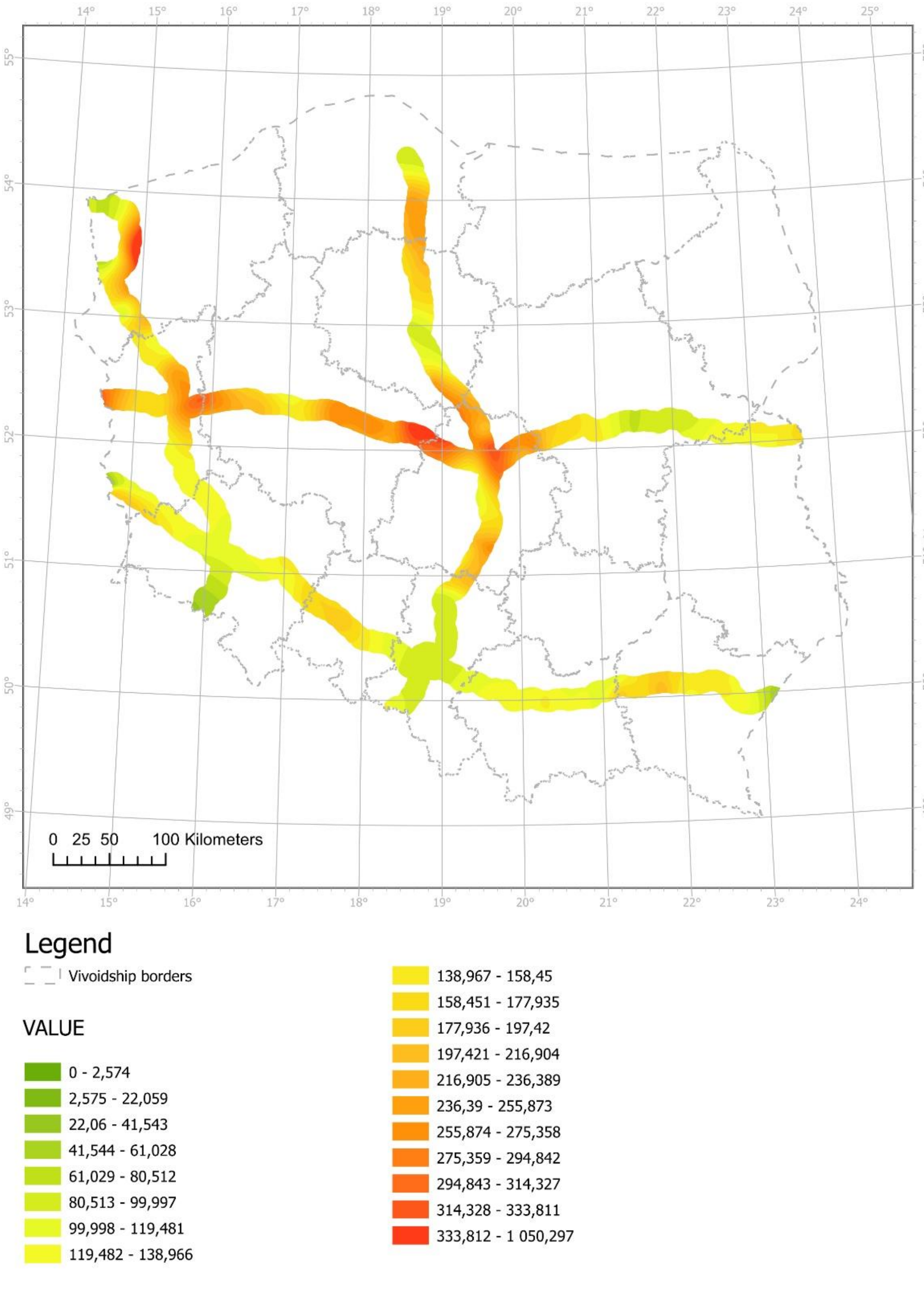

Figure 5. Charging point density on the A1 and A2 motorways of the TEN-T network in Poland – forecast scenario

Source: prepared by the authors.

Analyzing the above, and particularly considering the main goal of the study, which is to analyze and forecast infrastructure needs for electric truck transport along the A1 and A2 motorways in Poland, it can be concluded that the above figure represents a response to the directionality of truck electrification on TEN-T roads in Poland. The accumulation of charging points in the Łódź Voivodeship is not accidental. The city of Łódź is closely linked to the directionality of the A1 motorways towards Gdańsk and the A2 motorways towards Poznań. Therefore, the concentration of charging points in this location is not due to the size of the leading city, Łódź, but rather to transport hubs and goods storage, as in the case of the Central European Logistics Hub – the largest warehouse in

Poland. The same applies to the concentration near the intersection of the A1 motorway and the S3 expressway in the Lubuskie Voivodeship. The latitudinal directionality dominates the development of charging points here. This is related to the very high volume of freight traffic and the increased number of tourists traveling east-west and west-east. This can also be attributed to the constantly expanding warehouse park in Greater Poland, which significantly influences the creation of new charging points to shorten the idle time of electric vehicles.

However, it should not be forgotten that the flow of cargo from Europe's largest military port – Rotterdam – is constantly increasing, for example, towards Ukraine, where the war is ongoing. Defense objectives, therefore, determine the increase in cargo, primarily through the recognition of this port as a so-called military gateway to Europe, associated with the transfer of NATO troops and military equipment..

Conclusions

To summarize the discussion so far, the electrification of road freight transport presents engineers and decision-makers with considerably greater challenges than passenger cars. Due to their unladen weight and intended use in long-distance travel, electric trucks require batteries with a capacity of several hundred kilowatt-hours (kWh). To ensure maximum functionality, it is essential to create high-quality charging infrastructure for high-powered electric vehicles, enabling rapid charging.

With these issues in mind, the European Union has introduced Regulation (EU) 2023/1804 of the European Parliament and of the Council on the deployment of alternative fuels infrastructure (AFIR), which entered into force on April 13, 2024. However, implementation targets for the installation of charging stations for electric trucks on EU roads are expected to be finalized in 2030. This is primarily due to the fact that CO_2 emissions from new trucks are to be reduced by 30% by 2030 compared to 2019 levels. Furthermore, the "Fit for 55" strategy envisages further tightening of emission standards for the transport sector. This focus is intended to accelerate the transition to more environmentally friendly modes of transport. This will be linked to the planned increase in the share of renewable energy sources in transport and will also ensure a 55% reduction in greenhouse gas emissions by 2030.

The interpolation shown in Figure 5 is consistent with the European Union's overall strategy to increase the number of electric trucks. In the coming years, a dynamic increase in registrations and the development of the electric truck fleet is forecast in Europe. The increase in Europe is expected to reach approximately 46,000 vehicles by the end of 2025 and approximately 190,000 by the end of 2025. in 2030. Therefore, with this in mind, the proposed forecast for the implementation of charging points coincides with the general trend in the road truck transport market.

This also applies to addressing travel costs, primarily related to military transport. In the current situation and existing solutions, where standard fuel-powered wheeled transport is used, this poses a significant threat, primarily from drone attacks. Switching to alternative fuel sources offers significant opportunities not only for cargo safety but also for minimizing the effects of an explosion on the blast zone.

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