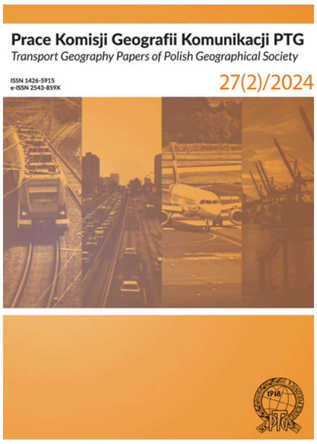

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SPATIAL DISTRIBUTION AND TYPOLOGY OF PUBLIC TRANSPORT ELECTRIC TRACTION NETWORKS IN CENTRAL EUROPE

Rozkład przestrzenny i typologia sieci trakcji elektrycznej transportu publicznego w Europie Środkowej

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Abstract:
This study presents a consistent and transferable methodology for identifying and analyzing continuous urban electric traction networks—specifically trams, trolleybuses, and metro systems—in Central European cities. Using data from OpenStreetMap, enriched with official transport sources and field verification, we defined 113 integrated networks across Czechia, Hungary, Germany, Poland, Austria, Slovakia, and Switzerland. Key absolute and relative indicators—such as total network length and composite density—were calculated for each system, and linked to standardized statistical units (LAU, NUTS).

At least minimal electric public transport infrastructure was identified in 366 municipalities. The study examines spatial patterns in network distribution and tests several hypotheses, including whether capital cities with metro systems also host the most extensive tram and trolleybus networks, and how urbanization levels affect network density. The findings confirm that larger and more urbanized cities tend to support more complex and denser electric transport systems, but also reveal exceptions influenced by historical and spatial factors. The analysis demonstrates that using only urbanized areas yields more meaningful comparisons than relying on entire administrative boundaries.

A seven-category typology was developed to enable comparative assessment of network significance and urban transport potential across the region. The results offer a robust database for further spatial and transport analyses and highlight the value of network density as an indicator of public transport quality. This approach can be applied in other regions worldwide, supporting sustainable mobility research and planning.

Key words: Urban public transport, integrated network, Central Europe, electric traction, rail

1. Introduction

The character of a city, along with the diverse spatial distribution of its various functions, naturally leads to the need for population mobility. Depending on the area, compactness of the built-up zone, and of course the size and structure of the population, the question of the efficient use of transport modes arises. Alongside individual mobility, the system of urban public transport (hereafter referred to as PT) represents a functional alternative, especially as city size and travel distances increase. PT plays a crucial role in facilitating the mobility of the population in densely populated urban areas. It is characterized by the provision of reliable, efficient, and affordable transport services. PT typically includes various types of transport modes—most commonly buses, trams, metros, and trolleybuses—which are integrated into a network of lines and stops designed to best meet the needs of residents in different parts of the city. One of the key factors that makes PT systems indispensable in urban environments is their ability to minimize individual car usage. This helps to reduce congestion and, in turn, improves traffic flow and accessibility, which has a direct positive impact on the environment and the quality of life for the population.

The scope and level of use of electric rail infrastructure can be considered a significant universal factor in evaluating the efficiency of public transport. A higher network density within a city means, from a spatial perspective, better accessibility, connectivity, and overall operational flexibility. Economically, in the long term, it is advantageous to use a higher proportion of electric high-capacity vehicles, which are naturally tied to the rail network. Rail vehicles are also characterized by lower energy consumption and smoother driving performance.

However, in order to maintain objectivity, it is also necessary to acknowledge potential drawbacks. The high costs of constructing a rail network represent a major barrier to the rapid development of infrastructure in smaller cities with lower mobility needs and limited budgets. Compared to conventional bus services, rail systems are bound to specific routes, which cannot be easily changed in the event of an accident or reconstruction. In modern operations, partial (hybrid) vehicles with partial independence from overhead power lines are used as an alternative, allowing them to bypass obstacles. Moreover, an extensive network does not necessarily guarantee faster or more comfortable transport if it is not properly maintained and continuously modernized.

The general aim of this study is to spatially analyse, evaluate, and categorize all currently operating urban electric rail networks (modes of metro, tram, trolleybus) within the countries of Central Europe. One of the partial objectives is to explore the relationship between the urban characteristics of cities and the parameters of their electrified transport networks. We will focus on the geographical distribution of networks across the Central European region and test the assumption that in countries with larger populations and higher levels of urbanization—such as Germany, Poland, and Switzerland—the longest and most complex networks are concentrated in large metropolitan areas. Furthermore, we will examine whether the presence of a metro system in a capital city always corresponds to having the longest and densest tram and trolleybus networks in the country, and whether all electric rail networks in large agglomerations are, by nature, multimodal. We also assume that network density will be significantly influenced by the proportion of urbanized area to the total administrative area of a municipality, and thus that the results may differ substantially when only urbanized areas are considered. These hypotheses will be tested using a quantitative analysis, which will form the foundation for the typology and comparison of the individual networks.

2. Definition of Urban Public Transport Subsystems

The definition of urban public transport (PT) may vary depending on the technical specifications of the vehicles used, the degree of system integration, or the terminology in different languages. When focusing on general shared features that appear across the professional literature, PT is most commonly divided into bus, trolleybus, rail (tram, rapid transit, cable), waterborne, and other unconventional subsystems. Globally, electric propulsion is gaining a dominant position, allowing us to speak primarily of electric PT. Buses, due to their deployment flexibility and relatively low entry costs, are by far the most widespread form of PT. In addition to independent operations, many cities are part of large integrated transport systems, where the boundary between urban and regional public transport becomes blurred. In areas prioritizing lower noise levels and cleaner air, electric buses or trolleybuses are being introduced in place of older diesel buses. Unlike electric buses, trolleybuses are tied to overhead wiring and do not rely on batteries or diesel generators. Between buses and trolleybuses lie partial (also called hybrid) trolleybuses equipped with batteries for operating in sections without overhead lines.

In the Anglophone world, terms such as rapid or semi-rapid transit are commonly used. BRT (Bus Rapid Transit) refers to high-capacity buses operating at shorter intervals, with the possibility of dedicated lanes, as described by Vuchic (2007). In Czech, the equivalent term is metrobus. In the case of rapid transit systems, this either refers to LRT (Light Rail Transit)—typically light metro systems operating as elevated lines—or HRT (Heavy Rail Transit), which denotes standard metro systems. Tram and rapid transit subsystems are difficult to separate due to their wide range of applications. Evolving urban structures require more efficient forms of mass transit while maintaining existing benefits. One such solution is the tram-train system, which, as described by Novales et al. (2002), combines LRT and urban tram systems so that the same vehicles can operate on both railway and tram tracks. A unique tram-train system is the so-called Karlsruhe model, which, according to Kraśkiewicz and Oleksiewicz (2015), enables efficient integration of city trams with regional railways without requiring transfers. Another example of tram-train can be found in the Hungarian city of Hódmezővásárhely. As mentioned by Csehy (2019), the local tram system is connected to the Szeged urban tramway via a non-electrified railway section and wireless trams. Topp (1999) classifies the tram-train as one type of LRT. In German terminology, most LRT forms are encompassed under the term Stadtbahn (urban rail).

It is not always necessary for tram systems to rely on overhead lines. Vuchic (2007) distinguishes two types of wireless tram operations: one draws electricity from the ground, and the other uses batteries, similar to partial trolleybuses. Another hybrid form, this time combining buses and trams, is the Translohr system, which operates on the principle of rubber-tyred trams guided by a central rail. The same principle is used for rubber-tyred metro systems (Guerrieri, 2019).

In the context of subsystem integration and the functional relationships between core and periphery, suburban and regional rail can also be considered part of PT. This is particularly relevant in larger metropolitan areas, where the boundaries between city and suburb are unclear. Grava (2003) defines this as the important subsystem commuter rail. The internationally adopted German term S-Bahn also refers to such regional express rail systems. Cableways can be broadly divided into funicular and aerial types. Unlike the previously mentioned subsystems, they are generally used to overcome significant elevation differences, for tourism, or for mass transport over short distances. Waterborne PT exists only in cities with favorable landscape conditions, typically involving major rivers, canal networks, or larger water bodies. According to Drdla (2018), unconventional subsystems include monorails, magnetic levitation trains, as well as moving walkways and escalators. A special example of a suspended monorail system is the Eugen Langen system in Wuppertal, Germany, known in German as the Schwebebahn. According to Kuczyk et al. (2021), with a length of 13.3 km and more than 65,000 passengers on average per day, it ranks among the most significant systems of its kind in the world.

3. Efficiency of Electric Urban Rail Systems in Public Transport

The mere classification of individual PT subsystems does not fully explain their current distribution and actual efficiency of use. This applies specifically to trolleybuses, trams, metros, and rapid transit systems. Bus transport is internationally widespread across all categories of cities, whereas the presence of waterborne transport is entirely determined by local natural conditions. Cableways, due to their high capacity, ability to connect otherwise inaccessible locations, independence from traffic congestion, and environmental friendliness, have the potential to expand and enhance existing transport systems (Hoffmann, 2006; Težak et al., 2016). However, they have so far been used only as complementary modes to other, more extensive transport systems. For unconventional subsystems, much depends on the specific technology—ranging from the widespread use of escalators to rare cases of magnetic levitation systems.

A specific comparison of different public transport modes is provided by Brand and Preston (2003), who found that commuter rail and metro perform best in terms of capacity and energy efficiency. The main disadvantage lies in the high initial construction costs, which are eventually offset due to their higher passenger capacity and longer average trip lengths—thus surpassing other modes in the long term. The size of the served population thus partly determines the cost-effectiveness of operating a specific mode. Although no universal rule exists, metro systems—being the most expensive—are typically implemented in cities with populations over 500,000 to 1 million.

Lighter rail solutions such as light metro or tram-train systems offer easier implementation and can be operated sustainably, both economically and environmentally, in larger agglomerations and medium-sized cities. However, in areas with existing rail infrastructure, converting to a dual-mode system often faces formal and technical obstacles (Durzyński et al., 2018). Another key parameter is the right combination of modes in a given city, aiming for synergies between their respective strengths. For this reason, Kołoś and Taczanowski (2016) argue that cities with existing electric rail-based systems might not benefit from implementing a light metro.

Wireless trams are particularly suitable for historical city centers, where there is demand for higher capacity, reliability, safety, and minimal environmental impact (Guerrieri, 2019). Classic trams, thanks to their long-standing expansion, are utilized in almost all city size categories, especially in those with over 100,000 inhabitants. The trolleybus subsystem is typically considered optimal for cities that require a passenger capacity between that of buses and trams (Zavada et al., 2010). Apart from capacity, a major advantage is the significantly lower level of pollutants released during energy production, especially from thermal or hydropower plants (Tica et al., 2011).

While electric traction offers the key benefit of zero direct emissions at the point of use, transmission losses to overhead wires can reach up to 30%, making the improvement of energy efficiency in public transport crucial (Bartłomiejczyk & Połom, 2017). Additionally, road obstacles on trolleybus lines necessitate maintaining backup diesel buses to detour problematic segments. This challenge is being addressed by the introduction of hybrid trolleybuses. According to Połom (2019), battery-powered operation reduces the required length of overhead lines by 10–30%, with newer technologies allowing charging during driving and enabling reductions of up to 60–80%. Although hybrid trolleybuses are more expensive than conventional ones, this is offset by the lower costs of overhead infrastructure. These efficient modifications have led to renewed interest in trolleybus systems, as shown in the case studies by Wołek et al. (2020) and Połom (2018).

Nevertheless, the global long-term trend shows a gradual decline in trolleybus systems. Costa & Fernandes (2012) highlight the potential inefficiency of replacing existing modes. According to Stepanov (2019), trolleybus operations are currently being discontinued, especially in countries of the former Eastern Bloc. In Central and Western Europe, the number of systems has remained mostly unchanged. Trolleybuses are increasingly being replaced by battery-electric, hydrogen, or hybrid vehicles, which in practice are referred to as second-generation electromobility (Kołoś et al., 2023). As Połom (2021) notes, even cities with well-developed tram and trolleybus networks are opting to implement electric buses. Guzik et al. (2021), using Polish cities as examples, confirm the hypothesis that the adoption of electromobility is positively correlated with a city's position in the urban hierarchy, and that the pace of adoption is clearly linked to the general level of local socioeconomic development.

The gradual shift from diesel-powered municipal buses to electric buses does come with certain limitations in operational flexibility, primarily due to the required battery charging time (Czerepicki et al., 2020). This drawback is especially evident when compared to the dynamic charging capability of in-motion hybrid trolleybuses. Furthermore, the consumption of electrical energy by both electric buses and hybrid vehicles is significantly affected by non-traction (auxiliary) demands—mainly heating and air conditioning. Bartłomiejczyk and Kołacz (2020) point out that under normal weather conditions, auxiliary systems account for nearly half of total energy consumption, and this figure can reach up to 70% during extreme temperatures.

The undeniable benefit of electric buses lies in their minimal environmental impact. According to Mišanović et al. (2015), comparing the energy efficiency of three transport modes in Belgrade—diesel bus, electric bus, and trolleybus—the electric bus performs best. Nonetheless, many studies point out specific disadvantages such as high purchase costs (significantly higher than diesel buses) (Pyza et al., 2019), limited range, battery longevity, charging systems, and long-term operational costs (Taczanowski et al., 2018), as well as increased consumption and battery strain in low temperatures (Papa et al., 2022). However, Pyza et al. (2019) emphasize that purchase prices and overall costs are expected to decrease in the future as technology advances and mass production drives prices down, improving their overall attractiveness.

As demands for speed, capacity, and reliability increase, rapid transit systems are seeing the most growth—especially in Europe (Topolnik et al., 2005). A well-balanced combination of rapid transit, tram, trolleybus, and modern bus subsystems, along with complementary modes, offers a sustainable, economical, and environmentally friendly solution for both urban and suburban mobility.

4. Methodology

In all analyses of urban electric rail systems, we work with three transport modes: metro, tram, and trolleybus. The classification of trolleybuses as a form of rail transport is often disputed. Our methodology is based on Czech and Slovak legislation, specifically Czech Act No. 266/1994 Coll., on Railways, and Slovak Act No. 513/2009 Coll., on Railways and on Amendments to Certain Acts. According to both laws, rail transport includes not only track-based systems but also cableways and trolleybus lines. However, we did not include cableways, partial (non-continuous) trolleybus networks, nor suburban and regional railways due to their due to their different nature and importance, or integration with other forms of railway transport.

The analyses are conducted using GIS tools. The base maps for public transport networks are derived from the community-driven OpenStreetMap database. Publicly editable OSM data are always cleaned of inaccuracies and updated in QGIS based on available materials from transport operators managing the respective networks. The cut-off date was set to June 30, 2025. Therefore, the final network representation includes all operational or temporarily non-operational lines as of this date, subject to several important criteria.

Each network consists of an interconnected system of lines belonging to a single transport mode. To be classified as an urban public transport network, the network must serve at least one municipality with city status. A network is considered a continuous or minimally fragmented system of a given transport mode with at least one terminal turnaround loop. If a route transitions seamlessly without changes in parameters to another transport mode (e.g., a tram subsystem to regional rail), it is not included in the statistics. Each street segment is counted only once, and lines must not overlap. Thus, the network length is measured as one-way (linear) length.

All turnaround loops serving either active line operation or merely as parking loops are included in the network length. Generally, all open sections that provide service coverage are included, except those sections solely connecting the network to depots. Depot areas are entirely excluded.

The routing of lines follows the shortest curved street paths; ambiguous points and intersections are simplified as much as possible. Despite careful efforts, minor inaccuracies due to source data and manual processing are acknowledged; therefore, the resulting length of each network is rounded to the nearest hundred meters.

Figure 1 illustrates the final processing phase of the largest electric rail network within the Visegrád Group, located in Budapest, Hungary, which uniquely includes all examined transport modes (metro, tram, trolleybus). The map also depicts the delineation of urbanized areas relative to the total city area.

Administrative and statistical division of territorial units was adopted from the official Eurostat portal, both for LAU corresponding to municipalities (GISCO-LAU, 2025) and for all four NUTS levels (GISCO-NUTS, 2025). Eurostat provides the latest data only up to 2023. With the help of national statistical offices, we updated population data at least until December 31, 2022, or January 1, 2023. Specifically, these are databases for the Czech Republic (CZSO, 2023), Slovakia (DATAcube, 2023), Poland (GUS, 2023), Hungary (KSH, 2023), Austria (Statistik, 2023), Germany (BBSR, 2024), and Switzerland (BFS, 2024). Length and density are analyzed for all statistical territorial units of the European Union, i.e., LAU, NUTS 3, NUTS 2, NUTS 1 (and NUTS 0). The definition of LAU corresponds to the basic administrative units of territorial self-government municipalities. Based on the population count in municipalities with an established network, one can approximate how much of the population of a given country or region has access to one of the electric rail networks of public transportation. NUTS regions allow the comparison of more extensive intercity networks and the concentration of networks in general. At the same time, the status of cities and ordinary municipalities is compared to define standard urban transportation and transportation with suburban to rural elements.

The conditions mentioned apply to all three examined modes of transportation. Thanks to a unified methodology, it is possible to process the following characteristics for each network:

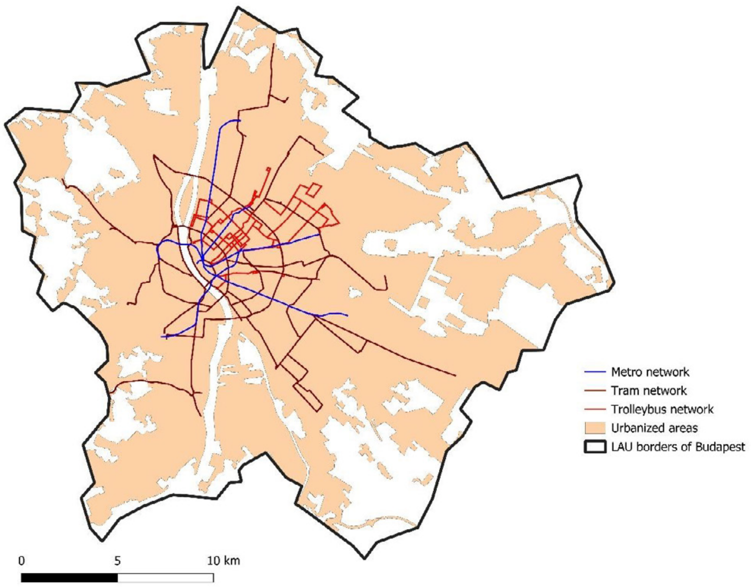

Fig. 1. Sample distribution of electric rail networks (metro, trams, trolleybuses) and delineation of urbanized areas in the LAU territory of Budapest as of 30 June 2025

Source: Own data processing from (OSM, 2025), CORINE Land-Copernicus (2022)

1) Transport mode
2) Status of municipalities belonging to a specific network
3) Sum of the population for all municipalities belonging to a specific network
4) Sum of the area in km^2 for all municipalities belonging to a specific network
5) Length in km
6) Composite density (the square root of the product of the area in km^2 and population, multiplied by a factor of 10,000) for the total area of the administrative unit, and separately composite density for the urbanized areas

Although OpenStreetMap (OSM) data form the foundation of the spatial analysis, we are aware of their limitations, especially the variable quality and completeness across countries and urban contexts. To ensure consistency and reliability, all OSM-derived layers were carefully verified and updated in QGIS using official sources from transport operators (e.g., infrastructure maps, GTFS feeds, timetables), supplemented where needed by field visits conducted between 2022 and 2025 and the authors' long-term empirical knowledge of the systems. This process helped eliminate outdated segments, correct routing errors, and add missing lines or loops.

While the availability of supplementary data varied by country, the applied validation approach was systematic and unified. As a result, the overall level of data accuracy does not significantly differ between cities, regardless of their size or location. Although the highest priority was given to metropolitan systems with multimodal integration, basic verification was carried out for all 114 networks included in the database. The final dataset thus represents a consistent and robust foundation for spatial comparison of electric urban public transport infrastructure across Central Europe.

5. Network distribution

In total, we processed 43 trolleybus networks, 87 tram networks, and 10 metro networks. However, for a comprehensive description of distribution, it is not necessary to separate individual trolleybus, tram, and metro networks from the integrated network consisting of two or more subsystems. Based on the chosen criteria, we defined 113 integrated networks in the Central European region according to their affiliation with municipalities and municipalities with city or town status.

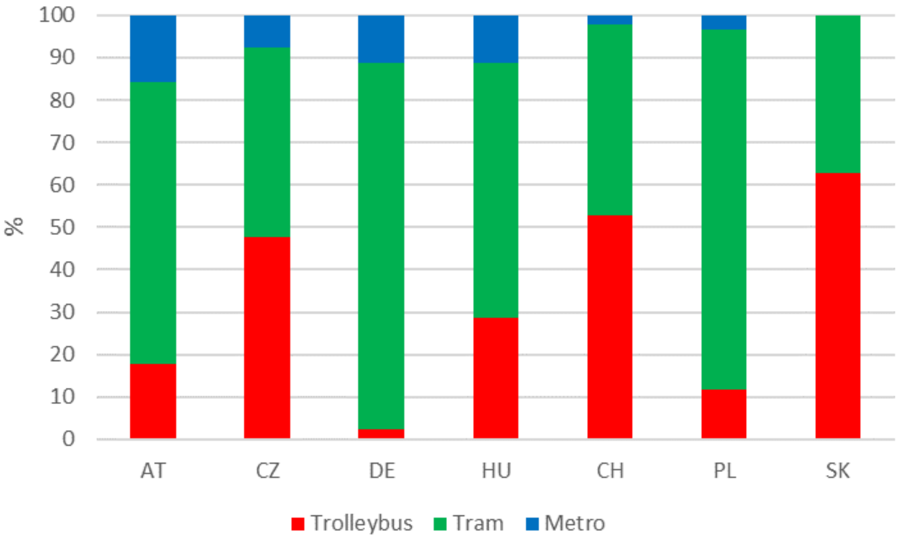

Fig. 2 – Percentage distribution of trolleybus, tram, and metro network lengths in Central European countries (network status updated as of June 30, 2025)
Country codes: AT = Austria, CZ = Czech Republic, DE = Germany, HU = Hungary, CH = Switzerland, PL = Poland, SK = Slovakia

Source: Own processing of layers from (OSM, 2025)

For example, the integrated network in Berlin includes both the metro and three separate tram subsystems (Berlin, Schöneiche bei Berlin, Woltersdorf). The common characteristic is their affiliation with Berlin, and at least a portion of each network extends into the territory of Berlin. The entire integrated network then spans across five municipalities and one city.

Among the Central European countries, only Liechtenstein and Slovenia do not have any of the examined subsystems. Slovakia lacks only the metro. As evident from Fig. 2, the distribution of network lengths varies significantly in the other seven states concerning the sum of all three modes. Trolleybuses represent a share of 52.8% in Switzerland and even 64.3% in Slovakia. Trolleybuses are relatively least represented in Germany, where tram transport dominates with 86.5%, similarly to Poland with 84.9%. Czechia and Switzerland are characterized by their balanced structure of trolleybuses and trams. Tram subsystems significantly prevail over trolleybuses in Central Europe, and the metro reaches its highest share of 16.6% in Austria. Except for Switzerland and Germany, metro networks concentrate only in the capitals of the states. In absolute numbers, the total length of 113 integrated networks is 7,234.2 km, with 1,304.8 km for trolleybuses, 5,293.6 km for trams, and 635.8 km for the metro. The largest shares are in Germany with 48.7% and Poland with 16%. Slovakia has the fewest networks at 2.9%. In the Czech Republic, there are 878.2 km in operation or temporarily closed, representing 12.1% and making it the third-largest system in Central Europe after Germany and Poland.

In addition to purely national networks, in the southwestern part of the studied area, there are three unique international tram networks. Firstly, a trilateral system with a length of 94 km between Switzerland, Germany, and France, centered around Basel. After subtracting the French section, 88 km fall within Central Europe. The second network connects Swiss Geneva with French Annemasse. Excluding the 2 km on French territory, 37.3 km belong to Switzerland. The last network lies between French Strasbourg and German Kehl. Unlike the previous two, there is a marginal 1.8 km section in Central Europe, with France having 47.2 km.

5.1 Networks across the entire NUTS and LAU areas

For a more relevant comparison, we are using the composite density indicator. The average density for all observed countries is 5.6, with Switzerland having the highest value of 10.4, Czechia 9.4, Germany 6.5, and Austria 6.2, all above average. Looking at the opposite end of the ranking, Poland achieves 3.5, Hungary 3.5, and Slovakia with 4.1, the lowest values. The level of individual countries corresponds to the NUTS 0 classification. From Fig. 3, it is easy to observe that with an increasing number of smaller regions, the area without any examined subsystem gradually increases. At the NUTS 1 level, there are only two regions, Dunántúl covering western Hungary and the German federal state of Saarland. However, a partial tram line runs through the Saarbrücken administrative city, freely connecting in both directions to a regional railway line; thus, it was not included in this study. The unique train-tram system represents the so-called Karlsruhe model, which, according to (Kraśkiewicz, Oleksiewicz 2015), allows an effective connection between urban trams and regional railways without the need for transfers. We included it in our list of networks as a tram subsystem serving the cities of Karlsruhe, Stutensee, and Rheinstetten, with a total length of 91.8 km. Unlike the system in Saarbrücken, it is clearly delimitated by a comprehensive network with separate turnarounds from the connecting regional route. Similarly, we can define the tram subsystem in Kassel with six associated municipalities, or cities, whose network length in line with the methodology is 78.3 km.

At the lowest level of administrative-statistical division into municipalities, or LAU according to Eurostat, there are 366 territorial units (including cities) with at least the minimum length of the examined subsystems. Out of the total of 29,538 municipalities, this represents about 1.2%. The population size in these 366 units is just under 47,000,000 inhabitants, meaning that approximately 28% of the total population has access to trolleybus, tram, or metro networks through their place of residence. The best availability of the examined subsystems occurs with a share of 33.1% in Austria. Czechia is just above 30% in second place, and Germany is third. Switzerland ranks fourth with 29.6% of its population. Slovakia performs significantly worse with 16.3%. A simplified measure of urbanization and its impact on distribution can be obtained by including precisely those municipalities with city status. Availability is evident in 261 cities, representing about 46,000,000 inhabitants. In the end, approximately 98% of the population with availability comes from cities. Fig. 4 illustrates the distribution of municipalities with networks according to their city or town status. Municipalities without city status significantly predominate in German-speaking countries.

The amplitude of values of the composite density of networks in LAU in Fig. 5 ranges from 0 (or undefined) in the case of two uninhabited LAUs (Gutsbezirk Kaufunger Wald, Perlacher Forst) to 433.8, belonging to the territorial unit Bratislava-mestská časť Staré město. The cities of Bratislava and Košice, uniquely within LAU and basic administration, are further divided into 9 and 16 urban districts, respectively. Excluding this anomaly, the highest density (358.6) is achieved by the Czech municipality without city status, Dolní Lhota (Ostrava-město district), with tram network accessibility. The highest composite density within municipalities with city status is reached by Czech Teplice (229.2), followed by Swiss Zurich (221.0). In general, higher densities are more common in Switzerland, Austria, and Czechia. An important factor is, of course, the non-uniform delineation of municipalities and the resulting differences in the average size of LAUs in different states and regions. Hungary, Poland, and some federal states of

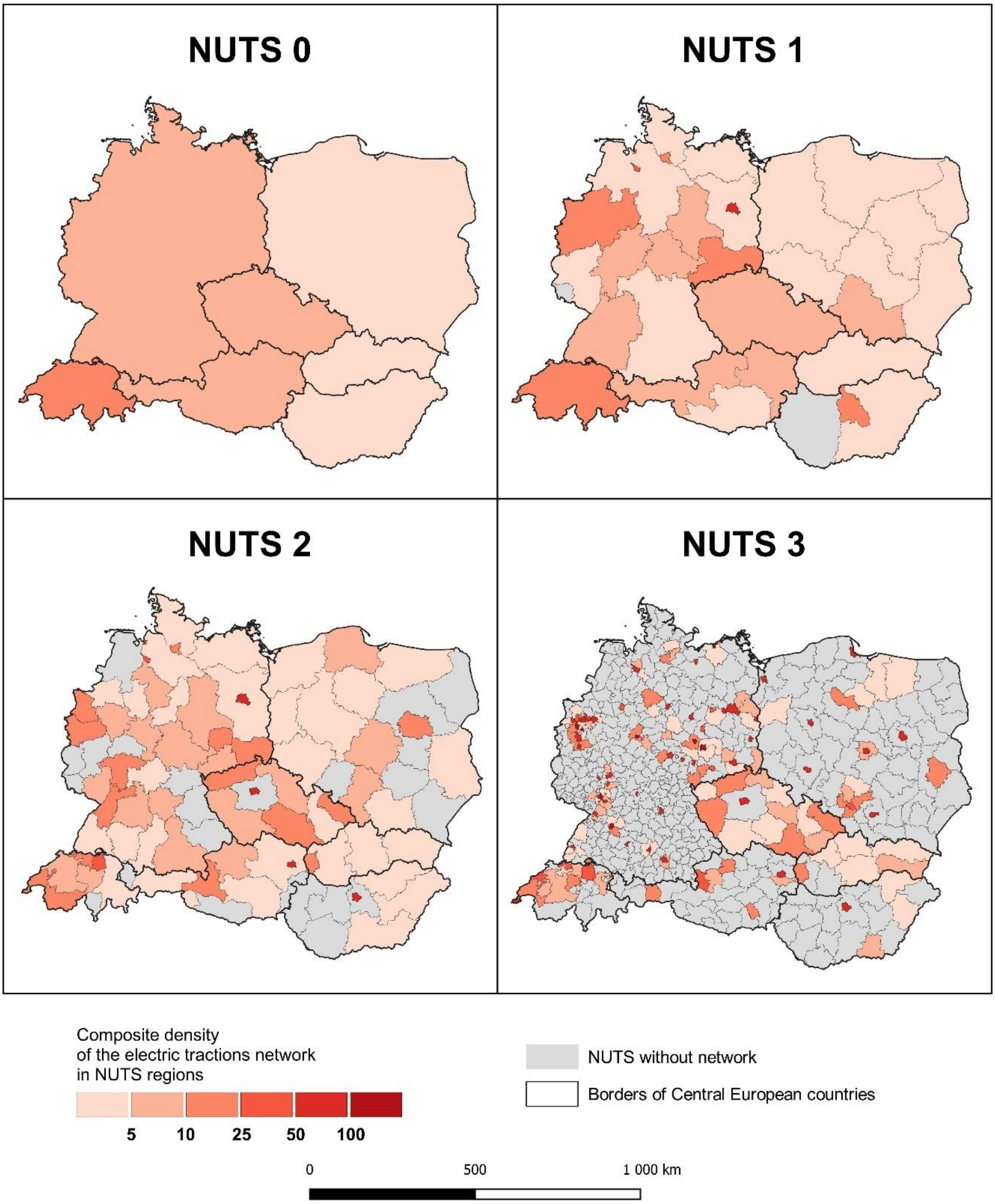

Fig. 3 – Composite density of metro, tram, and trolleybus networks in NUTS regions of Central Europe (network status updated as of June 30, 2025; NUTS population based on national statistical offices as of December 31, 2022, or January 1, 2023)

Source: Own processing of layers from (OSM, 2025) and (GISCO-NUTS, 2025) using population data from statistical offices

Germany have LAUs defined more broadly in terms of both area and population. As a result, the density of networks in the LAUs of these areas tends to be average (around 80) to below-average values. An example could be the Hungarian city of Hódmezővásárhely, with an area of approximately 488 km^2, significantly exceeding the area of the much larger Vienna. As stated by Csehy (2019), the local tram system is connected to the city tram in Szeged via a non-electrified railway section and wireless trams. The overall network with

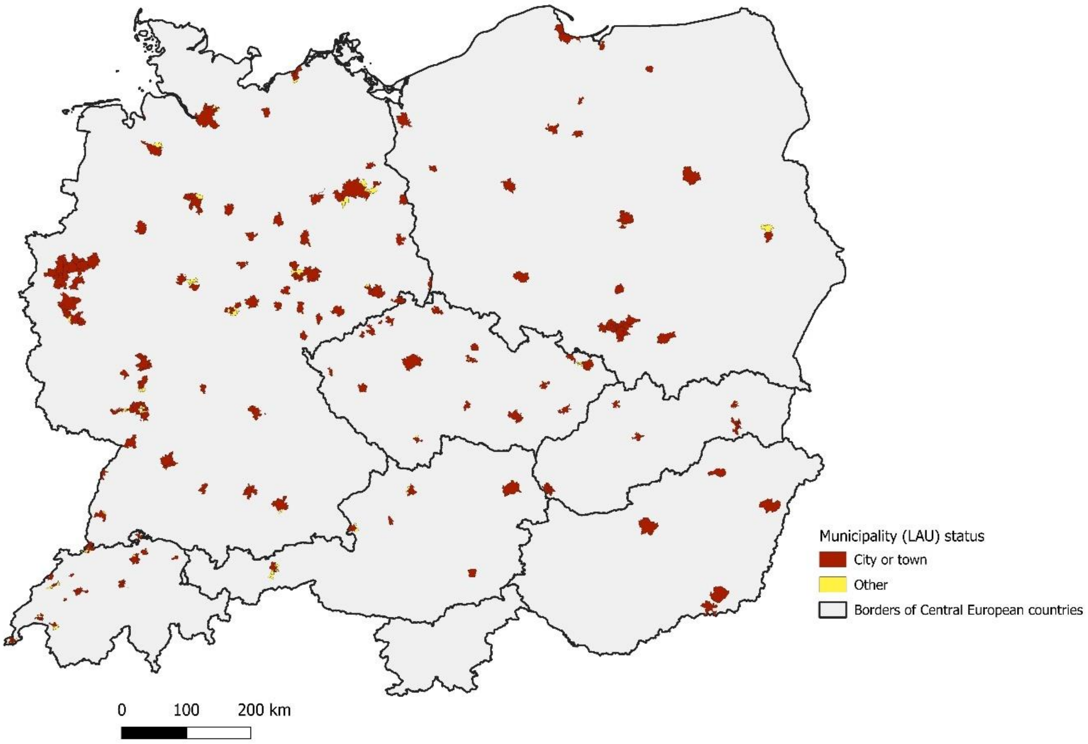

Fig. 4 – Distribution of networks according to urban and other statuses of municipalities in Central European countries (network status updated as of June 30, 2025; municipal status based on national statistical offices as of December 31, 2022, or January 1, 2023)

Source: Own processing of layers from (OSM 2025) and (GISCO-LAU 2025) using data from statistical offices

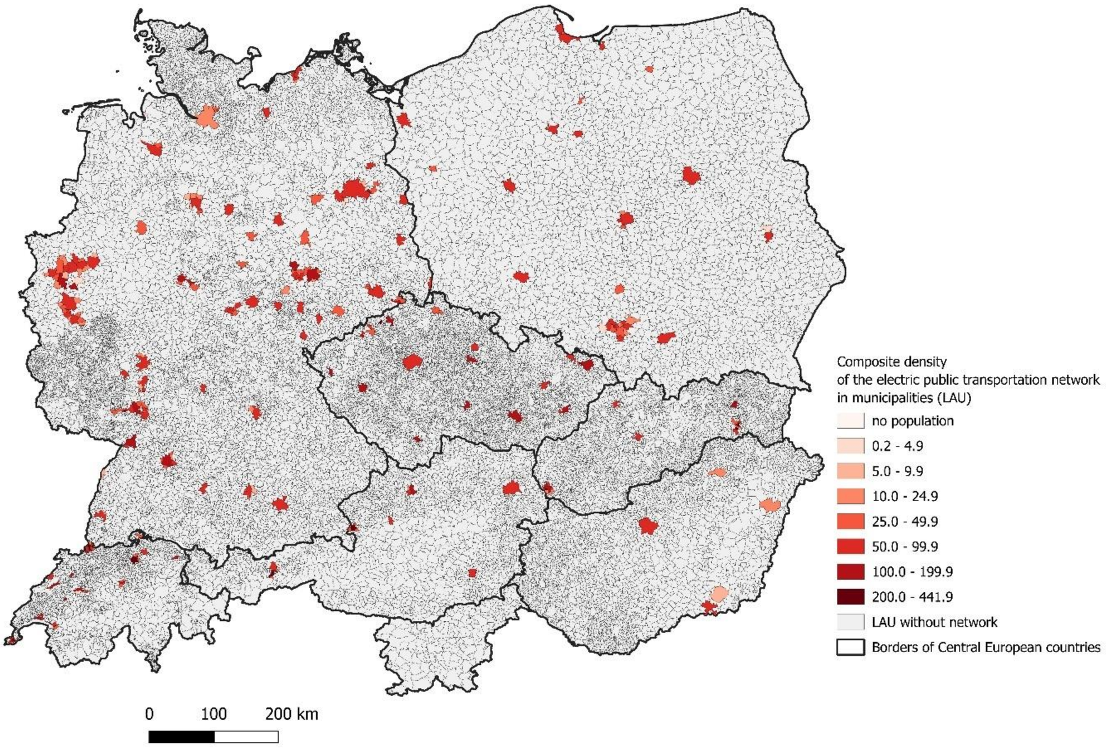

Fig. 5 – Distribution of the composite (aggregated) density of the electric urban rail network in LAUs of Central European countries (network status as of June 30, 2025; LAU population based on national statistical offices as of December 31, 2022, or January 1, 2023)

Source: Own processing of layers from (OSM 2025) and (GISCO-LAU 2025) using population data from statistical offices traction lines covering a length of 21.6 km is partially fragmented. Some tram networks, by their nature, lie on the boundary between traditional urban public transport and more marginal tourist operations, ex. Bad Schandau or Naumburg in Germany. Unlike other isolated railway lines with direct current power of 600 or 750 V, especially in Austria, they differ by at least one city with city status. Czechia has 34 municipalities with networks, of which 25 are cities. The average composite density approaches the value of 110. The densest subsystem in Central Europe is found in Teplice with a trolleybus network of length 24.1 km and a density of 229.2.

5.2. Networks in the urbanised areas of LAU

When comparing the spatial efficiency of electric urban rail networks within administratively defined units, it is essential to be aware of potential inaccuracies caused by often incomparable compositions and proportions of land cover classes. The functions of a city are directly linked to human activities (housing, industry, and services). Urban public transport should primarily ensure serviceability and connectivity in areas with the highest concentration of these activities.

Using land cover geodata available from CORINE Land Cover–Copernicus (2022), we can divide each LAU territory into two parts: urbanised and non-urbanised areas. The urbanised class includes urban fabric, industrial and commercial zones, transport infrastructure, mining areas, landfills, construction sites, artificial surfaces, and non-agricultural green spaces (especially parks). Non-urbanised areas include the remaining four land cover classes: agricultural land, forested areas, humid areas, and water bodies.

In evaluating efficiency, a higher density of the electric rail network in the urbanised part of the municipality is naturally a positive indicator. The optimal situation depends on several additional factors, such as adequate coverage of major roads to ensure easy transfers between lines, the even distribution of stops across the network for optimal walkability, and the effective use of multimodal transport. The specific threshold values for efficiency are therefore difficult to define. However, given the actual range of network lengths and surface areas, and the general comparative purpose, we can apply a simple rule: the higher the density, the greater the efficiency.

Fig. 6 illustrates the distribution of composite density within all LAUs that contain a non-zero length

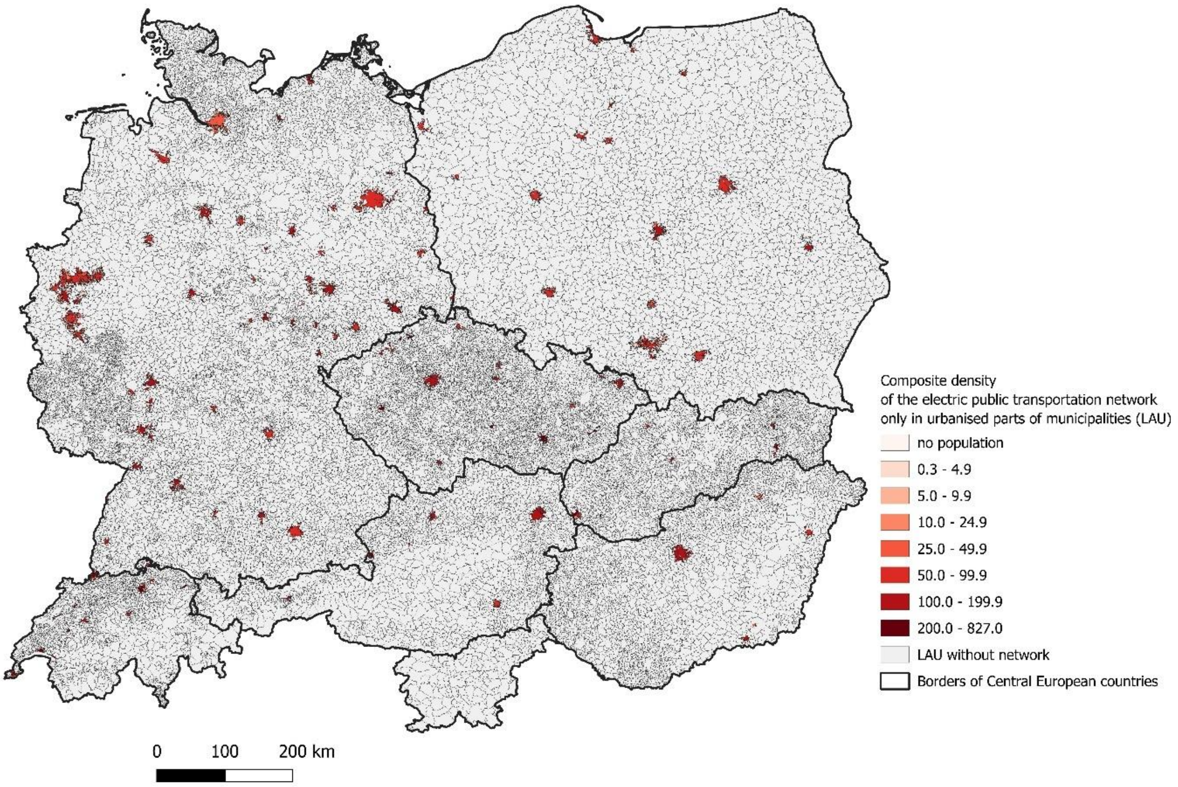

Fig. 6 – Distribution of the composite (aggregated) density of the electric urban rail network in the urbanized area of LAUs in Central European countries (network status as of June 30, 2025; LAU population based on national statistical offices as of December 31, 2022, or January 1, 2023)

Source: Own processing of layers from (OSM 2025) and (GISCO-LAU 2025) using population data from statistical offices, CORINE Land-Copernicus (2022) of electric urban rail network infrastructure within urbanised areas, presented separately for each country. Compared to total area calculations, considering only urbanised areas leads to a significant reduction in the surface area of LAUs and network fragmentation. The total area of the 366 municipalities amounts to approximately 27,232.4 km². The urbanised portion represents 42.2% of that total (11,505.3 km²)..

Looking at network lengths, the urbanised share accounts for approximately 94.5%. Population-wise, we can assume (with few exceptions) that nearly 100% of the population is concentrated in urbanised parts, resulting in significantly higher average composite density values. The range of values spans from 0.3 in the German city of Offenbach am Main to 826.9 in the Swiss municipality of Veytaux (without city status, part of the Vevey-Montreux trolleybus network). Among integrated networks, the highest composite density (320.4) is again found in Teplice. In second place, with only a slight difference (308.5), is another spa town, Mariánské Lázně, with the municipality of Velká Hleďsebe.

Higher ratios of composite densities between urbanised and total area indicate oversized administrative units where non-urbanised areas often dominate. Examples include Mariánské Lázně, which has 2.7 times higher density in urbanised space, integrations in Szeged (2.68×), Debrecen (2.4×), and the Czech city of Jihlava with surrounding municipalities Střítež and Štoky (2.2×). Conversely, the lowest ratios, around 1.2×, occur in the largest cities overall (Budapest, Berlin, Warsaw, Zurich, Prague).

6. Network distribution

By analyzing the distribution of 113 integrated networks based on the transport modes of metro, tram, trolleybus, we obtained diverse results that can be classified into 7 universal categories based on examined characteristics (see chapter Methodology). The final typology of electric rail networks was structured as follows:

1) Transport subsystem

a) Trolleybus, b) Tram, c) Metro, d) Hybrid, e) Funicular, f) Cog railway

From the originally unified tram subsystem, a sub-type of light rail tramways can be distinguished. These are mainly found in German-speaking countries and represent a combination of underground and surface railways. Except for suburban and regional segments, this subtype corresponds with the German term “Stadtbahn” (urban railway). However, we do not consider it a separate type due to its integration with the tram subsystem. Subsystems of hybrids, funiculars, and cog railways networks were not included in the comparison. The hybrid subsystem, being usually the only one without overhead traction, is always connected to either the tram or trolleybus subsystem.

2) Integration of subsystems

a) Unimodal, b) Bimodal, c) Trimodal, d) Multimodal (4 or more modes)

This category is based on the combination of transport modes within an integrated network. Unimodal and bimodal types are the most common within the Central European countries, with all combinations occurring including trolleybus and metro, which only operate together in Lausanne, Switzerland. The trimodal type often combines tram, trolleybus, and hybrid (partial) systems.

3) Number of Cadastrally Affected Municipalities

a) Monomunicipal, b) Polymunicipal (2 or more)

A municipality, as the basic unit of self-government, administers the urban transit system within its cadastral area. In Central Europe, the municipal level corresponds to the LAU classification. Networks that pass through multiple municipalities indicate a higher level of political and economic integration.

4) Urban Character Based on the Status of Affected Municipalities

a) Urban (M), b) Partially Urban (M, O)

This classification allows us to determine whether a network qualifies strictly as urban public transport or includes elements of suburban and regional services.

5) Population Size of Affected Municipalities

a) Small urban (<20,000 inhabitants), b) Medium urban (20,000–99,999 inhabitants), c) Large urban (100,000–999,999 inhabitants), d) Metropolitan (≥1,000,000 inhabitants)

For defining city size categories, we use a modified German classification commonly applied with the terms Kleinstadt, Mittelstadt, Großstadt, and Metropole.

6) Total Network Length (km)

a) Very short (<10 km), b) Short (10.0–24.9 km), c) Medium (25.0–49.9 km), d) Long (50.0–99.9 km), e) Very long (≥100 km)

This characteristic reflects the absolute size of the network. Interval settings are based on symmetrical distribution, which best fits the relative frequency.

7) Values of Composite Density (Total Area, Urbanized Area)

a) Extremely sparse (<5), b) Very sparse (5.0–9.9), c) Sparse (10.0-24.9), d) Medium (25.0-49.9), e) Dense (50.0-99.9), f) Very dense (100.0-199.9), g) Extremely dense (200.0 and more)

Using this most important relative indicator of composite density, we can easily compare networks of any size and assess their significance and potential within the respective municipalities. Due to significant differences in administrative boundaries, it is more appropriate to work only with the urbanized area, where the majority of the population and economic activity is concentrated. The frequency of networks within each type will differ considerably when comparing Central Europe, the Benelux countries, and Singapore on one hand, with the rest of the world on the other.

A complete list of the data collected for 113 integrated networks is provided within Appendix. However, it should be emphasized that for bimodal, trimodal, and multimodal systems, the data represent sums of individual subsystems. If treated separately, this results in a total of 136 networks (10 metro networks, 84 tram networks, 42 trolleybus networks) Networks are ranked in descending order based on total length.

7. Discussion

The Definition and Subsequent Analysis of Subsystems of the Electric Railway Network of Public Transportation for such a vast and diverse region as Central Europe inevitably raises a number of questions regarding the validity, comparability of data, and especially the transferability of the chosen methodology. Given that a study with a similarly ambitious scope has not been conducted before, it was not easy to avoid possible inaccuracies while also not overlooking all exceptions. Our methodology is based on a combination of publicly available materials and long-term empiricism with many European transportation systems. Freely editable map layers from OpenStreetMap were carefully updated with data from transport companies and on-site inspections. The results provide a relatively accurate quantitative picture of the linear infrastructure for selected modes of transportation. An objective shortcoming can be considered the limited selection of transportation subsystems, favoring the most common trams, trolleybuses, and metro. Without suburban and regional railways, cable cars, and some unconventional systems, it does not represent a comprehensive list of electric mass transit. Further narrowing is due to the processing of only electrified tracks. These significant limitations have a simple explanation. Our goal was to describe the extent and density of electric fixed routes, whose advantages become apparent with long-term mass utilization. Equally important was the necessity of clearly delineating continuous urban networks from other long-distance transportation. Specific parameters for calculating the extent of networks may slightly differ in other methodologies depending on the utilization method. Thanks to the consistency of rules for each network, the risk of potential inaccuracies in our study is at least proportionally minimized.

When comparing the obtained length data with data from (SYDOS 2023) on the electric traction infrastructure of urban public transportation in the Czech Republic as of 2022, the value of 929.3 significantly differs from our calculated 878.2 km. This could be partially caused by the inclusion of temporarily closed networks under reconstruction. A more significant discrepancy is evident when looking at the time series from 2015, according to which the trolleybus network gradually grows in contrast to almost stagnating tram tracks, which does not correspond to the recent expansion of tram networks in Prague, Pilsen, Olomouc, and Brno. In the context of the Slovak transport yearbook (RDPT 2023), the breakdown of infrastructure length by mode of transport is missing. Berlin-based publisher Robert Schwandl provides very detailed information on all public transportation networks, with publications (Schwandl 2017a) describing the eastern part of Central Europe, including the Czech Republic. It also separately addresses Poland (Schwandl 2017b). Although all networks are accompanied by numerous map outputs, the data on the extent are drawn from available data from transport companies, making it difficult to compare the validity and consistency of methodologies. In Germany, classical urban trams and trolleybuses are analyzed together (Schwandl 2019a), as well as metro systems and underground urban railways (Schwandl 2019b). It specifically explains suburban and regional trains, including tram-trains (Schwandl 2022). Our approach differs most significantly in the broad understanding of network integration, where, for example, the conurbation tram and rapid transit network in the Rhine-Ruhr region led by Düsseldorf and Essen is counted as one integrated system. However, the rapid transit trams in Dortmund are considered separately. Switzerland, the country with the densest rail network, is described in the most technically detailed manner by (Wägli 2010). However, it does not include the trolleybus subsystem. The best comparison is again offered with the complete Austrian and Swiss public transportation infrastructure (Schwandl 2023). Despite the very specific topic and methodological approach, our study allows for an easy and reliable comparison of the largest segment of electric traction public transportation in Central Europe. Both absolute length values and relative composite densities can estimate the significance of a given network for a specific city or municipality without city status. We consider the main advantage to be the easy transferability of the typology to most areas of the world with the possibility of additional expansion. The extensive database of 113 integrated networks can serve as a primary source and inspiration for subsequent, more sophisticated transportation studies."

8. Conclusion

This study focused on the spatial analysis, evaluation, and categorization of all currently operating urban electric rail networks in Central European countries. The objective was not only to describe the extent and density of tram, trolleybus, and metro systems, but also to uncover the relationships between the urban characteristics of cities and the parameters of their electrified public transport systems.

The analysis confirmed that the longest and most complex networks are indeed concentrated in large metropolitan areas, particularly in countries with larger populations and higher levels of urbanization such as Germany, Poland, and Switzerland. These findings validate the main hypothesis regarding the strong link between demographic and urban factors and the extent of electrified transport infrastructure.

At the same time, the assumption that the presence of a metro system in a capital city automatically implies the existence of the most extensive tram or trolleybus networks was not universally confirmed. While some cities (e.g. Vienna or Prague) exhibit well-developed multimodal networks with coexisting subsystems, in other cases (e.g. Budapest or Berlin) one mode clearly dominates. This indicates that the development of individual subsystems is not solely determined by city size, but also by historical evolution, investment priorities, and available urban space for infrastructure.

The hypothesis concerning the influence of the proportion of urbanized area on network density was also confirmed. When only built-up urban areas were considered, many cities showed a significant increase in composite density values. This highlights the importance of critically assessing methods that rely on total administrative areas, and supports the need for more refined comparisons across cities with varying urban forms and structures.

Despite limitations—such as the exclusion of suburban and regional electrified systems and the simplified selection of subsystems—the study succeeded in creating a consistent and easily transferable methodology for assessing urban electrified networks. The extensive database of 113 integrated networks can serve as a valuable foundation for future analyses and international comparisons.

The findings suggest that the level of electrification and network density is a meaningful indicator of public transport quality in urban settings. However, it is equally important to complement these quantitative indicators with qualitative aspects such as service frequency, travel speed, fare integration, and passenger comfort. These dimensions should be incorporated into future studies, which could build on the typology presented here and contribute to the ongoing development of sustainable urban mobility in Central Europe and beyond.

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Appendix 1

Tab. 1. Selected characteristics of trolleybus, tram, light rail tram, and metro networks in Central Europe (network status updated as of June 30, 2025, LAU population based on national statistical offices as of December 31, 2022, or January 1, 2023, or December 31, 2023)

Order (by length)	**LAU belonging to the network**	**Municipality status**	**Country**	**Transport mode**	**Population**	**Area (km^2)**	**Network Length (km)**	**Composite Network Density**
1	Düsseldorf, Neuss, Meerbusch, Ratingen, Krefeld, Tönisvorst, Duisburg, Dinslaken, Oberhausen, Mülheim an der Ruhr, Essen, Gelsenkirchen, Bochum, Herne, Hattingen, Witten	M	DE	TM, M	4,183,276	1954.5	464.2	51.3
2	Berlin, Ahrensfelde, Hoppegarten, Schöneiche bei Berlin, Rüdersdorf bei Berlin, Woltersdorf	M, O	DE	M, T	3,825,446	1078.4	362.3	56.4
3	Wien, Perchtoldsdorf	M	AT	M, T	1,997,023	426.3	273.0	93.6
4	Budapest	M	HU	M, T, O	1,671,004	525.2	256.7	86.7
5	Köln, Bonn, Bergisch Gladbach, Frechen, Hürth, Brühl, Wesseling, Bornheim, Alfter, Sankt Augustin, Siegburg, Königswinter, Bad Honnef	M, O	DE	TM	1,969,687	1084.7	251.8	54.5
6	Praha	M	CZ	M, T, O	1,338,530	496.6	233.7	90.7
7	Mannheim, Heidelberg, Ludwigshafen am Rhein, Bad Dürkheim, Friedelsheim, Gönnheim, Ellerstadt, Fußgönheim, Maxdorf, Heddesheim, Viernheim, Weinheim, Hirschberg an der Bergstraße, Schriesheim, Dossenheim, Leimen, Eppelheim, Edingen-Neckarhausen	M, O	DE	T	869,906	682.5	189.0	77.6
8	Warszawa	M	PL	M, T	1,861,975	517.2	180.8	58.3
9	München, Garching bei München, Grünwald, Perlacher Forst	M, O	DE	M, T	1,541,399	359.9	180.7	76.7
10	Konurbacja górnośląska (Katowice, Mysłowice, Sosnowiec, Dąbrowa Górnicza, Czeladź, Będzin, Chorzów, Świętochłowice, Ruda Śląska, Zabrze, Bytom, Gliwice, Siemianowice Śląskie)	M	PL	T	1,559,425	991.5	180.7	46.0
11	Zürich, Zollikon, Wallisellen, Schlieren, Rümlang, Opfikon, Kloten, Dübendorf	M, O	CH	T, O	554,497	160.0	149.3	158.5
12	Stuttgart, Fellbach, Remseck am Neckar, Gerlingen, Leinfelden-Echterdingen, Ostfildern, Esslingen am Neckar	M	DE	TM, O	900,33	374.0	156.0	85.0

13	Brno, Modřice, Šlapanice	M	CZ	T, O	409,526	254.9	149.9	146.7
14	Leipzig, Schkeuditz, Taucha, Markkleeberg	M	DE	T	675,621	443.2	142.7	82.5
15	Dresden, Radebeul, Coswig, Weinböhla	M, O	DE	T	628,468	382.4	140.2	90.4
16	Frankfurt am Main, Oberursel (Taunus), Bad Homburg vor der Höhe, Offenbach am Main, Neu-Isenburg	M	DE	TM	1,048,563	413.7	133.4	64.1
17	Łódź, Zgierz (miasto), Pabianice, Ksawerów, Konstantynów Łódzki,	M, O	PL	T	800,622	410.6	128.0	70.6
18	Hannover, Langenhagen, Garbsen, Isernhagen, Laatzen, Sarstedt	M, O	DE	TM	748,734	492.8	119.5	62.2
19	Wrocław	M	PL	T	674,079	292.8	105.7	75.2
20	Ostrava, Vřesina, Dolní Lhota, Horní Lhota, Budišovice, Kyjovice	M, O	CZ	T, O	290,371	247.0	103.0	121.6
21	Hamburg, Großhansdorf, Ahrensburg, Ammersbek, Norderstedt	M, O	DE	M	2,028,053	877.4	103.0	24.4
22	Kraków	M	PL	T	803,282	326.8	99.5	61.4
23	Karlsruhe, Stutensee, Rheinstetten	M	DE	TM	354,570	251.4	91.8	97.2
24	Bratislava (mestská časť Karlova Ves, Nové Mesto, Podunajské Biskupice, Ružinov, Staré Mesto, Vrakuňa, Rača, Dúbravka, Petržalka)	M	SK	T, O	427,519	211.6	90.2	94.8
25	Basel, Muttenz, Riehen, Pratteln, Allschwil, Oberwil, Therwil, Aesch, Münchenstein, Reinach, Arlesheim, Ettingen, Binningen, Bottmingen, Witterswil, Birsfelden, Bättwil, Rodersdorf, Weil am Rhein	M, O	CH, DE	T	397,717	160.3	88.0	110.2
26	Bremen, Lilienthal	M, O	DE	T	589,689	390.7	83.3	54.9
27	Halle (Saale), Schkopau, Merseburg, Leuna, Bad Dürrenberg	M, O	DE	T	312,99	412.5	80.1	70.5
28	Genève, Bernex, Meyrin, Vernier, Plan-les-Ouates, Lancy, Chêne-Bougeries, Thônex, Onex, Confignon, Carouge , Chêne-Bourg, Cologny, Le Grand-Saconnex	M, O	CH	T, O	426,242	83.0	78.3	131.7
29	Kassel, Vellmar, Baunatal, Kaufungen, Helsa, Hessisch Lichtenau, Gutsbezirk Kaufunger Wald	M, O	DE	T	282,132	366.4	78.3	77.0
30	Nürnberg, Fürth	M	DE	M, T	654,459	249.8	78.2	61.2
31	Poznań	M	PL	T	541,316	261.9	76.7	64.4
32	Dortmund, Lünen	M	DE	TM	680,185	340.1	71.5	47.0
33	Salzburg, Elsbethen, Wals-Siezenheim, Hallwang	M, O	AT	O	180,607	129.4	71.2	147.3

34	Lublin, Niemce	M, O	PL	O	352,86	288.4	68.7	68.1
35	Plzeň	M	CZ	T, O	181,24	137.7	67.8	135.7
36	Lausanne, Le Mont-sur-Lausanne, Lutry, Pully, Renens, Prilly, Chavannes-près-Renens, Paudex, Epalinges	M, O	CH	M, O	233,63	77.7	66.5	156.1
37	Magdeburg	M	DE	T	239,364	200.9	65.6	94.6
38	Gdańsk	M	PL	T	486,345	261.7	64.4	57.1
39	Linz, Leonding, Pasching, Traun, Puchenau	M, O	AT	T, O	276,555	155.8	59.6	90.8
40	Szczecin	M	PL	T	391,566	300.6	57.3	52.8
41	Augsburg, Königsbrunn, Stadtbergen, Friedberg	M	DE	T	375,159	258.0	52.1	53.0
42	Solingen, Wuppertal	M	DE	O	519,519	257.4	50.5	43.7
43	Košice (mestská časť Dargovských hrdinov, Džungľa, Juh, Košická Nová Ves, Myslava, Sever, Sídlisko KVP, Sídlisko Ťahanovce, Staré Mesto, Západ, Pereš, Barca, Nad jazerom, Šaca, Poľov, Luník IX)	M	SK	T, O	211,951	186.9	48.9	77.7
44	Innsbruck, Telfes im Stubai, Mutters, Fulpmes, Aldrans, Natters, Lans, Thaur, Rum	M, O	AT	T	159,569	219.7	46.2	78.0
45	Erfurt	M	DE	T	214,969	270.3	45.9	60.2
46	Bydgoszcz	M	PL	T	330,038	176.0	44.5	58.4
47	Gdynia, Sopot	M	PL	O	275,15	152.6	44.3	68.4
48	Bern, Köniz, Worb, Muri bei Bern	M	CH	T, O	201,692	131.6	44.1	85.6
49	Ústí nad Labem, Trmice	M	CZ	O	95,277	100.6	43.9	141.8
50	Darmstadt, Griesheim, Pfungstadt, Seeheim-Jugenheim, Alsbach-Hähnlein	M, O	DE	T	241,116	229.9	43.4	58.3
51	Graz	M	AT	T	298,479	128.7	41.9	67.6
52	Szeged, Hódmezővásárhely	M	HU	T, O	200,773	768.9	40.1	32.3
53	Braunschweig	M	DE	T	251,804	192.7	39.4	56.6
54	Freiburg im Breisgau, Gundelfingen	M, O	DE	T	248,117	167.3	38.4	59.6
55	Pardubice, Rybitví, Lázně Bohdaneč	M, O	CZ	O	93,279	109.7	35.5	111.0
56	Rostock, Papendorf	M, O	DE	T	212,445	191.8	35.4	55.5
57	Bielefeld	M	DE	TM	338,332	258.8	35.4	37.8
58	Neuchâtel, Boudry, Milvignes, Saint-Blaise, La Tène, Hauterive	M, O	CH	T, O	71,293	61.9	33.6	159.9
59	Zlín, Otrokovice	M	CZ	O	91,825	122.5	33.3	99.3
60	Potsdam, Nuthenal, Stahnsdorf	M, O	DE	T	211,024	285.2	33.3	42.9
61	Luzern, Ebikon, Emmen, Horw, Kriens	M	CH	O	173,908	99.8	33.0	79.2
62	Chemnitz	M	DE	T	248,563	221.0	32.0	43.2
63	Mainz	M	DE	T	217,556	97.7	30.9	67.0
64	České Budějovice, Hrdějovice, Borek	M, O	CZ	O	99,517	66.5	30.6	118.9
65	Prešov, Ľubotice	M, O	SK	O	86,757	78.8	28.3	108.3
66	Gotha, Waltershausen, Bad Tabarz, Georgenthal, Friedrichroda	M, O	DE	T	77,263	263.0	27.2	60.3
67	St. Gallen	M	CH	O	76,931	39.6	26.6	152.5

68	Hradec Králové	M	CZ	O	93,506	105.7	25.4	80.8
69	Cottbus	M	DE	T	99,512	165.0	25.1	61.9
70	Toruń	M	PL	T	195,69	115.7	24.7	51.9
71	Jena	M	DE	T	111,191	114.8	24.3	68.0
72	Teplice	M	CZ	O	50,843	23.8	24.1	219.2
73	Jihlava	M	CZ	O	52,548	87.9	23.7	110.3
74	Žilina	M	SK	O	81,219	80.0	23.7	93.0
75	Winterthur	M	CH	O	116,906	68.0	23.5	83.3
76	Schwerin	M	DE	T	98,596	130.5	23.3	65.0
77	Tychy	M	PL	O	123,105	81.8	22.4	70.6
78	Liberec, Jablonec nad Nisou	M	CZ	T	153,219	137.5	21.3	46.4
79	Debrecen	M	HU	T, O	201,582	461.7	21.3	22.1
80	Zwickau	M	DE	T	87,172	103.2	21.0	70.0
81	Frankfurt an der Oder	M	DE	T	58,32	147.7	20.9	71.2
82	Gera	M	DE	T	93,634	152.2	20.5	54.3
83	Ulm	M	DE	T	128,928	118.7	20.4	52.2
84	Würzburg	M	DE	T	127,81	87.6	20.3	60.7
85	Most, Litvínov	M	CZ	T	86,551	167.5	20.1	52.8
86	Brandenburg an der Havel	M	DE	T	73,609	229.5	18.2	44.3
87	Plauen	M	DE	T	64,763	101.6	17.8	69.4
88	Elbląg	M	PL	T	113,567	79.8	17.6	58.5
89	Olsztyn	M	PL	T	168,212	88.3	17.0	44.1
90	Banská Bystrica	M	SK	O	74,59	103.4	16.9	60.9
91	Olomouc	M	CZ	T	101,825	103.4	16.5	50.9
92	Chomutov, Jirkov	M	CZ	O	66,245	46.3	16.4	93.7
93	Eberswalde	M	DE	O	41,103	93.6	15.8	80.5
94	Częstochowa	M	PL	T	208,182	159.7	15.8	27.4
95	Biel/Bienne, Nidau	M	CH	O	62,188	22.7	14.9	125.5
96	Opava	M	CZ	O	55,512	90.6	14.8	65.9
97	La Chaux-de-Fonds	M	CH	O	36,527	55.5	13.9	97.6
98	Fribourg, Villars-sur-Glâne, Givisiez	M, O	CH	O	53,164	18.3	13.5	136.8
99	Vevey, La Tour-de-Peilz, Montreux, Veytaux, Villeneuve	M, O	CH	O	65,293	78.7	13.2	58.2
100	Miskolc	M	HU	T	145,248	236.6	13.1	22.3
101	Gorzów Wielkopolski	M	PL	T	116,436	85.7	12.9	40.8
102	Görlitz	M	DE	T	56,574	67.3	11.8	60.5
103	Dessau-Roßlau	M	DE	T	79,655	246.3	11.6	26.2
104	Mariánské Lázně, Velká Hleďsebe	M, O	CZ	O	16,109	56.4	11.4	119.7
105	Grudziądz	M	PL	T	89,45	57.8	10.1	44.4
106	Halberstadt	M	DE	T	40,457	143.0	9.9	41.2
107	Bad Schandau, Sebnitz	M	DE	T	12,943	136.0	7.9	59.6
108	Schaffhausen, Neuhausen am Rheinfall	M	CH	O	48,696	49.9	7.8	50.0
109	Nordhausen	M	DE	T	41,339	108.3	7.5	35.5
110	Strausberg	M	DE	T	27,344	67.7	6.0	44.1
111	Gmunden	M	AT	T	13,312	63.5	4.8	86.7
112	Naumburg (Saale)	M	DE	T	32,289	130.3	2.8	13.7
113	Kehl	O	DE	T	38,154	75.2	1.8	10.6

Municipality Status (M = city or town, O = non-urban municipality), Country (AT = Austria, CZ = Czech Republic, DE = Germany, HU = Hungary,
CH = Switzerland, PL = Poland, SK = Slovakia), Transport Mode (O = Trolleybus, T = Tram, TM = Light rail tram, M = Metro)

Source: Own data processing from (OSM 2025) and (GISCO-LAU 2025) using population data from statistical offices