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THE CONCEPT FOR IMPLEMENTING METHOD OF MULTIDIMENSIONAL COMPARATIVE ANALYSIS FOR ASSESSING ELECTROMOBILITY IN SMART CITIES IN POLAND

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ABSTRACT

Purpose: *The aim of this study is to develop a concept for implementing the multidimensional comparative analysis method in the assessment of electromobility in smart cities in Poland. Electromobility, as one of the key elements of sustainable urban development and intelligent management, has gained increasing importance in recent years. However, its implementation in the Polish context requires a comprehensive multi-faceted analysis.*

Need for the study: *The choice of research topic was determined by its relevance. Previous analyses and published studies have focused primarily on issues related to sustainable development, urban mobility, or electromobility. However, theoretical gaps have been identified in the literature concerning a holistic approach—particularly in terms of comparing electromobility within smart cities.*

Methodology: *The research methodology is based on applying the multidimensional comparative analysis method to compare smart cities that have implemented electromobility development strategies. The analysis includes collecting both quantitative and qualitative data, such as the number of charging stations, the number of registered electric vehicles, and surveys of residents and local authorities. Statistical techniques and multidimensional methods will be used to create a comprehensive assessment model, which will serve as a foundation for future actions in the development of electromobility in Polish smart cities.*

Findings: *The research hypothesis assumes that the use of multidimensional comparative analysis method enables a reliable, objective, and multidimensional assessment of the current state and development prospects of electromobility in Polish cities, taking into account various criteria such as charging infrastructure, availability of electric vehicles, urban policies, and social attitudes.*

Practical Implications: *The conducted analysis may provide cities and their local authorities with a ready-made solution for assessing electromobility in smart cities, in the form of a key set of indicators accompanied by the desired direction of their development. Moreover, the study includes a ranking-based assessment of the potential for electromobility development in smart cities in Poland, along with an analysis of the factors contributing to the respective positions within the ranking.*

Keywords: Sustainable development; Electromobility; Smart cities; Multidimensional comparative analysis method; Management

Jel codes: Q01; R41; O18; C38; C43; M10; O32

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1. INTRODUCTION

Electromobility is increasingly recognized as a key element of smart city management strategies. Intelligent transportation management is an approach that utilizes modern technologies, data, and innovative management systems to improve the efficiency, safety, and sustainability of urban transportation. Actions and investments in this field not only contribute to reducing carbon dioxide emissions but also pave the way for the creation of innovative solutions related to mobility, energy efficiency, public services, infrastructure, urban systems, and promoting behavioral changes among residents towards more sustainable practices.

The ongoing initiatives and investments in this area have the potential not only to reduce emissions but also to support other aspects of smart city development, such as innovative solutions in mobility, energy efficiency, public services, residential and commercial infrastructure, as well as broader urban systems.

The research methodology is based on the application of the multidimensional comparative analysis method to assess smart cities in Poland in terms of their electromobility development. The aim of this paper is to analyze which smart city indicators are essential for evaluating the development of electromobility and to assess the progress of smart Polish cities over the past years using the multidimensional comparative analysis method.

The application of the multidimensional comparative analysis method allows for a reliable, objective, and multidimensional assessment of the current state and development prospects of electromobility in Polish smart cities.

The following research thesis accompany the implementation of the objectives:

H1: the use multidimensional comparative analysis method enables a reliable, objective, and multidimensional assessment of the current state and development prospects of electromobility in Polish cities, taking into account various criteria.

H2: the development of electromobility is an important element of the implementation of the smart city concept in cities.

The collected research material will enable the development of a comprehensive concept presenting a holistic approach to the development of electromobility in smart cities. This concept will include a list of key sustainable development indicators, along with a ranking of cities accompanied by assessments and future recommendations for improvements.

2. LITERATURE REVIEW

2.1. Electromobility as part of the smart city strategy

Electromobility encompasses the integration of innovative transportation technologies powered by electricity, aimed at reducing carbon dioxide emissions, promoting sustainable development in cities, and striving for a smart future. Although its definition is not entirely consistent, two main approaches can be distinguished: narrow and broad. According to the definition by Grauers et al. (Grauers et al., 2013, p. 10-21), electromobility refers to a road transport system based on vehicles powered by electricity. These vehicles can generate energy on their own or draw it from external sources, typically from the power grid. Mataczyński (Mataczyński, 2018, p. 77) describes electromobility as transportation using electric wheeled vehicles that store energy in battery packs. Janczewski (Janczewski, 2017) defines electromobility as the concept of replacing traditional fossil fuel-powered vehicles with environmentally friendly, zero-emission electric cars, while Schuler (Schuler, 2019) refers to it as the development of vehicles powered by electricity, using batteries or fuel cells for propulsion.

Additionally, Bartłomiejczyk and Kołacz (Bartłomiejczyk and Kołacz, 2020, p. 22), Połom (Połom, 2021, p. 7), and Fernández (Fernández, 2021, p. 21) emphasize that the growing presence of electric vehicles is a sign of the development of electromobility and smart cities. However, smart cities encompass much more than just electric vehicles or individual transport. They include issues such as the use of alternative fuels, hybrid technologies, hydrogen and CNG vehicles, public transport systems, and heavy-duty vehicles. Electromobility is increasingly recognized as a key element of smart city strategies. Actions and investments in this area not only contribute to the reduction of carbon dioxide emissions but also pave the way for the creation of innovative solutions related to mobility, energy efficiency, public services, infrastructure, urban systems, and promoting the shift toward more sustainable practices among residents.

The development of electromobility can be defined as the process of introducing, adapting, and widespread adoption of electric vehicle technologies and the associated infrastructure, aiming to meet transportation needs while minimizing the negative impact on the environment. In a broader context, the development of electromobility includes the following elements: the increase in the number of electric vehicles, charging infrastructure, sustainable energy development, changes in the transportation system, social and economic transformations, technological advancements, environmental protection, and emission reduction.

In a broader sense, electromobility (Politt, 2020) is a comprehensive process that encompasses the implementation of electricity-based technologies in transport, as well as the development of the appropriate supporting infrastructure and systems. In this context, electromobility refers not only to electric vehicles but also to the entire structure supporting their use, including charging stations, smart energy grids, energy storage systems, and interactions with traffic and transport intelligent management systems. The context of the article considers elements related to the holistic approach to electromobility (broad approach in the literature) and its connection to smart cities.

Electromobility is one of the key elements of smart city development strategies. Current initiatives and investments in this area have the potential not only to reduce emissions but also to support other aspects of smart city development, such as innovative solutions in mobility, energy efficiency, public services, housing and commercial infrastructure, as well as broader urban systems. Moreover, they influence citizen engagement and the shaping of new social attitudes and behaviors (https://smart-cities-marketplace.ec.europa.eu/action-clusters-and-initiatives/action-clusters/sustainable-urban-mobility/electric-vehicles-smart).

2.2. Intelligent management in smart cities

Smart city intelligent management means the implementation of modern technologies and solutions aimed at improving the quality of life of residents, effective resource management and sustainable development. To help select and assess which cities around the world have the characteristics and potential to be considered smart cities, the IESE Cities on the Move Index (https://www.iese.edu/media/research/pdfs/ST-0649-E) was created. This index evaluates cities according to nine key categories: human capital, social cohesion, economy, governance, environment, mobility and transport, urban planning, international profile and technology. All indicators are interconnected and are aligned with the strategic goal of supporting economic and social development and smart governance, leading to the creation of a global city that promotes entrepreneurship, innovation and social justice. In addition to technological and economic development, citizens and their involvement are key to transforming cities into smart cities.

Many Polish cities are taking steps towards becoming smart cities by utilizing information, tools of intelligent management and communication technologies (ICT) in managing infrastructure, transport, energy, and environmental protection. Among the cities in Poland that can be considered smart cities are: Warsaw, Wrocław, Kraków, Gdynia, Gdańsk, Białystok, Rzeszów, Kielce, Poznań, and Szczecin (https://almine.pl/smart_city_przyklady_polska/?utm_source=chatgpt.com). Smart cities face two main challenges in the field of electromobility: ensuring efficient mobility, often over large areas, and achieving sustainable urban mobility. Therefore, the transport and environmental indicators from the IESE Cities in Motion Index were considered in the analysis.
Table 1 contains a list of the indicators used for this category, along with descriptions of each and the sources from which they were derived.

Table 1. Indicators for assessing electromobility in smart cities

Indicator	Description	Source
Bicycle, moped or scooter rental service	Whether or not the city has a bicycle, moped or scooter rental service.	NUMO
Bike sharing	Number of shared bicycles in the city.	Bike-Sharing World Map
Metro stations	Number of metro stations in the city.	Metrobits

Traffic Inefficiency Index	This index estimates traffic inefficiencies. High values represent high driving inefficiencies, such as long travel times.	Numbeo
Traffic and congestion index	Index of traffic and congestion in the city.	Numbeo
Exponential traffic index	This index is estimated by considering time spent in traffic. It is assumed that travel time dissatisfaction increases exponentially beyond 25 minutes.	Numbeo
Metro lines	Number of metro lines in the city Metrobits	Metrobits
Length of metro system	Length of the metro system in the city.	Metrobits
Percentage of households with bicycles	Percentage of households with bicycles.	Euromonitor
High-speed train	Binary variable that shows whether the city has a high-speed train or not.	OpenRailwayMap
Vehicles in the city	Number of commercial vehicles in the city.	Euromonitor
Flights	Number of inbound flights (air routes) in a city.	OpenFlight
CO_2 emissions	Carbon dioxide emissions from fossil fuel use and cement production. Measured in kilotons	World Bank
Methane emissions	Methane emissions caused by human activities such as agriculture and industrial methane production. Measured in kilotons of CO_2 equivalent	World Bank
Environmental Performance	Index Environmental Performance Index (from 1 [poor] to 100 [good]).	Yale University
Emission Index	Index of carbon dioxide emissions	Numbeo
Pollution Index	Index of pollution	Numbeo
PM10	A measure of particles in the air with a diameter of less than 10 µm. Annual mean. IQAir	Global Residence Index
PM2.5	A measure of particles in the air with a diameter of less than 2.5 µm. Annual mean. IQAir	IQAir
Percentage of population with access to water supply	Percentage of the population with reasonable access to an appropriate quantity of water resulting from an improvement in the supply.	World Bank
Renewable water resources	Renewable water resources per capita.	FAO
Solid waste	Average amount of municipal solid waste generated annually per person (kg/year)	Waste Management for Everyone
Climate vulnerability	Risk to the city due to climate change	National Geographic

Source: own elaboration.

Other important indicators include PM2.5 and PM10, fine particulate matter suspended in the air, containing substances such as dust, soot, heavy metals, cement, and pollen. PM2.5 particles have a diameter of 2.5 microns or smaller, while PM10 particles have a diameter of up to 10 microns. The composition of these particles includes inorganic elements such as silicates and aluminates, as well as organic and carbon compounds. These indicators are included in the environmental pollution assessment and in indices that classify cities based on air quality, assigned with a negative sign.

The Environmental Performance Index (EPI), developed by Yale University, is based on the assessment of two main areas: environmental health and ecosystem vitality. Environmental health includes the impact of air pollution on human health, water quality, and environment-related diseases. Ecosystem vitality considers aspects such as air quality, biodiversity, the state of forests, fisheries, agriculture, and climate change.

Water is a key renewable resource vital for combating the effects of climate change. The indicator for total renewable water resources per capita takes into account both internal and external surface water resources, reflecting water availability for a given country and its ability to ensure sustainable development. Therefore, this indicator is included in the index with a positive sign.

The climate change vulnerability indicator assesses cities' sensitivity to climate change by the year 2070, assuming the continuation of current CO_2 emission levels. It includes predicted changes in temperatures across different seasons, which may have serious consequences for public health and economic stability. This indicator is included in the index with a negative sign.

Waste management issues are also significant. The amount of municipal waste produced annually per person (kg/year) poses a potential threat to public health and the environment. Improper waste management increases the risk for those working in waste collection and processing, which is why this indicator is included with a negative sign.

The availability of bike, electric scooter, and e-scooter rental services reflects the level of micromobility in the city. If such a system is operational, the indicator takes a value of 1; otherwise, it is 0.

Indicators such as commute time, traffic intensity, and transportation inefficiency relate to transportation issues that affect residents' quality of life and comfort. They also reflect road safety and the efficiency of public transport. A well-organized and efficient public transport system helps reduce accidents and traffic congestion. Due to the negative impact of these factors on urban development, these indicators are included in the CIMI with a negative sign.

Developed bicycle systems, assessed based on the urban bicycle system indicator, support daily mobility within the city and are positively considered in the CIMI.

Additionally, the number of metro stations, the length of the network, and the number of lines reflect the city's investments in public transportation. These indicators, like the number of flight routes and the availability of high-speed trains, indicate the level of development of transportation infrastructure, which positively affects the sustainable development of cities.

Finally, the number of vehicles and the percentage of households owning bicycles are indicators that have an inverse impact on the index. The bicycle ownership indicator has a positive impact, whereas the number of vehicles is considered with a negative sign.

3. METHODOLOGY

Methods of multidimensional comparative analysis allow for comprehensive studies on complex phenomena, enabling broad and objective understanding of them. In Poland, Hellwig was the first to attempt to describe complex phenomena using a synthetic feature (Hellwig, 1968, p. 307-327). A key aspect when creating a ranking based on the level of a complex phenomenon is the selection of an appropriate ordering method. The goal of linear ordering is to arrange a set of objects by determining their order according to a specific criterion. These methods are used in situations where a specific criterion can be adopted, allowing for the ranking of objects. The tool used in linear ordering is an aggregation function, which combines the partial information contained in individual variables and is calculated for each object. At the beginning of the analysis, the nature of each included variable must be determined. It is important to establish whether high values of a given variable have a positive significance for the phenomenon being analyzed (in which case they are called stimulants), or if lower values are more beneficial (in which case the variable is called a destimulant).

Methods and main formulas for normalization have been presented by authors such as Borys (Borys, 1978, p. 227-239),Grabiński (Grabiński, 1984, p. 45-48), and Abrahamowicz (Abrahamowicz, 1985, p. 54-58). In particular, Abrahamowicz emphasizes the need to link the choice of normalization formula with the selection of the appropriate aggregation method. According to studies described in the literature, two methods have the best formal properties: classical standardization and unitarization. In the unitarization method, the distance between a given value and the observed "worst" value is divided by the range. Importantly, this method also satisfies the non-negativity requirement, which is recommended by some researchers. The normalization process is carried out according to the appropriate formulas.

For stimulants:

$$x'ij = \frac{x_{ij} - \min\{x_{ij}\}}{\max\{x_{ij}\} - \min\{x_{ij}\}}$$

For destimulants::

$$x'ij = \frac{\max\{x_{ij}\} - x_{ij}}{\max\{x_{ij}\} - \min\{x_{ij}\}}$$

Where:
- i - object number
- j – characteristic number
- $\max\{x_{ij}\}$ and $\min\{x_{ij}\}$ are sought in the set of objects for the given characteristic.

In this work, an aggregate measure is used, which involves calculating the arithmetic mean of the transformed diagnostic variables. These variables were made comparable through the process of unitarization, and then the average value was expressed on a scale ranging from 0 to 100. The formula for the aggregate measure is as follows:

$$W_i = \frac{100}{m} \sum_{j=1}^{m} \alpha_i \cdot x'_{ij}$$

Where:
- m- the number of features (criteria) considered
- α_i – the weight of the i-th feature (criterion)

The table 2 presents a structured set of indicators for assessing electromobility in smart cities. Each indicator is classified based on whether it acts as a stimulant or a destimulant, along with the corresponding weight obtained. This classification provides a comprehensive framework for assessing the relative importance of each indicator in the context of the development of electromobility in smart cities.

Table 2. Indicators for assessing electromobility in smart cities

Indicator	Stimulant	Destimulant	Weight
Bicycle, moped or scooter rental service	x		4
Bike sharing	x		4
Metro stations	x		4
Traffic Inefficiency Index		x	5
Traffic and congestion index		x	5
Exponential traffic index		x	5
Metro lines	x		3
Length of metro system	x		3
Percentage of households with bicycles	x		3
High-speed train	x		4
Vehicles in the city		x	5
Flights		x	3
Methane emissions		x	2
Environmental Performance	x		4
CO_2 emissions		x	4
Pollution Index		x	5
PM10	x		5
PM2.5	x		5
Percentage of population with access to water supply	x		3

Renewable water resources	x		2
Solid waste		x	2
Climate vulnerability	x	x	3

Source: own elaboration.

Renewable water resources constitute a crucial element of sustainable urban development. The availability of drinking water and energy generated by water (e.g., hydropower) can facilitate the development of technologies that support electromobility, such as photovoltaic panels, wind farms, and hydropower plants. In cities utilizing renewable energy sources, it is possible to power electric vehicles with clean energy, contributing to CO_2 emission reduction and promoting sustainable transportation.

The use of renewable water resources in urban energy systems contributes to sustainable development and, consequently, may support electromobility as an integral part of urban transportation systems.

In cities effectively managing waste, for example, through recycling, material reuse, and waste minimization, waste can be utilized for energy production, which fosters the development of zero-emission technologies. Improved waste management also influences the use of secondary raw materials that can be employed in the production of electric vehicles, including batteries. Efficient resource management within cities supports the advancement of sustainable technologies, including electromobility, as a component of comprehensive urban policy.

The development of public transportation, including the number of metro lines, is one of the key elements of smart cities. Metro systems provide an efficient form of public transport that reduces road congestion, lowers exhaust emissions, and promotes sustainable mobility. In cities with well-developed metro systems, dependence on combustion vehicles is reduced, which favors the promotion of alternative, eco-friendly transportation modes, such as electric vehicles. Additionally, in cities with a well-established public transportation network, electric vehicles can complement the system, for example, in the form of electric buses or taxis. Therefore, the development of public transportation in the form of metro systems supports electromobility by improving air quality and reducing traffic congestion.

Cities with a high Environmental Performance Index (EPI) tend to invest more in environmentally friendly technologies, including electromobility. Good environmental practices promote the implementation of electric transport solutions that are more sustainable. High levels of air pollution (e.g., PM10, PM2.5) can motivate the development of electromobility. In cities with severe air pollution, the introduction of electric vehicles becomes a key solution for improving air quality. Electromobility contributes to the reduction of exhaust emissions, which can help enhance air quality and decrease pollution.

High municipal waste production can indicate inefficient resource management within a city. In cities where waste is not properly segregated, recycling is limited, and material reuse is insufficient, this can lead to greater consumption of natural resources, including those essential for the production of electric vehicles, such as batteries. Moreover, waste management that does not consider recycling can lead to increased energy and fossil fuel consumption, ultimately diminishing the benefits of electromobility development. In cities with high per capita waste production, effective implementation of electromobility-related technologies may be hindered by insufficient infrastructure for sustainable resource management.

High climate change risks, such as floods, droughts, heatwaves, and rising sea levels, can present significant challenges to the development of electromobility. Cities that must address climate change impacts often need to redirect resources toward adaptation measures, which can delay or limit investments in electromobility-related technologies. Additionally, climate change can lead to energy instability, affecting the availability of power for charging electric vehicles. For example, cities prone to frequent flooding may face challenges in developing electric vehicle charging infrastructure. Furthermore, climate change may affect the generation of renewable energy sources, such as solar and wind power, which are critical for powering electric vehicles.

An increase in the number of commercial vehicles within a city can intensify traffic congestion and exhaust emissions, potentially hindering the growth of electromobility. A greater number of combustion vehicles increases demand for fossil fuels and may discourage investments in electric vehicle charging infrastructure, as the transportation system remains dominated by internal combustion engines.

A high number of airplane arrivals indicates significant air traffic, resulting in high greenhouse gas emissions. Although air transportation and electric transportation are distinct sectors, high emissions from aviation can negatively impact urban sustainability and hinder the ability to implement low-emission technologies such as electromobility.

A higher Environmental Performance Index indicates the effectiveness of a city's efforts in environmental protection, sustainable resource management, and emission reduction. On the other hand, a high CO_2 emission index indicates a substantial amount of carbon dioxide emissions resulting from industrial activities, transportation, and other factors. In cities with high CO_2 emissions, the development of electromobility may be challenging, as it requires an increase in the number of electric vehicles to reduce greenhouse gas emissions. High emissions may also indicate a lack of pro-environmental policies, which can lead to insufficient investment in infrastructure supporting electromobility.

Indicators related to sustainable transportation, such as the availability of urban bicycles, metro systems, and environmental performance (e.g., EPI, renewable water resources), act as stimulants for the development of electromobility. Conversely, indicators related to air pollution, greenhouse gas emissions, and traffic intensity, which highlight issues with transportation efficiency, function as deterrents.

Analyzing Table 2 reveals that 10 indicator positions are considered deterrents—desired values are those decreasing in magnitude—while the remaining 12 are stimulants. The characterization of variables and their assigned ratings serve as the basis for further analysis.

4. RESULTS

The set of indicators obtained in the research became the basis for establishing rankings of smart cities in Poland in the analyzed time period - 5 years, which is considered statistically acceptable, using the linear ordering method. The prepared rankings concern the predispositions of the development of electromobility in smart cities due to the number of low-emission cars in use over the years 2019-2023. The positioning results are presented in figures 1-5.

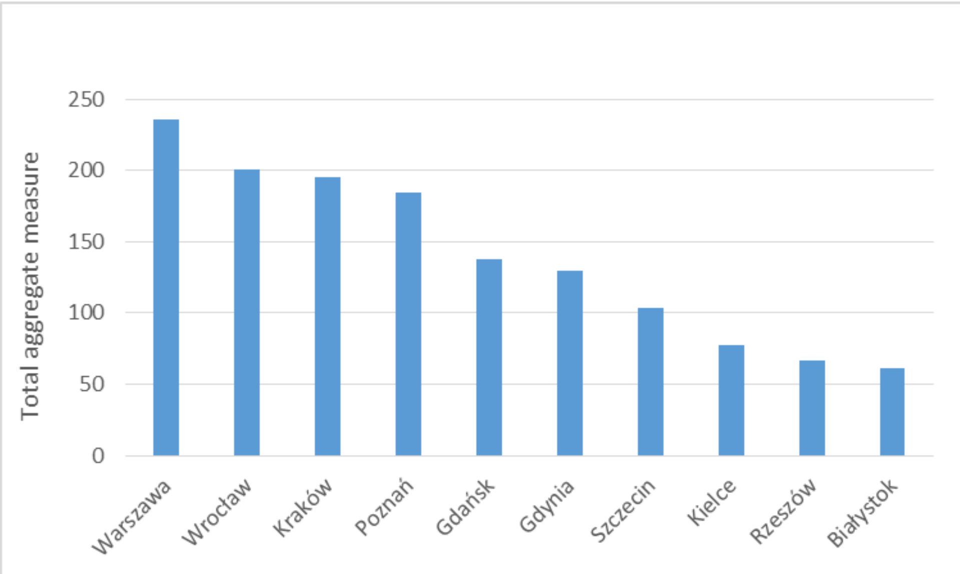

Figure 1. Predispositions for the development of electromobility - results for 2019
Source: own elaboration.

In cities such as Warsaw, Wrocław, Kraków, Poznań, and Gdańsk, we observe a significantly higher aggregate index measure. This may suggest that these cities are more advanced in terms of electromobility development.

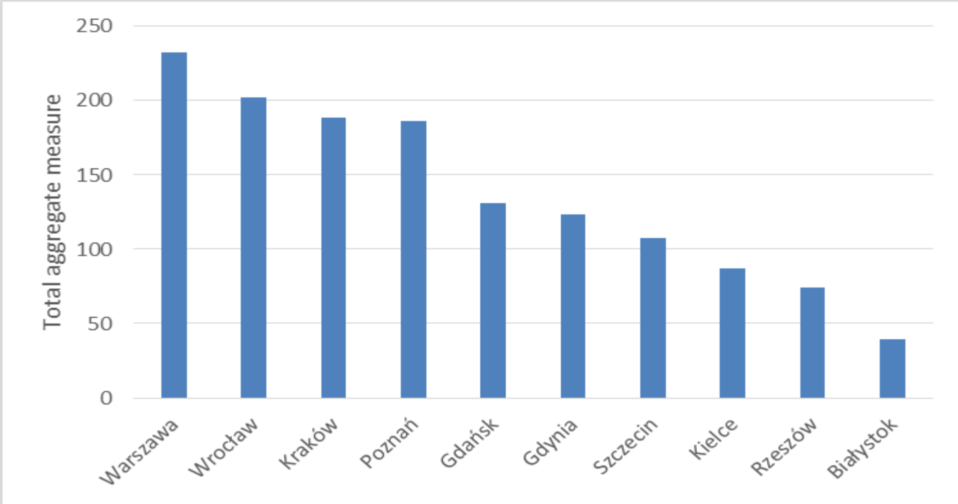

Figure 2. Predispositions for the development of electromobility - results for 2020
Source: own elaboration.

Warsaw (232.5) remains the leader, indicating that the capital is home to the largest investments and developments in electromobility. It is likely that Warsaw has the highest number of charging stations, electric vehicles, and initiatives related to electric transport and smart city projects. Wrocław (201.9), Kraków (188.7), and Poznań (186.3) also rank among the top cities, suggesting that these cities are intensively developing their infrastructure and supporting the growth of electric vehicles. In cities with larger populations and better infrastructure, such as Gdańsk (131.4) and Gdynia (123.2), electric mobility is developing steadily, although it may not yet be at the same level as in the largest cities. However, we observe a growing investment in eco-friendly infrastructure here. Szczecin (107.9) is also among the cities that may focus on the development of electric mobility, given its geographical location and the increasing pro-environmental trend. Cities such as Kielce (87.3), Rzeszów (73.9), and Białystok (39.7) are beginning to recognize the benefits of electric mobility. Although the figures in these cities are lower, the trend towards introducing electric transport solutions is still rising, and smaller cities may benefit from the development of new technologies and changing regulations that support investments in electric vehicles. Białystok (39.7), despite having a noticeably lower index, may be in the initial phase of electric mobility development. This could be due to smaller investments compared to larger cities, but over time, the number of electric vehicles and charging stations may increase.

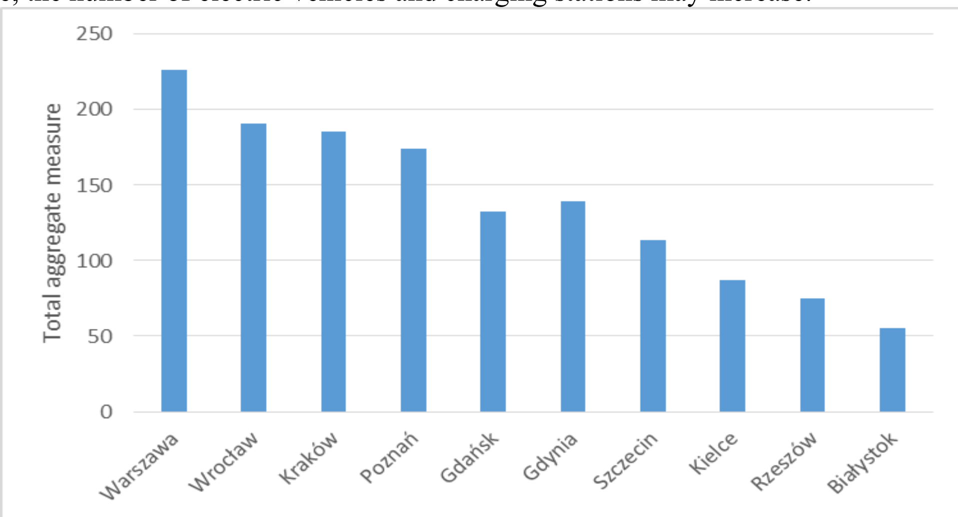

Figure 3. Predispositions for the development of electromobility - results for 2021
Source: own elaboration.

Warsaw (226.2) remains at the forefront, indicating its strong dominance in the development of electromobilty in Poland. The capital is investing in charging infrastructure, electric vehicles, and eco-friendly transport solutions. Wrocław (190.5), Kraków (185.7), and Poznań (174.2) also exhibit significant growth in electric mobility, driven by increasing ecological awareness, improved air quality, and a growing number of investments in modern transport technologies. Cities like Gdańsk (132.3) and Gdynia (139.2) also report solid progress, showing that more urban areas have invested in electric vehicles and charging stations. Gdańsk and Gdynia benefit from their port locations, which may foster the implementation of eco-friendly transport solutions. Szczecin is seeing growth in electric mobility, but it has not yet reached the levels of larger cities like Wrocław or Kraków. This may suggest that the city is gradually introducing more charging stations and initiatives, but the development process is slower compared to larger centers. Kielce (87), Rzeszów (75), and Białystok (55) are examples of cities that are gradually introducing electric mobility solutions. While their figures are lower than those of larger cities, there is a noticeable increase in interest in eco-friendly transport solutions, which may soon result in further growth in the number of electric vehicles and charging stations.

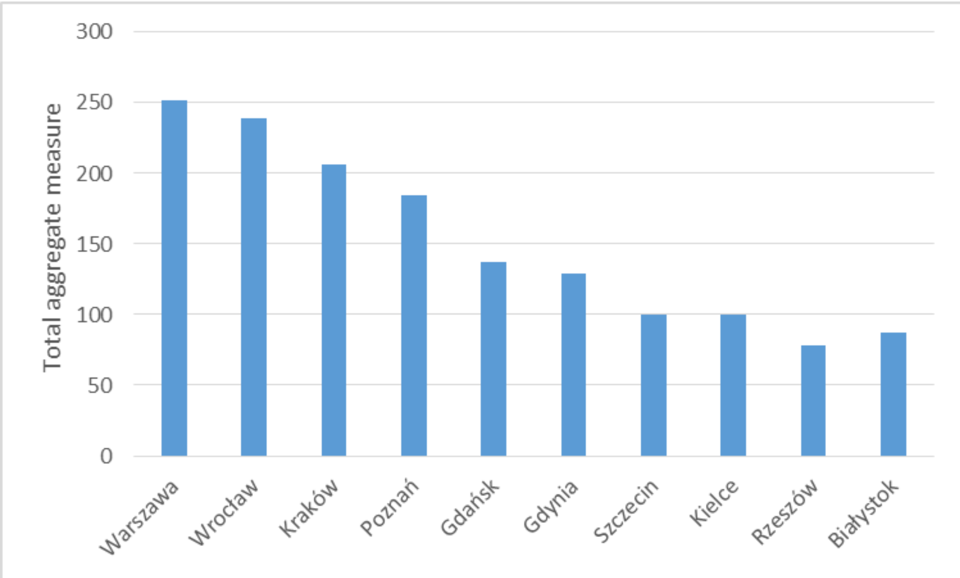

Figure 4. Predispositions for the development of electromobility - results for 2022
Source: own elaboration.

Warsaw (252.2) remains in the lead and shows a clear increase compared to previous data. This suggests that the capital continues to invest in the development of charging infrastructure, electric vehicles, and eco-friendly transport solutions. Wrocław (239), Kraków (206), and Poznań (184.2) also maintain high scores, indicating that these cities continue to advance electric mobility. The increasing demand for electric vehicles and the growing number of charging stations are key drivers in these urban centers. Gdańsk (137.3) and Gdynia (129.2) may be experiencing rapid development in electric mobility, which could be linked to their port characteristics and the growing interest in eco-friendly transport. These cities are likely investing in modern infrastructure that supports the growth of electric mobility in regions with high transport traffic. Szczecin (100.3) and Kielce (99.7) are still in the development phase, but noticeable progress in electric mobility can be observed. We can expect further growth in the number of electric vehicles and charging stations in these cities, especially as ecological awareness increases and local authorities support pro-environmental initiatives. Rzeszów (78) and Białystok (87) still show lower results compared to other cities, but their figures are gradually rising. Both cities are beginning to recognize the benefits of electric mobility and are investing in charging infrastructure and electric vehicles. The pace of electric mobility development in these cities may be slower, but it is expected to increase as it gains in popularity.

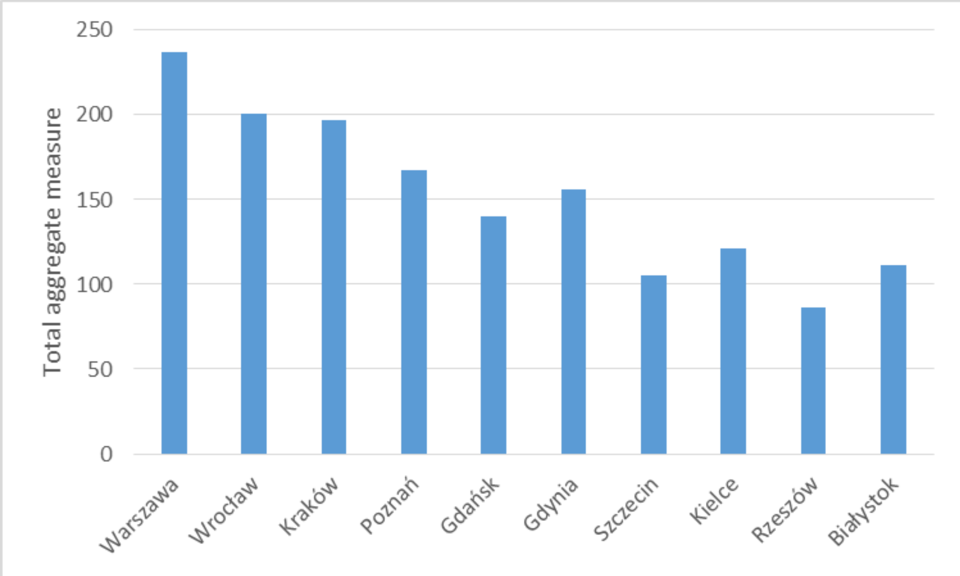

Figure 5. Predispositions for the development of electromobility - results for 2023
Source: own elaboration.

In cities such as Warsaw, Wrocław, Kraków, and Poznań, we observe a continued increase in the number of electric vehicles, driven by growing ecological awareness, pro-environmental policies, and the availability of charging infrastructure. In larger cities, the further development of the charging station network is evident. At the same time, cities like Gdańsk, Gdynia, Szczecin, Kielce, and Białystok are also beginning to invest heavily in the development of this infrastructure to increase accessibility and facilitate the use of electric vehicles for their residents.

In cities with a higher aggregate index, such as Warsaw, Wrocław and Kraków, electric vehicles are becoming increasingly common thanks to the support of local governments and their intelligent management. Emission-reducing regulations and tax incentives are being introduced, which is conducive to further development of electric mobility. Moreover, in cities with higher levels of air pollution, such as Warsaw and Kraków, electric vehicles are becoming a natural solution in the fight against smog. Local governments often implement policies to promote the development of electric mobility, such as bans on older combustion vehicles from city centers. The growth of electric mobility may also depend on the demographic and economic diversity of cities and the skills of their intelligent management. Large cities with higher per capita income, such as Warsaw and Wrocław, may have a larger population ready to invest in electric vehicles. Although larger cities such as Warsaw and Wrocław are leading the development of electric mobility, smaller and medium-sized cities such as Szczecin, Kielce, Rzeszów and Białystok are also starting to see the benefits of this technology and are intensifying their efforts to develop this sector. Gdańsk and Gdynia continue to develop electric mobility, probably due to their port features and the growing demand for sustainable, intelligent transport in the region. The development of charging infrastructure, as well as pro-ecological initiatives in these cities, make them significant players in the electromobility sector in Poland. In cities where more companies are involved in electric vehicle rental (e.g. Gdańsk and Gdynia) or where electric bikes, scooters and other forms of micromobility are offered, we observe a greater increase in electromobility. Smaller cities, such as Rzeszów or Białystok, may have lower demand for electromobility due to smaller populations and weaker infrastructure. The lower combined indicator in Białystok (compared to larger cities) may indicate a lower level of environmental awareness of residents or a lack of appropriate programs encouraging electromobility.

5. DISCUSSION

The development of electromobility is a complex process that includes the implementation of electric vehicle technology, the development of appropriate infrastructure, the transition to renewable energy sources and changes in society and governance aimed at creating a more sustainable, intelligent transport system that contributes to environmental protection and improves the quality of life of its inhabitants. Electromobility is one of the key elements of sustainable development strategies for cities and entire regions, as well as for intelligent transport. Increasing the number of electric vehicles, expanding charging infrastructure, integrating renewable energy sources, supporting technological innovations and intelligent solutions will be crucial for the further widespread adoption of electric mobility. Electric mobility has the potential to transform transport systems worldwide, contributing to the fight against climate change, improving the quality of life and creating new economic opportunities. Its implementation enables the reduction of exhaust emissions, improves air quality and brings economic, social, governance benefits, while solving challenges related to infrastructure, costs and recycling.

6. CONCLUSION

Electromobility is a key element in the pursuit of smart cities and intelligent transport management contributing to the reduction of greenhouse gas emissions and the improvement of air quality. In the context of smart city management, the integration of technology and data enables more effective management of both public and private transport. The implementation of multi-criteria analysis allows for a comprehensive assessment of electric mobility as a key step towards becoming a smart city. The multidimensional comparative analysis method is undoubtedly an appropriate tool for assessing smart cities in Poland in terms of their development of electromobility. In future research works, the authors will focus on further examination of the level of electromobility implementation in cities in Poland, including in the structure of the work a comparison of metropolises in Europe.

Future work in this area must focus not only on solutions for individual motorization, public transport and micromobility, but also freight transport. Initial work on the assessment of electromobility in all areas is already underway. In addition, the decision criteria for the development of electromobility will be analyzed in detail, taking into account technical, economic, environmental and social aspects.

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