energies

Article

The Second Generation Electromobility in Polish Urban Public Transport: The Factors and Mechanisms of Spatial Development

Robert Guzik *, Arkadiusz Kołoś, Jakub Taczanowski, Łukasz Fiedeń, Krzysztof Gwosdz, Katarzyna Hetmańczyk and Jakub Łodziński

Institute of Geography and Spatial Management, Jagiellonian University, Gronostajowa 7, 30-387 Krakow, Poland; arkadiusz.kolos@uj.edu.pl (A.K.); jakub.taczanowski@uj.edu.pl (J.T.); lukasz.fieden@uj.edu.pl (Ł.F.); krzysztof.gwosdz@uj.edu.pl (K.G.); katarzyna.hetmanczyk@student.uj.edu.pl (K.H.); jakub.lodzinski@student.uj.edu.pl (J.Ł.)

* Correspondence: robert.guzik@uj.edu.pl; Tel.: +48-60-798-0974

Citation: Guzik, R.; Kołoś, A.; Taczanowski, J.; Fiedeń, Ł.; Gwosdz, K.; Hetmańczyk, K.; Łodziński, J. The Second Generation Electromobility in Polish Urban Public Transport: The Factors and Mechanisms of Spatial Development. *Energies* **2021**, *14*, 7751. https://doi.org/10.3390/en14227751

Academic Editors: Marcin Połom and Andrea Mariscotti

Received: 12 October 2021
Accepted: 15 November 2021
Published: 18 November 2021

Abstract: One of the key challenges on the road to sustainable mobility is the development of low/zero emission urban public transport (UPT). This is crucial in order to meet environmental requirements aiming at reducing greenhouse gas (GHG) emission. In some countries (e.g., Poland) reduction of air pollution is also an important reason behind the implementation of low/zero emission UPT. The aim of this study is to investigate the factors and mechanisms influencing the development of modern electromobility in Polish UPT. We have examined all 242 UPT systems in the country in terms of the characteristics of the relevant urban municipalities, such as size, economic prosperity, level of human and social capital, development paths of urban public transport in the long term as well as the institutional context and proximity and connections to other cities with experience in electromobility. Classification and statistical methods are used based on a variety of approaches, as assigning a score to various preliminarily identified indicators or applying correlation between quantities to verify the formulated hypotheses. Our analysis demonstrates that electromobility adoption is the result of a combination of favourable economic, urban, social and technological characteristic features of a given city. Zero or low emission buses are more common in large cities which are highly positioned in urban hierarchy, economically sound and which are characterized by a well-developed tertiary economy as well as by high human capital. An additional factor that positively influences the implementation of electromobility—in particular at the very first stage—is proximity to the location of low emission bus producers. The leadership in modern electromobility can be understood as part of a broader, proactive development policy of the cities aimed at improving the quality of life of their residents. This is especially important in medium-sized towns where utilizing electric vehicles can be an instrument to maintain or even develop their role and status. The results of the article may provide a basis for creating sustainable urban policies, especially sustainable mobility and improving environmental quality.

Keywords: electromobility; zero and low-emission buses; urban public transport; cities; sustainable mobility; energy transition; Poland

1. Introduction

Transport is one of the main sources of greenhouse gas (GHG) emission and as such, one of the main drivers of climate change; what is more, its role here is constantly growing [1–4]. This is particularly true in urban areas, e.g., in the Brazilian megalopolis San Paolo, the transport sector accounts for 68% of total GHG emissions [5]. What is more, the increase in transport performance, in particular in car traffic, leads to growth in GHG emissions despite efficiency improvements driven by CO_2 limits, e.g., by the EU [6]. In order to mitigate these negative environmental consequences, the means of transport should be made "greener" and "cleaner" and public transport should become more important in mobility [7,8]. This is the way to make our transport systems more sustainable.

In this paper we would like to focus on the implementation of innovations in the field of 2nd generation electromobility (vehicles powered while driving from an on-board source) as opposed to 1st generation electromobility (vehicles requiring a permanent connection to an external power source). However, we cannot ignore (in part) this older form of electromobility (which peaked in the early 20th century) but also low-carbon technology vehicles. It is worth pointing out here that in the case under consideration (the Polish law on electromobility and alternative fuels [9]), that some electric vehicles (e.g., trams) are not considered electric, and gas buses may be an alternative instead.

The energy transition in public transport and its outcomes are largely dependent on a nexus of various institutional factors mediated by national, regional and local socio-economic contexts. The ambition of enhancing this transition towards its environmental and societal goals by setting the regulatory framework and providing well fitted toolbox of incentives requires the recognition of how this process of greening takes place and what factors are shaping its speed. It is interesting to know if it follows the usual top-down/hierarchical diffusion of innovation and what the role of geographical proximity to places of successful implementation of electromobility and places of failure alike is. Although the problem of energy transition in public transport is recently a frequent research subject, studies analysing this issue in broader spatial and socio-economic context, and investigating a large set of factors and their influence, are not common. However, the presented problems are crucial not only from a purely scientific point of view, but also for practical application. The recognition of the patterns and mechanisms of the energy transition process should facilitate taking relevant decisions by decision-makers from local administration and municipal transport management. To study this, there is a need for a reasonably large country to be able to reach credible conclusions. There are few such countries in Europe, which are large enough and adequately advanced in implementing electromobility in urban public transportation—e.g., Germany or Poland to run such a study.

Poland is a particularly interesting case for studying the development of electromobility. Firstly, it was one of the first countries to introduce low-emission buses. Moreover, the country is one of the European centres of bus production with plants of leading international brands (e.g., Volvo, MAN, Scania) as well as domestic ones (Solaris, Ursusbus, Autosan) [8]. In recent years Poland has become the largest bus producer and bus exporter in the EU (Figure 1). Because of this well-developed production base and changes in bus manufacturing towards its greening, Poland has become the largest producer of e-buses in Europe, and since 2020, the largest exporter (Figure 2). Solaris, a Polish company acquired in 2018 by Spanish CAF Group, is the largest European manufacturer of e-buses in Europe and its largest supplier. This company is presented in Poland as a success story which may influence popularity and adoption of electromobility in Poland. In fact, this company is very important not only due to its large volume of production, but also due to the fact that it has been producing electric vehicles of different types (trolleybuses, trams and electric buses) since the very beginning [10]. Another reason why Poland is a particularly interesting research area is because it is a country large in area and internally diversified enough to study the processes of spatial diffusion in electromobility as well as looking into the influence of this differentiation on studied phenomena. In particular, several substantially different models of public transport organisation and its management exist there (as in Poland, they are organised by regional and local governments), which makes the country a perfect example for studying the implementation and diffusion of electromobility.

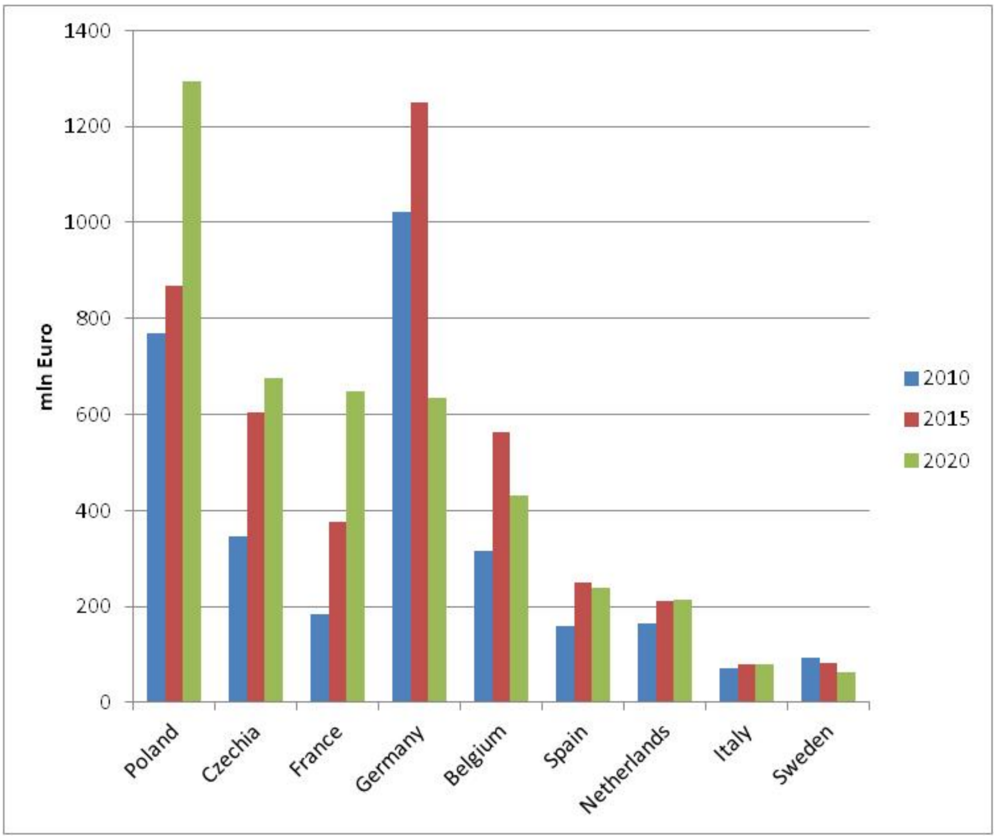

Figure 1. Exports of buses from main producing countries in the EU. Source of data: Eurostat COMEXT database.

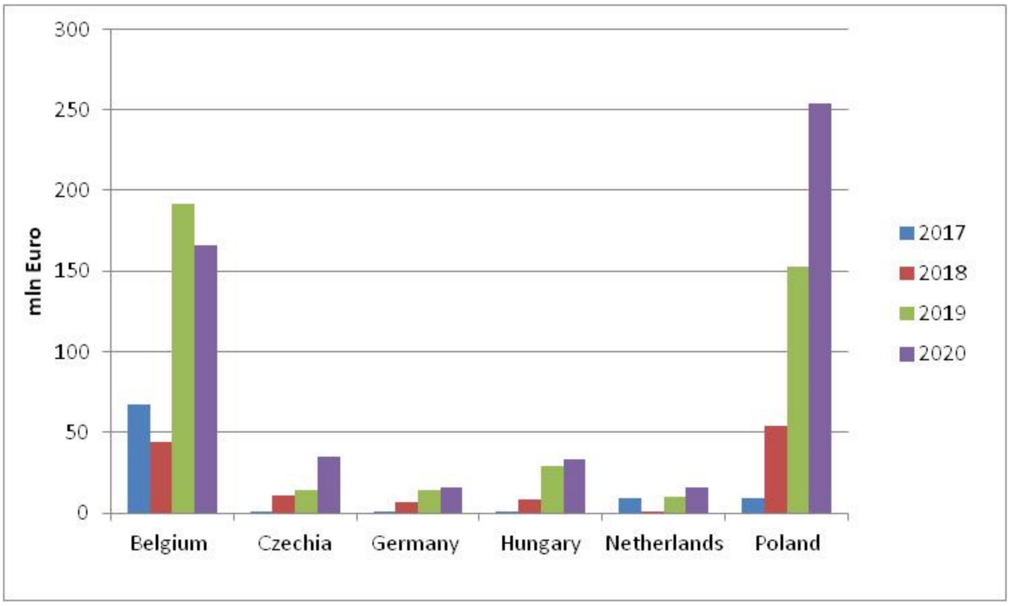

Figure 2. Exports of electric buses from main producing countries in the EU. Source of data: Eurostat COMEXT database.

The article is structured as follows: Section 2 provides a literature review, Section 3 presents the aim of our study and the methodology, in Section 4 we show the results of our analyses and Section 5 includes discussion and conclusions from the study.

2. Literature Review

The main reason behind the implementation of electric vehicles (EV) and low-emission vehicles (LEV) in general, is the tendency to limit the negative environmental consequences of the use of combustible engines, in particular greenhouse gas (GHG) emission and air pollution. This is crucial in the context of the requirements set by the Paris Climate Agreement from 12 December 2015. The goal of the Paris Climate Agreement, announced by representatives of 195 countries, is to limit the future emission of greenhouse gases (GHG) in order to limit the rise of global mean surface temperature within 1.5 °C (target) or 2.0 °C (upper limit) above the pre-industrial level [11,12]. In fact, the environmental aspect, together with the economic and social ones, are goals and constitutive elements of sustainability [13–16]. This sustainability approach can be clearly seen in the policy of the European Union. The most important strategic EU documents concerning transport and climate policy include goals and measures to ensure transport development. This is one of the priority objectives of the Seventh General EU Environment Action Program to 2020 adopted by the European Parliament and the Council of the European Union [17]. This great emphasis placed on transport in numerous strategies and the strict link between transport and environment is obvious if we realise that—as Wimbadi et al. [18] state—"urban public transport could play a central role in facilitating a holistic approach to reduce CO_2 emissions". A particularly important measure to achieve this is electrification of public urban transport. Electric engines are energy efficient, do not cause local emissions and they reduce noise [19]. This is why—as Holden et al. [20] state—electromobility is central to achieving environmental sustainability.

Electric vehicle implementation—be it in public or in private transport—is a rather difficult and complex task, involving technological and economic aspects. The main technological challenge is connected with the reliability and safety of the most important components of electric vehicles: batteries, power electric convertors and electric motors [21]. A crucial question here is the battery technology and lifecycle [22–25], but environmental aspects of their production and recycling cannot be forgotten either [26,27]. From the point of view of electric transport functioning, a critical issue is the charging infrastructure [28,29]. This is a very important factor influencing the range of electric vehicles, which is one of the most discussed problems in EV research [30–32]. On the other hand, large-scale implementation of charging facilities influences the increase in energy consumption as noticed for instance by Lazzeroni et al. [33]. This may lead to creation of new supply systems, preferably based on renewable energy, as proposed by Badea et al. [34]. Nevertheless, generally there is no doubt that electric and hybrid vehicle implementation should reduce energy consumption in comparison with gasoline vehicles [35,36]. Besides the environment, this is a very important argument in favour of electric and hybrid powertrains. That is why electric vehicle utilization field is not only passenger transport as the work of [37,38] demonstrate. The increasing importance of private electric cars may lead to an interesting development of their secondary market as [39] show. In the discussion about the possible future development of technological solutions for low-emission and electric urban transport the question of hydrogen powertrain is one of the most relevant ones. Fuel cell (FC) buses are already in operation in some European cities; however, this technology is still in its initial stages. According to [40], it is clear that from the environmental point of view, hydrogen produced via electrolysis using renewable power is highly advantageous compared with diesel buses, however, such vehicles are still expensive and it is predicted that their price will remain high up to 2030. Discussion about economic factors influencing electro- and low-emission transport has been broad as well. One of the crucial questions here are operational costs of electric vehicles [41]. Different economic effects of implementing electromobility have been analysed inter alia by [42,43]. One of the most interesting observations in terms of economy of low-emission transport is that electric mobility can and should be a crucial element of circular economy which is a strategy for the development of the economy that allows increasing prosperity while reducing and optimizing resource consumption [44–46].

However, the change from the current high carbon mobility towards low carbon mobility of the future is—besides its technological and economic aspect—also a great political and organizational challenge. Givoni [47] notices that in order to achieve low carbon mobility economic growth, mobility and emissions have to be decoupled [48–50]. This is because the present high carbon mobility is the result of the centrality of economic growth in political discourses and of the high positive correlation between economic growth and mobility level and between mobility level and carbon emission. Givoni [47] proposes three different pathways to achieve low carbon mobility: “improve” (i.e., promote mobility with less emissions), “shift” (i.e., promote growth with less mobility) and “avoid” (i.e., promote a change in lifestyle rethinking the idea of growth). According to this author it is unlikely that the first attitude will bring us nearer to low carbon mobility, because of the lack of significant reduction of absolute emissions of transport and due to the transfer of emission to other sectors. Such a risk may not be low. In countries where electric energy production is based predominantly on fossil fuels (like Poland) [51], transport electrification may indeed lead only to a geographical shift of air pollution from urban areas to zones located near power stations, but not to a general decrease of CO_2 emission [52,53]. Certainly, Givoni [47] is right when he highlights that current decarbonisation policy efforts are too concentrated on what to change inside the transport system whereas external factors—which are more important—are being neglected. However, the changes inside transport systems are not easy to introduce either. That is why a fundamental way to introduce new solutions is experimentation by introducing and developing novel solutions through small-scale initiatives [18]. This is because an immediate large-scale implementation would be too risky.

Although the general tendency to switch from diesel to hybrid and electric powertrains can be clearly seen all over the world; the decision whether and how to develop low-emission public transport vehicles is not easy. In fact, the implementation of electric or hybrid buses into urban bus fleets is a complex process which in connected with all aspects of public transport functioning: political, organizational, technological, social and spatial. Such a transition is strongly influenced by place specificity, including items such as urban and regional visions and policies, informal localised institutions, local technological and industrial specialization, consumers and local market formation and local natural resource endowments [54]. The features of the place can play a very important role while implementing electromobility. For instance, Zhang et al. [55] observe that in Chinese urban areas the introduction of electric vehicles has contributed in large scale reduction of CO_2 emissions across all urban zones, but the policy effectiveness has turned out to be more pronounced in the city centres than in peripheral areas. That is why, according to these authors, “core-periphery disparities in emission reduction need to be taken into account to establish spatially differentiated policies that support low-carbon development”. This seems to be particularly important in the European Union where public transport stakeholders are often influenced by transnational policy measures valid in the entire EU which clearly promote environmentally-friendly means of transport and provide a general legal framework for their development [56]. Here, more regional and local-oriented policies may be worth taking into consideration. The attitudes of several public transport stakeholders, even located in the same region of the country, may be completely different. As Pelletier et al. [57] noticed, public transport stakeholders introduce electric vehicles in order to meet legal requirements connected with more severe environmental norms but in some cases the decision is voluntary. Similar observations were made by Domański et al. [56] and Taczanowski et al. [8].

3. Aims of the Study and Research Methodology

3.1. Objectives

The main objective of the authors is to determine the pattern of the spatial development of electromobility in public transport in Poland and the underlying factors. It is accompanied by set of supporting objectives (see Table 1) which have guided our research.

Hence, we have investigated the spatial, political and organizational aspect of low/zero emission public transport vehicle implementation in particular. Technological and economic issues have been treated rather as a background of our analysis and more detailed research into these questions is beyond the scope of our work, especially those that that have been studied recently [40,56].

Table 1. Research objectives and corresponding hypothesis.

Main Objective	Supporting Objectives/Examined Factors	Hypotheses
To determine the pattern of the spatial development of the second generation electromobility in urban public transport in Poland and to examine the underlying factors	Proximity to plants of electric buses manufacturers; Proximity and linkages (geographical and institutional) to other cities with electromobility experiences. (diffusion of innovation); History and the development paths of urban public transport in long time-perspective	Hypothesis (1)
	Type and size of the city; Rank of the city in the urban hierarchy	Hypothesis (2)
	Economic prosperity of the city; Level of human and social capital; Institutional * context including regional and national programmes, funds and incentives	Hypothesis (3)

* Although, we explicitly state regulative institutions here, we assume that other types of institutions (normative and cognitive) (see Geels [58]) are equally important. It should be remembered that formal institutions consist of regulations and laws which shape actions (who should do what) whereas informal (soft) institutions guide actions by attitudes, preferences, norms, etc. [59].

3.2. Research Hypotheses

The authors, regarding the current state of knowledge, put forward three hypotheses, which would help to explain observed patterns:

Hypothesis 1. *There is a positive relationship between the location of low emission bus producers (the manufacture of associated equipment, such as charging systems, can also play an important role here. For example, Zielona Góra is home to one of the key players in this market—Elektro System, which was highlighted in interviews as an important factor in the development of electromobility in this city) and early adoption of electromobility in areas where they have plants.*

According to Maté-Sánchez-Val and Harris [60], "geographical proximity favours firms' absorptive capacities and innovation activities fostering knowledge spillovers via the interaction of economic agents operating in close proximity". Earlier work (e.g., Taczanowski et al. [8]) identified a positive relationship between bus manufacturer location and purchasing decisions regarding the public transport fleet. This is due, among other things, to local demonstration effects. Although we assume, that the low-emission bus implementation is subject mainly to hierarchical diffusion (see Hypothesis 2), we assume, that the role of local learning—and also the local competition in development policies (as proposed by the theory of public choice)—may play a role [60–63]. As Boschma [64] writes, "short distances literally bring people together, favour information contacts and facilitate the exchange of tacit knowledge". However, there are more dimensions of proximity. Boschma [64] mentions five of them: cognitive, organizational, social, institutional and geographical. According to this author, cognitive proximity is a prerequisite for interactive learning, whereas the other four dimensions of proximity can bring together actors, so that the knowledge can be transferred between the actors enabling the innovation process.

Hypothesis 2. *Adoption of electromobility is positively associated with the rank of the city in the urban hierarchy.*

The process of spreading electromobility in public transport can be treated as the diffusion of a technological innovation. According to Hägerstrand, the adoption of an innovation is primarily the outcome of a communication process by which the potential adopter learns of the innovation [65]. In urban systems "hierarchy effect" is supposed to be observed with the diffusion which is expected to proceed from larger to small centres. Features of the largest urban centres due to the level of human capital (including environmental awareness of inhabitants), institutional and capital predispose them to the role of early innovators. It is also necessary to point to the presence of a long tradition of electromobility, connected with the operation of electric trams in main urban centres.

However, it should be highlighted that the researchers are not unanimous, whether it is always in the large centres that the innovations are adopted at first. Whereas some scientists assume that larger firms in larger urban agglomerations are earlier adopters, other analyses point out that earlier adopters are just as likely to be in less than the largest size urban areas. In the latter case, innovations would not be so much the result of a self-reinforcing, "cumulative and circular causation" and hierarchy effect, but of aggressiveness and innovativeness of management [65]. Sorenson et al. [66] observe that the advantages connected with being geographically close to the source of knowledge are different for different types of knowledge, and what is more, it cannot be said that there is always a general positive effect of proximity.

Hypothesis 3. *The pace of e-mobility adoption is positively associated with the general level of local socio-economic development.*

The general level of socio-economic development facilitates the policy priorities and the needs of residents [67–70]. On an individual (resident) level, it can shape environmental awareness and influence the rate of adoption of private low-carbon transport modes. This in turn, among other things due to network effects, will encourage the rate of adoption of low-carbon measures in public transport.

3.3. Research Procedure

The research procedure and relationship between its different tasks are presented in Figure 3. The crucial stage of the research was to build a database on electromobility in public transport. The database takes into account the state at the end of March 2021 and was prepared under a number of assumptions. Firstly, according to Polish law, public transport is defined as municipal transport organised by a municipality with the status of a city. The study took into account 398 cities with a minimum population of 10,000. Among them, 288 centres were identified; territories in which public transport was functioning. Ultimately, 242 urban centres (Table 2) organising public transport were included in the database. In a further step, 26 of them, which are served only by lines provided by an adjacent large city (mainly in the Warsaw agglomeration, but also in Kraków, Tricity, Łódź and Lublin) were excluded from the analysis. Furthermore, The ZTM GZM (Upper Silesian and Zagłębie metropolitan transport authority) metropolitan system covering 41 municipalities (including 23 cities with population over 10,000), which is obliged to organise joint metropolitan public transport, was also treated as the one case. In addition, 2 urban centres (Lidzbark Warmiński and Płońsk), which purchased electric buses and planned to launch them in the second half of 2021, were added to the database.

All in all, urban centres under analysis had nearly 17,000 vehicles at their disposal as of the end of 2020, of which about a one-third are "green" vehicles. The latter number consists of just over 3700 electric urban rail transport vehicles and 264 trolleybuses, in addition, 415 electric (battery) buses and 497 hybrid vehicles in operation. The database also includes 717 buses running on gas (liquefied natural gas—LNG, compressed natural gas—CNG). We are fully aware that, LNG and CNG propelled vehicles are not regarded by many authors as a low-emission means of transport (and there have even been authors claiming that Euro VI diesel engines cause less pollution [71,72]. Nevertheless, we assume that in this case the desire of local governments wishing to positively affect the state of local environment should also be taken into account.

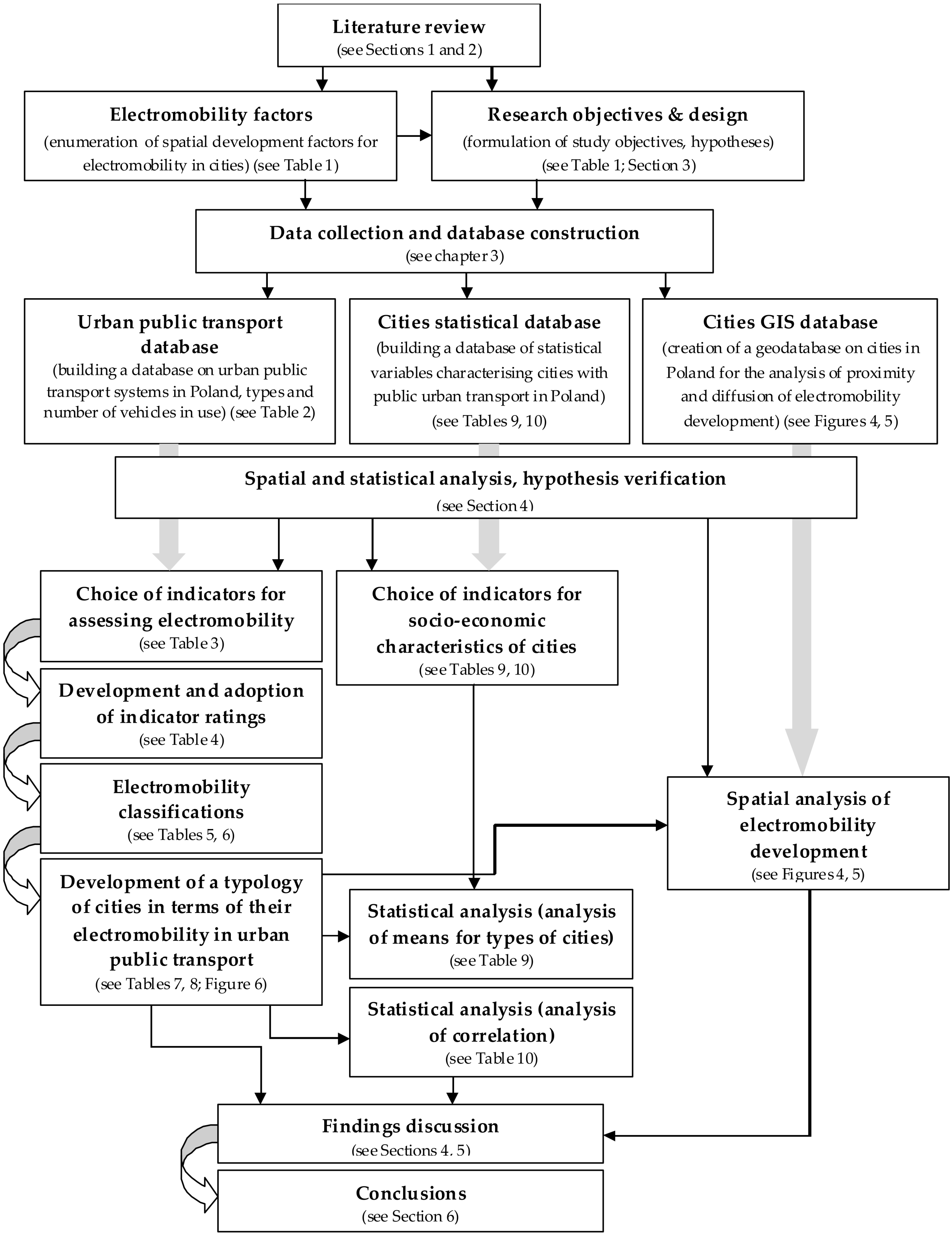

Figure 3. The research procedure scheme.

Table 2. The number of cities and towns and the number of urban public transport vehicles.

Categories	Total	Metropolitan Railway and Metro	Tram Networks	Trolleybus Networks	Bus Networks—Diesel	Electric Buses		Hybrid Buses		GAS Buses
						in Use	Planned	in Use	Planned	
Cities and towns	242	1	15	3	235	32	56	40	6	28
Vehicles	16,690	610	3099	246	11,106	415	836	497	35	717

Note: GZM metropolitan region (Katowice agglomeration) was treated as one city. The buses planned for purchase also apply to cities where they have already been operated. Furthermore, 39 cities without electric buses plan to buy them. Similarly, 4 cities planning to purchase hybrid buses did not have them before. Source: own elaboration of the authors (there is no complete and reliable database of electromobility vehicles in Poland, hence we have constructed it employing various sources, mainly materials of municipal transport companies, contracts for the provision of services, reports on competitions for the purchase of electric buses by various authorities, etc.).

3.4. Scoring and Synthetic Measures

The next stage of the research was the construction of indicators to assess the electromobility of urban transport. First, the selection of variables was made. It was conducted on the basis of literature studies. On the basis of these, classifications were created on the basis of measurable, available and complete diagnostic variables. Our classification takes into account the fact that electromobility of urban transport is not a new phenomenon—the first electric trams in Wrocław (then Breslau) were already put into operation in 1893, therefore trams and trolleybuses are referred to here as 1st generation electromobility and electric (battery) buses and hybrid buses as 2nd generation electromobility. In the expert discussion, 2 groups of indicators for 2nd generation electromobility were selected (EIIC—existing state in March 2021 and EIIF—planned in 2021), as well as indicators for total 1st and 2nd generation electromobility together (E) and total level of development of low- and zero-emission (LE) vehicle fleets (Table 3). Also taking into account that "traditional" 1st generation electromobility is important because literature about trams and trolleybuses is less frequent than on electric buses, and what is more, Polish policy towards electromobility foresees only the widest possible use of electric buses, but ignores the possibility of building other electrified transport systems (trams and trolleybuses) [17].

Table 3. Indicators used in the study.

Code	Indicator	Unit	Max Value *	Min Value *
EIIC (current second-generation electromobility)				
C1	Number of electric and hybrid buses	Piece	230 (1)	0 (179)
C2	Share of electric and hybrid buses in the total number of buses	%	100% (5)	0 (177)
C3	Number of electric and hybrid buses per 10,000 inhabitants	Piece/10,000 inh.	4.83 (1)	0 (179)
EIIF (future second-generation electromobility)				
F1	Number of planned electric and hybrid buses	Piece	121 (1)	0 (182)
F2	Share of electric and hybrid buses in the total number of buses	%	120% (1)	0 (182)
F3	Number of planned electric and hybrid buses per 10,000 inhabitants	Piece/10,000 inh.	4.84 (1)	0 (182)
E (first and second-generation electromobility)				
E1	Number of electric vehicles (including rail, metro, trams and trolleybuses)	Piece	1496 (1)	0 (198)
E2	Share of electric vehicles (including rail, metro, trams and trolleybuses) in the total number of vehicles	%	100% (3)	0 (196)
E3	Number of electric vehicles (including rail, metro, trams and trolleybuses) per 10,000 inhabitants	Piece/10,000 inh.	8.35 (1)	0 (198)

Table 3. *Cont.*

Code	Indicator	Unit	Max Value *	Min Value *
	LE ("0" and low emission vehicles)			
L1	Number of all electric, hybrid and gas vehicles	Piece	1794 (1)	0 (155)
L2	Share of all electric, hybrid and gas vehicles in the fleet	%	100% (5)	0 (153)
L3	Number of all electric, hybrid and gas vehicles per 10,000 inhabitants	Piece/10,000 inh.	10.02 (1)	0 (155)

*—in brackets the number of cities is shown.

In the third stage of the study, based on the indicators shown in Table 3, the urban centres under analysis were classified by the method of indicator weighting (Table 4), followed by their expert evaluation (Delphi method). Each city was assessed in terms of 12 indicators (listed in Table 3). A scoring (bonitation) method (see Equations (1)–(4)) was used to prepare the classification. Each city could receive from 1 to 10 points depending on the level of intensity of the phenomenon—for each indicator. Valuations (scores) are explained in Table 4 and the procedure is described with Equations (1)–(4).

$$EIIC_j = f(C1_j)_{<0-10>} + f(C2_j)_{<0-10>} + f(C3_j)_{<0-10>} \quad (1)$$

$$EIIF_j = f(F1_j)_{<0-10>} + f(F2_j)_{<0-10>} + f(F3_j)_{<0-10>} \quad (2)$$

$$E_j = f(E1_j)_{<0-10>} + f(E2_j)_{<0-10>} + f(E3_j)_{<0-10>} \quad (3)$$

$$LE_j = f(L1_j)_{<0-10>} + f(L2_j)_{<0-10>} + f(L3_j)_{<0-10>} \quad (4)$$

and

$$f(C1)_j, f(F1)_j, f(E1)_j, f(L1)_j = \begin{cases} 0\ if\ x_i = 0 \\ 1\ if\ 1 \le x_i < 3 \\ 2\ if\ 3 \le x_i < 5 \\ 3\ if\ 5 \le x_i < 8 \\ 4\ if\ 8 \le x_i < 11 \\ 5\ if\ 11 \le x_i < 21 \\ 6\ if\ 21 \le x_i < 31 \\ 7\ if\ 31 \le x_i < 41 \\ 8\ if\ 41 \le x_i < 51 \\ 9\ if\ 51 \le x_i < 101 \\ 10\ if\ x_i > 100 \end{cases}$$

$$f(C2)_j, f(F2)_j, f(E2)_j, f(L2)_j = \begin{cases} 0\ if\ x_i = 0 \\ 1\ if\ 0 < x_i \le 10 \\ 2\ if\ 10 < x_i \le 20 \\ 3\ if\ 20 < x_i \le 30 \\ 4\ if\ 30 < x_i \le 40 \\ 5\ if\ 40 < x_i \le 50 \\ 6\ if\ 50 < x_i \le 60 \\ 7\ if\ 60 < x_i \le 70 \\ 8\ if\ 70 < x_i \le 80 \\ 9\ if\ 80 < x_i \le 90 \\ 10\ if\ 90 < x_i \le 100 \end{cases}$$

$$\mathrm{f(C3)}_j, \mathrm{f(F3)}_j, \mathrm{f(E3)}_j, \mathrm{f(L3)}_j = \begin{cases} 0\ if\ x_i = 0 \\ 1\ if\ 0 < x_i \le 0.1(max_{\{i\}}) \\ 2\ if\ 0.1(max_{\{i\}}) < x_i \le 0.2(max_{\{i\}}) \\ 3\ if\ 0.2(max_{\{i\}}) < x_i \le 0.3(max_{\{i\}}) \\ 4\ if\ 0.3(max_{\{i\}}) < x_i \le 0.4(max_{\{i\}}) \\ 5\ if\ 0.4(max_{\{i\}}) < x_i \le 0.5(max_{\{i\}}) \\ 6\ if\ 0.5(max_{\{i\}}) < x_i \le 0.6(max_{\{i\}}) \\ 7\ if\ 0.6(max_{\{i\}}) < x_i \le 0.7(max_{\{i\}}) \\ 8\ if\ 0.7(max_{\{i\}}) < x_i \le 0.8(max_{\{i\}}) \\ 9\ if\ 0.8(max_{\{i\}}) < x_i \le 0.9(max_{\{i\}}) \\ 10\ if\ x_i > 0.9(max_{\{i\}}) \end{cases}$$

where $_j$—is a city *j*; f(C1$_j$ … L3$_j$) $_{<0–10>}$—scores (1 to 10) given for indicator *i* (C1 … L3) in city *j*; x_i—value of indicator *i*; $(max_{\{i\}})$—is maximum value for indicator *i*; synthetic measures (EIIC, EIIF, E, LE) and indicators *i* (C1 … L3) are explained in Table 3.

Table 4. Valuation criteria for individual indicators (scoring procedure).

Applies to Indicators:	C1, F1, E1, L1	C2, F2, E2, L2	C3, F3, E3, L3
Points	**Pieces**	**%**	**Pieces/10,000 inh.**
0	0	0	0
1	1–2	0–10.0	0–0.1 max
2	3–4	10.1–20.0	0.1 max–0.2 max
3	5–7	20.1–30.0	0.2 max–0.3 max
4	8–10	30.1–40.0	0.3 max–0.4 max
5	11–20	40.1–50.0	0.4 max–0.5 max
6	21–30	50.1–60.0	0.5 max–0.6 max
7	31–40	60.1–70.0	0.6 max–0.7 max
8	41–50	70.1–80.0	0.7 max–0.8 max
9	50–100	80.1–90.0	0.8 max–0.9 max
10	>100	90.1–100.0	0.9 max–max

Note: max–maximum observed value for a given indicator (C3, F3, E3, L3).

3.5. Electromobility Classifications

Two classifications were made: the first one based on the sum of points for indicators related to 2nd generation electromobility (EIIC, EIIF and EII together (EIIC + EIIF), and the second one referring to indicators related to both types of electromobility and low-emission (E, LE).

Detailed criteria for both classifications are listed in Tables 5 and 6. At a further stage of the work, both classifications were used to obtain a typology of cities, (4 types were obtained by combining the classes for 2nd generation electromobility and all electromobility and low-carbon), which was then used for the purposes of statistical analysis in Section 4.4) using comparison of the means method and Pearson's correlation.

Table 5. Criteria for ranking cities according to innovation in 2nd generation electromobility.

Code	Name	Values	Total Number of Cities
A	Innovative-expanding	all scores for indicators >0; at least 1 indicator (EIIC or EIIF or EII) > average and rank above average	19
Aa	Innovative fleeing chased	all scores for indicators >0 but < average or at least 2 indicators >0 including 1 > average and if EIIC > average and EIIF = 0	18

Table 5. *Cont.*

Code	Name	Values	Total Number of Cities
Ab	Innovative running late	all scores for indicators >0 but < average or at least 2 indicators >0 including 1 > average and if EIIC = 0 a EIIF > average	14
B	Intermediately innovative	all scores for indicators >0 but < average or at least 2 indicators >0 including 1 > average	10
C	Weakly innovative	at least 2 scores for indicators >0 or 1 indicator > average	33
D	Not innovative	indicators = 0	148

Table 6. Criteria for ranking cities according to electromobility and low-emission transport implementation.

Code	Name	Values	Total Number of Cities
1	Electromobile and low-emission	indicator E > average; indicator LE > average	21
NN *	Strongly electromobile	indicator E > average; indicator LE < average	no
2	Strongly low-emission	indicator E < average or = 0; indicator LE >average	16
3	Electromobile and weakly low-emission	indicator E < average; indicator LE < average	18
NN *	Weakly electromobile	indicator E > 0; indicator LE = 0	no
4	Weakly low-emission	indicator LE > 0; indicator E = 0	32
5	Not electromobile and not low-emission	indicators = 0	155

NN *—this class is not represented among studied cities.

4. Results

4.1. Distribution and Growth of Low-Emission Fleet

The size of public transport, expressed by the number of vehicles, is largely derived from the size of the city (Figure 4). The largest number of vehicles is used in Warsaw. The second system is formed by the cities of the Upper Silesian and Zagłębie Metropolis (GZM) and the third one is public transport in Kraków. The structure of vehicles used in public transport in Polish cities is mainly influenced by the presence of railway, underground, trams and trolleybuses. This is perfectly visible in the case of the largest systems in: Warsaw (railway, underground, trams), GZM (trams, trolleybuses), Kraków, Łódź, Wrocław, Poznań, Szczecin, Gdańsk, Bydgoszcz, Elbląg (trams) and Gdynia and Lublin (trolleybuses). A high share of electric buses can be observed in smaller cities, e.g., Zielona Góra, Jaworzno, Szczecinek and Kozienice, Miechów and Września (in those cases it is 100%, but only 1 or 2 vehicles). Significant use of hybrid buses is visible in cities of central Poland: Inowrocław, Tomaszów Mazowiecki, Pabianice; and southern: Lubin and Ząbkowice Śląskie (here 100%—7 vehicles). The relatively high use of gas propelled buses is interesting—the highest in south-eastern Poland, in the provinces of Podkarpacie (Rzeszów, Sanok, Przemyśl) and Małopolska (Chrzanów, Libiąż, Tarnów, Trzebinia). It is worth noting that among the analysed urban centres there are three towns based fully on electric buses (Kozienice, Miechów and Września), one town based on hybrid vehicles (Ząbkowice Śląskie) and one having only electric and hybrid vehicles in its fleet (Inowrocław).

The first hybrid buses appeared in Poland in 2002 in the town of Biała Podlaska, located close to the eastern border. It can be said that a period of experimentation began then, based on second-hand buses imported from abroad. After a few years, such vehicles also appeared in Brzesko and Tarnów. Połom [10] observes that since the EU pre-accession period, the idea of developing electric urban transport systems in Polish cities has been promoted. The purchase of alternative fuel buses (mostly CNG and LPG) or electric ones was perceived by the decision-makers as more profitable than building new tram or trolleybus lines. The first factory-new hybrid buses appeared in Polish cities, in 2008 in Poznań and 2011 in Warsaw. This can be seen as the real beginning of the development of second generation electromobility in urban public transport. In 2013, such vehicles were purchased in Białystok and Szczecin. Since 2014, the process of introducing fully or partially electric buses accelerated reaching its peak in 2018, when as many as 17 cities purchased them. The total number of electric buses purchased by Polish towns and cities in 2018 amounted to 65 [10].

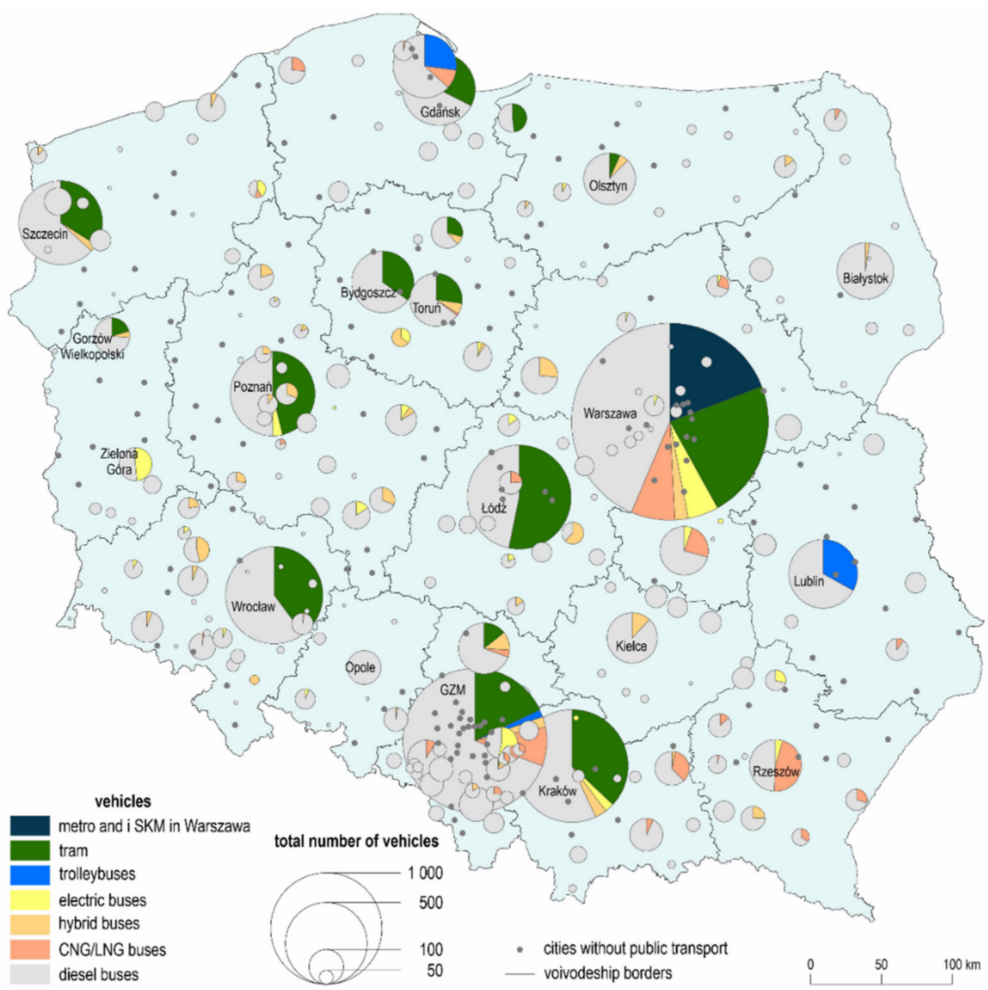

Figure 4. Distribution and structure of public transport vehicles in Poland.

Undoubtedly, Poznań was the first Polish city where second generation electromobility started developing. This was mainly due to the proximity of Europe's largest electric bus factory—Solaris Bus & Coach in Bolechowo. Today, in the vicinity of Poznań, hybrid or electric buses are still running in as many as 10 cities, even going beyond the border of the Wielkopolskie Voivodeship (Figure 5). Another area where intensive development of second generation electromobility can be observed (11 cities) is around Poland's largest city and capital, Warsaw, where hybrid buses were introduced in 2011. In the discussed topic, the year 2014 was very important, when hybrid buses were introduced in GZM and Wrocław. The latter was undoubtedly helped by the presence of the Volvo bus factory in the city. Although the second generation electromobility has not developed in Wrocław itself so far, the vehicles in question are present in as many as 12 other locations around the city. It should be emphasised that a decisive factor that has enabled electromobility implementation in Polish towns and cities are EU funds. De facto all electric bus projects are at least partially co-financed by European funds, as numerous examples demonstrate [8,73,74]. According to Połom [75], of 11 Polish regions which received EU funds for electric public transport in 2004–2013 the share of EU funds in the total sum of completed projects was between 40% and 75%.

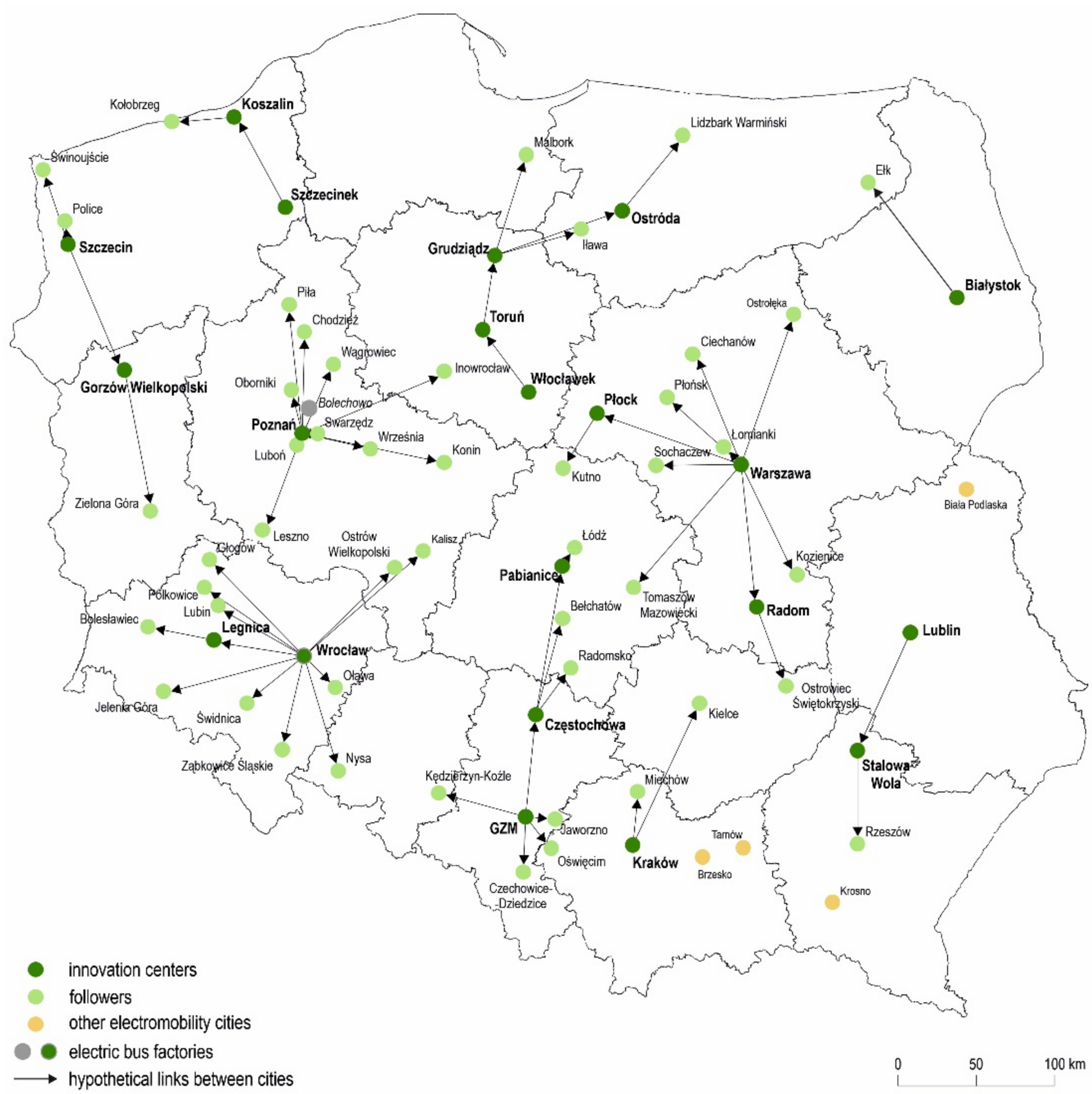

Figure 5. Hypothetical links between electromobility cities.

4.2. Classification of Cities in Terms of 2nd Generation Electromobility

The classification (Table 7) was based only on the 2nd generation electromobility indicators (EIIC and EIIF) and consists of six classes.

Notes: connections between cities were spatially limited to 100 km in a straight line, if there were vehicles in a given city, the abandonment of their use was not considered, avoiding indicating the flow of innovation from smaller to much larger cities.

Table 7. Classification of cities in terms of 2nd generation electromobility.

Class Code:			**A**	**Aa**	**Ab**	**B**	**C**	**D**
Class Name			**Innovative-Expanding**	**Innovative Fleeing Chased**	**Innovative Running Late**	**Intermediately Innovative**	**Weakly Innovative**	**Not Innovative**
Total number of cities and towns			19	18	14	10	33	148
Average number of inhabitants			304,296	159,605	81,056	68,532	106,452	31,248
Classification indicators	EIIC	Average share of electric and hybrid buses in the total number of buses	21%	45%	0%	9%	5%	0%
		Average number of electric and hybrid buses per 10,000 inh.	1.4	2.2	0.0	0.6	0.3	0.0
	EIIF	Average share of planned buses in the total number of buses	21%	0%	51%	10%	8%	0%
		Average number of planned electric and hybrid buses per 10,000 inh.	1.3	0.0	2.0	0.7	0.4	0
	E	Average number of electric vehicles per 10,000 inh.	2.4	0.8	0.3	0.3	0.6	0.0
	LE	Average number of ecological vehicles per 10,000 inh.	3.1	2.7	0.5	0.8	1.1	0.2
Examples			Kraków, Zielona Góra, Jaworzno	Warszawa, Inowrocław, Miechów	Gdynia, Lidzbark Warmiński, Chełm,	Białystok, Ełk, Chodzież	Wrocław, Tarnów, Szczytno	Bydgoszcz, Żory, Brzesko

According to the applied classification, 8% of cities can be regarded as the "expanding innovators in electromobility of the second generation". These cities varied from metropolitan centres (Kraków, Poznań, GZM) to Ząbkowice Śląskie with less than 15,000 inhabitants. These cities have pursued a fairly intensive policy of investing in electric or hybrid fleets (the average share is about 20% and is expected to double over the next two years). The position of expanding innovators is often based on previous experience with electric vehicles (trams, trolleybuses), but there are also cities (Jaworzno, Zielona Góra), which, having no previous experience, strive for a relatively fast and complete replacement of the rolling stock with low-emission vehicles. These observations coincide with the analyse of Połom M. [10] who states that Warsaw, Zielona Góra, Kraków, Jaworzno and Poznań "are five cities that have gained the greatest experience in management and maintenance of electric buses since the very beginning of their implementation in Poland" whereas the remaining cities may be regarded as those where electric buses have only been tested on a small scale.

There are another two specific groups among innovative cities. The first one (Aa—innovative fleeing chased, 7%) is made up of cities whose score is lowered by a lack of precise immediate plans to purchase further low-emission vehicles. This may, of course, result from a decrease in the interest in electromobility, but it is most often caused by the effect of saturation. This applies mainly to Inowrocław (which has already replaced its entire fleet with electric or hybrid vehicles) or Warsaw. At the moment, the Polish capital is by far the most electromobile city in Poland (including both electric rail transport and buses). However, the gigantic purchase in 2020 of 130 articulated electric buses has revealed some problems with this traction (two main problems can be identified: the first is typical of all large cities and is related to the need to ensure charging breaks, which is not always easy in congested conditions and, especially in the first period of operation, results in numerous unplanned "charging" trips. The second is specific to Warsaw and results from delays in the construction of the network of chargers. These delays are due to both lack of capacity and formal problems with construction law. Another interesting problem occurred in Kraków, where the bus manufacturer changed the location of pantographs, which resulted in the fact that the previously prepared 2-station charging spots can only serve 1 vehicle at a time) and the city must first put them into service effectively before further purchases.

Very interesting is the group Ab—innovative running late (6% of centres). Generally, it includes smaller cities with no previous experience with electric vehicles (with the exception of Gdynia, which has trolleybuses and Olsztyn which, however, introduced electric traction (trams), after a 50-year break, in 2015). These cities did not have electric or hybrid buses at the end of 2020, but had very advanced projects for their introduction. The most interesting case was that of Chełm, which in the coming years wants to replace its entire fleet with electric vehicles, half of them with hydrogen cells.

Group C (14%) consists of cities with residual innovativeness. Interestingly, there are not only small cities among them, but also large ones with extensive experience in electromobility (those are Łódź, Wrocław and Gdańsk; respectively the 3rd, 4th and 5th cities in Poland in terms of population). An extremely interesting case is Wrocław, where there is a Volvo bus factory. However, the city has stopped buying vehicles from it, as it currently only offers electric or hybrid vehicles. One of the reasons for the very cautious policy pursued in that city is the lack of conviction of the city's transport managers (the president of MPK (public urban transport company) in Wrocław pointed out "... that the electric bus market is still in such an "infant" stage that it is easy to make serious mistakes. I am waiting for the big manufacturers to show their solutions, e.g., Mercedes in the field of batteries, which can significantly change the situation. It really is sometimes better to wait a year or two and then use proven solutions than to try something unknown." [76]). Some decision makers also claim that the investment in an electric bus fleet is simply not worth it at the current state of affairs (Gdańsk, Białystok for example) (for example, the Gdańsk City Transport Authority indicated that "the analysis showed that the purchase of electric buses and provision of the necessary infrastructure is almost twice as expensive as purchasing and operating the most modern, ecological buses with the most restrictive exhaust emission standard Euro VI" [77]).

Out of 242 centres organising public transport, as many as 61% (group D) did not show any innovation in 2nd generation electromobility. These were mostly small or medium-sized cities, but also big cities (over 100,000 inhabitants) including the tram-running cities of Bydgoszcz and Elbląg.

4.3. Typology of Cities in Terms of Electromobility and Low-Emission Vehicles

As a result of the research procedure described in the methodological chapter, a typology consisting of four types was obtained, which includes both 1st and 2nd generation electromobility as well as low-carbon mobility (Table 8 and Figure 6).

Table 8. Typology of cities in terms of electromobility and low-emission.

Type Code			Strong S	Medium M	Weak W	No N
Type Name			**Strongly Innovative, Strongly Electromobile**	**Strongly Innovative, Weakly or Not Electromobile**	**Weakly or Not Innovative, However, Electromobile or Low-Emission**	**Not Innovative, Not Electro-mobile**
Classification codes *			A1, Aa1, Ab1,	A2, A3, A4, Aa2, Aa3, Aa4, Ab3, Ab4, B2, B3, B4,	Ab5, C1, C2, C3, C4, C5, D1, D2, D4	D5
Number of cities and towns			16	35	58	133
Average number of inhabitants			443,348	81,126	89,571	26,197
Classification Indicators	EII-c	Average share of electric and hybrid buses in the total number of buses	32%	23%	3%	0%
		Average number of electric and hybrid buses per 10,000 inhabitants	1.2	1.5	0.2	0.0
	EII-f	Average share of planned buses in the total number of buses	13%	11%	15%	0%
		Average number of planned electric and hybrid buses per 10,000 inh.	0.9	0.7	0.6	0.0
	E	Average number of electric vehicles per 10,000 inh.	3.4	0.4	0.4	0.0
	LE	Average number of ecological vehicles per 10,000 inh.	3.8	1.7	1.0	0.0
Examples of cities and towns			Warszawa, Gdynia, Jaworzno Miechów	Białystok, Inowrocław, Ełk, Chodzież,	Wrocław, Bydgoszcz, Tarnów, Szczytno,	Bielsko-Biała, Żory, Brzesko

* The codes consist of two elements representing the first and second classifications contained in Tables 5 and 6.

The innovative cities (with the exception of subgroup Ab5) were divided according to their electromobility also including 1st generation electromobility (trams and trolleybuses). This resulted in two interesting groups: S (comprising 7% of cities organising municipal transport) combining innovation with developed electromobility, and M (14%) in which electric propulsion innovation was still in the start-up phase in 2021.

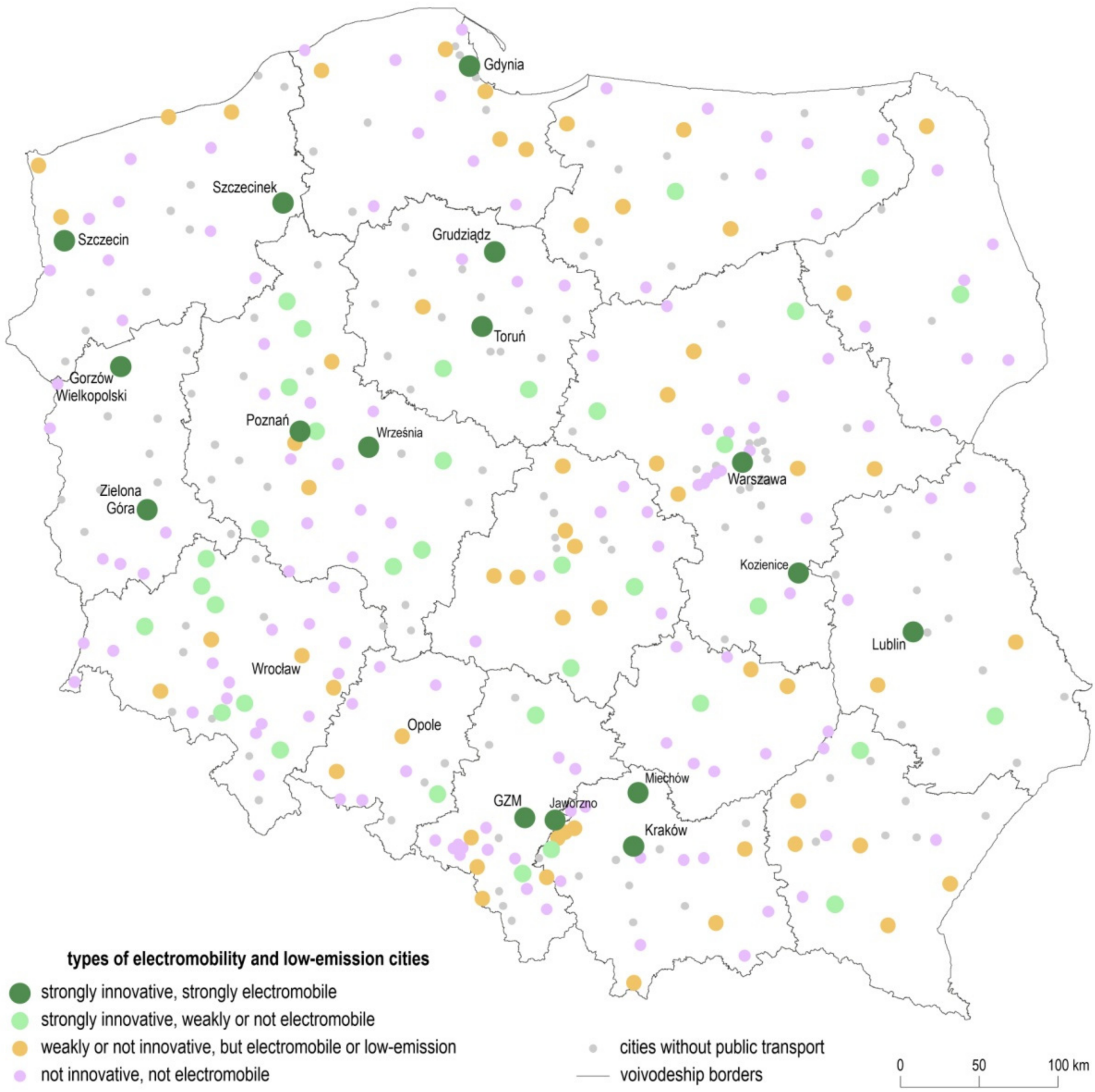

Figure 6. Cities and towns in Poland by types of electromobility and low-emission. Source: own elaboration of the authors.

4.4. Statistical Analysis

In order to verify Hypotheses 2 and 3 relating to size characteristics of the cities, their position in the settlement system and their general level of socio-economic development as conditions for electromobility development, a statistical analysis of average values of selected characteristics describing those cities was conducted (comparison of the means method) in accordance to electromobility typology (Table 8)—the result is presented in Table 9. Cities not organising public transport were included as a separate type "X". The selection of 24 indicators (column 1 in Table 9) was made from a broader set of 124 variables available for cities in the public statistics (Polish Statistical Office—Local Data Bank), after rejecting those that either did not show any significant correlation with electromobility indicators ($r < 0.2$) or were highly correlated with each other ($r > 0.9$).

Table 9. Socio-economic characteristics of electromobility-adoption city types (comparison of the means method).

Indicator			Unit	Year	Types of Localities According to Electromobility Adoption					Total
					Strong (S)—Strongly Innovative, Strongly Electromobile	Medium (M)—Strongly Innovative, Weakly or Not Electromobile	Weak (W)—Weakly or Not Innovative, However, Electromobile or Low-Emission	No (N)—Not Innovative, Not Electromobile	(X) Cities and Towns Not Organising Public Transport	
	number of localities	n	number	2020	16	35	58	133	134	376
Size	area	X1	square km	2020	244.9	54.6	61.5	25.3	20.4	41.2
	number of inhabitants	X2	thousands	2020	432.1	81.1	89.6	26.2	16.6	54.9
	population density	X3	population per 1 km^2	2020	1646	1629	1513	1269	1121	1304
Economic prosperity and entrepreneur-ship	average monthly gross wages and salaries	X4	thousands of PLN	2019	5.2	4.7	4.7	4.4	4.3	4.5
	own revenues of budget of cities per capita	X5	thousands of PLN	Average for 2017–2020	10.6	9.1	8.2	7.1	6.8	7.5
	average price per 1 m^2 of residential premises	X6	thousands of PLN	Average for 2017–2020	4.5	3.3	3.6	2.9	3.1	3.2
	natural persons conducting economic activity per 100 population	X7	number	2019	10.1	8.5	8.7	8.5	8.6	8.7
	value of grant contracts/decisions from EU funds per capita in thousands PLN	X8	number	2016–2020	24.3	18.5	19.0	17.3	18.4	18.4
	dwelling stocks per 100 inhabitants	X9	number	2019	44.7	41.2	41.3	39.1	38.3	39.6
	dwellings completed per 100 inhabitants	X10	number	Average for 2017–2019	19.6	9.9	13.2	11.2	11.1	11.7

Table 9. *Cont.*

	Indicator		Unit	Year	Types of Localities According to Electromobility Adoption					
					Strong (S)—Strongly Innovative, Strongly Electromobile	**Medium (M)—Strongly Innovative, Weakly or Not Electromobile**	**Weak (W)—Weakly or Not Innovative, However, Electromobile or Low-Emission**	**No (N)—Not Innovative, Not Electromobile**	**(X) Cities and Towns Not Organising Public Transport**	**Total**
Human capital and innovativeness	Net internal and international migration for permanent residence per 1000 population	X11	number	Average for 2017–2019	0.1	−10.0	−7.3	−7.2	−6.8	−7.0
	Share of inhabitants aged 13 years and more with tertiary education	X12	%	2011	23.8	19.9	19.1	17.4	16.9	18.0
	students in higher education institutions per 1000 inhabitants	X13	number	2019	64.4	20.0	24.7	2.8	1.7	10.0
	patents granted by Patent Office of the Republic of Poland per 10,000 inhabitants	X14	number	2018–2019	25.9	12.6	10.4	5.1	5.2	7.5
Labour market and structure of local economy	number of entities in sections J, K, L, M, N and R in Poland PKD per 1000 inhabitants (information and communication services, business and financial services, real estate activities, research and science activities, arts activities)	X15	number	2019	30.1	21.5	21.4	19.1	18.6	19.9
	number of registered unemployed persons per 100 inhabitants	X16	number	Average for 2017–2019	2.3	2.7	2.6	3.3	4.1	3.6
	registered unemployment rate	X17	%	Average for 2017–2019	4.9	6.2	6.5	7.5	8.4	7.5
	employed persons per 100 inhabitants	X18	number	2019	34.7	35.0	30.5	29.4	29.6	30.4

Table 9. *Cont.*

	Indicator		Unit	Year	Types of Localities According to Electromobility Adoption					
					Strong (S)—Strongly Innovative, Strongly Electromobile	Medium (M)—Strongly Innovative, Weakly or Not Electromobile	Weak (W)—Weakly or Not Innovative, However, Electromobile or Low-Emission	No (N)—Not Innovative, Not Electromobile	(X) Cities and Towns Not Organising Public Transport	Total
	employed persons in industry and construction per 100 inhabitants	X19	number	2019	9.2	11.8	9.9	8.4	7.8	8.7
	employed persons in trade; repair of motor vehicles; transportation and storage; accommodation and catering; information and communications per 100 inhabitants	X20	number	2019	8.8	6.8	6.2	4.4	4.2	5.0
	employed persons in financial and insurance activities; real estate activities per 100 inhabitants	X21	number	2019	1.7	0.8	0.8	0.5	0.4	0.6
Quality of living	medical doctors working per 1000 inhabitants	X22	number	2019	9.0	5.8	5.8	3.3	3.4	4.2
	share of children up to the age of 3 staying in nurseries	X23	%	2019	20.0	18.9	17.3	16.3	14.8	16.3
	number of cultural events (concerts, exhibitions, performances, festivals) per 10,000 inhabitants	X24	number	2017–2019	10.7	12.4	7.9	6.0	4.9	6.7

Source: Statistical data from BDL GUS, authors own classifications.

The analysis has shown that cities that are electromobile and innovative (Strong S) are much larger than the remaining cities (X1, X2), they are also much wealthier, which is directly reflected in revenues to the city budget (X5) and higher salaries (X4), and, indirectly, in significantly higher real estate prices (X6) and higher level of construction activity (X10) translating into a larger housing stock (X9). Cities in this group were also at the forefront in terms of absorption of EU structural funds (X8), which to a large extent, finance the transformation towards sustainable mobility. Cities in this group can boast high human capital (X12, X13), which translates, among other things, into higher entrepreneurship among their inhabitants (X7). Interestingly, while cities in Poland generally lose residents to their suburban zones, cities in this group recorded a positive migration balance in the period 2017–2019 (X11). High human capital, as well as the status of academic centres, translates into higher innovativeness of local economies, as evidenced by the rate of granted patents (X14). The above-described characteristics, as well as the size of these centres and their position in the settlement hierarchy, are also associated with higher economic activity of the inhabitants (X18), lower unemployment (X16, X17) and a higher level of tertiary economy (X19, X20, X21), including a very well-developed information economy services sector (X15). These cities enjoy a high level of life and social activity, which may indirectly indicate social capital (X22, X23, X24), although here the differences with respect to the second group (IN) are not as significant as in the previously mentioned characteristics.

The difference between the group (Strong S) in terms of the features distinguished in the table in relation to subsequent typology groups, as well as in relation to the average for all cities, allows assuming Hypotheses 1 and 3 to be confirmed. While it is not surprising that it is the largest cities (with 400,000 inhabitants on average) that are leaders in electromobility due to their wealth and higher awareness of inhabitants and authorities, it is interesting, from the perspective of the hypotheses put forward, to look at the next groups of cities between which there are no longer such large differences in size but which are huge in electromobility. Especially between the second group (Medium M) and the third group (Weak W), finding differences in the studied characteristics could indicate specific determinants of electromobility. The only features for which there were significant differences were greater migration outflow (X11) and associated lower construction activity (X10) in the cities of the group (Medium M), it is possible to hypothesize that these cities just through electromobility want to reverse this process. Additionally, it is all the easier for them to do so, as relative to the group (Weak W) they have significantly higher budget revenues (X5), which may be connected with their more industrial character (X19) and generally higher employment level (X18). They have slightly more educated residents (X12) and are characterized by the highest rate of organized cultural and artistic events (X24), which may reflect higher activity of local authorities, associations and higher involvement of residents. Thus, these characteristics strengthen the positive verification of Hypothesis 3.

Cities that are not electromobile and those without public transport are clearly smaller, less prosperous and less economically vibrant than the first three groups, which also reinforces the positive verification of Hypotheses 2 and 3.

The high correlation coefficients (Pearson's R) between indicators of socio-economic development and electromobility can also be seen as an indication of which indicators of electromobility can be related to the diffusion of electromobility in urban transport systems. Table 10 shows the correlation matrix for those features, the correlation of which with even one electromobility indicator can be considered strong ($r > 0.4$). The analysis was conducted only for the set of cities with public transport ($n = 242$). The indicators most highly correlated with the level of electromobility (Y1), but also with the share in the fleet of environmentally friendly vehicles (Y2) (hybrid buses and those using LPG/LNG as fuel), were those related to city size and their position in the hierarchy of urban centres. In addition to the city size, these were indicators of the tertiary sector of the economy and the importance of the knowledge-intensive services sector; here there were also high correlations with education indicators, the number of students or patents granted.

Table 10. Correlation matrix (Pearson's correlation coefficients **).

	Indicators of Urban Transport Greening	
Indicators/Socio-Economic Characteristics	**Number of Electric Buses per 10,000 Inhabitants (Y1)**	**Number of Environment Friendly Buses * per 10,000 Inhabitants (Y2)**
Employed persons in financial and insurance activities; real estate activities per 100 inhabitants * (X20)	0.746	0.709
Number of population (city size) (X2)	0.661	0.593
Students in higher education institutions per 1000 inhabitants ** (X13)	0.638	0.615
Patents granted by Patent Office of the Republic of Poland per 10,000 inhabitants ** (X14)	0.546	0.544
Medical doctors working per 1000 inhabitants ** (X22)	0.545	0.596
Own revenues of budget of cities per capita (X5)	0.521	0.499
Employed persons in trade; repair of motor vehicles; transportation and storage; accommodation and catering; information and communications per 100 inhabitants ** (X19)	0.507	0.556
Dwelling stocks per 100 inhabitants (X9)	0.493	0.452
Number of entities in sections J, K, L, M, N and R in Poland PKD per 1000 inhabitants (information and communication services, business and financial services, real estate activities, research and science activities, arts activities) (X15)	0.490	0.433
Average price per 1 m^2 of residential premises (X6)	0.487	0.440
Share of inhabitants aged 13 years and more with tertiary education (X12)	0.438	0.416

* Electric, hybrid and LNG/LPG buses, ** Equation for Pearson's coefficient (for population) is as follows: $\rho XY = \frac{cov(X,Y)}{\sigma X \sigma Y}$ where cov(X,Y) is covariance X and Y, σX—is the standard deviation of X; and σY is the standard deviation of Y. The correlation was calculated for population, all data was checked for outlier or bad data by tracking extreme values and observing their distribution.

What is interesting, of course, are also indices which were expected to be highly correlated with the electromobility index (Y1), but were not, such as structural funds obtained from the EU per capita (r = 0.149) or the importance of tourism in the local economy (−0.120). It was assumed that cities that attract a large number of tourists would be more likely to invest in electromobility and use this in their promotion, but no relationship was found here. Furthermore, the very low correlation with the share of electric or hybrid passenger cars (r = 0.117) was somewhat surprising. They are much more popular in large cities than outside them, but there is little variation between large cities while the level of electromobility of public transport shows a lot of variation.

5. Discussion and Conclusions

The implementation of low-emission vehicles in urban public transport systems is a relatively new phenomenon that is constantly developing and changing. What we can observe at the moment is a process that is still in its initial stage. That is why all conclusions have to be drawn carefully, taking into consideration that the near future can bring even large-scale changes—also due to the technological progress in electric and hybrid bus construction. We have to realise that we still do not know what sort of long-run economic, social and spatial consequences the implementation of low-emission vehicles will bring to the cities. However, some patterns of the analysed phenomenon can already be characterized, which enables us to verify our hypotheses.

Hypothesis 1 has been partly confirmed. Our analysis demonstrates that the first Polish city where second-generation electromobility started developing was Poznań, located next to Europe's largest electric bus factory—Solaris Bus & Coach in Bolechowo. Today, in the vicinity of Poznań, hybrid or electric buses are running in as many as 10 towns and cities. The influence of the location of the bus manufacturers on their actual implementation could be observed in particular at the very first stage of modern electromobility development in Poland (about 2015–2016), as reported by Taczanowski et al. [8]. With time, this factor seems to have weakened. A good illustration of that is the case of another large electric and hybrid bus producer—Volvo in Wrocław. Its presence has not influenced the local decision-makers to purchase low-emission vehicles. Quite the opposite, the city has stopped buying buses from Volvo when the manufacturer switched from diesel to electric or hybrid vehicles only. On the other hand, low-emission Volvo buses are in service in as many as 12 towns in the vicinity of Wrocław. The above-mentioned observation about the changing role of the proximity to bus producers would suggest that different factors can play an important role in different stages of the analysed process. The effect of geographical proximity at an early stage may be due, for example, to the demonstration effect [78], while the decision to adopt the technology more widely may be more strongly shaped by factors unrelated to proximity, i.e., the institutional capacity.

Hypothesis 2 has been generally confirmed. As supposed, a high ranking of the city in the urban hierarchy and a large number of inhabitants usually have a positive influence on electromobility implementation. What is more, cities which are characterized by a high degree of electromobility and innovation are not only large but—unlike most cities in Poland—do not lose but gain new inhabitants. The role of the largest cities is also crucial because they are leaders in decision-making processes, and as such are treated as examples to follow by the administration of smaller towns. According to our interview conducted with the head of the local municipal transport company in one of the leading electromobility cities in Poland, even if an interesting innovative idea appears in a medium-sized or small town, it will not catch on across the country if it is not accepted by decision-makers in the largest and most important cities. This is consistent with results of classical and the newest studies in spatial diffusion and so called "cascaded-effect" in particular [79,80]. However, it cannot be forgotten that factors, other than the rank of the city, are important as well, in particular those connected with the historical development of the city and its past functions. To a certain extent, a sort of path-dependence could be the case here, as it can be seen especially in many post-industrial cities (e.g., Łódź—the largest textile industry centre in Poland before 1989) which tend to be much more reluctant in electromobility implementation. Low et al. [81] distinguished three types of path-dependence in urban transport: technical, organisational and discursive. It should be emphasised that high ranking of the city can be important in particular for the durability of electric transport. It was noticed by Połom and Wiśniewski [17], that acquisition of electric buses in very small provincial urban centres, which have no experience with these kinds of vehicles, may increase the costs of public transport functioning and rather become a threat to the electromobility development.

Hypothesis 3 has been completely confirmed. Indeed, cities that are wealthy and are characterized by high salaries, high economic activity of the inhabitants, a high level of tertiary economy, low unemployment, well-educated residents and well-developed human capital are those which implement electromobility on a big scale. Characteristically, the organisation of many cultural and artistic events is also positively correlated with electromobility implementation. This would suggest that generally high activity of local authorities and associations favours technological innovations. An important factor explaining the differences in the level of innovation among similar cities seems to also be the level of human and social capital, both on the mesoscale (in a city, region) and microscale (human and institutional social capital in the management of the city and the local transport company). Firstly, attention should be paid to the availability of people with appropriate qualifications to implement electromobility, and then the appropriate operation of the electric rolling stock and energy infrastructure devices (power supply, chargers). Secondly, it is extremely important to involve decision-makers managing transport and transport companies. This is because electromobility projects are complex and risky and hence require the involvement of many high-qualified specialists. As the head of municipal transport company in Jaworzno highlights, without strong and effective cooperation of the local authorities and the municipal transport company, the electromobility project would not have had a chance for success. Hence, projects of this kind require highly-qualified specialists who believe in the sense of the change. The importance of advice and strategic information networks among decision makers, politics and senior bureaucrats in innovation was highlighted in the study by Considine and Lewis [82] on the nature of innovation inside government.

It should be highlighted that the patterns of second-generation electromobility implementation are influenced by various features of the given city or town. Their explanation is not possible through a cross-sectional quantitative analysis (as in this article) but require separate case studies. According to the above-mentioned interview with the head of the municipal transport company, these individual features of the city (e.g., area, urban density, length of bus lines, density of bus stops, maximum gradient of roads) should be determined when deciding whether to implement electric/hybrid buses or not. Hence, the crucial factor in the rate of electromobility adoption turns out to be a combination of favourable economic, urban, social and technological characteristic features of a given city or town.

What is more, the historical development of the city and its transport is also a significant factor. We have analysed the development of present low-emission urban public transport which we call second generation electromobility. This is because we would like to highlight that—unlike usually presented in the existing scientific literature—electromobility is not a new phenomenon resulting from modern tendencies to make our transport more sustainable and environmentally friendly. The electric powertrain in urban transport is not a new invention. Electric engines were the first to be adopted in municipal transport at the end of the 19th century. This obvious fact is important in countries that have never dismantled their tram and trolleybus networks and can now utilize their experiences with them in developing low-emission bus technologies. We would like to emphasise that the development of the 1st generation electromobility was quite similar to the present one. Both electric powertrain technologies—the "traditional" from the end of the 19th century and the "modern" from the 21st—were innovative at that time and hence they appeared in the most innovative cities and towns. Similar to the phenomena observed at present with regards to the 2nd generation electromobility, the "traditional" one also started in affluent cities with high human and social capital and consequently it progressed through the diffusion of innovations both hierarchically and contagiously (copying from neighbours) [83–85]. Of course, the centres which were innovative over 120 years ago have not always maintained this status, which makes the discussed relation even more interesting. Although we have not identified an unequivocal influence of the first generation electromobility on this of the second generation, the relationship between them certainly should not be neglected. An illustrative example is the fact that all three trolleybus cities in Poland have resulted in being highly innovative in the implementation of low-emission vehicles. This may be connected with the fact that trolleybus networks give a possibility to increase the share of zero-emission transport using trolleybuses equipped with onboard batteries, charged in motion, as observed by [86].

It should be stressed that the observed early leadership in modern electromobility can be understood as part of a broader, proactive development policy of the cities aimed at improving the quality of life of their residents. Being a leader in electromobility is a brand indicator and this may lead to investment decisions and affect economic, social and demographic development trajectories of the cities which have decided to invest in large-scale electromobility projects. This is especially important in medium-sized towns which are generally losing their functions—and their inhabitants. We believe that these findings may also be of interest for local authorities and public transport organisers, delivering them suggestions for transport policy implementation. In particular, the above-mentioned link between electromobility and proactive development policy can be an incentive for decision-makers to venture towards investing in zero/low emission public transport not only due to purely transport or environmental reasons, but also because it is an instrument to create attractive, liveable and prosperous towns and cities. Utilizing electric vehicles to maintain or even develop the role and status of the city is not a coincidence. Whereas electric powertrain tends to be concentrated in urban areas because it demands technological facilities (and well-educated staff—see above) which can both be found in cities, the diesel powertrain favours urban sprawl—or even deurbanisation.

Electromobility implementation, being a very complex subject that is connected with numerous economic, social and spatial aspects, requires further research. It seems that one of the crucial fields should be in-depth research into local factors influencing low-emission vehicles purchase including the influence of the first generation electromobility.

Author Contributions: Conceptualization, A.K., R.G. and J.T.; methodology, A.K. and K.G.; software, Ł.F. and R.G.; validation, A.K. and J.T.; formal analysis, A.K., Ł.F. and R.G.; investigation, A.K., Ł.F., J.T., K.G., R.G., J.Ł. and K.H.; resources, A.K., Ł.F., J.T., K.G., R.G., J.Ł. and K.H.; data curation, R.G.; writing—original draft preparation, A.K., R.G., Ł.F., J.T. and K.G.; writing—review and editing, K.G. and R.G.; visualization, Ł.F. and R.G.; supervision, A.K.; project administration, A.K.; funding acquisition, A.K. and K.G. All authors have read and agreed to the published version of the manuscript.

Funding: The open access APA fee of the publication was funded by the Priority Research Area Society of the Future under the program "Excellence Initiative–Research University" at the Jagiellonian University in Krakow.

Informed Consent Statement: Not applicable.

Data Availability Statement: Publicly available datasets were analysed in this study. This data can be found here: http://epp.eurostat.ec.europa.eu/newxtweb/ (accessed on 1 September 2021), and https://bdl.stat.gov.pl/BDL/ (accessed on 10 September 2021), www.openstreetmap.org/ (accessed on 30 August 2021).

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Thaller, A.; Posch, A.; Dugan, A.; Steiniger, K. How to design policy packages for sustainable transport: Balancing disruptiveness and implementability. *Transp. Res. Part D* **2021**, *91*, 102714. [CrossRef]
2. Charabi, Y.; Al Nasiri, N.; Al Awadhi, T.; Choudri, B.S.; Al Bimani, A. GHG emissions from the transport sector in Oman: Trends and potential decarbonization pathways. *Energy Strategy Rev.* **2020**, *32*, 100548. [CrossRef]
3. Danish, K.; Zhang, J.W.; Hassan, S.T.; Iqbal, K. Towards achieving environmental sustainability target in Organization for Economic Cooperation and Development countries: The role of real income, research and development, and transport infrastructure. *Sustain. Dev.* **2019**, *28*, 83–90. [CrossRef]
4. Rattanachot, W.; Wang, Y.; Chong, D.; Suwansawas, S. Adaptation strategies of transport infrastructures to global climate change. *Transp. Policy* **2015**, *41*, 159–166. [CrossRef]
5. Menezes, E.; Gori Maia, A.; Silva de Carvalho, C. Effectiveness of low-carbon development strategies: Evaluation of policy scenarios for the urban transport sector in a Brazilian megacity. *Technol. Forecast. Soc. Chang.* **2017**, *114*, 226–241. [CrossRef]
6. Byrne, L.; Bach, V.; Finkbeiner, M. Urban transport assessment of emissions and resource demand of climate protection scenarios. *Clean. Environ. Syst.* **2021**, *2*, 100019. [CrossRef]
7. Logan, K.G.; Nelson, J.D.; Hastings, A. Electric and hydrogen buses: Shifting from conventionally fuelled cars in the UK. *Transp. Res. Part D* **2020**, *85*, 102350. [CrossRef]
8. Taczanowski, J.; Kołoś, A.; Gwosdz, K.; Domański, B.; Guzik, R. The development of low-emission public urban transport in Poland. *Bull. Geogr. Socio-Econ. Ser.* **2018**, *41*, 79–92. [CrossRef]
9. Ustawa z dnia 11 stycznia 2018 r. o elektromobilności i paliwach alternatywnych. Dziennik Ustaw 2021 poz. 110.
10. Połom, M. E-revolution in post-communist country? A critical review of electric public transport development in Poland. *Energy Res. Soc. Sci.* **2021**, *80*, 102227. [CrossRef]
11. United Nations Climate Change. Available online: https://unfccc.int (accessed on 11 June 2021).
12. Salawitch, R.J.; Canthy, T.P.; Hope, A.P.; Tribett, W.R.; Benett, B.F. *Paris Climate Agreement: Beacon of Hope*; Springer: Cham, Switzerland, 2017; ISBN 978-3-319-46939-3.
13. Litman, T. *Well Measured: Developing Indicators for Sustainable and Livable Transport Planning*; Victoria Transport Policy Institute: Victoria, BC, Canada, 2021.

14. Rao, S.-H. Transportation synthetic sustainability indices: A case of Taiwan intercity railway transport. *Ecol. Indic.* **2021**, *127*, 107753. [CrossRef]
15. Illahi, U.; Mir, M.S. Assessment of transport sustainability using a hybrid approach: A comparison of four metropolitan cities of India. *Case Stud. Transp. Policy* **2021**, *9*, 703–714. [CrossRef]
16. Tanguay, G.A.; Rajaonson, J.; Lefebvre, J.-F.; Lanoie, P. Measuring the sustainability of cities: An analysis of the use of local indicators. *Ecol. Indic.* **2010**, *10*, 407–418. [CrossRef]
17. Połom, M.; Wiśniewski, P. Implementing Electromobility in Public Transport in Poland in 1990–2020. A Review of Experiences and Evaluation of the Current Development Directions. *Sustainability* **2021**, *13*, 4009. [CrossRef]
18. Wimbadi, R.W.; Djalante, R.; Mori, A. Urban experiments with public transport for low carbon mobility transitions in cities: A systematic literature review (1990–2020). *Sustain. Cities Soc.* **2021**, *72*, 103023. [CrossRef]
19. Figenbaum, E.; Assum, T.; Kolbenstvedt, M. Electromobility in Norway: Experiences and Opportunities. *Res. Transp. Econ.* **2015**, *50*, 29–38. [CrossRef]
20. Holden, E.; Banister, D.; Gössling, S.; Gilpin, G.; Linneruda, K. Grand Narratives for sustainable mobility: A conceptual review. *Energy Res. Soc. Sci.* **2020**, *65*, 101454. [CrossRef]
21. Gandoman, F.H.; Ahmadi, A.; Van den Bossche, P.; Van Mierlo, J.; Omar, N.; Nezhad, A.E.; Mavalizadeh, H.; Mayet, C. Status and future perspectives of reliability assessment for electric vehicles. *Reliab. Eng. Syst. Saf.* **2019**, *183*, 1–16. [CrossRef]
22. Gandoman, F.H.; Ahmed, E.M.; Ali, Z.M.; Berecibar, M.; Zobaa, A.F.; Abdel Aleem, S.H.E. Reliability Evaluation of Lithium-Ion Batteries for E-Mobility Applications from Practical and Technical Perspectives: A Case Study. *Sustainability* **2021**, *13*, 11688. [CrossRef]
23. Barbosa, J.C.; Gonçalves, R.; Costa, C.M.; Lanceros-Mendez, S. Recent Advances on Materials for Lithium-Ion Batteries. *Energies* **2021**, *14*, 3145. [CrossRef]
24. Diouf, B.; Pode, R. Potential of lithium-ion batteries in renewable energy. *Renew. Energy* **2015**, *76*, 375–380. [CrossRef]
25. Geisbauer, C.; Wöhrl, K.; Koch, D.; Wilhelm, G.; Schneider, G.; Schweiger, H.-G. Comparative Study on the Calendar Aging Behavior of Six Different Lithium-Ion Cell Chemistries in Terms of Parameter Variation. *Energies* **2021**, *14*, 3358. [CrossRef]
26. Peters, J.F.; Baumann, M.; Zimmermann, B.; Braun, J.; Weil, M. The environmental impact of Li-Ion batteries and the role of key parameters—A review. *Renew. Sustain. Energy Rev.* **2017**, *67*, 491–506. [CrossRef]
27. Sobianowska-Turek, A.; Urbańska, W.; Janicka, A.; Zawiślak, M.; Matla, J. The Necessity of Recycling of Waste Li-Ion Batteries Used in Electric Vehicles as Objects Posing a Threat to Human Health and the Environment. *Recycling* **2021**, *6*, 35. [CrossRef]
28. Kersten, A.; Rodionov, A.; Kuder, M.; Hammarström, T.; Lesnicar, A.; Thiringer, T. Review of Technical Design and Safety Requirements for Vehicle Chargers and Their Infrastructure According to National Swedish and Harmonized European Standards. *Energies* **2021**, *14*, 3301. [CrossRef]
29. Schmidt, M.; Żmuda-Trzebiatowski, P.; Kiciński, M.; Sawicki, P.; Lasak, K. Multiple-Criteria-Based Electric Vehicle Charging Infrastructure Design Problem. *Energies* **2021**, *14*, 3214. [CrossRef]
30. Varga, B.O.; Sagoian, A.; Mariasiu, F. Prediction of Electric Vehicle Range: A Comprehensive Review of Current Issues and Challenges. *Energies* **2019**, *12*, 946. [CrossRef]
31. Bi, J.; Wanga, Y.; Shaoa, S.; Cheng, Y. Residual range estimation for battery electric vehicle based on radial basis T function neural network. *Measurement* **2018**, *128*, 197–203. [CrossRef]
32. Kambly, K.; Bradley, T.H. Geographical and temporal differences in electric vehicle range due to cabin conditioning energy consumption. *J. Power Sources* **2015**, *275*, 468–475. [CrossRef]
33. Lazzeroni, P.; Caroleo, B.; Arnone, M.; Botta, C. A Simplified Approach to Estimate EV Charging Demand in Urban Area: An Italian Case Study. *Energies* **2021**, *14*, 6697. [CrossRef]
34. Badea, G.; Felseghi, R.A.; Varlam, M.; Filote, C.; Culcer, M.; Iliescu, M.; Răboacă, M.S. Design and Simulation of Romanian Solar Energy. *Energies* **2019**, *12*, 74. [CrossRef]
35. Liu, J.; Santos, G. Plug-In Hybrid Electric Vehicles' Potential for Urban Transport in China: The Role of Energy Sources and Utility Factors. *Int. J. Sustain. Transp.* **2015**, *9*, 145–157. [CrossRef]
36. Pielecha, J.; Skobiej, K.; Kurtyka, K. Exhaust Emissions and Energy Consumption Analysis of Conventional, Hybrid, and Electric Vehicles in Real Driving Cycles. *Energies* **2020**, *13*, 6423. [CrossRef]
37. Muñoz-Villamizar, A.; Montoya-Torres, J.R.; Faulin, J. Impact of the use of electric vehicles in collaborative urban transport networks: A case study. *Transp. Res. Part D* **2017**, *50*, 40–54. [CrossRef]
38. Tsakalidis, A.; Krause, J.; Julea, A.; Peduzzi, E.; Pisoni, E.; Thiel, C. Electric light commercial vehicles: Are they the sleeping giant of electromobility? *Transp. Res. Part D* **2020**, *86*, 102421. [CrossRef]
39. Wróblewski, P.; Lewicki, W. A Method of Analyzing the Residual Values of Low-Emission Vehicles Based on a Selected Expert Method Taking into Account Stochastic Operational Parameters. *Energies* **2021**, *14*, 6859. [CrossRef]
40. Lozanovski, A.; Whitehouse, N.; Ko, N.; Whitehouse, S. Sustainability Assessment of Fuel Cell Buses in Public Transport. *Sustainability* **2018**, *10*, 1480. [CrossRef]
41. Drábik, P.; Krnáčová, P. Socio-economic barriers and development opportunities of electromobility as key technological innovation of transportation. *Int. J. Multidiscip. Bus. Sci.* **2018**, *4*, 91–98.
42. Pietrzak, O.; Pietrzak, K. The Economic Effects of Electromobility in Sustainable Urban Public Transport. *Energies* **2021**, *14*, 878. [CrossRef]

43. Wangsness, P.B.; Proost, S.; Rødseth, K.L. Optimal policies for electromobility: Joint assessment of transport and electricity distribution costs in Norway. *Util. Policy* **2021**, *72*, 101247. [CrossRef]
44. Leal Filho, W.; Abubakar, I.R.; Kotter, R.; Grindsted, T.S.; Balogun, A.-L.; Salvia, A.L.; Aina, Y.A.; Wolf, F. Framing Electric Mobility for Urban Sustainability in a Circular Economy Context: An Overview of the Literature. *Sustainability* **2021**, *13*, 7786. [CrossRef]
45. Wurster, W.; Heß, P.; Nauruschat, M.; Jütting, M. Sustainable Circular Mobility: User-Integrated Innovation and Specifics of Electric Vehicle Owners. *Sustainability* **2020**, *12*, 7900. [CrossRef]
46. Motowidlak, U. An Assessment of the Effectiveness of Actions to Implement the Principles of Circular Economy in the Electromobility Ecosystem. *Ann. Univ. Mariae Curie-Skłodowska Sect. H Oeconomia* **2020**, *54*, 67–77. [CrossRef]
47. Givoni, M. Alternative pathways to low carbon mobility. In *Moving towards Low Carbon Mobility*; Givoni, M., Banister, D., Eds.; Edward Elgar Publishing: Cheltenham, UK, 2013; pp. 209–230. ISBN 978-1-78100-722-8.
48. Tapio, P. Towards a theory of decoupling: Degrees of decoupling in the EU and the case of road traffic in Finland between 1970 and 2001. *Transp. Policy* **2005**, *12*, 137–151. [CrossRef]
49. Kveiborg, O.; Fosgerau, M. Decomposing the decoupling of Danish road freight traffic growth and economic growth. *Transp. Policy* **2007**, *14*, 39–48. [CrossRef]
50. Wang, Q.; Zhao, M.; Li, R.; Su, M. Decomposition and decoupling analysis of carbon emissions from economic growth: A comparative study of China and the United States of America. *J. Clean. Prod.* **2018**, *197*, 178–184. [CrossRef]
51. Wójcik-Jurkiewicz, M.; Czarnecka, M.; Kinelski, G.; Sadowska, B.; Bilińska-Reformat, K. Determinants of Decarbonisation in the Transformation of the Energy Sector: The Case of Poland. *Energies* **2021**, *14*, 1217. [CrossRef]
52. Pietrzak, K.; Pietrzak, O. Environmental Effects of Electromobility in a Sustainable Urban Public Transport. *Sustainability* **2020**, *12*, 1052. [CrossRef]
53. Zamasz, K.; Stęchły, J.; Komorowska, A.; Kaszyński, P. The Impact of Fleet Electrification on Carbon Emissions: A Case Studyfrom Poland. *Energies* **2021**, *14*, 6595. [CrossRef]
54. Hansen, T.; Coenen, L. The geography of sustainability transitions: Review, synthesis and reflections on an emergent research field. *Environ. Innov. Soc. Transit.* **2015**, *17*, 92–109. [CrossRef]
55. Zhang, R.; Zhang, J.; Long, Y.; Wu, W.; Liu, J.; Jiang, Y. Long-term implications of electric vehicle penetration in urban decarbonization scenarios: An integrated land use–transport–energy model. *Sustain. Cities Soc.* **2021**, *68*, 102800. [CrossRef]
56. Domański, B.; Guzik, R.; Gwosdz, K.; Kołoś, A.; Taczanowski, J. European semi-periphery under environmental pressure: The case of urban public bus transportation and private bus-makers in Poland. *Int. J. Autom. Technol. Manag.* **2016**, *16*, 301–318. [CrossRef]
57. Pelletier, S.; Jabali, O.; Mendoza, J.E.; Laporte, G. The electric bus fleet transition problem. *Transp. Res. Part C Emerg. Technol.* **2019**, *109*, 174–193. [CrossRef]
58. Geels, F.W. From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Res. Policy* **2004**, *33*, 897–920. [CrossRef]
59. Wirth, S.; Markard, J.; Truffer, B.; Rohracher, H. Informal institutions matter: Professional culture and the development of giogas technology. *Environ. Innov. Soc. Transit.* **2013**, *8*, 20–41. [CrossRef]
60. Maté-Sánchez-Val, M.; Harris, R. The paradox of geographical proximity for innovators: A regional study of the Spanish agri-food sector. *Land Use Policy* **2018**, *73*, 458–467. [CrossRef]
61. Boyne, G.A. Competition and Local Government: A Public Choice Perspective. *Urban Studi.* **1996**, *33*, 703–721. [CrossRef]
62. Rallet, A.; Torre, A. Which need for geographical proximity in innovation networks at the era of global economy? In Proceedings of the ERSA Conference Papers, 39th Congress of the European Regional Science Association: "Regional Cohesion and Competitiveness in 21st Century Europe", Dublin, Ireland, 23–27 August 1999.
63. Desrochers, P. Geographical Proximity and the Transmission of Tacit Knowledge. *Rev. Austrian Econ.* **2001**, *14*, 25–46. [CrossRef]
64. Boschma, R. Proximity and Innovation: A Critical Assessment. *Reg. Stud.* **2005**, *39*, 61–74. [CrossRef]
65. Brown, L.A. Diffusion. In *International Encyclopedia of Human Geography*; Kitchin, R., Thrift, N., Eds.; Elsevier: Amsterdam, The Netherlands, 2009; pp. 170–184. ISBN 978-008-044-9104.
66. Sorenson, O.; Rivkin, J.W.; Flemng, L. Complexity, networks and knowledge flow. *Res. Policy* **2006**, *35*, 994–1017. [CrossRef]
67. Crescenzi, R.; Rodriguez-Pose, A. Infrastructure and regional growth in the European Union. *Pap. Reg. Sci.* **2012**, *91*, 487–513. [CrossRef]
68. Crescenzi, R.; Di Cataldo, M.; Rodriguez-Pose, A. Government quality and the economic returns of transport infrastructure investment in European regions. *J. Reg. Sci.* **2016**, *56*, 555–582. [CrossRef]
69. Pike, A.; Rodriguez-Pose, A.; Tomaney, T. Shifting horizons in local and regional development. *Reg. Stud.* **2017**, *51*, 46–57. [CrossRef]
70. Storper, M. *Keys to the City: How Economics, Institutions, Social Interaction and Politics Shape Development*; Princeton University Press: Princeton, NJ, USA, 2013; p. 288. ISBN 978-069-114-3118.
71. Gis, M.; Pielecha, J.; Gis, W. Exhaust emissions of buses LNG and Diesel in RDE tests. *Open Eng.* **2021**, *11*, 356–364. [CrossRef]
72. Ally, J.; Pryor, J. Life-cycle assessment of diesel, natural gas and hydrogen fuel cell bus transportation systems. *J. Power Sources* **2007**, *170*, 401–411. [CrossRef]

73. Mercik, A. Elektromobilność w autobusowym transporcie publicznym organizowanym przez Górnośląsko-Zagłębiowską Metropolię jako narzędzie realizacji idei zrównoważonej mobilności [Electromobility in bus public transport organised by the GZM Metropolis as a tool of sustainable mobility implementation]. *Prace Komisji Geografii Komunikacji PTG* **2020**, *23*, 18–33. [CrossRef]
74. Połom, M. Koncepcja wzrostu znaczenia elektromobilności w transporcie zbiorowym Trójmiasta [The comcept of the growing importance of electromobility in the Tri-City public transport]. *Zeszyty Naukowe Uniwersytetu Szczecińskiego. Probl. Transp. Logistyki* **2014**, *842*, 181–193.
75. Połom, M. European Union Funds as a Growth Stimulant of Electromobility on the Example of Electric Public Transport in Poland. *Barom. Reg.* **2015**, *13*, 89–96.
76. Dybalski, J. Prezes MPK Wrocław: Zamiast Elektryków z NCBR Mogą być Gazowce. Available online: https://www.transport-publiczny.pl/wiadomosci/prezes-mpk-wroclaw-zamiast-elektrykow-z-ncbr-moga-byc-gazowce-61861.html (accessed on 6 June 2021).
77. Rogala, B. 5 Wykresów Pokazujących, na Jakim Etapie Jest Elektryfikacja Transportu w Polskich Miastach. Available online: https://300gospodarka.pl/300klimat/5-wykresow-pokazujacych-jak-przebiega-proces-elektryfikacji-transportu-w-polskich-miastach (accessed on 9 June 2021).
78. Duesenberry, J.S. *Income, Saving and the Theory of Consumer Behavior*; Harvard University Press: Cambridge, CA, USA, 1949.
79. Haggett, P. *Geography: A Modern Synthesis*; Harper & Rwoe: London, UK, 1984; p. 670. ISBN 978-006-350-3298.
80. Lengyel, B.; Bokányi, E.; Di Clemente, R.; Kertész, J.; González, M.C. The role of geography in the complex diffusion of innovations. *Sci. Rep.* **2020**, *10*, 15065. [CrossRef]
81. Low, N.; Gleeson, B.; Rush, E. A multivalent conception of path dependence: The case of transport planning in metropolitan Melbourne, Australia. *Environ. Sci.* **2005**, *2*, 391–408. [CrossRef]
82. Considine, M.; Lewis, J.M. Innovation and Innovators Inside Government: From Institutions to Networks. *Governance* **2007**, *20*, 581–607. [CrossRef]
83. Kołoś, A. *Rozwój Przestrzenny a Współczesne Funkcjonowanie Miejskiego Transportu Szynowego w Polsce [Relations between Spatial Evolution and Actual Functioning of Urban Rail Transport in Poland]*; Instytut Geografii i Gospodarki Przestrzennej UJ: Kraków, Poland, 2006, ISBN 978-83-88424-21-2.
84. Vance, J.E., Jr. *Capturing the Horizon: The Historical Geography of Transportation since the Transportation Revolution of the Sixteenth Century*; The Johns Hopkins University Press: Baltimore, MD, USA; London, UK, 1990, ISBN 978-0060468057.
85. Hoyle, B.S.; Knowles, R. *Modern Transport Geography*; Willey: Hoboken, NJ, USA, 1999, ISBN 978-0-471-97777-3.
86. Bartłomiejczyk, M.; Połom, M. Possibilities for Developing Electromobility by Using Autonomously Powered Trolleybuses Based on the Example of Gdynia. *Energies* **2021**, *14*, 2971. [CrossRef]