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Analysis of Innovative Electromobility Development and the Advancement of Eco-Friendly Transport Infrastructure

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Abstract: Fuel combustion products cause considerable damage to the environment and human health. Therefore, it is necessary to switch to environmentally friendly vehicles. This study analyzed the dynamics of the number of cars and trucks with electric and hybrid engines, predicted their number at the current rate of change in their number, and the degree of provision and potential need for charging points in European countries. According to the results obtained, 73% of the territory of the European Union has a provision of charging points below the average level. This emphasizes the need to change the approach to structuring infrastructure upgrades by systematizing the process of creating new charging points. A mathematical model was created using the least-squares method to predict the number of vehicles with environmentally friendly engines over the next three years. The predicted number of such cars in the EU in 2026 is 12.5 million, which requires an increase in the number of charging points by 2.7 times compared to the existing ones. Under such conditions, it will be possible to reduce atmospheric emissions by 120 million tons by 2024, 160 million tons by 2025, and more than 200 million tons annually by 2026. The rapid growth of charging stations will lead to an increase in the electricity demand, which, in turn, will become an impetus for a sharp increase in electricity production by alternative sources. With the timely adaptation of infrastructure to the growing needs associated with environmentally friendly transport, achieving the maximum positive effect from these innovations is possible.

Keywords: environmental protection; emission reduction; transport; charging station density

Academic Editor: Maxim A. Dulebenets

Received: 30 December 2024
Revised: 18 January 2025
Accepted: 22 January 2025
Published: 26 January 2025

Citation: Koval, V.; Shmygol, N.; Đurović, S.; Pavićević, Đ.; Honcharova, I. Analysis of Innovative Electromobility Development and the Advancement of Eco-Friendly Transport Infrastructure. *Sustainability* **2025**, *17*, 1010. https://doi.org/10.3390/su17031010

1. Introduction

1.1. Motivation and Objectives of the Study

Transport development has long been associated with a constant increase in harmful environmental effects. The implementation of the first emission standards for gasoline and diesel engines was a response to the growing number of harmful substances emitted into the atmosphere, which significantly worsened living conditions. Because the harmful effects were direct on human health and indirect through the deterioration of agricultural products, the emission problem acquired significance.

Along with other tasks, one of the main tasks of the European Union is a significant reduction in harmful emissions. To achieve this goal, it is necessary not only to develop the production of vehicles with engines that do not produce emissions into the atmosphere, but also to provide infrastructure for their use. According to the European Parliament [1], harmful emissions should be reduced by 55% by 2030 compared with the 1990 level.

The problem of emissions of gasses and solid substances into the atmosphere when using gasoline or diesel engines in cars is very relevant since the scale of emissions is quite impressive. There is a car with a gasoline engine, the fuel consumption of which is 7 L per 100 km, and this car travels 10,000 km per year. During this period, about 16 tons of carbon dioxide (CO_2), 80 kg of oxides of nitrogen (NO_x), 30 kg of carbon monoxide (CO), 16 kg of hydrocarbons (HC), and 3 kg of solid particles (Ps), including soot, heavy metals, carcinogens, and other harmful substances, will be emitted into the atmosphere. Considering that about 9 million new cars are registered in the EU annually, the transition to alternative fuels is relevant. For the successful use of environmentally friendly vehicles, an appropriate infrastructure is needed, which, as shown in this study, is developing very unevenly in the countries of the European Union.

This study aims to investigate infrastructure support for the operation of environmentally friendly transport and to develop proposals for improving transport infrastructure development to maximize the reduction in harmful emissions into the atmosphere.

1.2. Features of the European Union Policy in the Field of Development of Eco-Friendly Transport

The rapid development of transportation in the second half of the 20th century led to serious problems with the health and quality of life of the European population [2]. This issue began to be actively discussed in EU governing bodies in the 1990s, which led to the motivation to expand the scope of developments in alternative sources of traction for car engines. Consequently, technological opportunities for the development of more environmentally friendly types of transport have emerged [3].

The European Parliament adopted several documents to streamline the implementation of technologies with a gentle impact on the environment by industries and vehicles [4]. Documents 52020DC0562 "Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions" [5] and 52023DC0796 "Communication from the commission to the European parliament, the council, the European economic and social committee and the committee of the regions EU wide assessment of the draft updated national energy and climate plans an important step towards the more ambitious 2030 energy and climate objectives under the European Green Deal and RepowerEU" [6] are the most relevant in the study framework. The adoption and implementation of these documents are considered the basis for the further development and implementation of technologies that allow obtaining the benefits of civilization with minimal environmental impact. However, these documents need a clear vision of infrastructure development for servicing technical devices, including vehicles that use environmentally friendly energy [7].

1.3. Innovative Activity as a Type of Economic Activity

When forming infrastructure innovations, different authors consider several factors from different points of view. Baboyan [8] considers innovation as a structural renewal of functioning, which allows us to assert the need to introduce significant changes in the activities of organizations that will implement these innovations into the plans for the development of infrastructure innovations. Pascalau [9] argues that it is necessary to offer entrepreneurs more opportunities when implementing strategic innovations; that is, unlike Baboyan, he considers innovations as a self-regulating process under the influence of entrepreneurs.

Chkhaidze [10], when considering the problems of innovative business, defines the role of the state as the main stakeholder in the development of innovations and believes that in the first stages, innovative technologies do not always find support in the business environment due to the high cost of development and doubts about the effectiveness of investments. Burak (2019) also considers the state a fundamental factor whose interests not only support innovative activities but also responsibility for the infrastructural support of the further functioning of innovations [11].

However, when studying the works of various authors [7–11], no forecast was made of the required number of charging points depending on the existing density of the charging infrastructure. Implementing such a forecast will allow us to determine the amount of funds needed to implement this area of infrastructure development, taking into account local characteristics and the degree of availability of electricity from both non-renewable and renewable sources.

2. Theoretical Framework

2.1. Features of Innovations in Transport

Due to the large number of vehicles involved in ensuring the lives of people and the functioning of the economy, innovations are needed to create conditions for minimizing the harmful impact of transportation on the environment. The innovative development of many industries, including transport, has been studied. Koval (2024) considers the technology of formation and development of innovations in the transport cluster while paying special attention to planning a preliminary analysis of the effectiveness of innovations to adjust both intra-transport innovations and infrastructure innovations that provide a favorable external climate not only for the implementation but also for the further use of innovations [12].

Penev (2024) provides a more specific interpretation of the analysis of marketing innovations in multimodal transportation, focusing on the importance of the level of development of logistics infrastructure for the functioning of innovations. Since most innovations in the transport sector are associated with cross-border operations, many authors have simultaneously focused on forming an innovative environment in several countries [13]. The specifics of cross-border financing and taxation in the implementation of innovative processes, including those of an infrastructural nature, were explored by Coppola (2021), focusing on the importance of a systems approach to transforming logistics infrastructure in several countries simultaneously [14].

Some authors have drawn attention to the nature of legal support and the need for infrastructure transformations when carrying out cross-border transportation. Honcharova (2023) considered the specifics of passenger cross-border transportation and the infrastructure innovations necessary for their implementation [15].

2.2. The Environmental Aspect of Innovations in Transport

Mia (2022) considers improving the environmental safety of transport an important factor that influences the level of green entrepreneurship development. In addition to technological factors, Mia (2022) also considered the impact of decisions on innovation in transport on the social environment and drew attention to the broad social impact of infrastructure transformation on the overall perception of measures aimed at continuous development by the population [16]. Wynes (2024) draws attention to the problems of uneven reduction in carbon dioxide emissions into the atmosphere by different countries due to varying degrees of readiness to perceive and implement innovations in the transport sector, including infrastructural ones [17]. Koval (2022) provides a model for analyzing environmental innovations, which allows for obtaining better information not only on the progress of environmental innovations but also on the progress of related innovations, including infrastructural innovations [18].

2.3. Cases of Previous Research

The most illustrative is the study conducted by the European Automobile Manufacturers' Association based on the results for 2023 [19]. However, this study only revealed the quantitative characteristics of the availability of charging points in each EU country. The results of this study are generally informative, without giving an idea of how intensively these points are located in the territory of the countries or with the number of potential users. The Association also studied the number of new cars sold with electric motors but did not consider the characteristics of passenger cars and trucks.

Other studies are also informative and do not include an analysis of the quality of the transport infrastructure that ensures the functioning of transport with electric and hybrid motors , in general, and elements of the availability of charging points in particular. The proposed study aims to supplement and expand on previous studies.

This study aims to examine the current state of the infrastructure that supports the operation of vehicles with environmentally friendly engines. Also, the dynamics of using electric and hybrid engines in cars and trucks from 2019 to 2023 will be studied.

RQ1: To analyze the current state of the infrastructure to support the operation of vehicles with electric and hybrid engines in terms of charging points per 100 square kilometers of area and the number of cars with environmentally friendly engines per charging point.

RQ2: To forecast the number of vehicles with environmentally friendly engines for the next three years, to determine the need for charging points at the current average occupancy rate of existing charging points, both for all countries of the European Union as a whole and groups of countries in terms of the provision of charging points per 100 square kilometers of territory.

RQ3: To identify and conduct a comparative analysis of the best practices in infrastructure provision within the European Union and beyond.

3. Materials and Methodology

The data used in this study are those submitted by each EU country to the European Statistical Office. In addition to EU member states, some positions are submitted by non-EU countries on their initiative.

Two methods were employed in this study. The first method is quantitative. Data provided by countries in cooperation with the European Statistical Office (Eurostat) were used to apply quantitative methods. The required engine types are selected on relevant pages to obtain information on the required engine types for passenger cars and trucks.

This study considered cars with electric and hybrid engines, that is, with the ability to connect gasoline or diesel fuel. The quantitative information provided by the European Alternative Fuels Observatory was used to obtain information on the current state of the infrastructure to ensure the operation of electric engines.

The following quantitative information processing methods were used. Statistical data on the number of vehicles of this type with electric and hybrid motors were considered to determine the dynamics of passenger and freight vehicles. To determine the dynamics, the ratio of the number of vehicles in 2022 to the number of vehicles at the beginning of the period is determined.

The proposed methodology can be used to calculate the forecast for the total number of cars with environmentally friendly engines, and separately for passenger and freight transport, for a separate country or a group of countries. Considering that in some countries, a decrease in the number of trucks with environmentally friendly engines was initially observed during the study period, which then changed to an increase, for greater accuracy of the forecast it is necessary to construct a quadratic function that will take into account the different nature of the change in the dynamics of cars.

The density of the charging points was determined by calculating the number of charging points per 100 square kilometers of area. To form a concept of the level of provision of this transport infrastructure facility, five groups were created by the number of charging points per 100 square kilometers of territory: over 100 points, from 10 to 100 points, from 5 to 10 points, from 3 to 5 points, and less than 2 points. The unevenness of the intervals indicates the need to apply various measures to create these elements of transport infrastructure, depending on the density of coverage of the territory with charging points.

The number of cars per charging station was calculated to determine the density of the charging points in the operation of vehicles with electric and hybrid engines. To develop recommendations for improving the use of the existing charging-point infrastructure, three groups of countries were formed: from three to six cars per charging point, six to nine cars, and more than nine cars. To forecast the number of cars with environmentally friendly engines in the European Union for the next three years, it is necessary to construct a functional dependence based on data from five years of research using Formula (1).

A quadratic dependence was chosen because the growth in the number of cars with environmentally friendly engines may not be clearly described by a simpler function, such as a linear function.

$$\begin{cases} 5c + b\sum_{i=1}^{5} Y_i + a\sum_{i=1}^{5} Y_i^2 = \sum_{i=1}^{5} Q_i\,, \\ c\sum_{i=1}^{5} Y_i + b\sum_{i=1}^{5} Y_i^2 + a\sum_{i=1}^{5} Y_i^3 = \sum_{i=1}^{5} Y_i Q_{i,} \\ c\sum_{i=1}^{5} Y_i^2 + b\sum_{i=1}^{5} Y_i^3 + a\sum_{i=1}^{5} Y_i^4 = \sum_{i=1}^{5} Y_i^2 Q_{i.} \end{cases} \quad (1)$$

where Y_i—number of year (2018-1, 2019-2, 2020-3, 2021-4, 2022-5),
Q_i—quantity of cars with electric and hybrid engines.

Based on the results of constructing a system of linear equations and solving it using Cramer's method, the coefficients of the quadratic function are determined. Starting from the sixth year of observations, that is, from the first year of the forecast, the number of cars with electric and hybrid engines will be determined by calculating the corresponding values of function (2).

$$Q(Y) = aY^2 + bY + c \quad (2)$$

The number of required charging points can be determined by first calculating the number of required charging points based on the predicted number of green cars. To calculate the number of required charging points, the current EU average of 7.1 cars per charging point can be used as the load per charging point.

To make a forecast for the next three years, the values of the independent variable are substituted into the resulting function: 6 for 2024, 7 for 2025, and 8 for 2026.

To calculate the potential reduction in emissions that is forecast for the following years, it is assumed that one car with an internal combustion engine emits 16 tons of carbon dioxide, 0.08 tons of nitrogen oxides, 0.03 tons of carbon monoxide, 0.016 tons of hydrocarbons, 0.003 tons of solids per year of operation.

4. Results

4.1. Dynamics of the Number of Vehicles with Electric and Hybrid Engines

Because the solution to the problem of harmful emissions from vehicle operation was proposed in the form of electric traction engines within the framework of scientific and technical progress, technologies related to the use of electric and hybrid engines have been rapidly developing in the automotive industry. Electric motors provide the entire movement of the vehicle owing to electric energy.

Hybrid engines allow, if necessary, switching the fuel use mode, that is, choosing either electric traction or traditional fuel types, such as gasoline or diesel fuel. It is necessary to consider the dynamics of changes in the number of passenger cars with electric and hybrid engines from 2018 to 2022. Figure 1 shows the results for all the European countries, including Turkey and Georgia.

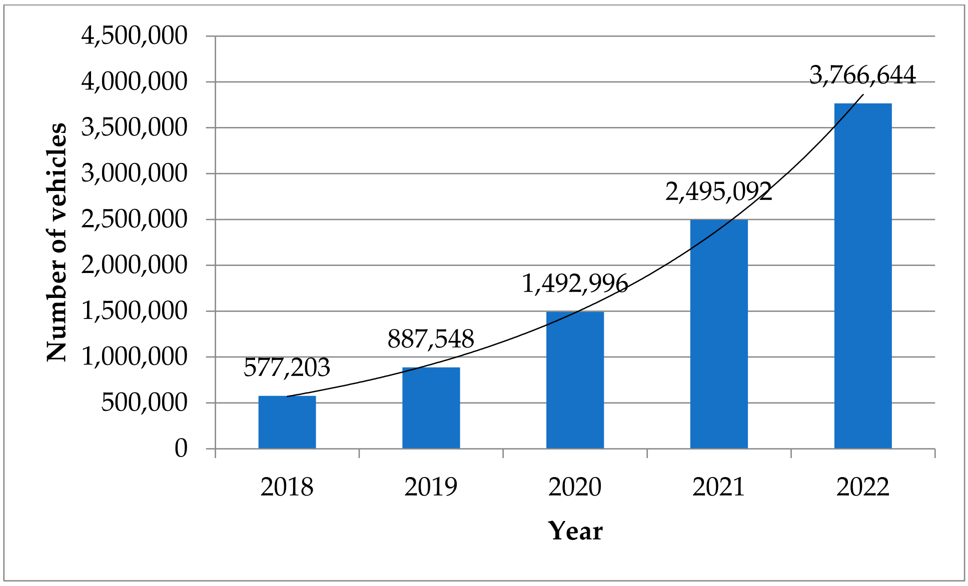

Figure 1. Passengers' cars with electric and hybrid engines [20].

The overall increase was 6.5 times, with the figures varying from 3.5 times (in Norway) to 84.1 times (in Turkey) in different countries. However, considering the absolute number of passenger cars with electric and hybrid engines, the number of such cars in Turkey currently amounts to 11.6% of the number of similar cars in Norway.

Suppose the situation is considered with trucks with similar types of engines. In that case, it should be noted that several countries, namely Greece, Croatia, Cyprus, Latvia, Malta, Slovenia, Liechtenstein, Bosnia and Herzegovina, Moldova, and Albania, do not have a single truck with an electric or hybrid engine. Some European countries have up to five vehicles of this type in their truck fleet, namely Estonia, Luxembourg, and Turkey with one vehicle each, Lithuania and Slovakia with two vehicles each, and Portugal with four vehicles. Figure 2 shows the dynamics of the number of trucks with electric and hybrid engines from 2019 to 2023.

The total increase in the fleet of trucks with electric and hybrid engines was two times. This increase was due to the increase in the number of trucks with electric and hybrid engines in Germany by 2160, France by 465, Norway by 433, Bulgaria by 200, Switzerland by 177, Sweden and Spain by 200, and in other countries the increase was less than 100 units.

However, despite the increase in the number of cars with electric and hybrid engines, some countries have observed a decrease in their number. Thus, in Poland, the decrease was 762 units (from 1416 to 654), in Italy, by 136 units (from 172 to 36), and in Portugal, by 6 units (from 10 to 4).

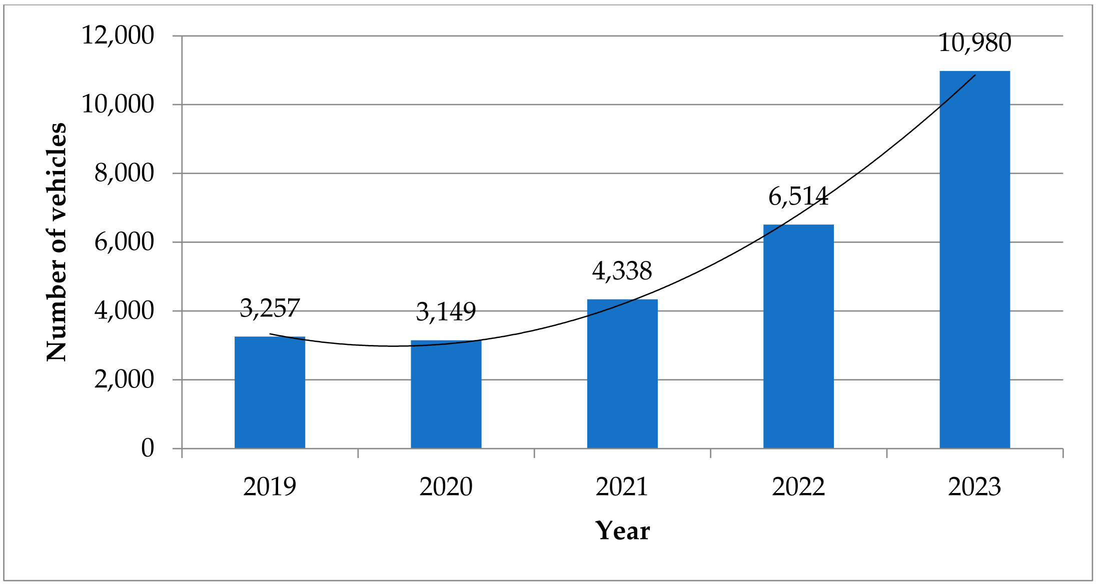

Figure 2. Lorry cars with electric and hybrid engines [21].

At the same time, in the above-mentioned countries, the number of passenger cars with electric and hybrid engines has increased 11 times in Portugal, 17 times in Poland, and 18 times in Italy.

4.2. Research into the Availability of Charging Stations and Calculation of Forecasts for EU Countries

Previous studies have shown that the density of charging points in different EU countries is not uniform, but no classification of countries by charging point density has been performed. The number of charging points per 100 sq. km of area for each EU country was calculated, and the density of the number of operating electric vehicle charging points in EU countries per 100 sq. km was obtained to determine the directions and components of innovation in the transport infrastructure system (Table 1). Based on the calculations of the density of charging points per 100 sq. km of area, groups of countries with different densities of charging points were formed. The most numerous group of countries is the one in which the density of charging points per 100 sq. km of area is from 10 to 100 (Luxemburg, Denmark, Germany, Malta, Austria, France, and Italy). The least numerous group is the one with a density of over 100 charging points per 100 sq. km (The Netherlands and Belgium).

Table 1. Provision of the territory of the European Union countries with charging points, points per 100 sq. km.

Level	Country	Number of Charging Points	Country Area, sq. km	Density of Charging Points
Over 100 points	The Netherlands	144,453	41,543	347.7
	Belgium	44,363	30,528	145.3
10–100 points	Luxemburg	2323	2586	89.8
	Denmark	23,072	42,947	53.7
	Germany	120,625	357,581	33.7
	Malta	101	315	32.1
	Austria	18,637	83,878	22.2
	France	119,255	543,941	21.9
	Italy	41,114	301,958	13.6
5–10 points	Sweden	37,166	438,574	8.5
	Slovenia	1608	20,273	7.9
	Portugal	7306	92,230	7.9
	Spain	30,385	498,485	6.1
	Czechia	4464	78,871	5.7
3–5 points	Slovakia	2380	49,035	4.9
	Ireland	2825	69,825	4
	Cyprus	329	9251	3.6
	Hungary	3319	93,025	3.6
	Finland	11,247	336,884	3.3
0–3 points	Poland	6102	312,679	2
	Lithuania	1313	65,286	2
	Croatia	1074	56,594	1.9
	Bulgaria	1624	110,372	1.5
	Estonia	683	45,399	1.5
	Romania	2754	238,298	1.2

Source: compiled by the authors based on EU information [22,23].

On average, across the entire territory of the European Union, this indicator is 15.4 charging points per 100 sq. km. To determine the degree of transport provision with charging points, we find the number of cars per charging point in each EU country. Table 2 presents the results. The grouping is carried out by the number of events per charging point: (a) from three to six cars, (b) from six to nine cars, and (3) over nine cars. The average indicator for the EU is 7.1 cars per charging point.

Table 2. Number of environmentally friendly vehicles per charging point.

Country	Total Number of Cars with Electric or Hybrid Engines	Cars per 1 Charging Point
The Netherlands	442,639	3.1
Slovakia	7898	3.3
Cyprus	1253	3.8
Greece	12,315	3.9
Belgium	181,479	4.1
Czechia	22,452	5
Spain	150,509	5
Italy	219,576	5.3
Croatia	7058	6.6
Bulgaria	11,683	7.2
Finland	86,036	7.6
France	916,617	7.7
Slovenia	12,743	7.9
Sweden	291,834	7.9
Austria	155,589	8.3

Estonia	5797	8.5
Poland	51,865	8.5
Denmark	200,248	8.7
Lithuania	11,426	8.7
Luxemburg	23,268	10
Germany	1,412,034	11.7
Latvia	6369	11.9
Hungary	41,227	12.4
Romania	39,317	14.3
Portugal	111,006	15.2
Ireland	58,646	20.8
Malta	4364	43.2

Source: compiled by the authors based on Eurostat data [20,21].

According to the data in Table 2, in 19 countries of the European Union, the number of cars with electric and hybrid engines exceeds the European average. In several countries, the number of cars per charging point is more than twice the European average; namely, in Romania, there are 14.3 cars per charging point; in Portugal, 15.2 cars; in Ireland, 20.8 cars; and in Malta, this figure is 43.2 cars per charging point.

To build a forecast of the number of cars with environmentally friendly engines, we use the solutions of the following system of Equations (3) as the coefficients of the quadratic function, which was obtained by substituting the total values of the indicators mentioned in the explanations to (1).

$$\begin{cases} 5c + 15b + 55a = 14{,}111{,}856 \\ 15c + 55b + 225a = 53{,}735{,}607 \\ 55c + 225b + 979a = 226{,}048{,}733 \end{cases} \quad (3)$$

By solving this system of linear equations with three variables, we obtain the coefficients of function (4), with the help of which a forecast of the number of cars with environmentally friendly engines will be made by substituting the obtained coefficients into the model (1).

$$Q(Y) = 172{,}720.2Y^2 + 103{,}682.6Y + 611{,}401 \quad (4)$$

When determining the values of function (4) with argument values of 6.7 and 8, we obtain a forecast of the number of cars with environmentally friendly engines for the next three years. With a calculated number of 7.1 cars per charging point, the calculated numbers of required charging points are shown in Figure 3.

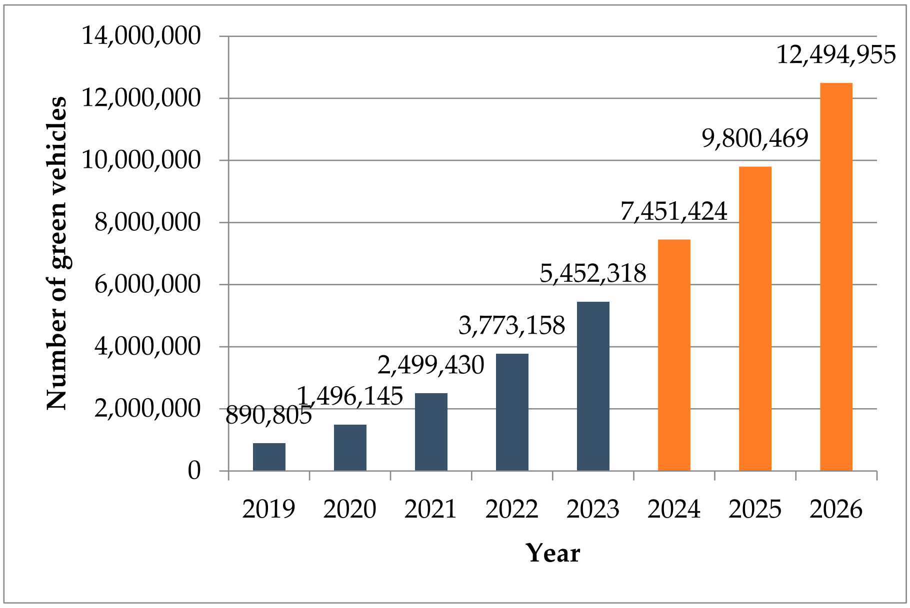

Figure 3. Forecast of changes in the number of vehicles with environmentally friendly engines and required charging points (three years) [20,21].

Table 3 presents the results of calculations of potential emission reductions and the required number of charging points for the EU. According to the results, in Europe as a whole and the countries united by the European Union, the functioning of both transports with alternative engines and the infrastructure that ensures the normal functioning of this transport segment is very heterogeneous [23–25].

Table 3. Forecast of emission reduction and required number of charging points for EU.

Year	Forecast of the Number of Eco-Friendly Vehicles	Forecast of Reduction in Harmful Emissions, t						Forecast of the Number of Required Charging Points
		CO_2	NO_x	CO	HC	Ps	Total	
2024	7,451,424	119,222,784	596,113.9	223,542.72	119,222.784	22,354.272	120,184,017.7	1,049,496
2025	9,800,469	156,807,504	784,037.5	294,014.07	156,807.504	29,401.407	158,071,764.5	1,380,348
2026	12,494,955	199,919,280	999,596.4	374,848.65	199,919.28	37,484.865	201,531,129.2	1,759,853

When studying the dynamics of the use of vehicles with electric and hybrid engines in the passenger transport sector, that is, in the passenger car sector, which is used for both personal and business purposes, a high growth rate of this segment is observed. The pan-European growth rate is 9.34 times.

Similar calculations yield the following results for each group of EU countries by the availability of charging points per 100 sq. km. The group of countries with availability of over 100 charging points per 100 sq. km consists of two countries: The Netherlands and Belgium. For this group of countries, a model of the total number of cars and trucks with environmentally friendly engines was obtained (Formula (5a,b)), and a forecast was constructed (Figure 4).

$$\begin{cases} 5c + 15b + 55a = 1{,}673{,}711 \\ 15c + 55b + 225a = 6{,}235{,}517 \\ 55c + 225b + 979a = 25{,}976{,}311 \end{cases} \quad (5a)$$

$$Q(Y) = 19{,}941.9Y^2 + 1787.3Y + 110{,}020 \quad (5b)$$

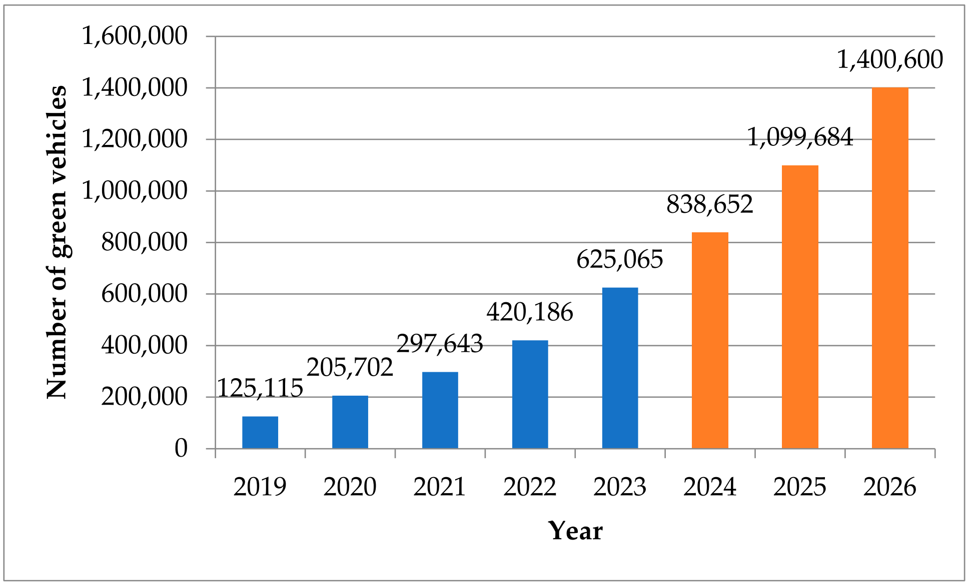

Figure 4. Number of cars and forecast of change in the number of cars with environmentally friendly engines and required charging points (for three years for a group of countries with more than 100 charging points per 100 sq. km).

Table 4 presents the results of calculations of potential emission reductions and the required number of charging points for The Netherlands and Belgium.

Table 4. Forecast of emission reduction and required number of charging points for The Netherlands and Belgium.

Year	Forecast of the Number of Eco-Friendly Vehicles	Forecast of Reduction in Harmful Emissions, t						Forecast of the Number of Required Charging Points
		CO_2	NO_x	CO	HC	Ps	Total	
2024	838,652	13,418,432	67,092.16	25,159.56	13,418.43	2515.956	13,526,618	232,959
2025	1,099,684	17,594,944	87,974.72	32,990.52	17,594.94	3299.052	17,736,803	305,468
2026	1,400,600	22,409,600	112,048	42,018	22,409.6	4201.8	22,590,277	389,056

For this group of countries, the total estimated need for charging points will be 232,959 in 2024, 305,468 in 2025, and 389,056 in 2026. The group of countries with 10 to 100 charging points per 100 sq. km consists of seven countries: Luxembourg, Denmark, Germany, Malta, Austria, France, and Italy. For this group of countries, a model of the total number of cars and trucks with environmentally friendly engines was obtained (Formula (6a,b)) and a forecast was made (Figure 5).

$$\begin{cases} 5c + 15b + 55a = 7{,}281{,}599 \\ 15c + 55b + 225a = 28{,}331{,}108 \\ 55c + 225b + 979a = 120{,}290{,}330 \end{cases} \quad (6a)$$

$$Q(Y) = 91{,}063Y^2 + 102{,}256Y + 147{,}864 \quad (6b)$$

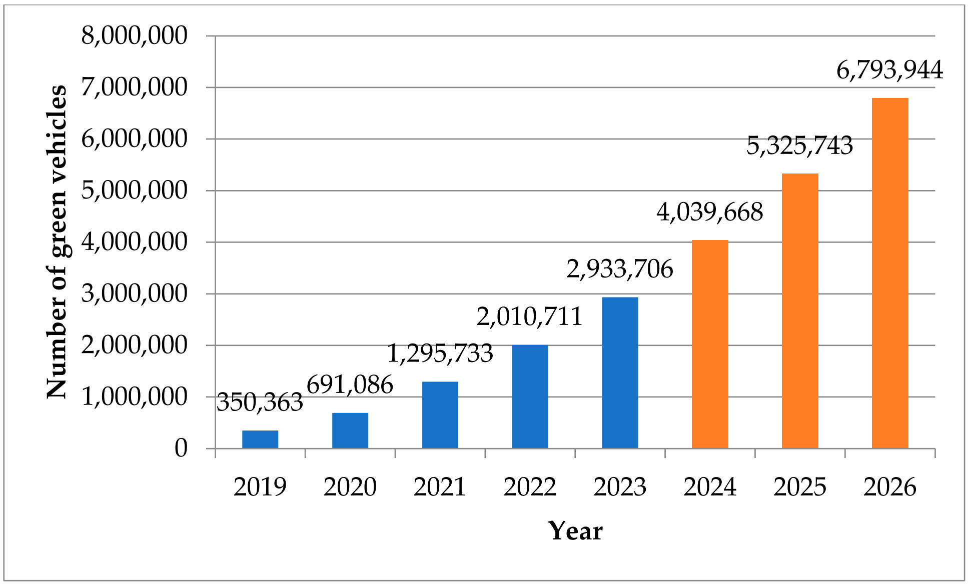

Figure 5. Number of cars and forecast of change in the number of cars with environmentally friendly engines and required charging points (for three years for a group of countries with 10–100 charging points per 100 sq. km).

Table 5 presents the results of calculations of potential emission reductions and the required number of charging points for the Luxembourg, Denmark, Germany, Malta, Austria, France, and Italy.

Table 5. Forecast of emission reduction and required number of charging points for the Luxembourg, Denmark, Germany, Malta, Austria, France, and Italy.

Year	Forecast of the Number of Eco-Friendly Vehicles	Forecast of Reduction in Harmful Emissions, t						Forecast of the Number of Required Charging Points
		CO_2	NO_x	CO	HC	Ps	Total	
2024	4,039,668	64,634,688	323,173.4	121,190	64,634.69	12,119	65,155,805.17	297,911
2025	5,325,743	85,211,888	426,059.4	159,772.3	85,211.89	15,977.23	85,898,908.85	392,754
2026	6,793,944	108,703,104	543,515.5	203,818.3	108,703.1	20,381.83	109,579,522.8	501,028

For this group of countries, the total estimated need for charging points is 297,911 in 2024, 392,754 in 2025, and 501,028 in 2026. The group of countries with 5–10 charging points per 100 sq. km consists of five countries: Sweden, Slovenia, Portugal, Spain, and the Czech Republic. For this group of countries, a model of the total number of cars and trucks with environmentally friendly engines was obtained (Formula (7a,b)) and a forecast was made (Figure 6).

$$\begin{cases} 5c + 15b + 55a = 1{,}425{,}921 \\ 15c + 55b + 225a = 5{,}537{,}573 \\ 55c + 225b + 979a = 23{,}595{,}805 \end{cases} \quad (7a)$$

$$Q(Y) = 25{,}130Y^2 - 24{,}796Y + 83{,}148 \quad (7b)$$

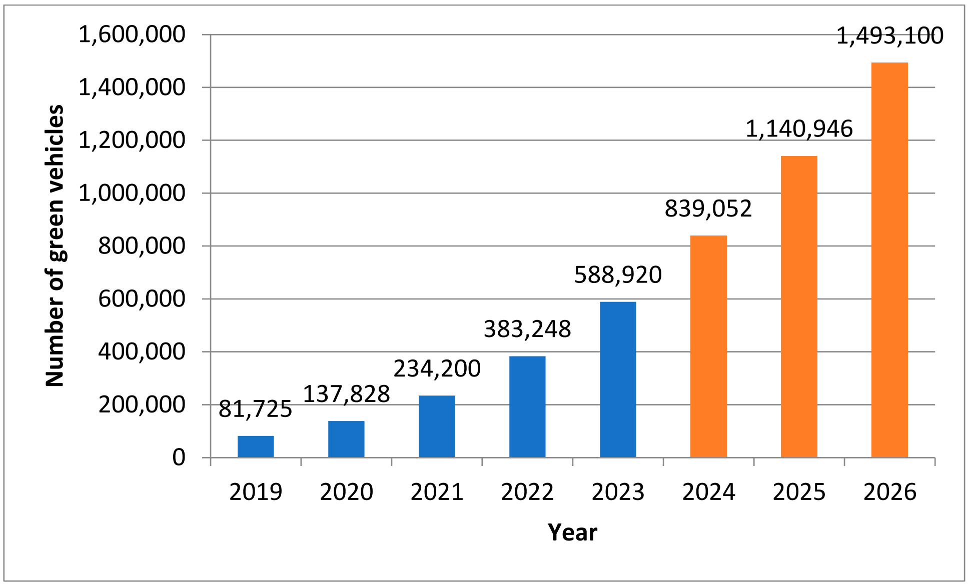

Figure 6. Number of cars and forecast of change in the number of cars with environmentally friendly engines and required charging points (for three years for a group of countries with 5–10 charging points per 100 sq. km).

Table 6 presents the results of calculations of potential emission reductions and the required number of charging points for the Sweden, Slovenia, Portugal, Spain, and the Czech Republic.

Table 6. Forecast of emission reduction and required number of charging points for the Sweden, Slovenia, Portugal, Spain, and the Czech Republic.

Year	Forecast of the Number of Eco-Friendly Vehicles	Forecast of Reduction in Harmful Emissions, t						Forecast of the Number of Required Charging Points
		CO_2	NO_x	CO	HC	Ps	Total	
2024	839,052	13,424,832	67,124.16	25,171.56	13,424.832	2517.156	13,533,070	102,323
2025	1,140,946	18,255,136	91,275.68	34,228.38	18,255.14	3422.838	18,402,318	139,140
2026	1,493,100	23,889,600	119,448	44,793	23,889.6	4479.3	24,082,210	182,085

For this group of countries, the total estimated need for charging points is 102,323 in 2024, 139,140 in 2025, and 182,085 in 2026. The group of countries with three to five charging points per 100 sq. km consists of five countries: Slovakia, Ireland, Cyprus, Hungary, and Finland. For this group of countries, a model of the total number of cars and trucks with environmentally friendly engines (Formula (8a,b)) was obtained and a forecast was made (Figure 7).

$$\begin{cases} 5c + 15b + 55a = 461{,}446 \\ 15c + 55b + 225a = 1{,}844{,}340 \\ 55c + 225b + 979a = 7{,}991{,}168 \end{cases} \quad (8a)$$

$$Q(Y) = 11{,}089Y^2 - 20{,}536Y + 31{,}914 \quad (8b)$$

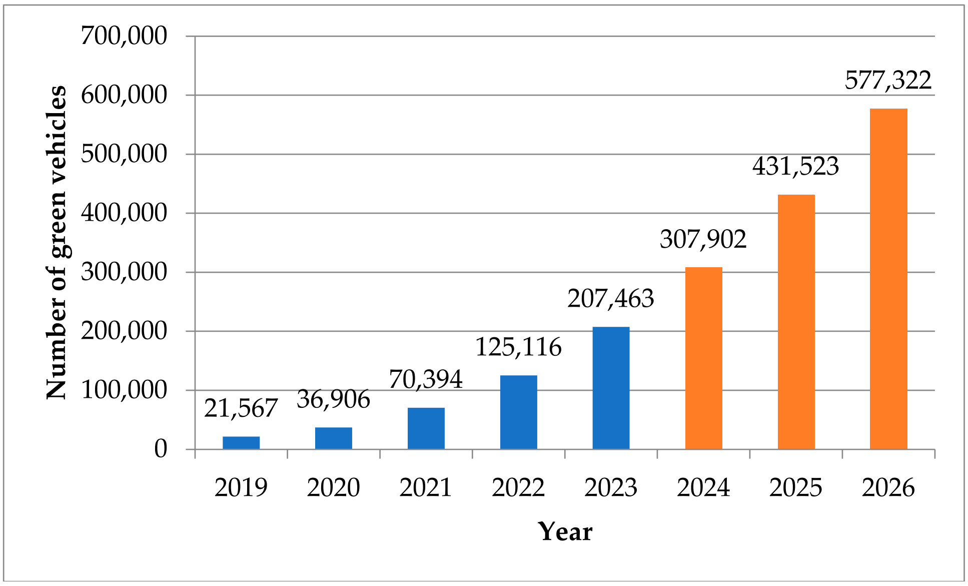

Figure 7. Number of cars and forecast of change in the number of cars with environmentally friendly engines and required charging points (for three years for a group of countries with 3–5 charging points per 100 sq. km).

Table 7 presents the results of calculations of potential emission reductions and the required number of charging points for the Slovakia, Ireland, Cyprus, Hungary, and Finland.

Table 7. Forecast of emission reduction and required number of charging points for the Slovakia, Ireland, Cyprus, Hungary, and Finland.

Year	Forecast of the Number of Eco-Friendly Vehicles	Forecast of Reduction in Harmful Emissions, t						Forecast of the Number of Required Charging Points
		CO_2	NO_x	CO	HC	Ps	Total	
2024	307,902	4,926,432	24,632.16	9237.06	4926.432	923.706	4,966,151	35,678

2025	431,523	6,904,368	34,521.84	12,945.69	6904.368	1294.569	6,960,034	50,003
2026	577,322	9,237,152	46,185.76	17,319.66	9237.152	1731.966	9,311,627	66,897

For this group of countries, the estimated need for charging points is 35,678 in 2024, 50,003 in 2025, and 66,897 in 2026. The group of countries with 0–3 charging points per 100 sq. km consists of six countries: Poland, Lithuania, Croatia, Bulgaria, Estonia, and Romania. For this group of countries, a model of the total number of cars and trucks with environmentally friendly engines (Formula (9a,b)) was obtained, and a forecast was made (Figure 8).

$$\begin{cases} 5c + 15b + 55a = 302{,}518 \\ 15c + 55b + 225a = 1{,}202{,}306 \\ 55c + 225b + 979a = 5{,}191{,}934 \end{cases} \quad (9a)$$

$$Q(Y) = 6837Y^2 - 11{,}549Y + 19{,}940 \quad (9b)$$

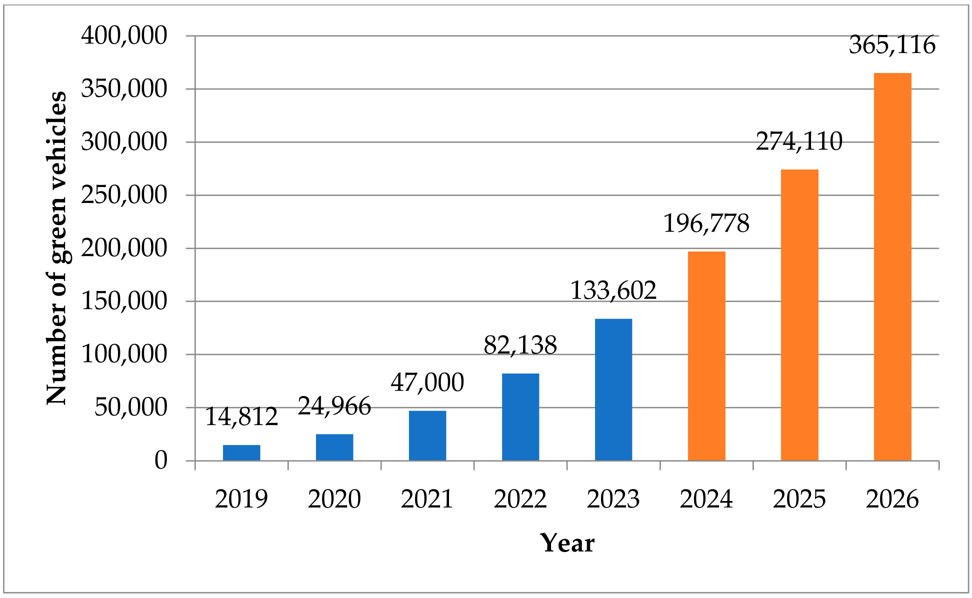

Figure 8. Number of cars and forecast of change in the number of cars with environmentally friendly engines and required charging points (for three years for a group of countries with 0–3 charging points per 100 sq. km).

Table 8 presents the results of calculations of potential emission reductions and the required number of charging points for the Poland, Lithuania, Croatia, Bulgaria, Estonia, and Romania.

Table 8. Forecast of emission reduction and required number of charging points for the Poland, Lithuania, Croatia, Bulgaria, Estonia, and Romania.

Year	Forecast of the Number of Eco-Friendly Vehicles	Forecast of Reduction in Harmful Emissions, t						Forecast of the Number of Required Charging Points
		CO_2	NO_x	CO	HC	Ps	Total	
2024	196,778	3,148,448	15,742.24	5903.34	3148.448	590.334	3,173,832	20,956
2025	274,110	4,385,760	21,928.8	8223.3	4385.76	822.33	4,421,120	29,192
2026	365,116	5,841,856	29,209.28	10,953.48	5841.856	1095.348	5,888,956	38,883

For this group of countries, the total estimated need for charging points is 20,956 in 2024, 29,192 in 2025 and 38,883 in 2026. According to the calculations obtained, significant investments are needed to expand the infrastructure to provide charging points for vehicles with environmentally friendly engines.

4.3. Exploring Best Practices to Improve Green Vehicle Infrastructure

When considering the practices of various countries in the system of stimulating the development of infrastructure for the operation of transport with environmentally friendly engines, it is revealed that each country is working on developing a unique approach to solving the issue of forming an effective network of charging points. When solving this problem, states consider their economic, geographical, and social characteristics. In The Netherlands, the state actively encourages municipalities' participation in installing charging points, and the state focuses on installing fast charging points and compatibility with international standards.

In addition to working with municipalities, the Dutch government introduced financial benefits for car owners. It offered free installation of charging points near the place of sale for owners of cars with environmentally friendly engines.

The government of Germany provides significant subsidies for the creation of charging stations, and financial support is provided to municipalities and business representatives. Analysis of the dynamics of change in the number of passenger cars with electric and hybrid engines in Germany is fascinating, where the number of passenger cars with electric and hybrid engines has increased 17 times. The percentage of the total number of cars with environmentally friendly engines in Europe has increased from 14.4% to 25.9%. At the same time, the number of trucks with environmentally friendly engines has increased 2.8 times from 2019 to 2022. These trucks make up 0.6% of the total number of trucks in Germany, but the trend is positive. However, considering the availability of charging points, Germany is not a country with a well-developed infrastructure in this area since there are 33.7 charging points per 100 sq. km, and there are currently 11.7 cars per point. The German government has developed and is implementing a program to construct high-speed charging stations (the Deutschlandnetz program). Citizens in Germany are offered subsidies for the purchase of electric vehicles and tax discounts for owners of environmentally friendly vehicles. Figure 9 shows an example of a charging point in Germany.

Figure 9. Example of a charging point in Germany.

The French government is also considering the need to improve the infrastructure of charging points, for which it has adopted the program "100,000 charging points" by 2025. This program focuses on the equal distribution of charging points in urban and rural areas, prioritizing developing charging points in public places, including shopping centers and parking lots. However, France mainly uses slow and fast charging and less attention is paid to high-speed charging.

The main incentives in France are tax deductions for charging point users and grants for apartment buildings to install charging points.

However, some disproportions were evident in the growth of passenger vehicles over the observation period. The lowest growth was observed in Norway, which had 33.8% of all European transport with electric and hybrid engines at the beginning of the study period [20–23]. Despite the climate, Norway is a leader in the use of electric vehicles. This result was achieved by introducing high tax rates on the use of cars with gasoline and diesel engines, the proceeds of which were used to create an infrastructure of charging points for electric vehicles. Since charging points are primarily of the fast type in Norway, this facilitates the use of electric transport. Another achievement of Norway is using renewable energy sources to ensure charging point operation. For owners of electric vehicles, there are such financial incentives as free parking, exemption from tolls on toll roads, and exemption from value-added tax when buying electric vehicles. However, the government's policy of creating public demand for environmentally friendly cars, coupled with a significant expansion of the charging point network, has led to a 3.5-fold increase in the number of cars, which is the lowest result in the group of countries studied but a good result of 12.7% of the total number of environmentally friendly cars in Europe. In freight transport, Norway strives to increase the number of vehicles with electric and hybrid engines.

Only 451 of the 68,538 trucks in Norway were equipped with electric or hybrid engines. However, given that this number has increased 25-fold from 2019 to 2022, there is a significant growth rate. Although Norway is not a member of the European Union, it adheres to a clean environmental policy. It has a good experience in implementing clean technologies, such as clean electricity and transportation.

The goal of the UK government policy is to entirely switch to electric vehicles by 2030, for which funds are allocated for creating charging points, among which the prerogative is given to fast charging points in residential and remote areas. The UK government is actively working on programs to create charging points depending on renewable energy facilities, and with the help of grants, encourages the population to install home charging points.

Countries strive to maximize the use of green energy in charging electric vehicles, which sometimes determines the location of charging points [26–28]. Many countries stimulate the participation of private investment in the creation of infrastructure facilities with built-in charging points. The few previously created charging points with non-standard ports are being transferred to a single charging port standard. All countries generally strive for the environmental friendliness of new infrastructure facilities, the standardization of ports, and support for electric transport users [29–31].

5. Discussion

The results obtained during this study allow us to estimate the near-term prospects for the need to create additional vehicle charging points [32,33]. Previous studies did not consider annual forecasts for the total number of environmentally friendly vehicles, which did not provide a common information base for forming forecasts regarding the need to develop charging point infrastructure [34,35].

There are apparent disproportions between the growth in the number of potential consumers of charging-point services and their actual number. When considering a group of countries where the number of passenger cars with electric and hybrid engines has increased by 20 times or more, the following conclusions can be drawn: in Denmark, the number of passenger cars with more environmentally friendly engines increased 20 times between 2018 and 2022, while the number of trucks with the same engines increased from 9 to 139.

Denmark's total number of trucks is 27,623, with trucks with more environmentally friendly engines accounting for 0.5%. However, the Danish government has found a way to influence electricity producers, which has led to qualitative changes in the infrastructure servicing the operation of cars with electric motors. Denmark currently has 53.7 charging points per 100 square kilometers of territory, the fourth best result in the EU. There are 8.7 vehicles with electric or hybrid engines per charging point and therefore, Denmark still needs infrastructural improvements.

There are also some European countries outside of the European Union where the number of passenger cars with electric or hybrid engines has increased sharply between 2018 and 2022, including Bosnia and Herzegovina (22.1 times), Moldova (25.5 times), and Albania (28.3 times). No electric or hybrid trucks are registered in these countries. The charging-point network in these countries is considered differently than in the EU. These countries have charging stations, often located within pan-European retail networks and separate charging points at various business infrastructure facilities.

However, there are no government programs to streamline the transport infrastructure facilities to ensure the functioning of environmentally friendly transport

[30–32]. In Finland, the number of passenger cars with electric and hybrid engines increased 34.4 times from 2018 to 2022, while the number of trucks with the same engines increased from 2 to 25, which amounted to 0.01% of the total number of trucks. Finland is characterized by a very low density of charging points (3.3 per 100 km^2) and a high occupancy rate of these points (7.6 cars per point).

Given the current growth rate of vehicles with electric and hybrid engines, Finland may soon face problems due to insufficient infrastructure support for operating vehicles with environmentally friendly engines. Similar problems can arise in Romania and Greece. In Romania, the number of passenger cars with electric and hybrid engines increased by 34.4 times between 2018 and 2022, while the number of trucks with the same engines remained unchanged at 46, corresponding to 0.03% of the total number of trucks. Romania ranks 25th out of 27 EU countries in terms of the number of charging points (1.2 per 100 sq. km) and 23rd in car accessibility (1 point per 14.7 cars). In Greece, the number of passenger cars with environmentally friendly engines increased by 57.3 times between 2018 and 2022; however, there was no single truck with such an engine.

In Greece, there are 2.4 charging points per 100 square kilometers, and 3.9 cars per charging point, which is not surprising since there are currently only 12,315 such cars in Greece.

It should be noted that the Greek authorities need to show interest in supporting innovation in the transport sector to reduce harmful emissions, which is reflected in the current state of affairs in this sector. Turkey has become the leader in the increase in the number of cars with electric and hybrid engines, and from 2018 to 2022, the number of such cars has increased by 84.1 times, from 952 to 80,043. However, only one truck with an environmentally friendly engine has been registered in Turkey. This means that large-scale infrastructure support is required to introduce electric and hybrid engines into truck fleets.

According to the forecast, in 2024, the number of vehicles with eco-friendly engines will be 7,451,424, and servicing them will require 1,049,496 charging points, which means an additional need for 417,273 charging points compared to 2023. For 2025, the predicted number of vehicles is 9,800,469, which will require 1,380,348 charging points, an additional 748,123 charging points compared to 2023. For 2026, the estimated number of vehicles will be 12,494,955, which will require 1,759,853 charging points and a record number of 1,127,630. Significant changes (2.78 times) are required to service vehicles with eco-friendly engines.

The following results were obtained when performing similar calculations for groups of countries with different numbers of charging points per 100 square kilometers of area. For a group of countries with more than 100 charging points per 100 square kilometers of area with an average of 3.6 cars per 1 charging point, it is necessary to increase the number of charging points by 44,143 in 2024, by 116,652 in 2025, by 200,240 in 2026 from the number in 2023.

There are enough points for a group of countries with the number of charging points per 100 square kilometers of area from 10 to 100 with an average of 13.6 cars per 1 charging point in 2024. However, increasing the number of charging points by 67,627 in 2025 and 175,901 in 2026 from 2023 is necessary. Reducing the number of cars per 1 charging point is necessary for more comfortable use of infrastructure facilities.

For a group of countries with 5–10 charging points per 100 square kilometers of the area with an average number of cars per 1 charging point of 8.2, it is necessary to increase the number of charging points by 21,394 in 2024, by 58,211 in 2025, by 101,156 in 2026 compared to the 2023 figure. For a group of countries with 3–5 charging points per 100 sq. km of area with an average number of cars per 1 charging point of 8.6, it is necessary to increase the number of charging points by 12,412 in 2024, by 26,737 in 2025, by 43,631 in

2026 compared to the 2023 figure. For a group of countries with 0–3 charging points per 100 sq. km of area with an average number of cars per 1 charging point of 9.4, it is necessary to increase the number of charging points in 2024 by 6,871, in 2025 by 15,107, in 2026 by 24,798 compared to the 2023 figure.

This study considered some limitations related to the quality of the initial data. Since the analysis used data provided by countries independently at the end of the year, the intra-annual dynamics of changes in the number of environmentally friendly vehicles were not taken into account, and the features of the intra-annual dynamics of changes in the number of charging points were also not taken into account.

Further development of this research may involve obtaining specific forecasts of the number of green transport vehicles and the required charging points for individual countries or regions of countries, both in the EU and beyond [36].

6. Conclusions

Since there is currently an evident disproportion between passenger cars and trucks with electric and hybrid engines, there is a need for more infrastructure support for freight transport, motivating owners of such vehicles to switch to more environmentally friendly technologies. The emerging disproportion between the growth of passenger cars (9.4 times growth) and trucks (2 times growth) with electric and hybrid engines is a consequence of the inadequacy of technological solutions offered for trucks and the complete absence of transport infrastructure elements that support the functioning of existing technological solutions in some European territories. Having studied the density of charging points, it was found that 73% of the territory of the European Union has a below-average coverage of charging points, which creates specific difficulties in using electric and hybrid engines in trucks. The significant total increase in passenger cars and trucks with electric and hybrid engines (6.12 times from 2019 to 2023) motivates the formation of an adaptive infrastructure that can be used equally by both passenger and truck drivers. In addition, there is currently no system for reserving places at charging points, which affects the choice of truck owners to refuse to use environmentally friendly engines. Since trucks carry out commercial transportation and drivers currently do not have the opportunity to plan their car charging, this leads to weak interest in developing environmentally friendly freight transport. Currently, there are infrastructural problems in switching trucks to more environmentally friendly fuel types.

The main recommendations for expanding the infrastructure to ensure the operation of environmentally friendly vehicles are the formation of a single worldwide network of charging points; standardization of ports at charging points; development of standards for the density of coverage of the territory by charging points; stimulation of owners of freight transport to switch to environmentally friendly vehicles; and activation of the involvement of owners of industrial and commercial infrastructure facilities in expanding charging point infrastructure.

The presented analysis of successful practices of countries in developing infrastructure that ensures the functioning of environmentally friendly vehicles indicates the decisive role of governments in stimulating the use of environmentally friendly transport and providing its free functioning throughout the country, regardless of the population level and the nature of the accessibility of the territories. The presence of incentives from the state and a conscious attitude of the population and managers of transport companies to the issue of switching to environmentally friendly transport will significantly reduce emissions of harmful substances into the atmosphere. According to the calculated forecast, annual emissions into the atmosphere from all EU countries will decrease by 120 million tons in 2024, 160 million tons in 2025, and more than 200 million tons in 2026. Thus, a set of measures to switch to environmentally friendly transport, consisting of stimulating the use of environmentally friendly vehicles and timely widespread development of charging point infrastructure with an emphasis on renewable energy, will allow for a colossal reduction in the harmful impact on the environment.

Author Contributions: Conceptualization, V.K.; methodology, V.K. and I.H.; software, I.H. and S.Đ.; validation, I.H. and S.Đ.; formal analysis, N.S. and S.Đ.; investigation, N.S. and Đ.P.; resources, N.S.; data curation, I.H.; writing—original draft preparation, V.K.; writing—review and editing, N.S. and Đ.P.; visualization, I.H. and Đ.P.; supervision, V.K.; project administration, V.K. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: All data used in the study are taken from Eurostat sources; the list of sources used provides links to the data used.

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

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