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Tenerife's Infrastructure Plan for Electromobility: A MATSim Evaluation

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Abstract: According to the Canarian government's plans, a complete decarbonization of the Canary Islands economy is foreseen from 2040 onwards, which includes the electrification of land transport in the archipelago. However, due to the current low penetration rate of electric vehicles (EVs) on the islands, the number of EVs in circulation is expected to grow significantly in the coming years. Despite this, the network of charging points in Tenerife is currently totally insufficient, which is why it is essential to carry out a study to design the network of charging points in such a way that it can absorb the entire fleet of EVs that is expected to be in place by 2040. To this end, there are studies on the capacity, in terms of parking space, available for the installation of these charging points, but to date there are no studies on this subject supported by mobility data. For this reason, a simulation of traffic in Tenerife in 2040 has been carried out using MATSim (Multi-Agent Transport Simulation) to determine the ideal places to install these charging points and to find the number of charging points needed for the network.

Keywords: electromobility; MATSim; electric vehicles; charging points; Tenerife

Citation: Rojano-Padrón, A.; Metais, M.O.; Ramos-Real, F.J.; Perez, Y. Tenerife's Infrastructure Plan for Electromobility: A MATSim Evaluation. *Energies* **2023**, *16*, 1178. https://doi.org/10.3390/en16031178

Academic Editor: Alberto Reatti

Received: 15 December 2022
Revised: 4 January 2023
Accepted: 17 January 2023
Published: 20 January 2023

1. Introduction

Faced with the challenge posed by the current climate emergency, it is essential to accelerate the so-called energy transition to mitigate the harmful effects on the planet caused by the increase in greenhouse gas emissions in its atmosphere over the last few decades [1]. One of the main pillars of this transition is the decarbonization of the economy, which includes the electrification of the transport sector, accompanied by a commitment to the generation of energy from 100% renewable sources.

In order to carry out this electrification of transport, the Spanish Government has committed in its Climate Change and Energy Transition Law (LCCTE) [2] to the complete decarbonization of the transport sector throughout the national territory by 2050, following the Communication of the European Green Pact of December 2019 [3]. This pact establishes a new growth strategy that aims to transform the economy of the European Union in a competitive and efficient way in the use of its resources, with the aim of achieving climate neutrality in the continent by that year. It is in this context that this national legislation is framed, which in turn contemplates the development of regulations and laws at the regional level, such as the Preliminary Draft Bill of the Canary Islands Climate Change and Energy Transition Law approved by the Canary Islands Government in November 2021 [4]. This bill sets the complete decarbonization of the economy of the archipelago for 2040, i.e., ten years earlier than in the rest of the national territory. In line with this draft bill, a series of energy planning instruments are included in the Canary Islands Energy Transition Plan 2030 (PTECan) [5], which establishes the main strategies to be followed in energy matters in the Canary Islands.

Against this background and anticipating the growing market demand for electric vehicles (EVs), which according to government plans will replace current internal combustion vehicles (ICEs) by 2040, it is essential to design a network of charging points capable of supporting the technical viability of the transport sector in the future.

To design such a network, it must be considered that there are different types of electric vehicle charging points, with different charging power. It will therefore be necessary to dimension the charging infrastructure and power networks according to the maximum power that will be required during a given period. For practical purposes, electric vehicles are seen by the electricity grid as batteries that demand a certain amount of energy, assuming a charging power that is established according to the type of connector to which it is plugged in with slow charging normally at 3.7 kW, semi-fast charging at 11–22 kW, and fast charging at 40–80 kW. Thus, in order to charge an electric vehicle battery, slow charging requires a continuous flow of energy between the vehicle and the power grid of 5–7 h, semi-fast charging of 2–4 h and fast charging of less than 30 min [6].

In addition to being classified by charging speed, charging infrastructures could also be differentiated according to the point at which the system is installed, with the following three possibilities:

- Origin: Located at the starting point of the trip, these are usually slow charging systems located in the garages of private homes or community buildings.
- Destination: Located at the end point of the trip, these are also usually slow charging systems, located in workplace parking lots.
- In itinerant: These are semi-fast or fast charging systems located in shopping centers, public roads, or parking lots. This group also includes the so-called charging stations, which always consist of fast charging systems.

Due to the relationship between the speed of charging systems and their location, it will be necessary to consider that the nature of vehicle travel will condition the type of charging system to be installed at each site. By elaborating our study, based on open-source software, we will provide a new approach to the need for infrastructure deployment based on mobility needs and compare it with the actual methodology used by the local government. By doing so, we will provide a counter evaluation of the needs and show the limit of the current policy analytical frame.

Given the absence of studies to date based on the analysis of existing traffic for the design of a network of charging points, this study aims to provide a clear methodology for that purpose, so that charging points are not placed randomly but according to mobility criteria, achieving an optimized network. In this way, users will not have to change their usual behavior to charge their vehicles, but rather the charging points will be strategically located where they are best suited to their needs. This methodology will be developed in this paper, which is structured as follows.

First, the current status and potential of the electrification of land transport in the case study, Tenerife (Spain), will be analyzed. In addition, the main strategies proposed by the Government of the Canary Islands to achieve the goal of a complete electrification of the vehicle fleet will be examined.

Subsequently, the principles on which the transport simulation software used for the development of this methodology, MATSim, is based will be detailed. The Supplementary Materials will also explain in more detail the procedure followed to carry out the simulation.

Finally, the results obtained will be presented, which include both an analysis of the geographical distribution of charging points for a specific configuration of the software parameters, in order to check the feasibility of the methodology used, and a comparison between two case studies, one with progressive electric vehicle penetration quotas and the other with non-progressive quotas.

2. Analysis of EVs Potential in Tenerife

Given the scenario presented, in which a large increase in the volume of EVs in circulation in Tenerife is foreseen, it is essential to design the charging infrastructure that will support this future transport network on the island. The study carried out by the Canary Islands Technological Institute (ITC), which depends on the Canary Islands Government, has been taken as a reference, setting out the main strategies to be followed in terms of EVs with the aim of achieving the complete decarbonization of land transport in the archipelago by 2040 [6]. This study, which is part of the PTECan 2030 [5], will allow a comparative analysis between the plans proposed by the Government of the Canary Islands and the results obtained by our study.

2.1. Case Study

The island of Tenerife, located in the Atlantic Ocean in southwestern Spain, 330 km from the coast of Morocco and with coordinates 28°28′ N, 16°15′ W, had a population of 927,993 inhabitants in 2021 [7]. This population is distributed dispersed mainly along the coastline of the island, as can be seen in Figure 1. The main areas with the highest concentration of population are the metropolitan area formed by Santa Cruz de Tenerife and San Cristóbal de La Laguna located to the northeast and the Orotava Valley located to the north and the southwest of the island, where most tourist activity is concentrated.

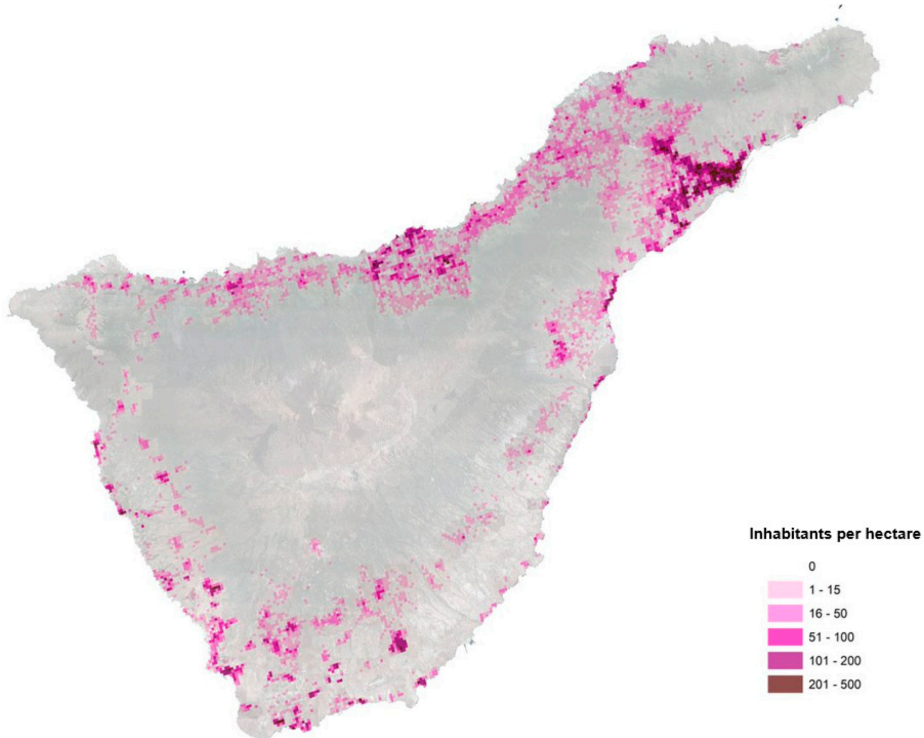

Figure 1. Distribution of the population on the island of Tenerife.

At present, with the latest available data for 2019, Tenerife's vehicle fleet is dominated by gasoline ICE (internal combustion engine) vehicles (67.18%) and, to a lesser extent, diesel (32.57%). EVs are relegated to a third position with only 7827 units out of a total of 751,702, which implies a penetration rate of 1.04%, and surpassing only the group of LPG (liquefied petroleum gas) vehicles [8], which barely account for 0.11% of the total [9]. It should be noted that considering the population of the island and the total number of vehicles, the rate of vehicles per inhabitant for that year was 0.828, which is considerably higher than the average for Spain.

These figures, together with the goal of complete electrification of the vehicle fleet by 2040, highlight the foreseeable large increase in the number of EVs in circulation on the island in the coming years, with the consequent need for planning and construction of charging points to meet this increase in EV demand, which has yet to be realized.

It should be noted that, given the insular nature of the case study, the implementation of such a network, with the consequent increase in energy demand that will be associated with it, may pose a great challenge, not only for the case of Tenerife, but for the whole of the Canary Islands in general. However, this fragmentation of the territory should not be seen as an added disadvantage, but as a window of opportunity in which the massive implementation of EVs, together with intelligent mechanisms for demand control, energy generation, and storage, can help to provide the electric grid with greater flexibility, reliability, and compensate for the current weaknesses associated with the isolation of its electric systems, both among themselves and from the rest of the national territory [10]. Furthermore, under this scenario, the Canary Islands could become a test bench which, if successful, could export this energy model of sustainable mobility to any continental region of Europe [11].

2.2. Impact of Transport Electrification on Electricity Generation

The complete electrification of the transport sector in Tenerife will lead to an increase in the demand for electricity. Specifically, it has been estimated that, for the year of complete electrification, 2040, the increase in this demand will be 2510 GWh/year, which, considering that current electricity consumption on the island is 3514 GWh/year, represents an increase in demand of 71.2%, as can be seen in Figure 2 [6]. However, this increase in electricity demand should not be considered as a negative point, since the final impact will mainly depend on the type of management carried out with the massive entry of EVs in Tenerife [12].

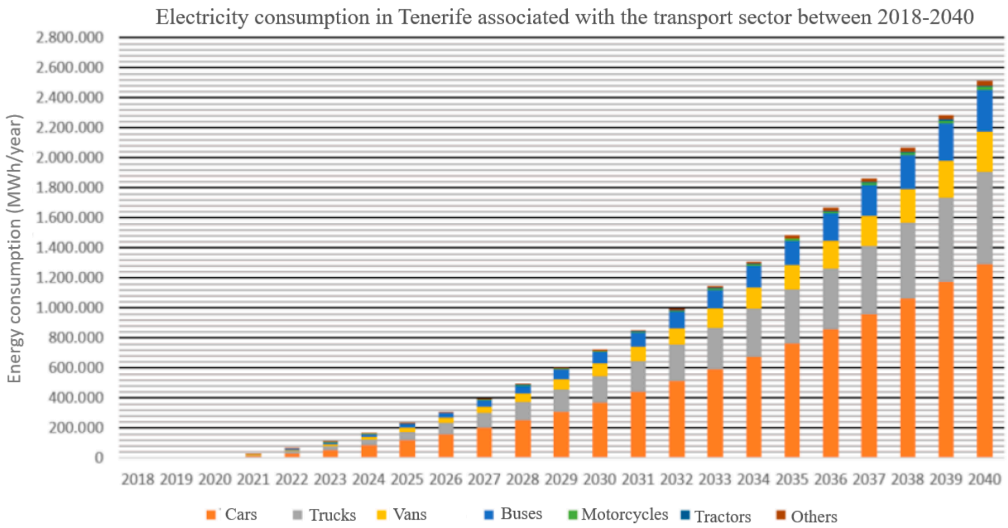

Figure 2. Electricity consumption increase in Tenerife associated with the transport sector between 2018–2040 [6].

Therefore, in addition to supplying this increase with non-manageable energy, mainly wind and photovoltaic energy, it would be desirable to apply an autonomous energy management system which, considering the state of charge of the vehicle's battery and the signal generated by the electricity system, and according to energy predictions, prioritizes EV charging at times when it is faced with a scenario of the greatest possible amount of renewable energy [13]. If this management system is also combined with the use of V2G technology, in which EVs go from being mere loads for the system to also becoming electricity suppliers during peak demand hours [14], V2G would provide the electricity system with a great capacity for manageability, helping to flatten the demand curve and therefore optimizing the energy production system. Additional benefits are also expected by reducing the storage capacity required and minimizing renewable energy curtailments [15].

It is therefore advisable that the charging points to be installed are, whenever possible, slow charging points, as these are the ones that allow the system to be more manageable for the reasons mentioned above [16].

On the other hand, in view of the increase in demand [17], the transmission, and distribution networks as well as the generation on the island will have to be repowered. To this end, and according to the estimates made by the Instituto Tecnológico de Canarias S.A. (hereafter ITC) using the ISLA (Insular Energy System Long-term Assessment tool) optimization model, the necessary renewable power equivalent to 1600 MW has been obtained, in addition to a storage capacity of approximately 600 MW/15,000 MWh. Such a system would produce annually approximately 3554 GWh, of which 1084 GWh could not be consumed, since despite taking into account the improvements with smart grids mentioned above, this surplus would be required to ensure the demand for EVs even at the worst possible time, i.e., when the available resource is minimal [18]. However, this surplus energy should not be considered as a waste as it could be absorbed by the system for other uses, such as the production of hydrogen by electrolysis, which in turn could be used in a complementary way in land vehicles or maritime transport.

Finally, also according to the forecasts of the ITC, it should be noted that the complete electrification of the land transport system in Tenerife, under the scenario in which this electrification is supported entirely by renewable energies, would mean an annual saving in pollutant emissions into the atmosphere of 674,915 kt of CO_2 eq. Figure 3 shows a pie chart of the reduction of CO_2 emissions to the atmosphere by type of vehicle.

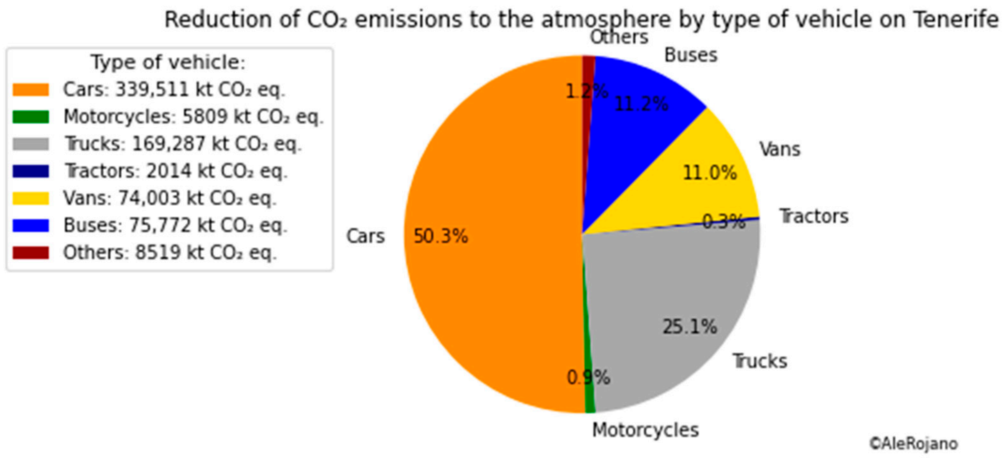

Figure 3. Reduction of CO_2 emissions to the atmosphere by type of vehicle.

2.3. Analysis of the Strategies and Policies on EVs of the Canary Islands Government

As mentioned, the starting point was the ITC study on the strategy to be followed for the electrification of land transport in the Canary Islands, the main objective of which was to calculate the number of EV charging points of each type to be installed on all the islands. In our study, we have focused on the case of Tenerife, so that after obtaining our own results, a comparative analysis can be made between the latter and those of the ITC study. The main steps followed by this study to arrive at the desired result will be detailed below.

Firstly, the total number of vehicles in circulation in Tenerife in the year 2040 was estimated. To do this, the latest data available at the time of the study were used, which are from 2019, with a total of 751,702 vehicles on the island. Subsequently, a multivariate regression model was applied to describe the relationship between a series of socioeconomic variables and the vehicle fleet, to estimate the vehicle fleet in 2040. Specifically, the historical evolution of the population and the gross domestic product (GDP) were used as variables, and the machine learning technique known as random forest was applied to find patterns between the evolution of these variables that can be used to estimate the vehicle fleet [6]. Figure 4 shows the data of the evolution of the population of Tenerife until 2020 and the projections of the same until the year 2050. Figure 5 shows the same data, but for the case of the GDP. Both graphs have been prepared using data from the ITC study.

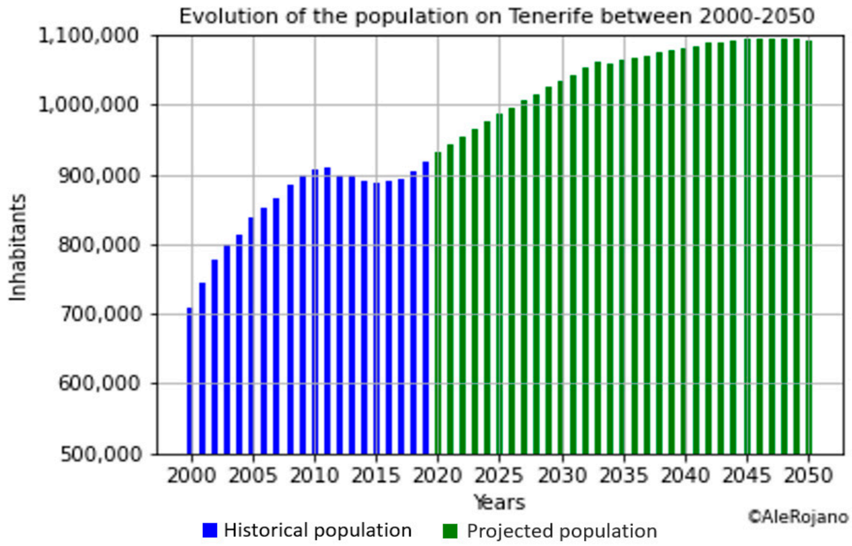

Figure 4. Evolution and projections of the population on the island of Tenerife between 2000–2050.

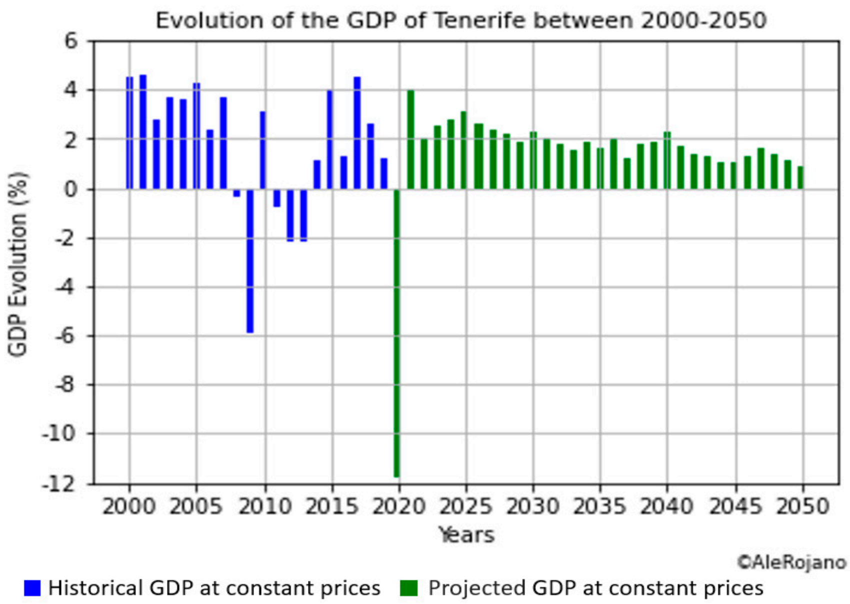

Figure 5. Evolution and projections of GDP on the island of Tenerife between 2000–2050.

Finally, to evaluate the correlation, a linear correlation analysis was carried out using Pearson's method, obtaining a correlation between population and GDP with the vehicle fleet of more than 70% in both cases. Figure 6 shows the data obtained on the estimation of the car fleet in Tenerife up to 2050, giving a total of 693,439 vehicles in the year 2040, in which the simulations will be carried out. It will be assumed, given the regulations, that the totality of this fleet corresponds to EVs.

Once the fleet of electric vehicles had been estimated, the number of charging points required for this volume of vehicles was calculated. To do this, we used the information available from the Dirección General de Catastro del Ministerio de Hacienda [19] relating to data on buildings, plots, and infrastructure. On the other hand, data collected by the Instituto Geográfico Nacional (IGN) [20] and published in the Spanish Land Occupancy Information System (SIOSE) [21], related to service stations in Tenerife, as well as access to the entire road network of the island and parking areas in buildings and above ground, were also used.

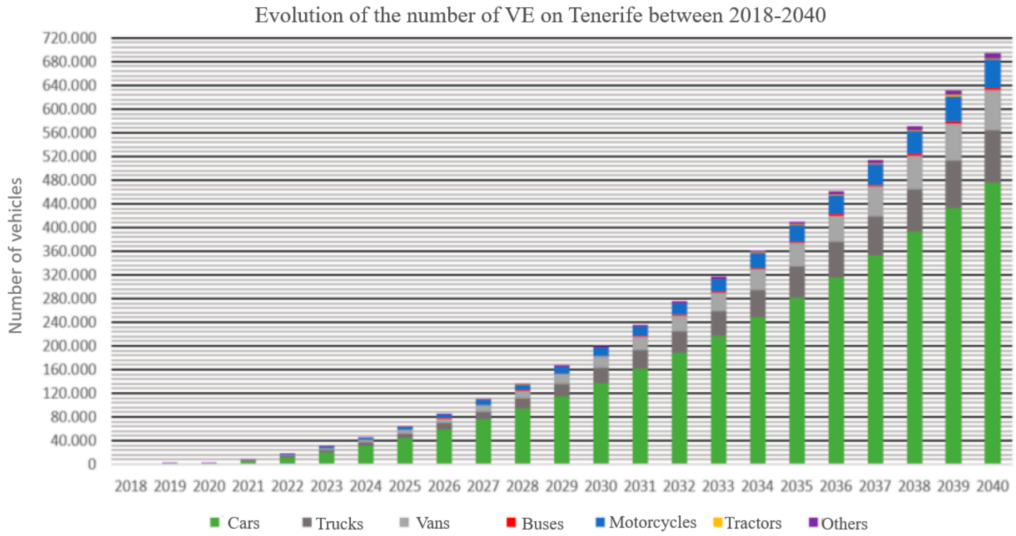

Figure 6. Evolution of the electric car fleet on the island of Tenerife between 2018–2040 [6].

In the case of private buildings, whether residential, commercial, or workplace, the number of parking spaces available was estimated based on data obtained from the DGC and occupancy rates, which were determined by means of telephone surveys in the case of residential buildings and via web-based information in the case of commercial buildings. A total of 252,873 parking spaces were made available in homes (charging systems at source) and 108,800 in shops, hotels, and workplaces (charging systems at destination), which will be used as far as possible as slow charging points, covering 52.16% of Tenerife's total vehicle fleet in 2040.

Subsequently, it was checked that the parking capacity on urban and conventional roads was sufficient to cover the remaining demand corresponding to 47.84%, which would use the "in itinerant" charging system. In this case, priority would also be given to slow charging systems, although it is foreseeable that in this group of charging points a higher proportion of semi-fast charging points, and even fast charging points in some cases, would be necessary. The total capacity of these roads was found to be 1,626,103 charging points, which is more than sufficient for the unmet demand of 331,766 vehicles.

Finally, the study carried out by the ITC also includes an additional analysis of the current service stations as a complement to the network, as these will provide a network of fast charging points that will support the network in the event of possible contingencies. Specifically, a total of 205 stations were counted in Tenerife, which would provide the system with 4315 fast charging points, considering that the surface area of the stations for this use accounts for approximately 40% of the total. This figure is considered sufficient to ensure that the support provided to the network is of sufficient quality to deal with the contingencies mentioned above.

3. Software Preparation

After the analysis of the study explained in the previous section, we proceeded to the correct configuration of the simulation software, MATSim (Multi-Agent Transport Simulation), and the subsequent launching of its simulation to obtain the expected results. This section will describe the fundamentals of this software, as well as the process necessary for its preparation before proceeding to perform the relevant simulations. This procedure will be further detailed in the Supplementary Materials part.

3.1. MATSim Fundamentals

MATSim is an open-source multi-agent simulation framework implemented in Java language. It is based on the principle of coevolution, i.e., each agent (vehicle in our case) repeatedly optimizes their daily activity schedule while competing for the same time slots with all other agents in the transportation infrastructure [22]. Each MATSim run contains a configurable number of iterations consisting of the following stages summarized in Figure 7.

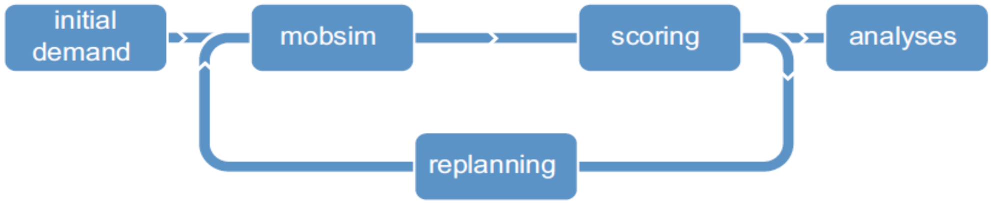

Figure 7. Evolution of the electric car fleet on the island of Tenerife between 2018–2040.

On the one hand, the initial demand comes from the population's daily activity chains. The people modelled are called agents, who have daily plans, where in turn each plan is composed of a daily activity chain and a score associated with that activity, known as an econometric utility function. On the other hand, there is the mobility simulation itself, known as Mobsim. This stage consists mainly in that, in each iteration, each agent selects a plan from its memory according to the scores assigned to each plan, which are calculated in each mobsim run. Finally, the replanning module produces the modifications of the plans, with the objective of finding the optimal option. For this, MATSim considers four characteristic parameters of the simulation: the departure time, the planned route, the way in which it will be carried out, and the destination of the activity. The described iterative process is repeated completely until the average score of the population stabilizes [23].

Another important note is that since MATSim is designed for large-scale scenarios, the software adopts the queuing approach, i.e., an agent enters a network link or road segment from an intersection and is added to the queue. Such an agent will remain there until the time to traverse the link has elapsed, it is at the head of the queue, and the next link allows it to enter. Therefore, the MATSim traffic model is based on two attributes of the links: on the one hand, the storage capacity, which denotes the number of cars entering a link in the network, and on the other hand, the flow capacity, which is nothing more than the exit capacity of a link, i.e., the number of agents that can leave the link per unit of time.

It should be noted that to carry out the simulations, the MATSim model needs at least the following files as inputs:

- Config: It contains all the possible MATSim configuration options. In this section, you will specify among other parameters the "controller", the number of iterations, the type of parameters, and the configuration of the parameters of the utility function, which will assign scores to the different plans, which will be used probabilistically for the choice of each plan by the software.
- Network: It is the infrastructure where agents can move, which consists of a set of nodes and links. The simplest network format should contain information regarding the length of the link, the link capacity, the number of lanes available in the specified direction, and the list of modes allowed on the link.
- Population: The population contains the data of the set of agents and their plans. Specifically, the files contain a list of people, where in turn each entry for a person contains a list of plans, and each plan contains a list of different activities. Each population file needs at least one plan associated with each person, for which it is not necessary to have a certain score assigned, as this can be obtained by MATSim. In addition, the activities can be located only by their coordinates and the section only needs one mode, so it is not necessary to specify the routes.

- The procedure followed to obtain each of the files will be detailed in the Supplementary Materials.

3.2. Mobility Data

Before the simulations could be carried out, it was necessary to prepare the model, specifically the three files described above. For this purpose, the following methodology was followed as detailed in this section.

We started from the mobility study conducted by the Cabildo de Tenerife in October 2018 [23] to analyze travel on the island and to allow access to citizenship, through a series of applications, of the data obtained, after processing and debugging them. Specifically, the information obtained from the geolocation records of mobile terminals, travel data from the Ten+ island public transport card, capacity data, and surveys of both residents and non-residents were used.

For this purpose, the island was divided into 150 zones, called transport zones, which can be seen in Figure 8. Since the study carried out by the Cabildo does not include information on these zones anywhere, a name has been assigned to each one of them, as well as the municipality to which they belong, and they are presented in Annex I in an orderly fashion.

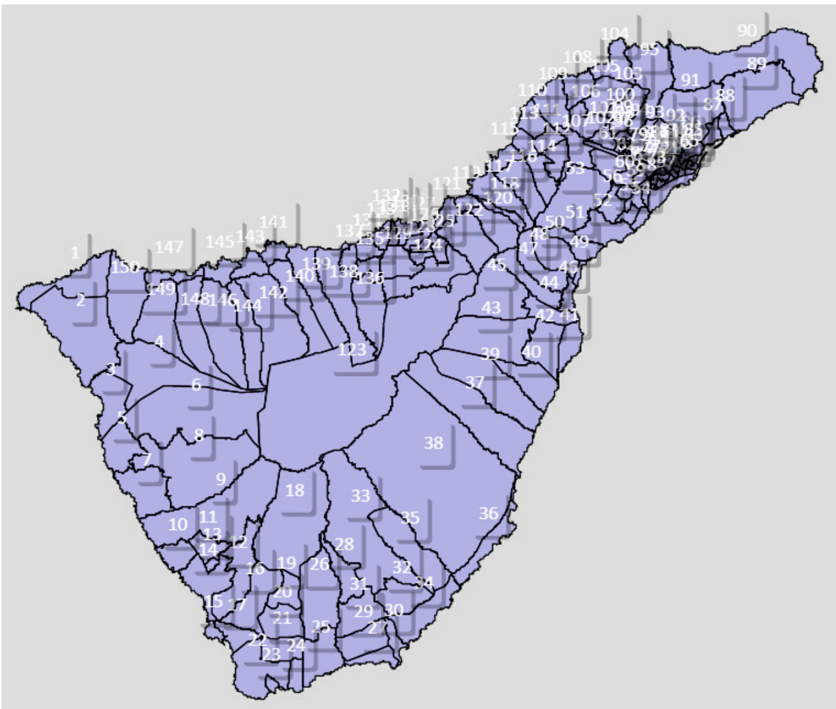

Figure 8. Numerically ordered transport zones into which Tenerife has been divided in the mobility study.

The result of the mobility study is a square matrix of rank 150, which describes the number of journeys made between the different transport zones during the month of October 2018, the period covered by the study, with the rows being the transport zones of origin of each journey and the columns being the transport zones of destination. In addition, the study carried out by the Cabildo also allows the information to be filtered by time of the start of each journey or by distance. In the latter case, it is only possible to filter the information into two different groups: journeys whose distance is equal to or less than 1 km and journeys with distances greater than 1 km.

All this information will be very important to consider when creating the necessary input files required by MATSim to carry out the simulation, which is why it has been detailed in this section. As mentioned above, this procedure is detailed in the Supplementary Materials section.

On the other hand, it must be taken into account that Tenerife is a tourist island, with a not inconsiderable number of visitors. However, these factors have already been taken into account both in the number of vehicles considered in this study and in the mobility study. On the other hand, the seasonality factor, although important, is not excessive, with 572,515 being the highest monthly rate of visitors and 421,763 the lowest [24], for the year 2018 in which the mobility study was made. Even so, it will be convenient to take this consideration into account when designing the charging network, e.g., considering the use of static wireless chargers, which allow charging the vehicle independently from the primary inverter and therefore distributing the charge over longer periods than conventional chargers [25].

4. Results and Discussion

This section will present the results obtained after the simulation, the methodology of which has been defined above, as well as in the Supplementary Materials. Specifically, for this simulation, the model was configured with about 250 iterations, which, as can be seen in Figure 9, are sufficient for the statistics of the utility function scores to stabilize, so that they can provide reliable results. Furthermore, the full simulation period is five days, which corresponds to a typical week between Monday and Friday.

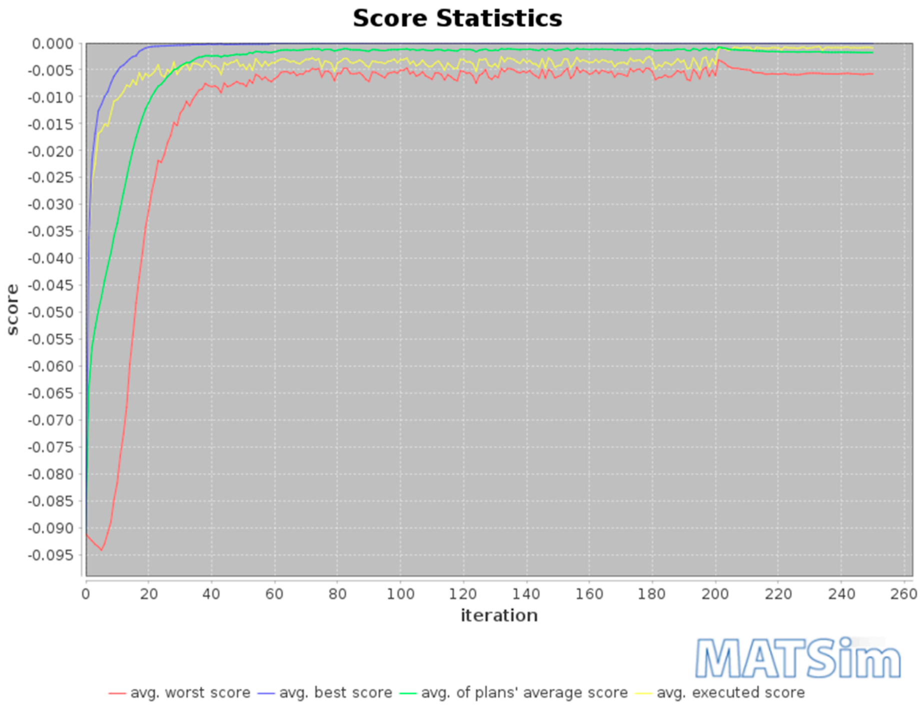

Figure 9. MATSim simulation scores statistics.

Before obtaining the results corresponding to the location of the charging points, a dynamic representation of the mobility was obtained, corresponding to the five days of simulation considered, and for which a synthetic population was used. As an example, Figure 10 shows a screenshot of the synthetic agents in movement visualized in Simunto Via, corresponding to the town of San Isidro, municipality of Granadilla de Abona.

Figure 10. Screenshot of the synthetic agents in motion visualized on Via Simunto, in San Isidro, municipality of Granadilla de Abona, where the agents in green represent flowing traffic and in yellow collapsed traffic.

4.1. Simulation with Progressive EV Quotas

In this simulation, the penetration rates of electric vehicles estimated by the ITC were used [6]. A three-year budget of 5 million euros was considered for this case. In addition, the power of the chargers is not fixed, so MATSim determines the charging power point accordingly.

Once the simulation process was completed, for this configuration described, the following points were obtained, as shown in Table 1.

Table 1. Number of EV charging points per power.

Years	Share of EVs (%)	Accumulated Budget (€)	Number of Points with 7 kW Power	Number of Points with 22 kW Power
2022	2.29	5,000,000	781	141
2025	8.40	10,000,000	1883	144
2028	18.10	15,000,000	2988	144
2031	31.36	20,000,000	4090	144
2035	49.65	25,000,000	5191	144
2037	72.20	30,000,000	6294	144

It can be seen that, in the first step, 141 semi-fast chargers (22 kW power) and the remaining slow chargers are obtained (7 kW power). These semi-fast chargers will practically remain constant while the slow chargers will increase over time.

Figures 11–16 show the distribution of charging points throughout the island of Tenerife in the different years, where each red dot corresponds to a charging point.

These previous maps have been elaborated after applying a data treatment in Python to the results provided by the MATSim simulator, which are given in xml format.

In total, with a budget of 30,000,000 euros, 6294 EV charging points with a power of 7 kW and 144 points with a power of 22 kW were obtained, corresponding to slow and semi-fast charging points, respectively. These points have been grouped by municipality by means of data processing to obtain Table 2, which shows the exact number of EV charging points obtained in each municipality of the island of Tenerife and in each step of the simulation.

It should be noted that these results do not correspond to census population criteria, but to the simulation built by synthetic agents from the mobility data available in the study conducted by the Cabildo de Tenerife in October 2018 [26]. Moreover, these results correspond to the optimal distribution of charging points for an available budget of 30,000,000 euros. This parameter could have varied, and therefore different results could have been obtained. Therefore, the possibility of adapting the results according to the specific needs of each moment remains open.

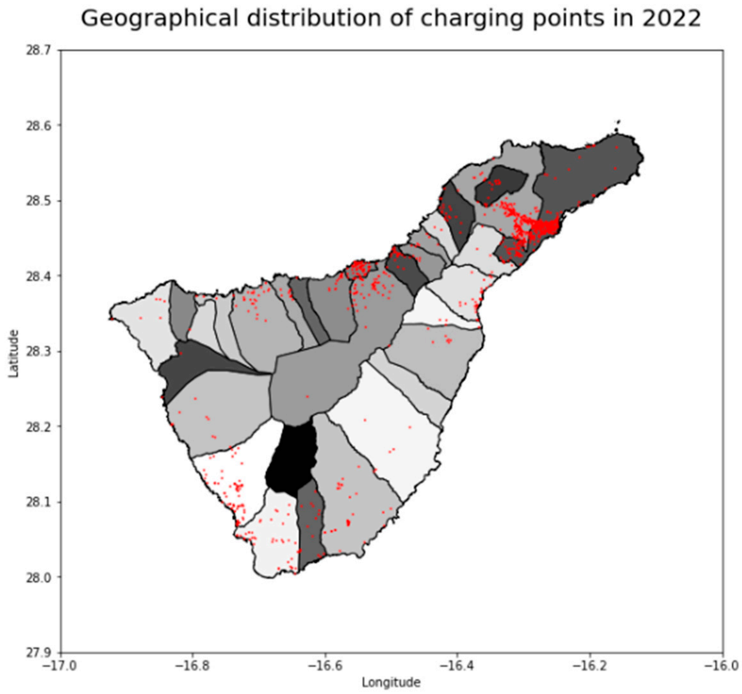

Figure 11. Map of the distribution of the charging points obtained in Tenerife for the year 2022.

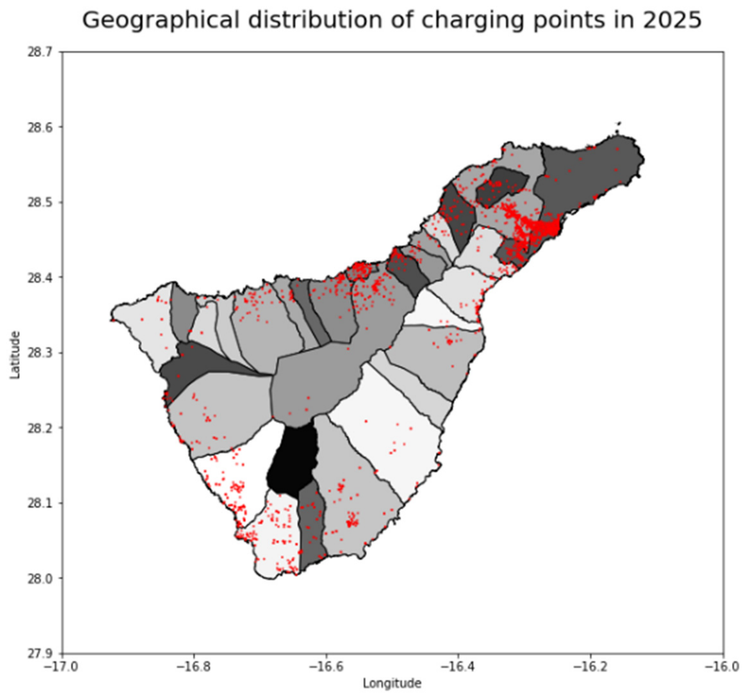

Figure 12. Map of the distribution of the charging points obtained in Tenerife for the year 2025.

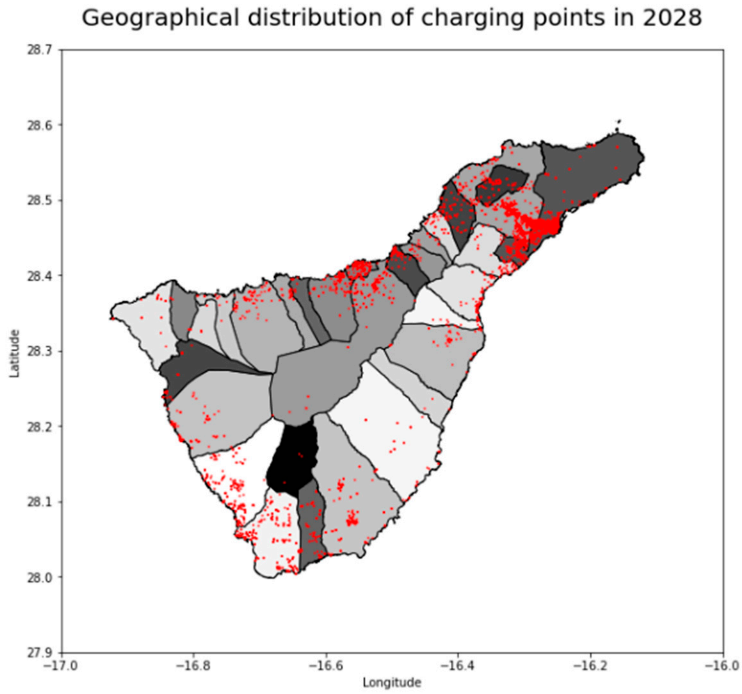

Figure 13. Map of the distribution of the charging points obtained in Tenerife for the year 2028.

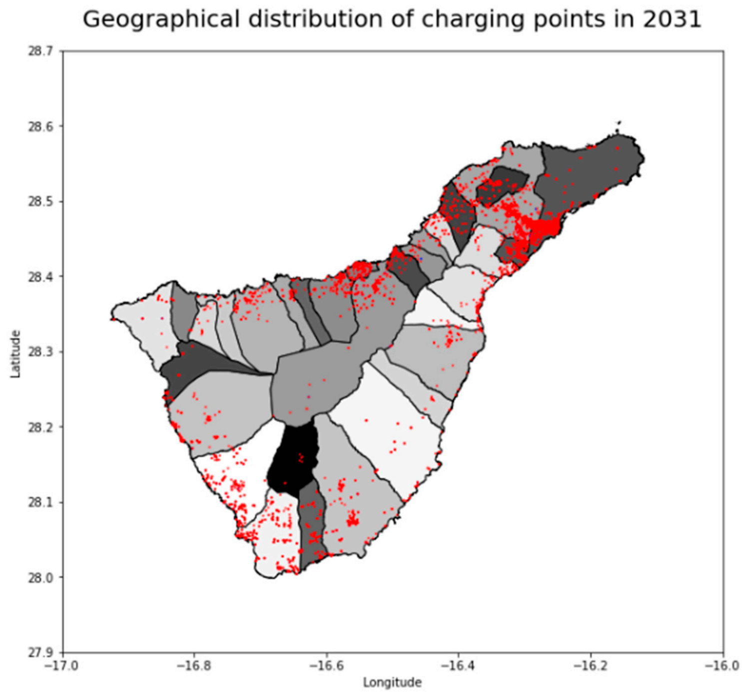

Figure 14. Map of the distribution of the charging points obtained in Tenerife for the year 2031.

It can be seen, both visually on the map and in Table 2, that there are two municipalities that stand out above the rest, namely the metropolitan area formed by Santa Cruz de Tenerife and La Laguna, which between them account for 36.41% of the total charging points on the whole island in 2037. Other areas with significant concentrations of points are the tourist municipalities in the south of the island, with the following standing out in particular: Arona, Adeje, and Granadilla de Abona with third, fourth, and fifth place, respectively, in the ranking of municipalities with the highest concentration of points. The municipalities of the Orotava Valley, i.e., La Orotava, Puerto de la Cruz, and Los Realejos, also stand out, occupying in this case the sixth, seventh, and eighth positions, all of them with more than 200 charging points in the year 2037. The rest of the municipalities of Tenerife have a lower concentration of charging points, although it should be noted that of the 31 municipalities, the simulation results show more than 10 charging points in 29 municipalities, with Los Silos and Vilaflor being the only municipalities with a lower concentration of points, with nine and eight chargers, respectively. This information can be seen more graphically in Figure 17, where the two municipalities of the metropolitan area clearly dominate: Santa Cruz de Tenerife and La Laguna.

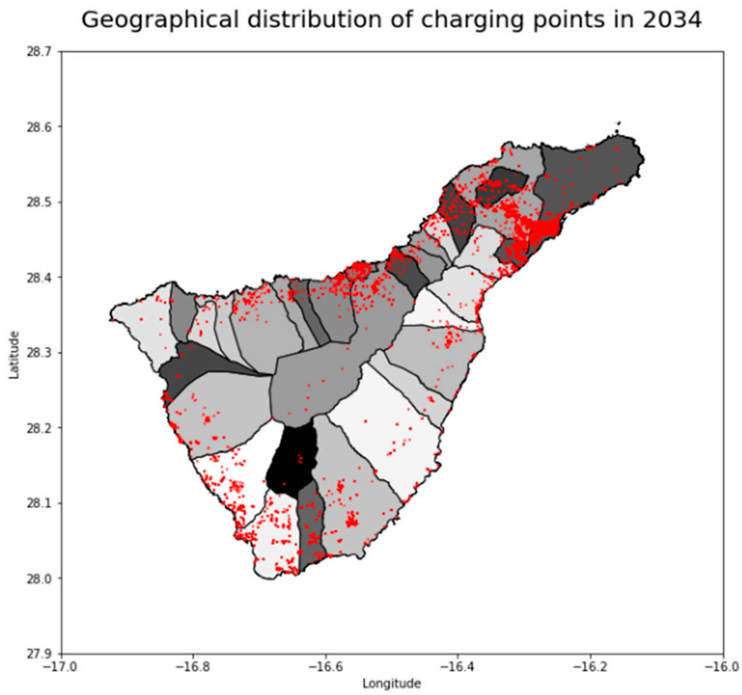

Figure 15. Map of the distribution of the charging points obtained in Tenerife for the year 2034.

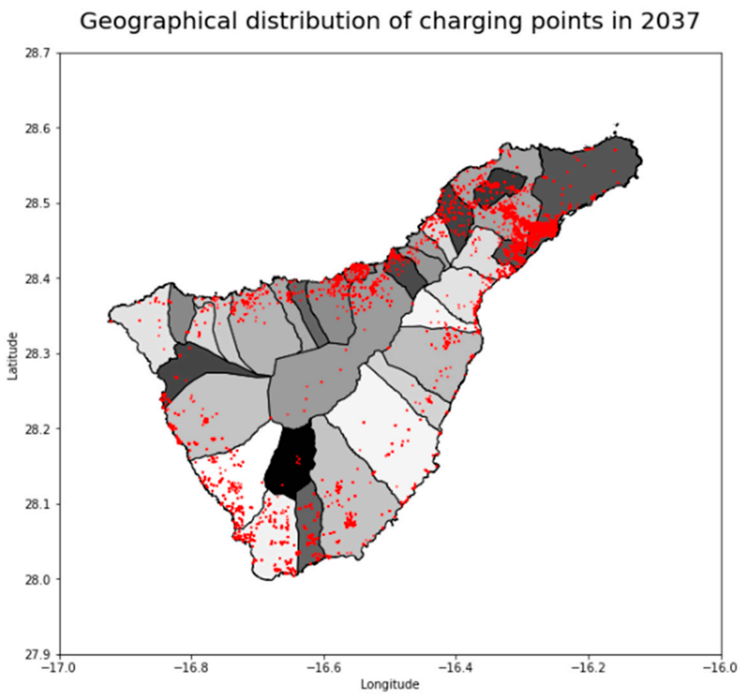

Figure 16. Map of the distribution of the charging points obtained in Tenerife for the year 2037.

Table 2. Number of EV charging points per municipality.

Municipality	**Years**					
	2022	**2025**	**2028**	**2031**	**2034**	**2037**
Santa Cruz de Tenerife	259	477	666	844	1014	1178
La Laguna	200	416	614	812	993	1166
Arona	39	133	229	320	408	485
Adeje	69	127	203	276	344	415
Granadilla de Abona	33	88	144	208	266	329
La Orotava	61	130	181	225	266	302
Puerto de la Cruz	59	102	158	205	253	296
Los Realejos	14	59	111	157	205	253
Guía de Isora	10	43	77	116	165	214
Tegueste	13	47	74	105	146	182
Tacoronte	17	48	77	111	143	179
Icod de los Vinos	25	44	73	105	139	177
San Miguel de Abona	14	34	66	101	138	174
Güímar	8	30	50	79	113	151
Santa Úrsula	22	42	63	87	110	131
Arico	6	22	40	62	92	124
El Rosario	6	29	50	72	95	118
Candelaria	27	50	68	81	96	113
El Sauzal	3	16	38	59	82	107
La Guancha	9	18	28	38	48	59
Santiago del Teide	2	17	24	32	44	54
El Tanque	1	5	9	22	29	40
Buenavista del Norte	6	16	24	29	32	39
Garachico	3	5	12	16	20	29
Fasnia	3	0	2	8	14	27
La Matanza de Acentejo	5	10	13	16	20	26
Arafo	4	5	10	11	15	20
La Victoria de Acentejo	6	11	13	15	18	19
San Juan de la Rambla	1	2	9	8	13	14
Los Silos	0	1	3	5	7	9
Vilaflor	0	0	3	7	7	8
Total	922	2027	3132	4234	5335	6438

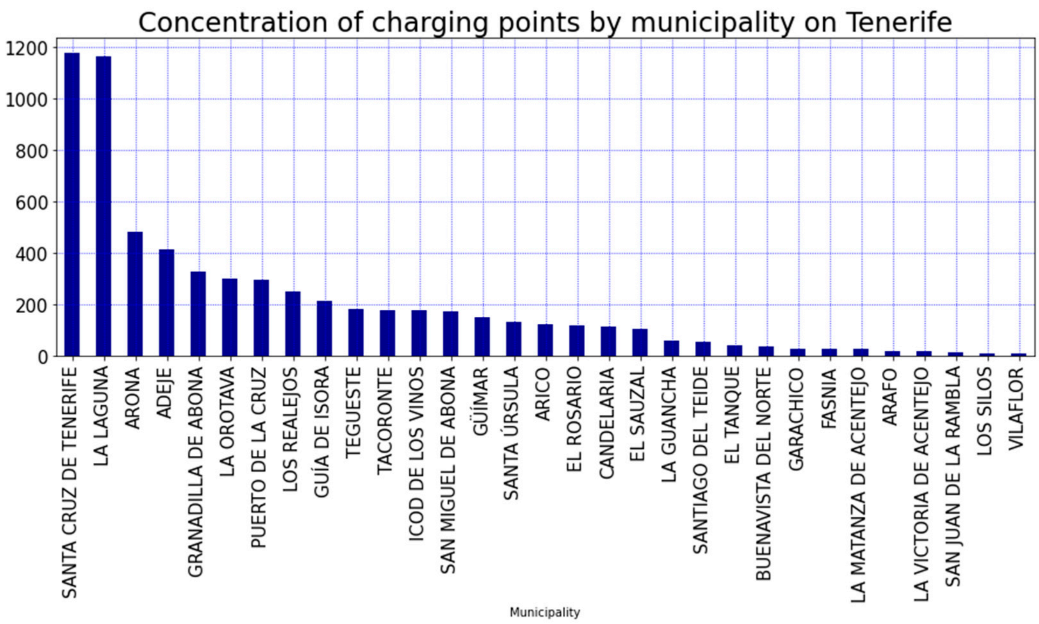

Figure 17. Concentration of charging points by municipality on the island of Tenerife in 2037.

To better visualize these areas where there is a higher density of points, it has been decided to represent, with a higher resolution and in urban-type map, the places where the charging points obtained are located in the year 2037. These maps are shown in Figures 18–23, which correspond to the metropolitan area (formed by the most populated areas of the municipalities of Santa Cruz de Tenerife and La Laguna), La Orotava Valley (formed by the municipalities of La Orotava, Puerto de la Cruz and Los Realejos), the most touristic areas in the South of the island (corresponding to the municipalities of Arona and Adeje), the municipalities of Granadilla and San Miguel de Abona, Güímar Valley (formed by Candelaria, Arafo, and Güímar), and the northeast region (comprising Santa Úrsula, La Victoria and La Matanza de Acentejo, El Sauzal, and Tacoronte), respectively.

Especially in areas where several charging points are grouped together, there are nodes with high energy demand, so it would be desirable to consider the use of supercapacitors as storage systems, which, given their high-power density, allow faster and more efficient charging [27].

4.2. Comparison between a Simulation with Progressive and Non-Progressive EV Quotas

In this case, a simulation was carried out in which the initial percentage of EVs in the year 2022 was considered to be 100%, so the differences between the previous simulation in which the population gradually acquired an EV and this latest simulation in which the land-based vehicle fleet is purely electric will be analyzed.

For this case, the same budget of 5 million euros per step was set, starting in 2022, and three steps were simulated, with each step again being triennial.

The results are presented in Table 3.

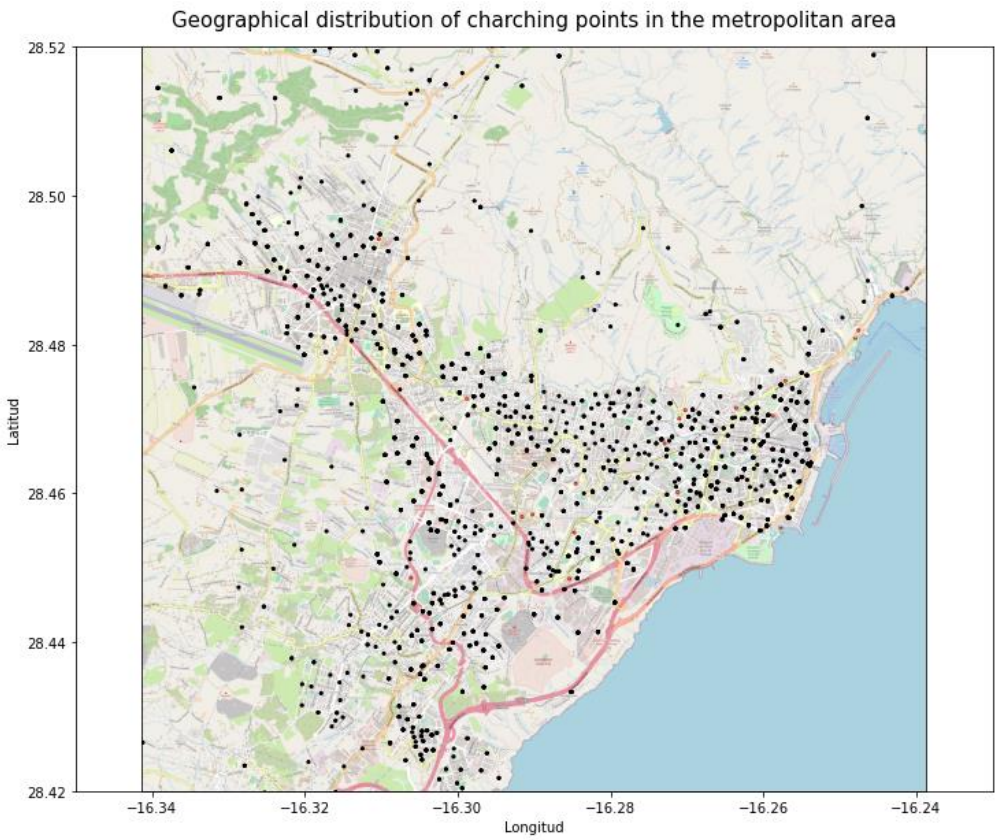

Figure 18. Distribution of charging points in the metropolitan area of Tenerife with each black dot representing a charging point.

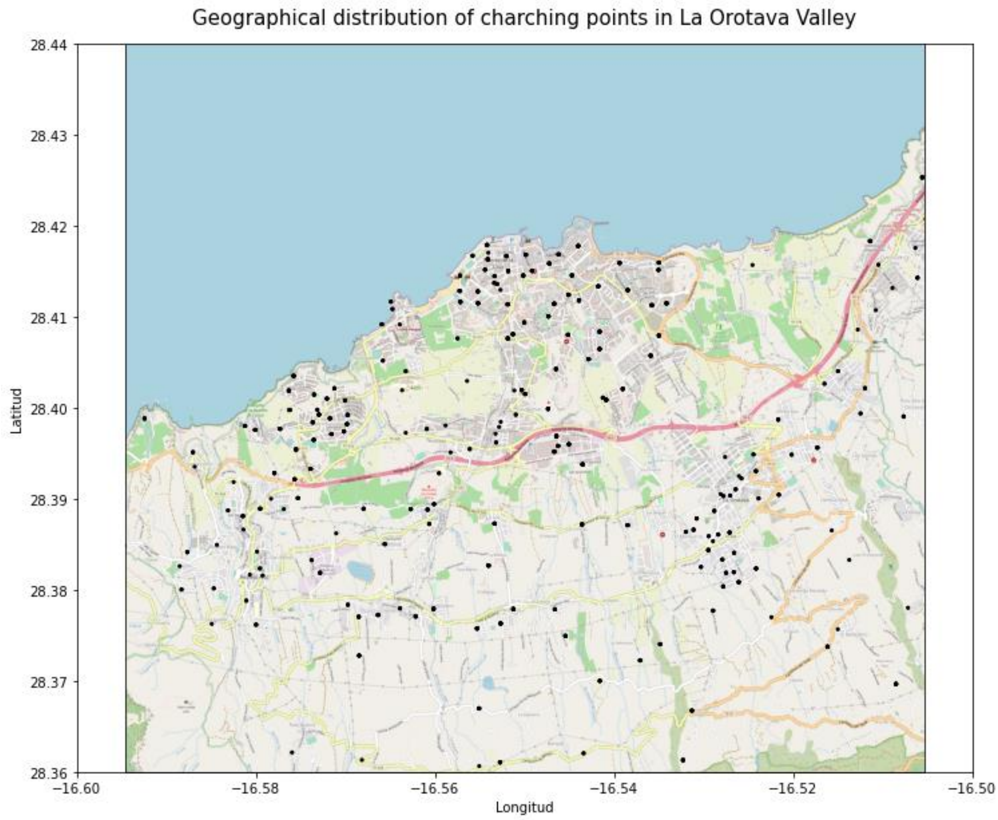

Figure 19. Distribution of charging points in La Orotava Valley with each black dot representing a charging point.

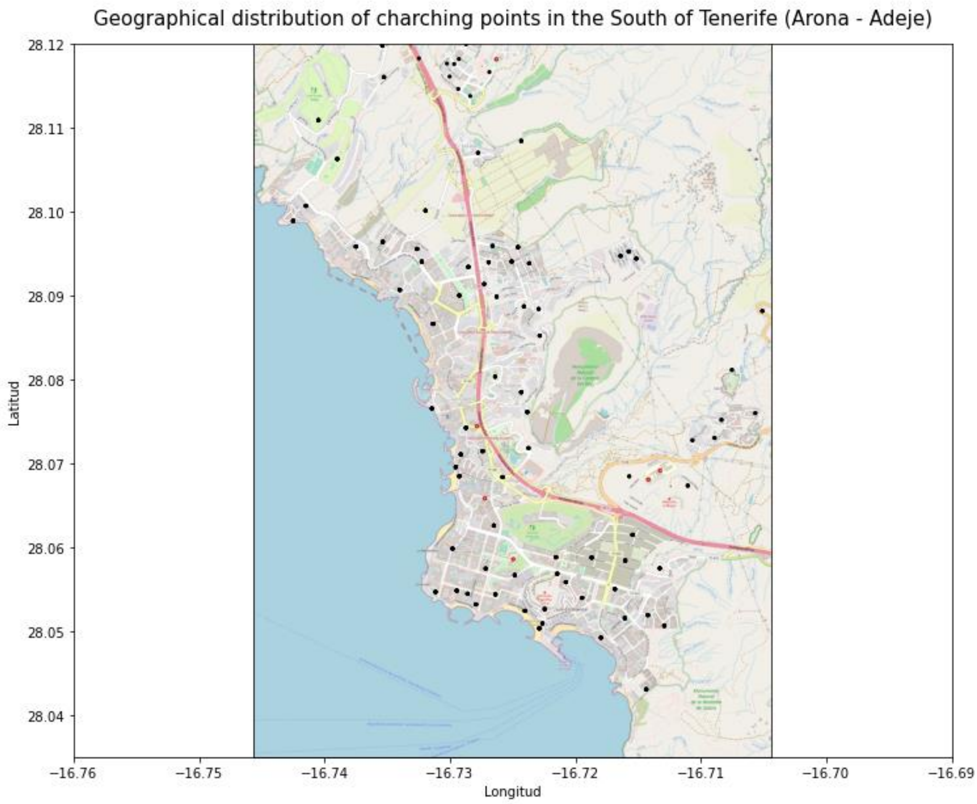

Figure 20. Distribution of charging points in the touristic areas of the South of Tenerife (Arona—Adeje) with each black dot representing a charging point.

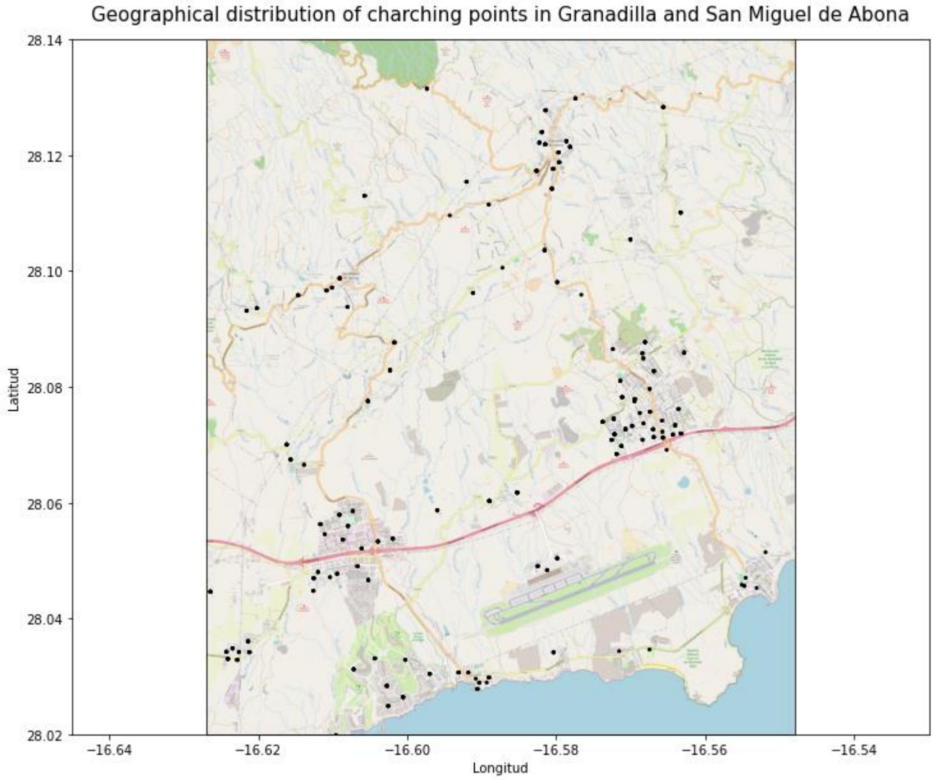

Figure 21. Distribution of charging points in Granadilla and San Miguel de Abona with each black dot representing a charging point.

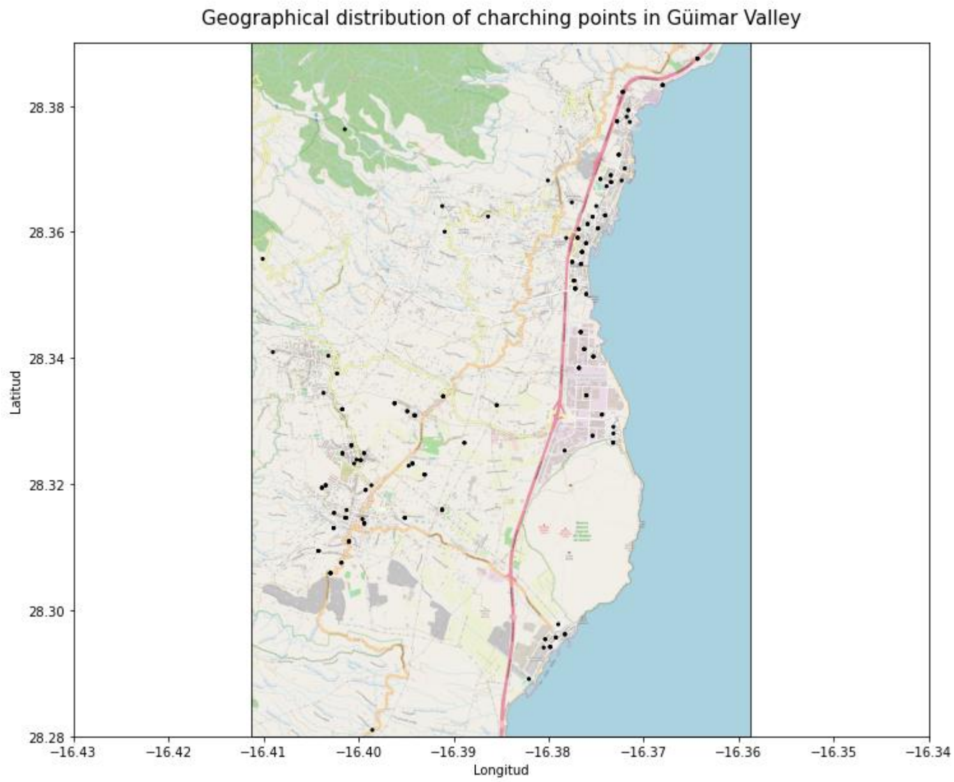

Figure 22. Distribution of charging points in Güímar Valley with each black dot representing a charging point.

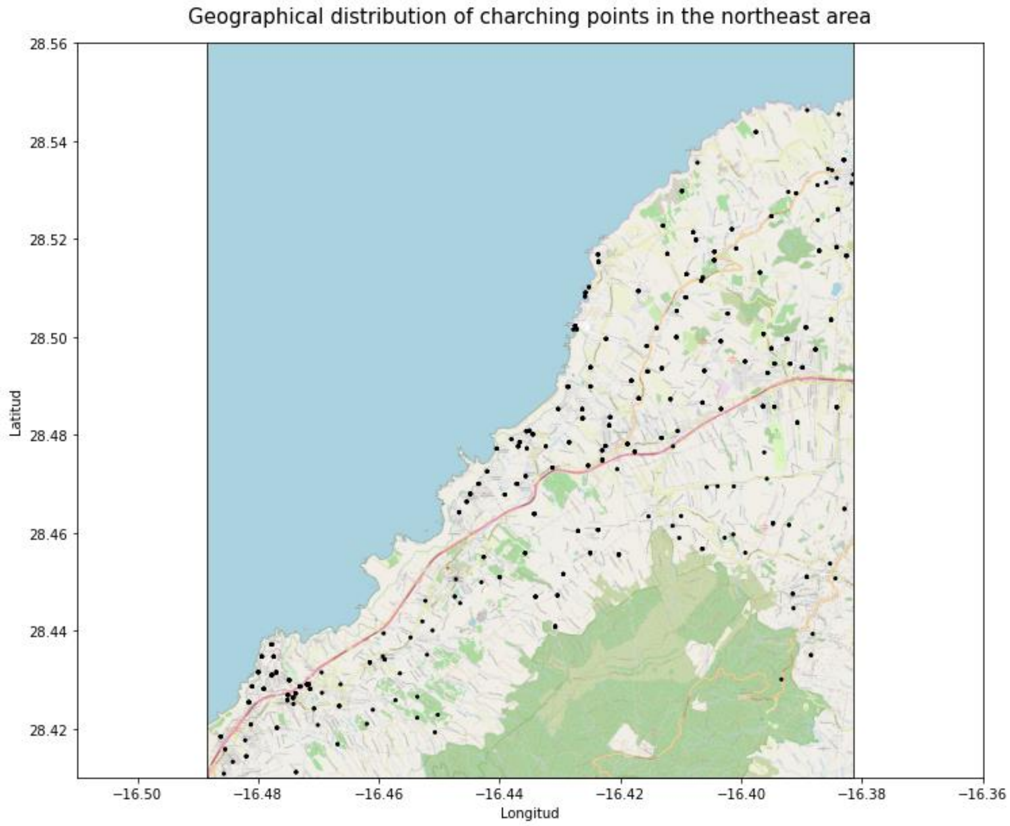

Figure 23. Distribution of charging points in the northeast region of Tenerife with each black dot representing a charging point.

Table 3. Number of EV charging points per power with progressive and non-progressive EVs quotas.

Years	Accumulated Budget (€)	Progressive EVs Quotas		Non-Progressive EVs Quotas	
		Number of Points with 7 kW Power	Number of Points with 22 kW Power	Number of Points with 7 kW Power	Number of Points with 22 kW Power
2022	5,000,000	781	141	1111	0
2025	10,000,000	1883	144	2215	3
2028	15,000,000	2988	144	3326	3

It can be seen that while in the case of the simulation with progressive VE quotas 141 semi-fast chargers (22 kW) are obtained in the first step, in the case of the non-progressive simulation none are obtained. This is probably due to the fact that, not being progressive, all users have an electric vehicle, and therefore MATSim will prioritize slow chargers (7 kW), which are cheaper than semi-fast chargers. Therefore, a greater number of points is obtained in order to place a charging point for the greatest possible number of agents.

This would explain why in the case of the above simulation, as in the first step, the share of electric vehicles was small (2.29%). There was enough funding to place several semi-fast chargers, but as the share of electric vehicles increased, and not in a way that would have been possible in the first step, there would have been enough funding to place several semi-fast chargers.

Finally, it is noteworthy that for the second step of the non-progressive simulation, three semi-fast loaders appear, which is the same increase of this type of loaders as in the progressive simulation, so it may be due to a residual error of MASTim.

Figures 24 and 25 show the distribution of points for 2028 for both cases, progressive and non-progressive, where it can be seen that in the latter there is a greater number of points distributed more homogeneously throughout the island, as the semi-fast load points are disregarded compared to the slow load points.

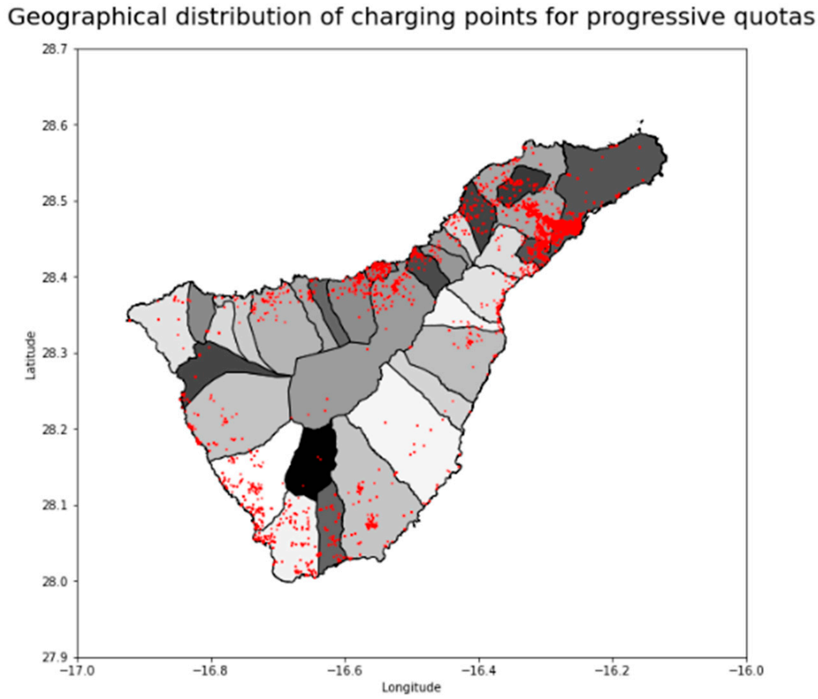

Figure 24. Distribution of charging points in Tenerife in 2028 for the progressive case.

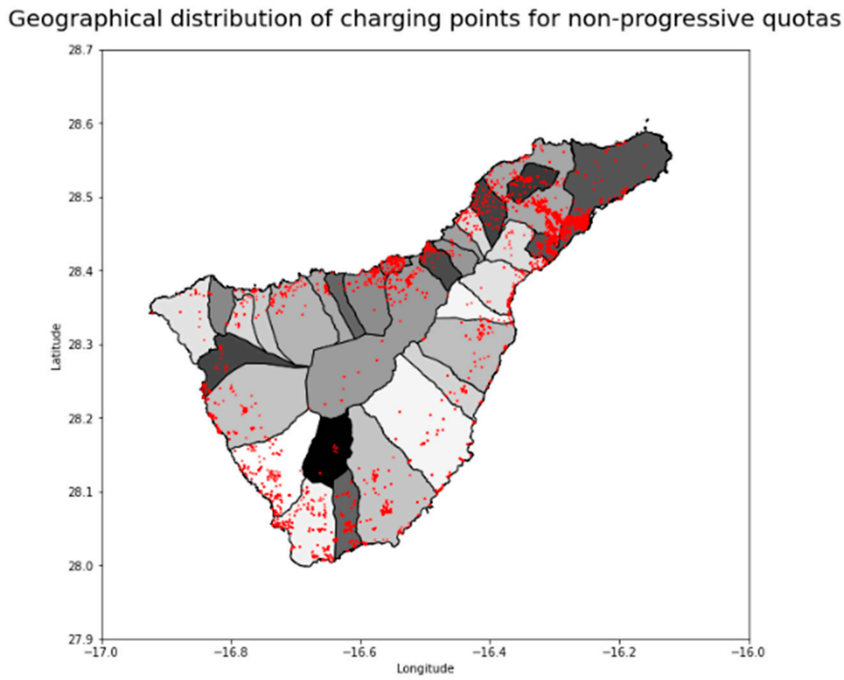

Figure 25. Distribution of charging points in Tenerife in 2028 for the non-progressive case.

5. Conclusions

In this study, we first obtained the most efficient geographical distribution of electric vehicle charging points to be installed on the island of Tenerife for a budget of 30,000,000 euros and with a horizon until 2037. For this purpose, a simulation of the island's traffic was carried out using MATSim, a multi-agent traffic simulation software. For the elaboration of such simulation, a synthetic population elaborated in Python was used from the data obtained from a mobility study carried out by the Cabildo de Tenerife in October 2018. Prior to the elaboration of the simulation, the different governmental plans and studies carried out to date in the Canary Islands on the preparation of the network of charging points for the growing number of EVs expected in the coming years were analyzed. In fact, these government plans contemplate that by the year 2040 all land vehicles will be electric, with the consequent preparation and design of the network of charging points that this entails, which is still pending.

With the allocated budget, the results obtained satisfy 10% of the synthetic population of the island, reflecting the optimal location of the 6438 charging points to be installed. This budget has been intentionally assigned to cover this percentage of the population and not to excessively lengthen the computation time of the simulations, since it has been considered a sufficient percentage to check the suitability of the results. This distribution of points, as can be seen in the paper, is coherent with the distribution of population density on the island, so it is deduced that it will make sense according to population mobility criteria. Therefore, the initial objective of the study, which was to obtain a methodology that could design the network of charging points for EVs based on mobility studies, and that is reliable, yielding consistent results, so that the model can be extrapolated to other regions, has been demonstrated.

Furthermore, these results represent an advance over the governmental plans prepared by ITC, since the latter are based solely on available parking space, whereas this study incorporates the analysis of population movements, allowing the network to be designed based on technical criteria. On the other hand, having carried out the study with progressive quotas of electric vehicle penetration and having obtained results every three years, it is possible to check how the installation of charging points would be gradual.

However, this study is subject to future improvements and extensions in order to achieve greater accuracy of its results for the design of an adequate electromobility infrastructure plan on the island of Tenerife. It would be desirable to have new, more up-to-date mobility studies carried out over a longer period, so that the synthetic population constructed for the simulations is as close as possible to the real population. The study was conducted with the data available to date corresponding to October 2018, but since they are data collected prior to the COVID-19 pandemic, it would be convenient to have subsequent mobility studies to check how the mobility of the island has changed. The possibility remains open to consider the charging demand as the primary condition and to minimize the budget needed to satisfy it, or to consider the charging speed as a variable, combining charging points with different power, and therefore with different charging speed, as was done in the second part of the results where we compared the case of progressive EV quotas with non-progressive quotas.

In addition to these improvements in the configuration of the simulations, another series of factors that may condition the reliability of the results must also be pondered.

Firstly, it is necessary to estimate the future number of public transport users, which is expected to increase due to the planning of new infrastructure under development, such as the railroad lines in the north and south of the island. Moreover, a possible modal change in mobility is expected, including the use of carpooling, bicycle transport for short distances, or the option of teleworking for those cases in which it is feasible. All of this could lead to a reduction in the number of vehicles per inhabitant, which should be considered. Another variable to be studied is the construction of new road transport infrastructures, as is the case of the highway island ring, which may cause changes in mobility and therefore also in the results obtained in relation to charging points.

Finally, according to ITC estimates, the complete electrification of road transport in Tenerife will mean an increase in energy demand of 71.2%, which will have to be covered by renewable energies, mainly photovoltaic and wind. However, this increase in energy demand is not necessarily a negative point. On the contrary, it will serve to make the electricity system more robust, since in an energy production system where renewable energies account for around 100% of production, the correct management of this increase in demand associated with the electrification of the transport system makes it possible to prioritize the charging of electric vehicles at times of greater availability of renewable energy, thus avoiding spills and energy losses. This flattens the energy demand curve by shifting the increase in energy demand to the off-peak hours of the curve, making the electricity system more efficient.

Moreover, the positive effect on the grid will be even greater if V2G technology is added to this, which considers cars as batteries as well and thus also avoids oversizing energy storage. In this way, EVs would act as manageable loads that absorb electricity from the grid during off-peak hours and supply energy during peak hours. Having a V2G network is more costly than a simple one-way charging infrastructure and this additional cost need to be carefully evaluated to exhibit a positive final contribution for the electricity system. However, studies have shown that if government support is provided through subsidies to offset the initial investment losses, the use of V2G technology is economically viable, and the optimal case, i.e., the one requiring minimal financial support, is when the V2G service operator adds AC chargers.

For all these reasons explained, this study is essential to lay the foundations for the preparation of an adequate network of EV charging points in Tenerife, as the methodology has been shown to work in the sense that it yields consistent and coherent results, and it can be applied to other different case studies. Such a charging infrastructure, as explained above, will not only be necessary due to the expected increase in the number of EVs in circulation, but will also improve the electricity system, helping to correct the weakest points of non-manageable energies.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/en16031178/s1. References [28–32] are cited in the Supplementary Materials.

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

Funding: This research received no external funding.

Data Availability Statement: Data is contained within the article. Further requests can made to the corresponding author.

Acknowledgments: This work was made possible thanks to the collaboration of CentraleSupélec and the Moulon Mésocentre, belonging to Paris-Saclay University, where the simulation was carried out. The principal author would like to thank this Institution for its collaboration with the University of La Laguna, which made this article possible.

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

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