COMILLAS
UNIVERSIDAD PONTIFICIA
ICAI

MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

SIMULATION OF FUTURE ELECTRIC TRUCK ELECTRICITY NEEDS

Autor: Juan Busto Celaya

Director: Manuel Pérez Bravo

Co-Directores: José Pablo Chaves Ávila

Madrid

Julio de 2025

Declaro, bajo mi responsabilidad, que el Proyecto presentado con el título

Simulation of future electric truck electricity needs

en la ETS de Ingeniería - ICAI de la Universidad Pontificia Comillas en el

curso académico 2024/2025 es de mi autoría, original e inédito y

no ha sido presentado con anterioridad a otros efectos.

El Proyecto no es plagio de otro, ni total ni parcialmente y la información que ha sido

tomada de otros documentos está debidamente referenciada.

Fdo.: Juan Busto Celaya Fecha: …22…/ …07…/ 2025……

Autorizada la entrega del proyecto

DIRECTORES DEL PROYECTO

Fdo.: Fecha: ……/ ……/ ……

PEREZ BRAVO MANUEL - 49114355V

Firmado digitalmente por PEREZ BRAVO MANUEL - 49114355V
Fecha: 2025.07.22 16:28:27 +02'00'

José Pablo Chaves Ávila

MÁSTER UNIVERSITARIO EN INGENIERÍA INDUSTRIAL

TRABAJO FIN DE MÁSTER

SIMULATION OF FUTURE ELECTRIC TRUCK ELECTRICITY NEEDS

Autor: Juan Busto Celaya

Director: Manuel Pérez Bravo

Co-Directores: José Pablo Chaves Ávila

Madrid

SIMULACIÓN DE LAS FUTURAS NECESIDADES ELÉCTRICAS DEL CAMIÓN ELÉCTRICO

Autor: Busto Celaya, Juan
Director: Manuel Pérez Bravo, José Pablo Chaves Ávila
Entidad Colaboradora: Instituto de Investigación Tecnológica (Universidad Pontificia de Comillas)

RESUMEN DEL PROYECTO

Este Trabajo de Fin de Máster presenta una metodología para el despliegue estratégico de infraestructura de recarga para camiones eléctricos a lo largo del Corredor Mediterráneo. Mediante la integración de análisis espacial, modelado basado en la demanda y técnicas de dimensionamiento técnico, el estudio identifica y prioriza ubicaciones óptimas, dando como resultado una red de 12 estaciones de recarga capaces de atender la demanda proyectada del transporte de mercancías para el año 2030. El marco propuesto es adaptable a diferentes niveles de adopción del camión eléctrico y puede extenderse a otros corredores logísticos en España y Europa.

Palabras clave: Camiones eléctricos, Infraestructura de recarga, Análisis espacial

1. Introducción

La transición hacia un transporte de mercancías sostenible es un objetivo central de la Unión Europea, que ha establecido metas ambiciosas para la reducción de emisiones de gases de efecto invernadero en el sector del transporte por carretera. Los camiones eléctricos representan una tecnología clave en este proceso, aunque su adopción generalizada depende del desarrollo de una infraestructura de recarga extensa y fiable, especialmente a lo largo de los principales corredores logísticos.

Este Trabajo de Fin de Máster se centra en el Corredor Mediterráneo, un eje fundamental para el transporte de mercancías en España. El estudio presenta una metodología que combina análisis espacial, modelado de demanda y dimensionamiento técnico para identificar y optimizar la localización y capacidad de las estaciones de recarga para camiones eléctricos. El objetivo es proporcionar un marco práctico de planificación de infraestructuras que impulse la electrificación del transporte de mercancías en este corredor y pueda replicarse en otras regiones.

2. Definición del proyecto

El objetivo principal de este Trabajo de Fin de Máster es diseñar una red optimizada de estaciones de recarga para camiones eléctricos de gran tonelaje a lo largo del Corredor Mediterráneo español. El proyecto se basa en una metodología orientada por la demanda y fundamentada en el análisis espacial, que integra datos reales de flujos de tráfico, la distribución actual de paradas de camiones y los requisitos normativos previstos.

El alcance del proyecto incluye la identificación de ubicaciones candidatas para las estaciones de recarga, la aplicación de un modelo de optimización de localización para priorizar y seleccionar los puntos más estratégicos, así como el dimensionamiento técnico de cada estación en función de la demanda estimada y las limitaciones operativas. La metodología también contempla la viabilidad económica mediante la estimación del coste total de la infraestructura en distintos escenarios de adopción del camión eléctrico, en línea con los objetivos marcados por la Unión Europea para 2030.

Combinando herramientas de análisis espacial (QGIS), un modelo gravitacional de atractivo logístico y teoría de colas para el dimensionamiento de cargadores, el proyecto busca ofrecer una solución flexible, escalable y transferible. El objetivo final es apoyar la transición hacia un transporte de mercancías libre de emisiones, no solo en el Corredor Mediterráneo, sino también como marco replicable en otros corredores logísticos de España y Europa.

3. Descripción del modelo/sistema/herramienta

La metodología desarrollada en este trabajo integra herramientas de análisis espacial, optimización de localización y dimensionamiento técnico para diseñar una red eficaz de estaciones de recarga para camiones eléctricos. Utilizando QGIS, se representan en el mapa datos reales sobre flujos de camiones y áreas de descanso, con el fin de identificar ubicaciones candidatas a lo largo del Corredor Mediterráneo.

Posteriormente, se aplica un modelo gravitacional para seleccionar los puntos más estratégicos, maximizando la cobertura y minimizando redundancias. Cada estación seleccionada se dimensiona mediante teoría de colas aplicada a los cargadores rápidos, garantizando un funcionamiento eficiente en situaciones de alta demanda. Los cargadores lentos, destinados a paradas nocturnas o de larga duración, se dimensionan mediante un modelo estático de ocupación. Este enfoque da lugar a un marco de planificación flexible y escalable, adaptable a datos actualizados o aplicable en otros corredores logísticos.

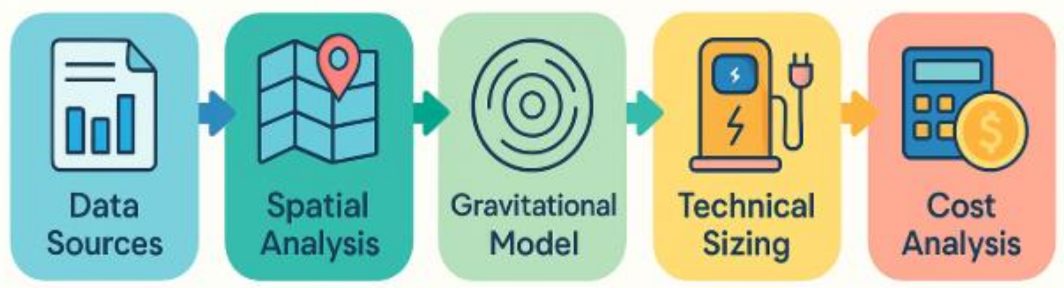


Figure 1. Diagrama que muestra la metodología de cinco pasos para la planificación de infraestructura de recarga para camiones eléctricos.

4. Resultados

La aplicación de la metodología propuesta al Corredor Mediterráneo permitió identificar 12 ubicaciones óptimas para estaciones de recarga de camiones eléctricos, seleccionadas a partir de un conjunto inicial de 18 candidatas. Estos puntos fueron escogidos en función de la demanda de transporte de mercancías proyectada para 2030, su accesibilidad y su valor estratégico dentro del corredor. La combinación del análisis espacial con el modelo gravitacional permitió configurar una red bien distribuida, que maximiza la cobertura y minimiza la superposición entre estaciones.

Cada estación fue dimensionada técnicamente para cumplir con los objetivos de tiempo de servicio y tasa de utilización, lo que dio lugar a una asignación diferenciada de cargadores rápidos y lentos, según los patrones de tráfico esperados. Se analizó el coste total de la infraestructura en distintos escenarios de adopción del camión eléctrico, demostrando que una estrategia de inversión escalonada, comenzando con una penetración del 5 % de la flota y ampliándose a medida que crece la adopción, puede atender eficazmente el aumento progresivo de la demanda. La metodología se mostró robusta y adaptable, ofreciendo una solución práctica para futuras expansiones en otras regiones o corredores logísticos.

Figure 2. Ubicaciones finales de las 12 futuras estaciones de recarga eléctrica para vehículos pesados a lo largo del Corredor Mediterráneo en España.

5. Conclusiones

Este estudio demuestra que una metodología basada en datos y orientada por la demanda permite planificar de forma eficiente la infraestructura de recarga para camiones eléctricos en corredores logísticos clave. Al priorizar ubicaciones estratégicas y dimensionar cada estación según las necesidades proyectadas, el marco propuesto favorece una transición escalable y rentable hacia un transporte de mercancías libre de emisiones. Este enfoque es adaptable a la evolución del mercado y puede replicarse en otras regiones, contribuyendo así a los objetivos generales de movilidad sostenible y cumplimiento normativo.

6. Referencias

1. ACEA. (2025). INTERACTIVE MAPS: ELECTRIC TRUCKS STOP LOCATIONS IN SOUTHERN EUROPE).
2. European Comission. (2022). European Road Freight Transport Flow Data .
3. Fraunhofer ISI. (2024). Optimized demand-based charging networks for long-haul trucking in Europe.
4. Bloomberg. (2024). Cheaper Truck Batteries Usher in Dawn of Emissions-Free Rigs. McKerracher, C.

5. International Council on Clean Transport. (2023). A total cost of ownership comparison of truck decarbonization pathways in Europe. Rodríguez, H. B. Transport.
6. Volvo. (s.f.). Towards zero emissions.

SIMULATION OF FUTURE ELECTRIC TRUCK ELECTRICITY NEEDS

Autor: Busto Celaya, Juan
Director: Manuel Pérez Bravo, José Pablo Chaves Ávila
Entidad Colaboradora: Instituto de Investigación Tecnológica (Universidad Pontificia de Comillas)

ABSTRACT

This Master's Thesis presents a methodology for the strategic deployment of electric truck charging infrastructure along the Mediterranean Corridor. By integrating spatial analysis, demand-based modeling, and technical sizing methods, the study identifies and prioritizes optimal locations, resulting in a network of 12 charging stations capable of meeting projected freight transport demand by 2030. The proposed framework is adaptable to different levels of electric truck adoption and can be extended to other logistics corridors in Spain and Europe.

Keywords: Electric trucks, Charging infrastructure, Spatial analysis,

1. Introduction

The transition towards sustainable freight transport is a central goal for the European Union, which has established ambitious targets for reducing greenhouse gas emissions in the road transport sector. Electric trucks represent a key technology in this transition, but their widespread adoption depends on the development of an extensive and reliable charging infrastructure, especially along major logistics corridors.

This Master's Thesis focuses on the Mediterranean Corridor, a vital axis for goods movement in Spain. The study presents a methodology that combines spatial analysis, demand modeling, and technical sizing to identify and optimize the location and capacity of electric truck charging stations. The aim is to provide a practical framework for infrastructure planning that supports the electrification of freight transport in this corridor and can be replicated in other regions.

2. Definition of the project

The main objective of this Master's Thesis is to design an optimized network of electric charging stations for heavy-duty trucks along the Spanish Mediterranean Corridor. The project is based on a demand-driven and spatially informed methodology that integrates real traffic flow data, the current distribution of truck stops, and future regulatory requirements.

The scope of the project includes the identification of candidate locations for charging stations, the application of a location optimization model to prioritize and select the most strategic sites, and the technical sizing of each station according to projected demand and operational constraints. The methodology also considers economic feasibility by estimating the total infrastructure cost for different electric truck adoption scenarios, in line with European Union targets for 2030.

By combining spatial analysis tools (QGIS), a gravitational attractiveness model, and queueing theory for charger sizing, the project aims to deliver a flexible, scalable, and transferable solution. The ultimate goal is to support the transition to zero-emission freight transport, not only in the Mediterranean Corridor but also as a replicable framework for other logistics corridors in Spain and Europe.

3. Description of the model

The methodology developed in this thesis integrates spatial analysis, location optimization, and technical sizing tools to design an effective charging network for electric trucks. Using QGIS, real data on truck flows and rest areas are mapped to identify candidate sites along the Mediterranean Corridor.

A gravitational model is then applied to select the most strategic locations, maximizing coverage and minimizing redundancy. Each selected station is sized with queueing theory applied to fast chargers, ensuring efficient operation under peak demand. Slow chargers, intended for overnight or long-duration stops, are dimensioned using a static occupancy model. This approach results in a flexible and scalable planning framework, adaptable to updated data or application in other logistics corridors.

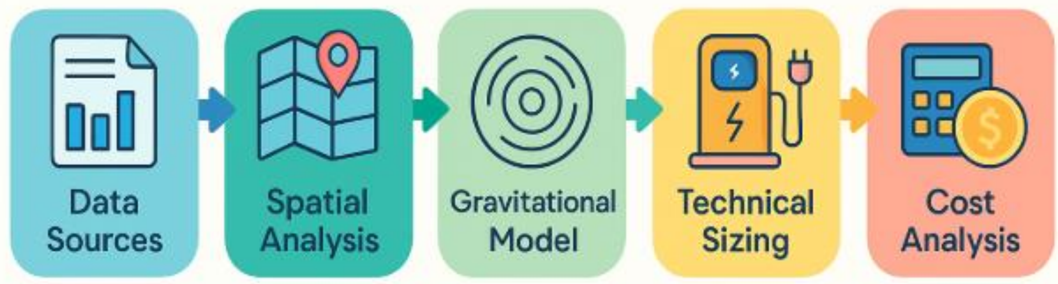


Figure 3. Diagram showing the five-step methodology for planning electric truck charging infrastructure

4. Results

Applying the proposed methodology to the Mediterranean Corridor led to the identification of 12 optimal locations for electric truck charging stations, selected from an initial set of 18 candidates. These sites were chosen based on projected freight demand for 2030, accessibility, and strategic value along the corridor. The combination of spatial analysis and the gravitational model ensured a well-distributed network that maximizes coverage and minimizes overlap.

Each station was technically sized to meet service time and utilization targets, resulting in a differentiated allocation of fast and slow chargers according to expected traffic patterns. The total cost of infrastructure was analyzed under several electric truck adoption scenarios, demonstrating that a phased investment strategy—starting at 5% fleet penetration and scaling up as adoption grows—can efficiently accommodate increasing demand. The methodology proved robust and adaptable, offering a practical solution for future expansion in other regions or corridors.

Figure 4. Final 12 locations of future electric charging stations for heavy-duty vehicles along the Mediterranean Corridor in Spain.

5. Conclusions

This study demonstrates that a data-driven and demand-oriented methodology enables the efficient planning of electric truck charging infrastructure on key logistics corridors. By prioritizing strategic locations and sizing each station according to projected needs, the proposed framework supports a scalable and cost-effective transition to zero-emission freight transport. The approach is adaptable to evolving market conditions and can be replicated in other regions, contributing to the broader goals of sustainable mobility and regulatory compliance.

6. Referencias

1. ACEA. (2025). INTERACTIVE MAPS: ELECTRIC TRUCKS STOP LOCATIONS IN SOUTHERN EUROPE).
2. European Comission. (2022). European Road Freight Transport Flow Data .
3. Fraunhofer ISI. (2024). Optimized demand-based charging networks for long-haul trucking in Europe.
4. Bloomberg. (2024). Cheaper Truck Batteries Usher in Dawn of Emissions-Free Rigs. McKerracher, C.
5. International Council on Clean Transport. (2023). A total cost of ownership comparison of truck decarbonization pathways in Europe. Rodríguez, H. B.
6. Volvo. (s.f.). Towards zero emissions.

Memory index

Index of figures

Table index

Chapter 1. INTRODUCCIÓN

In the coming years, electric trucks are expected to gain a significant presence on European roads, driven by the growing interest in reducing pollutant emissions and the potential for lower operating costs. Several factors support this trend. On the one hand, technological advancements in battery manufacturing are enabling electric trucks to offer greater range and shorter charging times, making them increasingly competitive compared to diesel trucks. On the other hand, European Union policies aimed at combating climate change are accelerating the adoption of cleaner alternatives by setting increasingly stringent emission reduction targets.

Furthermore, the European Union aims to reduce pollutant emissions among its member states, noting that approximately 6.25% of greenhouse gases originate from heavy commercial vehicles. In this context, replacing diesel trucks with electric models has emerged as an effective response to reducing the transport sector's carbon footprint. Although the initial investment in an electric truck may be higher, the lower long-term maintenance costs and the lower price of electricity compared to fossil fuels contribute to a gradual return on investment.

As a result, the transition to electric trucks is emerging as an ideal solution for meeting the targets set out in the European Climate Law, which requires member states to adopt concrete measures to achieve climate neutrality in the coming decades. In this way, electric trucks not only help mitigate environmental impact but also pave the way for a cleaner and more efficient future in freight transport.

However, as of today, neither the European Union nor Spain possesses the infrastructure necessary to support the large-scale deployment of electric trucks on their roads. Significant investment is still needed in charging facilities and in the modernization of the electrical grid. Therefore, the objective of this study is to adapt the Mediterranean Corridor to enable efficient circulation of these vehicles, meeting recharging needs while complying with the European Union's "Regulation on the Deployment of Alternative Fuels Infrastructure."

Specifically, this study proposes a comprehensive analysis of the logistics routes along the Mediterranean Corridor, with the aim of identifying the optimal locations for building electric charging stations for heavy-duty vehicles. The potential demand for charging will be assessed to appropriately size both the number of charging points and the power required to support freight transport operations.

Finally, a strategic plan will be developed outlining the selected locations, the total power capacity needed, and the power distribution per charger. This approach will facilitate a coordinated transition toward electrified heavy transport, promoting the adoption of cleaner mobility solutions while simultaneously reducing the sector's carbon footprint. In doing so, the study not only aligns with the objectives set by European regulations but also fosters innovation and strengthens the competitiveness of transport companies in an increasingly sustainability-driven market.

1.1 PROJECT MOTIVATION

As outlined in the previous sections, the electrification of heavy-duty transport is a necessary step toward achieving the European Union's climate goals. While there have been significant technical advancements, corporate commitments, and increasingly clear legislation, such as the AFIR regulation, the charging infrastructure for electric trucks remains insufficient.

The Mediterranean Corridor is one of the country's main logistical arteries, connecting key industrial regions from Catalonia to Murcia. However, the lack of a charging network tailored to electric heavy-duty vehicles along this corridor jeopardizes the feasibility of its electrification in the short and medium term. The issue lies not only in the scarcity of charging points, but also in their suboptimal placement and the absence of clear technical criteria for their proper sizing.

Existing European-level studies, such as the one conducted by the Fraunhofer Institute and Amazon Europe (2024), have demonstrated that an efficient charging network does not require uniform coverage, but rather planning based on actual demand and the specific capacity of each location. Nonetheless, these analyses have been carried out at a continental scale and do not address the territorial and logistical specificities of corridors such as the one in Spain.

For all these reasons, this project aims to apply a demand-based optimization methodology to the specific case of the Mediterranean Corridor. Using spatial analysis tools (QGIS) and integrating real data layers (truck stops, logistics hubs, traffic flows), the goal is to develop a realistic and efficient proposal aligned with European regulations.

This initiative addresses both an urgent technical need and a strategic opportunity: to facilitate the energy transition of freight transport in one of Spain's most active regions, while also contributing valuable insights for future public and private planning decisions.

1.2 DEFINITION OF THE PROJECT

1.2.1 JUSTIFICATION

This Master's Thesis responds to that need by proposing a replicable methodology to identify and dimension the most relevant points for the initial deployment of truck charging stations along the Mediterranean Corridor—one of the country's most critical logistics routes. The study integrates spatial analysis tools (QGIS), a demand-based gravitational model to optimize location selection, and a queueing theory model (M/M/s) to properly size the infrastructure based on estimated usage.

The selection of optimal locations is grounded in projected demand (Fraunhofer ISI, 2024), existing infrastructure data (ACEA, 2025), and regulatory alignment (European Comission, 2021) The gravitational model not only considers the attractiveness of each point but also incorporates a corrective term to penalize excessive proximity between stations, thus minimizing redundancy. Once the 12 most strategic locations were selected, demand was estimated at each station, and the number of fast and slow chargers was determined using a combination of queueing theory and static occupancy modeling.

This technical approach is also highly flexible: it can be adapted as real-world data becomes available—such as updated traffic flows, adoption rates, or power grid limitations—without requiring a complete reanalysis. Furthermore, the final cost estimation includes a sensitivity analysis under different electric truck penetration scenarios (5%, 7%, 10%, and 15%). While a 7% penetration rate is the most likely scenario by 2030, the actual rate remains uncertain. The analysis shows that the system can begin with a more limited investment to meet 5% demand and scale progressively as adoption increases, simply by adding chargers to the same sites.

From an economic perspective, identifying optimal locations helps avoid costly oversizing or underutilization of infrastructure. Environmentally, this network supports national decarbonization goals, as road freight accounts for over 25% of transport-sector emissions in Spain. By providing a technically rigorous and regulation-compliant deployment model, this project contributes to a more sustainable and efficient freight mobility system in alignment with both the European Green Deal and Spain's National Integrated Energy and Climate Plan (Ministerio para la Transición Ecológica y el Reto Demográfico, 2020).

In short, this work is justified by the legal obligation to meet EU targets, the urgency of starting infrastructure deployment, the need to prioritize high-impact investments, and the practical value of providing a data-driven framework for future planning.

1.2.2 OBJECTIVES

The main objective of this master's thesis is the design of a network of electric charging stations for heavy-duty trucks along the Mediterranean Corridor, following a methodology based on real freight transport demand and the use of spatial analysis tools.

By adapting a leading European study, the aim is to apply an optimization model at a regional scale to identify optimal locations and assess their technical and strategic feasibility. To achieve this, traffic data, current truck stop locations, and key logistics points will be integrated in order to properly size the charging infrastructure required to support the electrification of freight transport in this key section of Spain's logistics network.

Chapter 2. STATE OF THE ART

2.1 SECTOR OVERVIEW AND POLICY FRAMEWORK

In recent years, various institutions, such as Bloomberg, have forecasted that by 2030, the cost of electric trucks will be more competitive than that of their diesel counterparts. To accurately assess the viability of each option, the Total Cost of Ownership (TCO) tool is used. This metric considers not only the purchase price but also maintenance expenses, energy or fuel consumption, and vehicle depreciation over its useful life.

According to Bloomberg (McKerracher, 2024), battery prices have shown a significant downward trend in recent years. Specifically, in 2023, they dropped by 39%, reaching approximately $100 per kWh. If this trend continues, prices are expected to fall to $80 per kWh by 2030. In addition to the reduction in battery costs, increased production volumes and technological improvements in electric truck manufacturing are contributing to the overall decrease in prices.

Other studies, such as that by the International Council on Clean Transportation (Rodríguez, 2023), support these projections. Figure 5 compares of cost per kilometer by truck type in 2030 compares the cost per kilometer of various truck alternatives projected for 2030, showing that electric trucks could be up to 22% more cost-effective per kilometer than their diesel equivalents. This cost advantage would stem not only from the reduced maintenance requirements of electric motors but also from public policies aimed at discouraging pollutant emissions, such as carbon taxes or low-emission zones in urban areas.

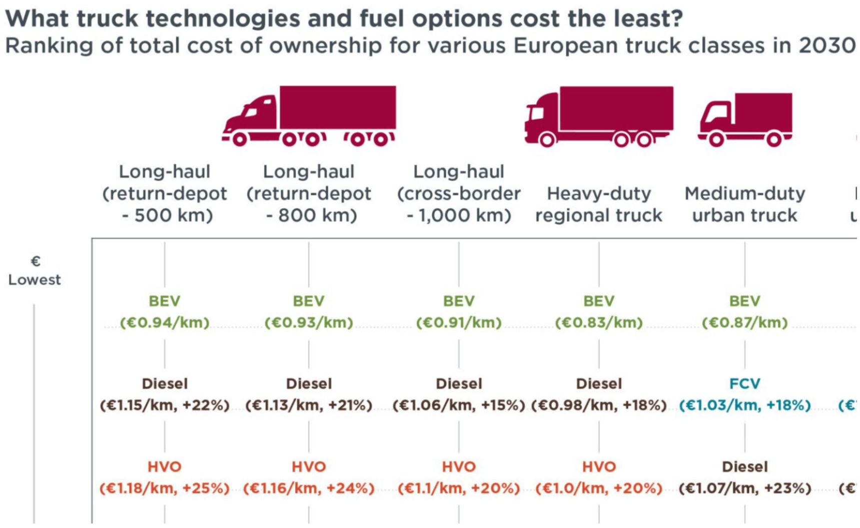


Figure 5. Comparison of cost per kilometer by truck type in 2030. Source: International Council on Clean Transportation

According to projections for 2040, electric trucks are expected to continue leading in terms of profitability, although hydrogen-powered trucks, also known as fuel cell vehicles, are anticipated to emerge as the second most cost-effective alternative. Beyond 2050, projections become less conclusive. It is estimated that hydrogen trucks could surpass electric ones in competitiveness, provided that green hydrogen can be produced at scale and at low cost. Conversely, if battery prices continue to fall and their energy density increases, electric trucks may retain their advantage. In any scenario, the transition toward low-carbon freight transport systems will require the development of public policies that promote research, production, and large-scale deployment of these technologies.

Major truck manufacturers such as Iveco, Volvo, and Scania are already launching electric models to meet sustainability requirements and comply with European emission reduction regulations. Volvo, for instance, has announced that by 2040, all of its vehicles will be zero-emission, in line with the European Union’s target of achieving climate neutrality by the same year (Volvo, s.f.). These corporate commitments reflect both EU policies promoting transport electrification and the growing demand for cleaner, more efficient logistics solutions. Through such efforts, the trucking industry is moving toward a more sustainable future, aligning with market trends and institutional goals to reduce the environmental impact of freight transport.

At present, the vast majority of trucks operating on European roads are powered by conventional diesel engines. In fact, according to data from the European Automobile Manufacturers' Association, electric trucks currently account for just 0.1% of the total fleet in the European Union, highlighting the limited adoption of this technology to date (ACEA, 2025).

Several factors help explain why a widespread shift to electric mobility in this sector has not yet occurred:

- Limited range: Although battery performance has improved substantially in recent years, electric trucks still fall short of matching diesel trucks in terms of long-distance capabilities. However, starting in 2025, new models are expected to offer ranges of approximately 400 to 500 kilometers—sufficient to cover the 4.5 hours of driving permitted before mandatory rest breaks. This advancement could eliminate one of the main barriers to electric truck adoption.

- Charging time: Another critical issue is battery recharging, which can require longer stops than the 45-minute rest period mandated by EU regulations. Nevertheless, the introduction of fast-charging systems such as the Megawatt Charging System (MCS) could reduce recharging times to under 45 minutes, aligning with regulatory breaks and minimizing operational inefficiencies.

- High initial investment cost: The purchase price of electric trucks, along with the cost of installing charging infrastructure, represents a significant barrier to entry, as it currently exceeds that of equivalent diesel models. Still, as technology matures and demand grows, prices are expected to gradually decline.

- Lack of infrastructure: The limited number of charging stations in Europe complicates route planning for long-haul journeys and threatens the continuity of freight services. Expanding this infrastructure is precisely the focus of this study, aiming to pave the way for a broader adoption of electric truck fleets.

In Spain specifically, the charging infrastructure for electric trucks remains in its early stages. While some charging points exist along strategic corridors such as the AP-7 (Mediterranean), A-2 (Madrid–Barcelona), and A-6 (Northwest), most are designed for passenger vehicles and lack the power capacity required for trucks. Nevertheless, important steps have been taken, including a dedicated charging hub in Sangonera la Seca (Murcia) to serve heavy-duty vehicles, and a planned project in Zaragoza to install truck-specific charging stations aimed at improving connectivity across the northeastern region of the country.

This lack of dedicated infrastructure for heavy-duty vehicles poses a significant challenge for transport companies seeking to electrify their fleets.

On a broader level, the European Union introduced the "Fit for 55" legislative package in 2021, which aims to reduce greenhouse gas emissions by 55% by 2030 compared to 1990 levels, and to achieve climate neutrality by 2050. To this end, the package revises existing legislation and proposes new measures across multiple sectors. Some components of "Fit for 55" have already been approved, while others are still undergoing the legislative process (European comission, 2021).

In relation to this study, particular attention must be given to the new AFIR regulation—Alternative Fuels Infrastructure Regulation (European comission, 2023). This regulation replaces the earlier AFID directive—Alternative Fuels Infrastructure Directive, adopted in 2014 (European comission, 2014). AFID was the European Union's first legislative measure aimed at promoting the deployment of electric charging stations for all types of vehicles. Subsequently, in 2023, AFIR was formally adopted to establish clearer, directly applicable targets for Member States.

One of the main innovations introduced by AFIR is the differentiation between charging stations designed for heavy-duty vehicles and those intended for other types of vehicles—a distinction not considered in the earlier directive. The category of heavy-duty vehicles includes trucks, which are the central focus of this study.

AFIR sets specific targets for (ISI, 2024) coverage and minimum power capacity along the Trans-European Transport Network (TEN-T), a large-scale European Union initiative that coordinates and improves transportation networks (including roads, railways, waterways, and ports) to enhance regional connectivity and promote faster, safer, and more sustainable movement of people and goods. This study focuses specifically on the road infrastructure within the TEN-T, as it constitutes the main corridor for heavy-duty vehicle traffic.

Below are some of the most significant milestones established by AFIR:

- By 2025: At least 15% of the TEN-T must be equipped with truck charging infrastructure, with a minimum total power capacity of 1,400 kW per area, and at least one charging point of 350 kW.
- By 2027: The coverage must expand to 50% of the TEN-T, reaching a minimum total power of 2,800 kW per area, with at least two chargers of 350 kW.
- By 2030: AFIR mandates the presence of at least one truck charging station every 60 km along the TEN-T, with a minimum total power capacity of 3,600 kW and at least two chargers of 350 kW.

Table 1. European Regulation on the deployment of high-power charging points. summarizes the various targets set by the European Union, along with their corresponding implementation deadlines.

By the end of the year	***% of TEN-T network covered***	***Minimum Total Power***	***Minimun Power charger(s)***
2025	15%	1.400 KW	1x 350KW
2027	50%	2.800KW	2x 350KW
2030	Cada 60 KM	3.600KW	2x 350KW

Table 1. European Regulation on the deployment of high-power charging points.

When AFIR refers to a percentage of coverage, it indicates the proportion of kilometers within the TEN-T network that must be equipped with suitable charging areas for trucks at regular intervals. In practice, this means that within those designated segments, the charging stations must comply with the regulation's requirements for power output and spacing.

However, certain exceptions are allowed in low-traffic areas or regions with geographic constraints, where Member States may request extended deadlines or specific conditions. These obligations are designed to ensure the availability of high-power charging points for heavy-duty vehicles, so that limited range and long charging times no longer pose a barrier to the electrification of trucks on long-distance routes.

2.2 DESCRIPTION OF THE TECHNOLOGIES

In the context of this project, QGIS serves as an essential tool, as it enables the integration, visualization, and simultaneous analysis of the various spatial data sources collected, thereby facilitating the optimal planning of charging infrastructure for electric trucks.

QGIS is an open-source Geographic Information System (GIS) that enables the visualization, analysis, and editing of geospatial data. This software provides powerful tools for managing multiple layers of geographic information, conducting advanced spatial analyses, and creating interactive maps that support decision-making across various fields, including transportation, urban planning, and energy infrastructure, among others.

The primary objective of using QGIS in this study is to bring together within a single analytical environment two main sources of geographic information related to the electrification of heavy-duty transport:

- Data from the Fraunhofer ISI study (20): The strategic locations recommended in this study are available in digital format through its online publication and associated documents. These data include the precise geographic coordinates of approximately 2,700 locations identified as strategic for the deployment of charging stations across Europe.

- Data from the ACEA interactive resource ("Interactive maps: Electric trucks stop locations in Southern Europe"): This resource is an interactive map displaying the current stop locations commonly used by trucks, primarily diesel vehicles. However, the data are not available for direct download in GIS-compatible formats, necessitating the creation of a custom Excel file for the project. In this file, all locations shown by ACEA were manually recorded, including their exact geographic coordinates and key attributes—particularly the stop type according to duration (short or long).

Once both data sources have been collected and prepared, they are imported into QGIS. By integrating them, it becomes possible to visualize in a single map the strategic locations identified by Fraunhofer alongside the actual stop points identified by ACEA.

This spatial analysis will enable us to identify which locations are common to both studies, thereby ensuring that the planning process is informed not only by theoretical models but also by actual usage patterns. This insight will be crucial in selecting the appropriate type of chargers, whether high-power MCS chargers or conventional ones, to be installed at each site.

By applying this methodology, the aim is to achieve a more accurate and realistic planning approach, ensuring that the proposed charging stations effectively meet the future demand of electric trucks on European roads.

Chapter 3. METHODOLOGY

This chapter describes the methodological process followed to design and optimize a network of electric charging stations for long-haul trucks in the Spanish Mediterranean Corridor. The approach integrates spatial data analysis, demand modeling, and technical sizing in a sequential and structured manner.

The process begins with the acquisition and preparation of data from two key sources: the Fraunhofer ISI (2024), which provides projections of truck traffic flows for 2030 across the European network, and the ACEA dataset, which maps the current distribution of truck rest areas. These inputs are used to identify high-relevance areas along the corridor.

Next, a spatial analysis is carried out using QGIS to determine 18 candidate locations based on logistical importance, accessibility, and alignment with the TEN-T core freight routes. Once selected, a gravitational model is applied to evaluate the relative attractiveness of each point, incorporating both projected demand and geographic accessibility, while penalizing excessive proximity between stations through a corrective term. This optimization process yields the 12 most suitable locations for initial infrastructure deployment.

Subsequently, the technical sizing of each station is performed based on expected truck flow and the probability of stopping. Fast chargers are dimensioned using M/M/s queueing theory to ensure short waiting times and efficient service, while slow chargers are sized using a static occupancy model focused on overnight or long-duration rest stops.

Finally, the total cost of infrastructure deployment is estimated by multiplying the number of chargers per station by the corresponding unit costs. This step allows for an evaluation of economic feasibility and supports phased implementation planning.

This methodology ensures that the resulting network is strategically located, technically feasible, demand-driven, and aligned with the European Union's regulatory framework for alternative fuel infrastructure.

3.1 DATA ACQUISITION

To determine the optimal locations for trucks electric charging stations, the process begins with a large pool of potential sites. For this purpose, two key studies are used as reference points:

3.1.1 OPTIMIZED DEMAND-BASED CHARGING NETWORKS FOR LONG-HAUL TRUCKING IN EUROPE (FRAUNHOFER ISI, 2024)

Published in 2024 by a team from the Fraunhofer Institute for Systems and Innovation Research (ISI) in collaboration with other researchers, this study presents a detailed framework for optimally locating high-power charging stations for long-haul electric trucks across Europe.

The study aims to identify optimal locations for installing truck charging points in Europe and, simultaneously, to define the minimum number of stations needed to cover the maximum percentage of long-haul routes. The analysis incorporates:

1. Traffic data (OD pairs): origins and destinations for freight transport across Europe.
2. Charging station candidates: thousands of potential locations (service areas, truck stops, etc.).
3. Capacity constraints: Each station has a limit on the number of trucks it can serve annually.
4. Travel parameters: truck autonomy, maximum driving times (linked to rest regulations), and recharging.

The study begins with over 50,000 truck stops across Europe, compiled from various sources including public databases and service area registries. Several filtering steps are then applied:

- Removal of duplicates and locations that are excessively close to each other (less than ~9 km).
- Prioritization of areas with higher potential (e.g., large service areas, stops with high truck traffic, or those near high-traffic corridors).

Following this filtering process, the number of locations is reduced to approximately 10,000. In the subsequent optimization phase, factors such as traffic density, accessibility, and the potential capacity of each site are analyzed. The algorithm then clusters and refines the results, generating a final set of 2,700 locations of strategic interest.

This means that, across various demand and coverage scenarios, these locations consistently emerge as ideal points for deploying charging infrastructure. However, it is important to note that this does not imply that charging stations must be installed at all of these locations; rather, they represent an expanded catalogue of options to be assessed based on specific needs and available resources.

From this strategic selection, the study processes approximately 1.5 million freight flows (OD pairs) across Europe, with projections extending to the year 2030. Only long-distance routes—defined as those exceeding approximately 335 kilometers—are considered in the analysis.

In this context, it is assumed that each station can serve up to 100,000 trucks per year. If the traffic volume on a route exceeds this capacity, additional stations must be added or alternative locations must be considered.

To determine the optimal placement of stations, the study employs an algorithm that, given a fixed "budget" of stations (e.g., 500, 1,000, etc.), selects their locations to maximize the coverage of electric truck traffic. This algorithm complies with several constraints: a maximum distance between stops based on EU driving and rest regulations (e.g., every 4.5 hours), a minimal route deviation (trucks cannot deviate more than 5% or add more than 30 minutes to their journey), and a capacity limit per station (no more trucks can be assigned than the station can handle annually).

Key findings show that with approximately 500 stations, it is possible to cover around 50% of all long-haul electric truck traffic, assuming 15% of the fleet is electrified. With 1,000 stations, coverage increases to 91% of long-distance traffic and approximately 75% of OD routes. Achieving coverage beyond 90% requires a substantial increase in the number of stations, particularly to serve lower-traffic routes or geographically challenging areas. The greater the capacity assigned to each station (e.g., 150,000 trucks/year instead of 100,000), the higher the coverage with the same number of locations. However, there are diminishing returns: increasing station capacity from 10,000 to 100,000 trucks brings substantial improvement, while increasing it further to 150,000 yields only marginal additional benefits.

The analysis also revealed several relevant insights. The algorithm tends to concentrate stations along the most heavily trafficked highways—such as the TEN-T network—demonstrating a natural clustering around major corridors. Additionally, assuming longer truck ranges (700 to 900 km) and high-power charging (650 to 1,000 kW) significantly reduces the number of required stations. In contrast, shorter ranges or lower charging power necessitate more charging points to meet the same demand.

Due to the vast number of OD routes, a random sampling system is used to manage the data volume efficiently. The study confirmed that even with samples representing just 1% of total routes, the results are consistent and can be extrapolated to the entire network.

Lastly, certain exceptions and limitations must be acknowledged. Areas with low traffic density or adverse geographical conditions may be excluded from the model or require tailored planning strategies. Moreover, this phase of the study does not take into account the actual electrical grid availability at each location—that is, whether the required megawatt-level power supply can realistically be installed.

The study demonstrates that with a relatively moderate number of high-power charging stations, a significant portion of long-haul electric truck traffic in Europe can be accommodated. The findings highlight the importance of focusing on high-traffic corridors and deploying high-capacity stations to effectively meet future demand.

Nevertheless, identifying 2,700 potential strategic locations does not imply that all of them should be developed into charging stations. These locations are presented as a broad set of options, offering flexibility in the design of charging networks. The final decision on how many stations to build, and where, depends on additional factors such as actual demand evolution, available investment, and the energy planning strategy of each region.

3.1.2 Interactive maps: Electric Trucks Stop Locations in Southern Europe (ACEA, 2025)

The interactive map published by the European Automobile Manufacturers' Association (ACEA)—Electric Trucks Stop Locations in Southern Europe—provides a georeferenced inventory of service areas frequently used by heavy-duty vehicles in Spain, Portugal, Italy, and Greece. Each record includes the exact location of the stop and the average duration of stay: less than one hour (regulatory driving break) or more than eight hours (daily rest or overnight stop).

This dataset is particularly valuable for two reasons. First, it confirms the corridors with the highest density of heavy traffic—most notably in Spain, the AP-7/A-7 corridor and access routes to major Mediterranean ports. This observation reinforces the initial selection of locations along the TEN-T network. Second, the distinction between short and long stops allows for a qualitative estimation of the power levels that future infrastructure may require: high-power charging for short driving breaks versus moderate-power charging for overnight stays.

It is important to note, however, that the ACEA map does not provide information on the availability of electrical connections or on planned deployments of charging infrastructure. Therefore, in this study, it is used as a snapshot of current truck operations—and as an empirical complement—but the sizing of chargers is based exclusively on the hourly traffic profiles provided by MITMA's permanent monitoring stations.

3.1.3 Complementing the Fraunhofer study and ACEA resource

The Fraunhofer ISI study and the interactive maps provided by ACEA offer a highly complementary approach, as each contributes essential elements for planning a charging network for electric trucks. ACEA provides an accurate depiction of current operational patterns, based on empirical data from the GPS tracking of approximately 400,000 trucks across Europe, accounting for around 750,000 stops aggregated into more than 30,000 distinct locations. Of this total, the top 50% of locations concentrate nearly 50% of all recorded stops, enabling the precise identification of the most relevant stopping points. This analysis is critical for prioritizing charging infrastructure in locations with established operational use, and ACEA recommends that these sites be equipped with MCS chargers by 2027.

On the other hand, the Fraunhofer ISI study also relies on real-world data—including the same GPS clusters recorded by ACEA—but enriches it with public station data and GIS criteria, resulting in a total of 10,624 candidate points. These locations are then processed through the CHALET model, which incorporates projected freight flows to 2030 in order to define an efficient network of up to 1,000 high-power MCS charging stations capable of covering 91% of long-distance transport demand. The goal of the Fraunhofer study is not to describe current stopping behavior, but to design an optimal infrastructure for the future electric fleet.

The complementarity between the two approaches is strategically articulated across three dimensions:

- Empirical validation: ACEA identifies where truck stops actually occur most frequently, while Fraunhofer proposes an optimized network. The overlap between the two datasets enables a consistency check of the model by highlighting both well-established nodes and underutilized sites with high future potential.
- Deployment prioritization: In the strategic proposal, priority is given to the charging sites identified by Fraunhofer as optimal that fall within a 5 km radius of any ACEA top-50% location. This proximity criterion ensures that selected sites are not only theoretically optimal but also demonstrate significant real-world usage. Moreover, a 5 km radius is logistically appropriate, as it minimizes route deviations and aligns well with the spatial resolution of both data sources.
- Energy needs coverage: By combining both studies, it becomes possible to determine not only the optimal locations but also the appropriate infrastructure sizing based on actual truck stopping patterns. This is essential for adapting deployment plans to the concrete demands of freight operations.

In conclusion, while Fraunhofer ISI provides a forward-looking optimized network based on real data and future projections, ACEA contributes a layer of current operational reality. Integrating both, through the application of a 5 km proximity filter between the optimized network and the top 50% of real-world stops, allows for the development of a deployment strategy that balances technical efficiency with operational feasibility.

3.2 SPATIAL ANALYSIS USING QGIS

To perform the spatial analysis required for selecting candidate locations, a QGIS project was created specifically for this study. The main objective of this phase was to integrate and visualize the relevant datasets in a geospatial environment in order to identify high-potential areas along the Mediterranean Corridor. The procedure began with the creation of a new QGIS project

3.2.1 CREATE PROJECT IN QGIS

The procedure begins with the creation of a new QGIS project and the configuration of the coordinate reference system to ensure compatibility with international datasets. As a visual aid, the Bing Maps base layer is added to the project. This map provides high-resolution satellite imagery and road information, which proved particularly helpful for contextualizing the locations of truck parking areas (from ACEA) and freight flow lines (from Fraunhofer), especially in less urbanized zones. In order to achieve all of this, the next steps must be followed.

Step 1:

Open QGIS (version 3.42.1). Create a new project from the top menu by clicking:

Project → New

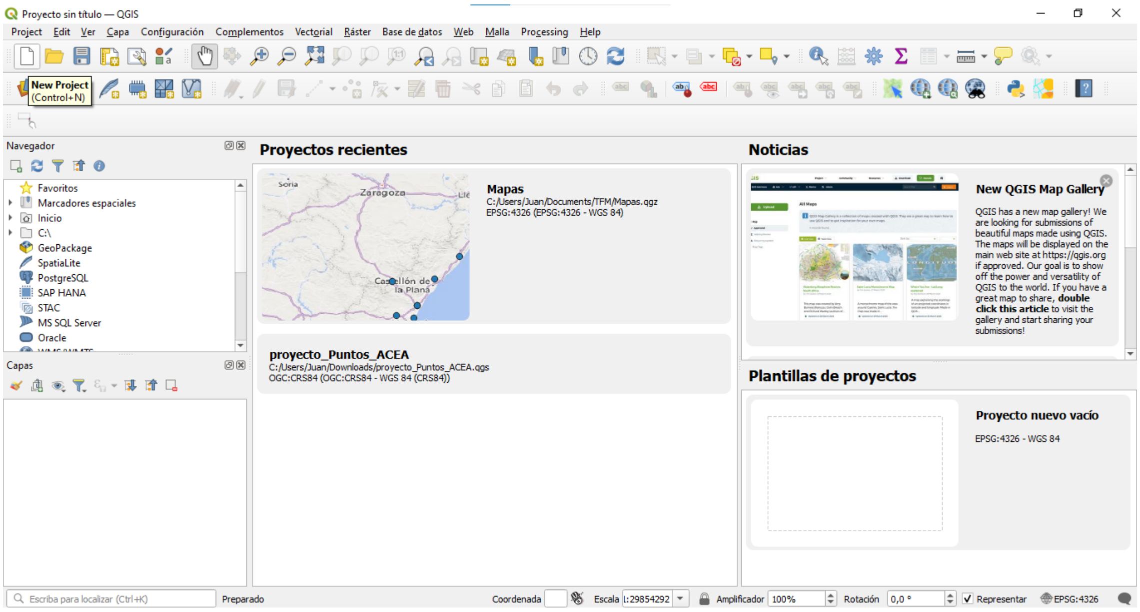


Figure 6. QGIS Main Menu

Step 2: Add Bing Basemap

To insert a Bing basemap using the plugin manager, follow these steps:

- Go to the top tab Plugins → Manage and Install Plugins
- In the pop-up window, search for QuickMapServices and click Install Plugin (if it is not already installed)

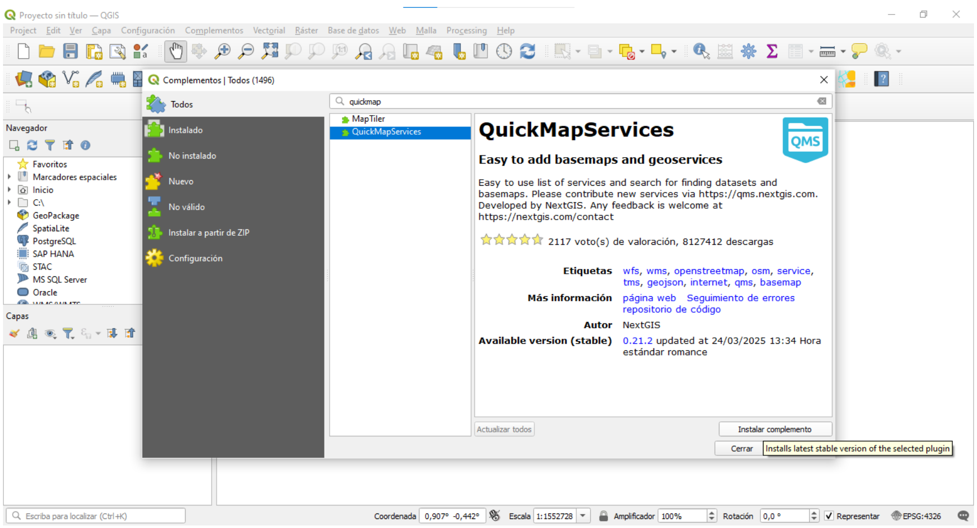


Figure 7. Installing QuickMapServices

- Once installed, go to the top menu Web → QuickMapServices → Bing → Bing Aerial (or select your preferred Bing map option)
- Upon selection, the Bing basemap will automatically be added to the QGIS project, providing a clear geographic reference for importing and visualizing project data

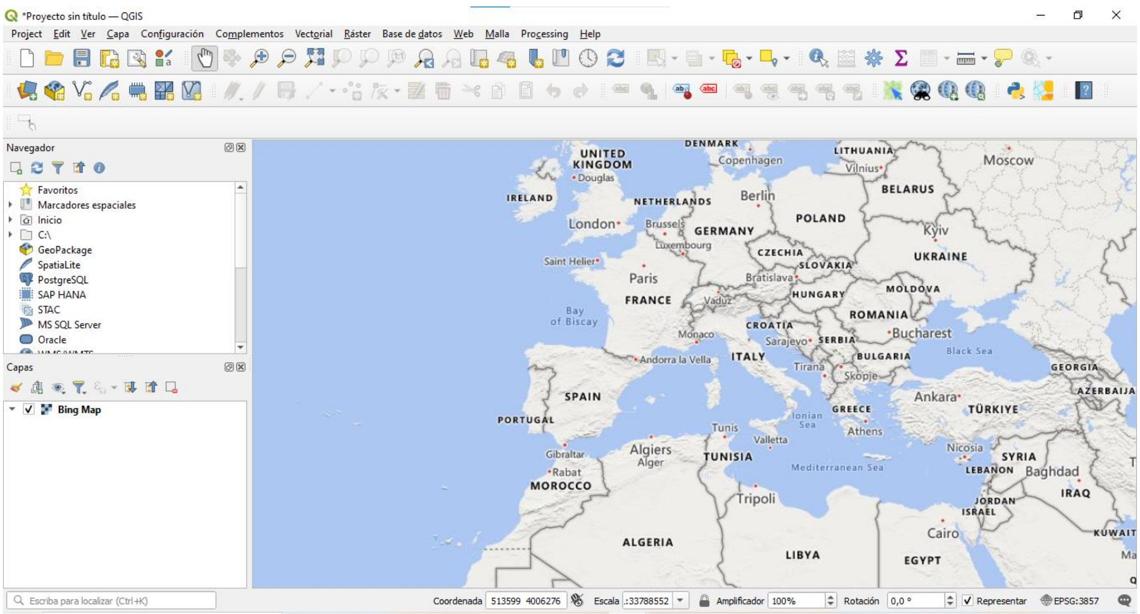


Figure 8. Adding Bing Map to QGIS

When adding the Bing basemap through QuickMapServices, it is common for it to load using a different Coordinate Reference System (CRS)—typically EPSG:3857. An EPSG code identifies the coordinate system used to accurately place geospatial data on the map.

To ensure all data layers align properly with this basemap, QGIS will automatically reproject any subsequently imported layers, if you correctly specify their original CRS (in this case, EPSG:3035 for the CSV files). Therefore, no manual adjustment is needed, just make sure to select the appropriate CRS during the import process for each dataset.

When adding the Bing basemap via QuickMapServices, it typically loads using a different Coordinate Reference System (CRS), most commonly EPSG:3857. An EPSG code identifies the coordinate system used to accurately position geospatial data on a map.

To ensure that all visualized data aligns correctly with the basemap, QGIS will automatically reproject any subsequently imported layers—as long as you specify their original CRS correctly during the import process. For the CSV files used in this project, the original CRS is EPSG:3035.

Therefore, no additional adjustment is required. Simply make sure to select the appropriate CRS (EPSG:3035) when importing each dataset, and QGIS will handle the reprojection to match the basemap.

3.2.2 IMPORT DATA INTO QGIS

Step 1:

The Fraunhofer dataset is provided in CSV format with geographic coordinates (longitude and latitude). To import it into QGIS:

Click on Layer → Add layer → Add Delimited Text Layer.

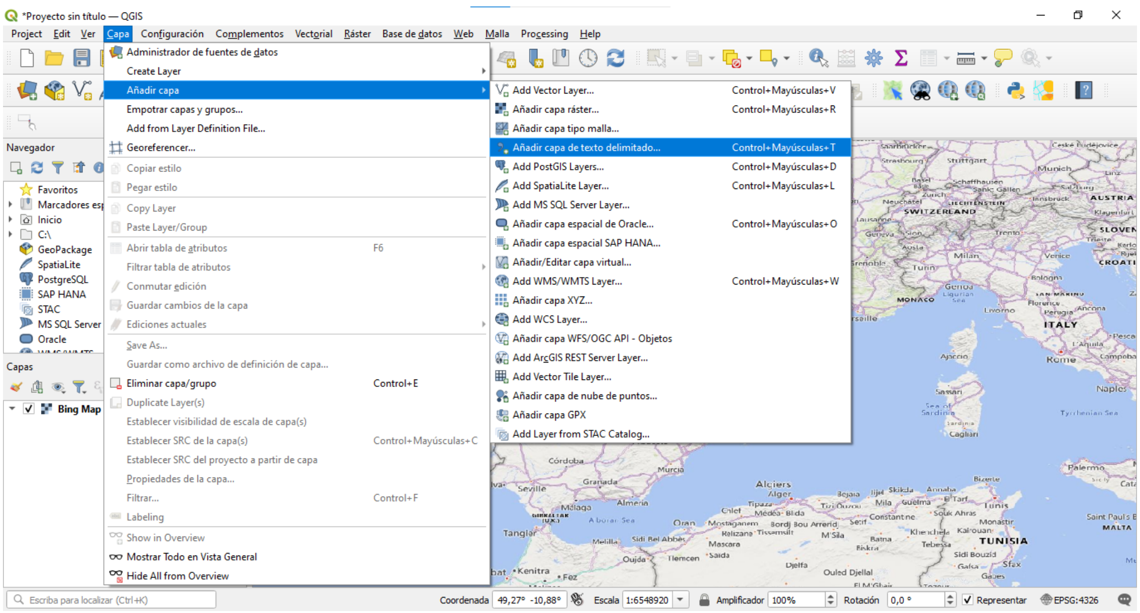


Figure 9. Adding a layer in QGIS

Step 2:

Configure Import Settings in the Pop-Up Window

- Click the button next to File Name and select the downloaded CSV file from the Fraunhofer study
- Set the Geometry Definition to Point (XY coordinates)
- Assign the coordinate fields correctly to the respective columns (typically named “longitude” and “latitude”)
- Choose the Coordinate Reference System (CRS): usually EPSG:4326 – WGS 84
- Finally, click Add to load the layer into the project

Once imported, the strategic points from the Fraunhofer study will be displayed on top of the Bing basemap.

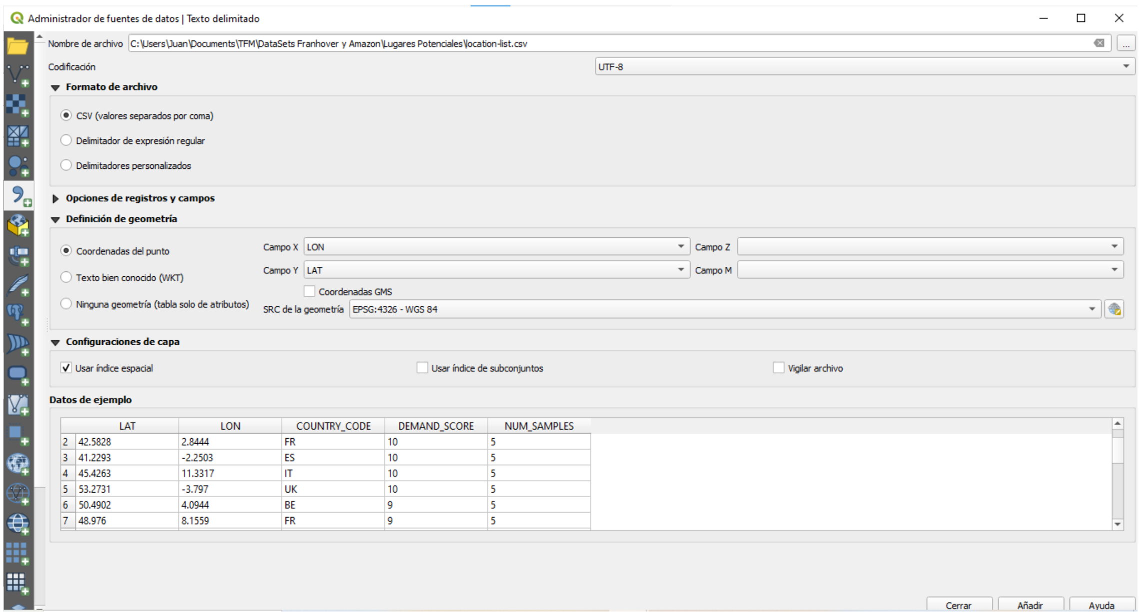


Figure 10. Layer import settings

3. Importing Data Collected from ACEA

The import process is identical to that used for the Fraunhofer dataset. The only difference is that, in Step 2, you select the manually compiled CSV file containing the ACEA data.

4. Combined Visualization and Preliminary Analysis

With both layers added to the Bing basemap, they can now be viewed simultaneously in QGIS.

This allows for a visual inspection of which strategic locations identified by the Fraunhofer study overlap with current truck stop points gathered from ACEA. This comparison helps determine the type of charging infrastructure (power and number of chargers) needed at each location.

To enhance readability and distinguish the datasets:

- In the Layers Panel (on the left side), right-click on each layer
- Select Properties → Symbology
- Choose different symbols or colors based on the data source (Fraunhofer vs. ACEA)

This visual distinction is key for effective spatial interpretation and informed decision-making.

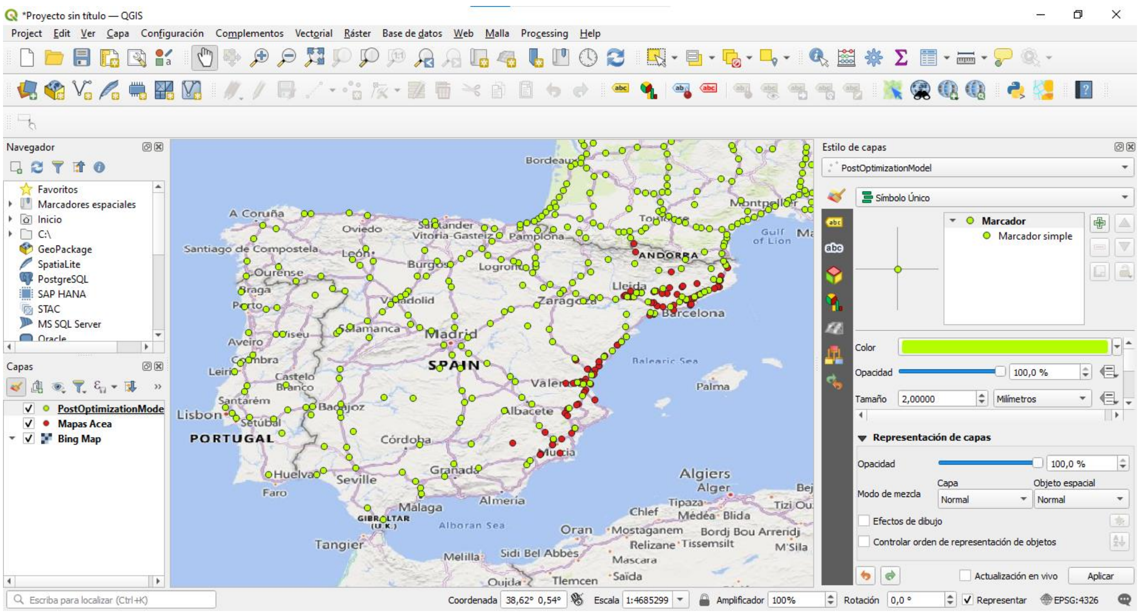


Figure 11. Fraunhofer and Acea spots

As shown in Figure 11. Fraunhofer and Acea spots, the Layers Panel located in the bottom-left corner displays the active layers currently being visualized on the map:

Mapas Acea: This layer corresponds to the data obtained from the ACEA interactive resource. It includes only the locations within the Autonomous Communities of Catalonia, Valencia, and Murcia, as data collection was limited to these regions, which constitute the study area for this project.

PostOptimizationModel: This layer contains the strategic points extracted from the Fraunhofer study.

On the right-hand side, the Layer Properties Panel corresponding to the selected layer (PostOptimizationModel) is displayed. In this case, the visual style of the layer has been set to yellow, allowing it to stand out on the map. Previously, the ACEA data layer was configured with a red color to clearly differentiate both data sources on the map.

This visual distinction facilitates direct spatial comparison between theoretical strategic locations (Fraunhofer) and actual truck stop usage patterns (ACEA), enhancing the clarity and utility of the analysis.

3.2.3 CREATING A BUFFER

All points from the Fraunhofer catalog represent real service areas or rest stations. However, the study selects them from a purely optimization-based perspective, taking into account factors such as route coverage, estimated vehicle range, and annual capacity. In contrast, the ACEA cartography adds a quantitative dimension: it indicates which areas are actively used by the diesel fleet and how frequently. The objective of the spatial cross-analysis is therefore not to discard non-existent locations, but rather to prioritize those where the strategic relevance identified by Fraunhofer converges with empirical evidence of use provided by ACEA.

The analysis was carried out in QGIS 3.42 following the steps described below. First, both layers were reprojected to the ETRS89 / UTM Zone 30N coordinate system (EPSG 25830) in order to work with consistent metric units. Then, a circular buffer with a radius of five kilometers was created around each ACEA stop. This distance corresponds to a maximum deviation of approximately five minutes of driving on a high-capacity road. The Intersect tool was subsequently used to determine which points from the Fraunhofer catalog fell within at least one of the ACEA buffers. The spatial cross-analysis made it possible to distinguish between two groups of locations. The first group consists of sites that have dual support: they are identified as optimal by the Fraunhofer model and are also located within five kilometers of a stop regularly used by the diesel fleet. The second group includes those points that are only supported by the theoretical Fraunhofer model, with no nearby stop recorded by ACEA.

For the Spanish Mediterranean corridor, approximately one-third of the locations fall into the first group, which represents dual evidence of demand. While both groups are retained in the analysis, the locations with dual support are considered high priority when planning the deployment phase, as they combine strategic coverage with anticipated operational acceptance. This prioritization criterion aligns with the coverage logic of the Fraunhofer model while also increasing the likelihood of successful and timely commissioning.

It is important to note that the five-kilometer buffer does not affect the calculations for power capacity or the number of chargers, which are determined based on the hourly traffic profiles provided by MITMA's permanent monitoring stations. The Fraunhofer–ACEA spatial overlay serves exclusively as a prioritization filter to enhance operational robustness, without altering the electrical sizing developed in the following chapters.

What follows is a step-by-step explanation of how to create the buffer in QGIS.

Step 1:

- In QGIS, go to the top menu: Vector→ Geoprocessing Tools→ Buffer.

When configuring the buffer using the MapasAcea layer, it is common for the distance to appear in degrees—units associated with the EPSG:4326 coordinate reference system—rather than in kilometers. This occurs because the original layer uses geographic coordinates (latitude and longitude), where degrees are the default unit of measurement, not metric units like kilometers.

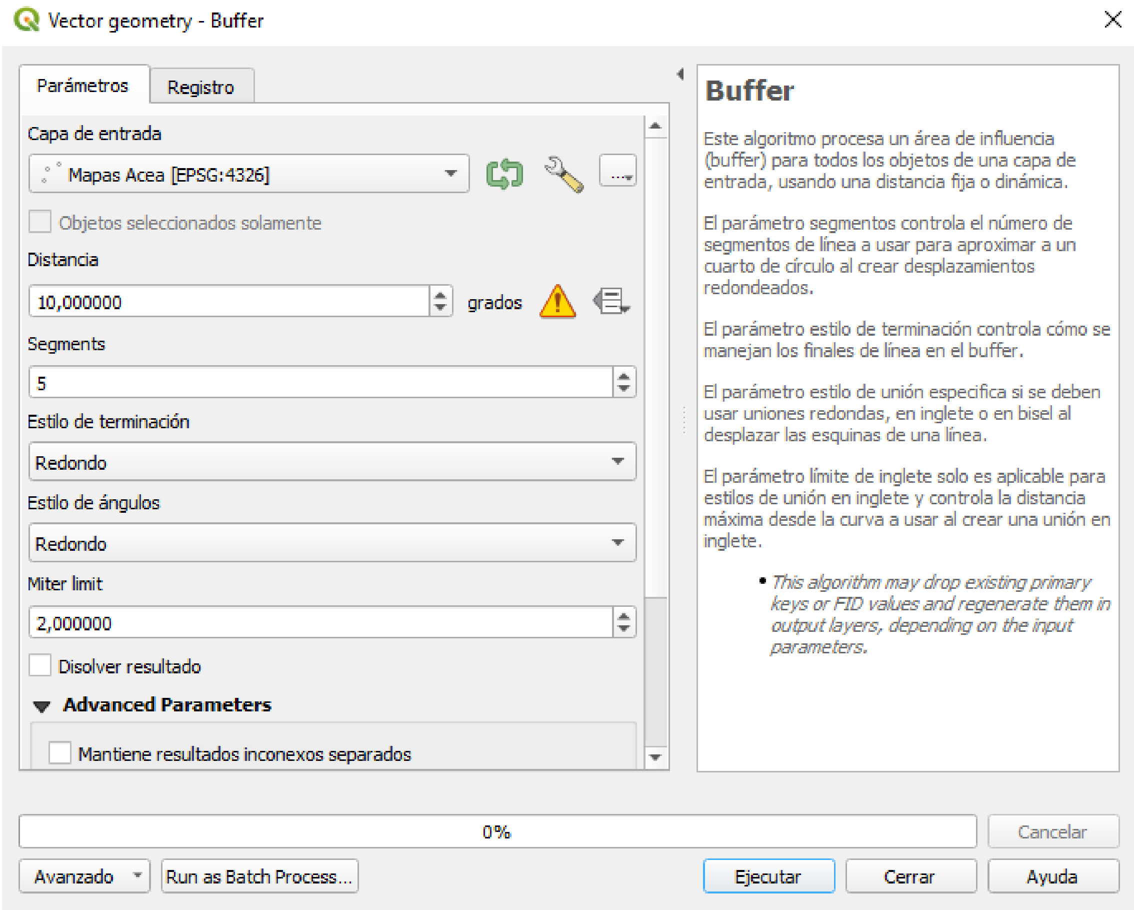


Figure 12. Buffer settings in degrees

Step 2:

To generate the buffer correctly in kilometers, it is first necessary to reproject the original layer to a projected coordinate system that uses meters as its unit of measurement. This can be done as follows:

- From the top menu, select:

  Vector → Data Management Tools → Reproject Layer.

- In the pop-up window, configure the following options:
  - Input Layer: Select original layer (MapasAcea).
  - Target SRC: Choose a projected system, such as EPSG:3035 (suitable for the Iberian Peninsula). If the study area covers other regions, select a CRS appropriate for that area
  - Click on Execute.

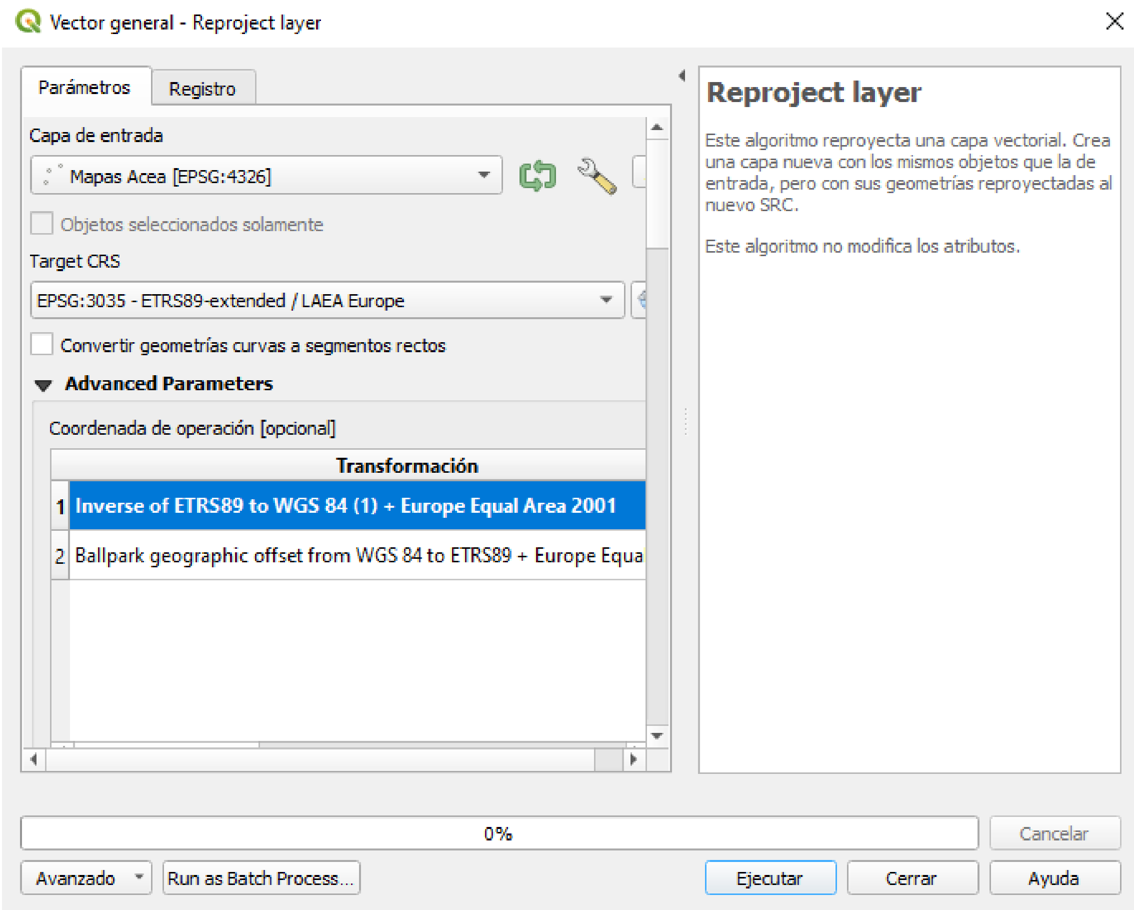


Figure 13. Reproject layer settings

The new layer will now appear in QGIS with the default name “Reprojected” and a randomly assigned color. To avoid confusion, it is advisable to rename this new layer to MapasAcea and delete the original one. Additionally, you should assign the same color to this new layer that was previously used, in order to maintain visual consistency. This updated layer now uses metric units, making it suitable for buffer generation.

Step 3:

Repeat the buffer creation process using the newly reprojected layer::

- Top Menú: Vector → Geoprocessing Tools → Buffer.
- In the pop-up window, configure the following settings:
  - Input Layer: "MapasAcea".

- Distance: Select 5 kilómetres.
- Click on Execute.

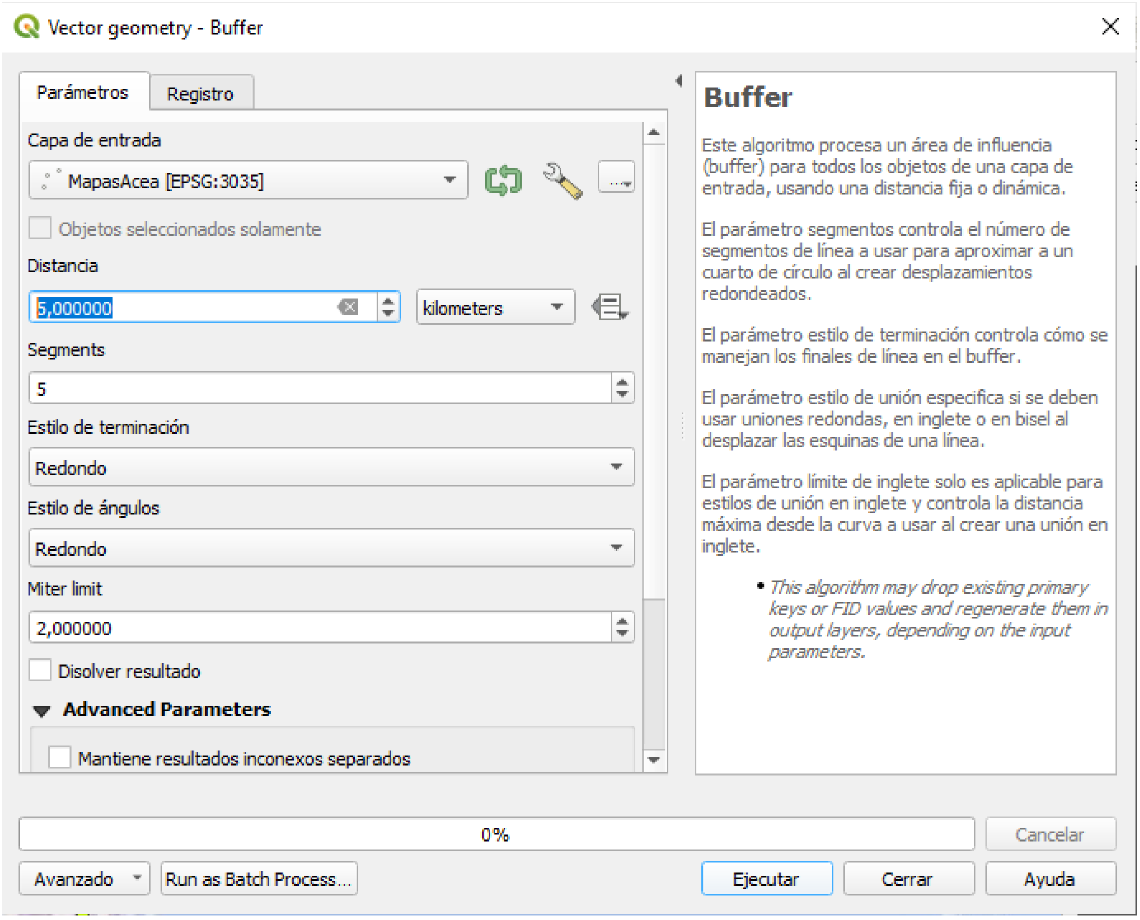


Figure 14. Buffer settings in kilometers

The newly generated layer correctly represents a 5-kilometer area of influence around each point.

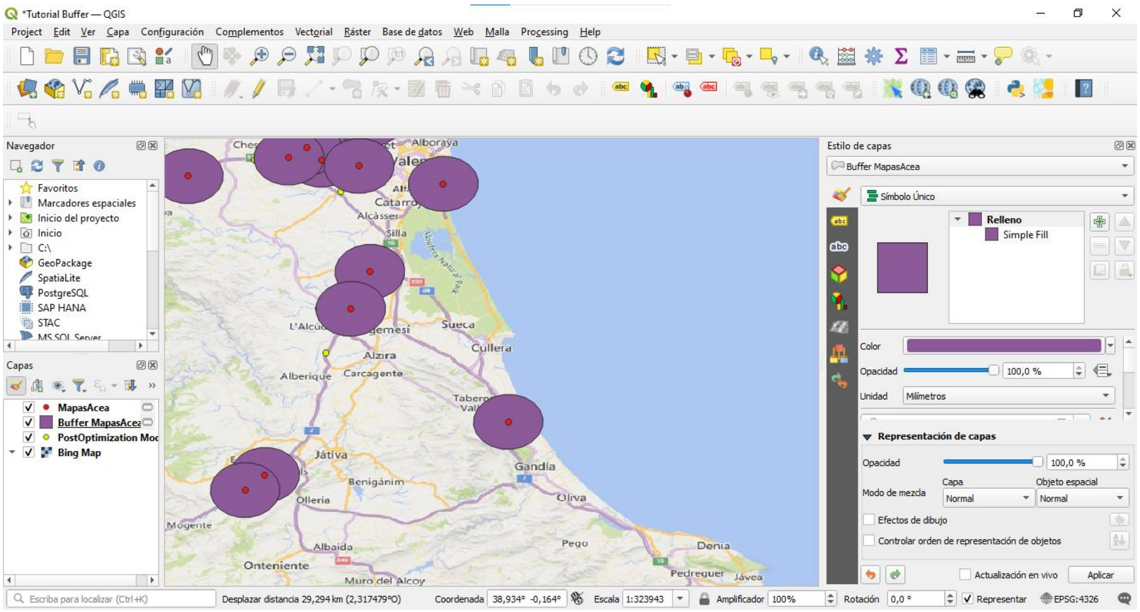


Figure 15. Visual representation of the buffers generated

3.2.4 Intersection to Identify Suitable Locations for Sizing

Once the 5-kilometer buffer has been generated around the ACEA points, the next step is to identify which of the strategic locations from the Fraunhofer study fall within this area of influence.

For the intersection analysis to be valid, the Fraunhofer layer must be in the same Coordinate Reference System (CRS) as the buffer layer—for example, EPSG:25830. Therefore, the Fraunhofer layer must also be reprojected using the same method as before.

Paso 1:

- Top Menu: Vector → Data Management → Reproject Layer.
  - Input Layer: Select Fraunhofer Layer ("PostOptimizationModel").
  - SRC objetivo: EPSG:25830.
  - Save the new Layer.
  - Click on Execute.

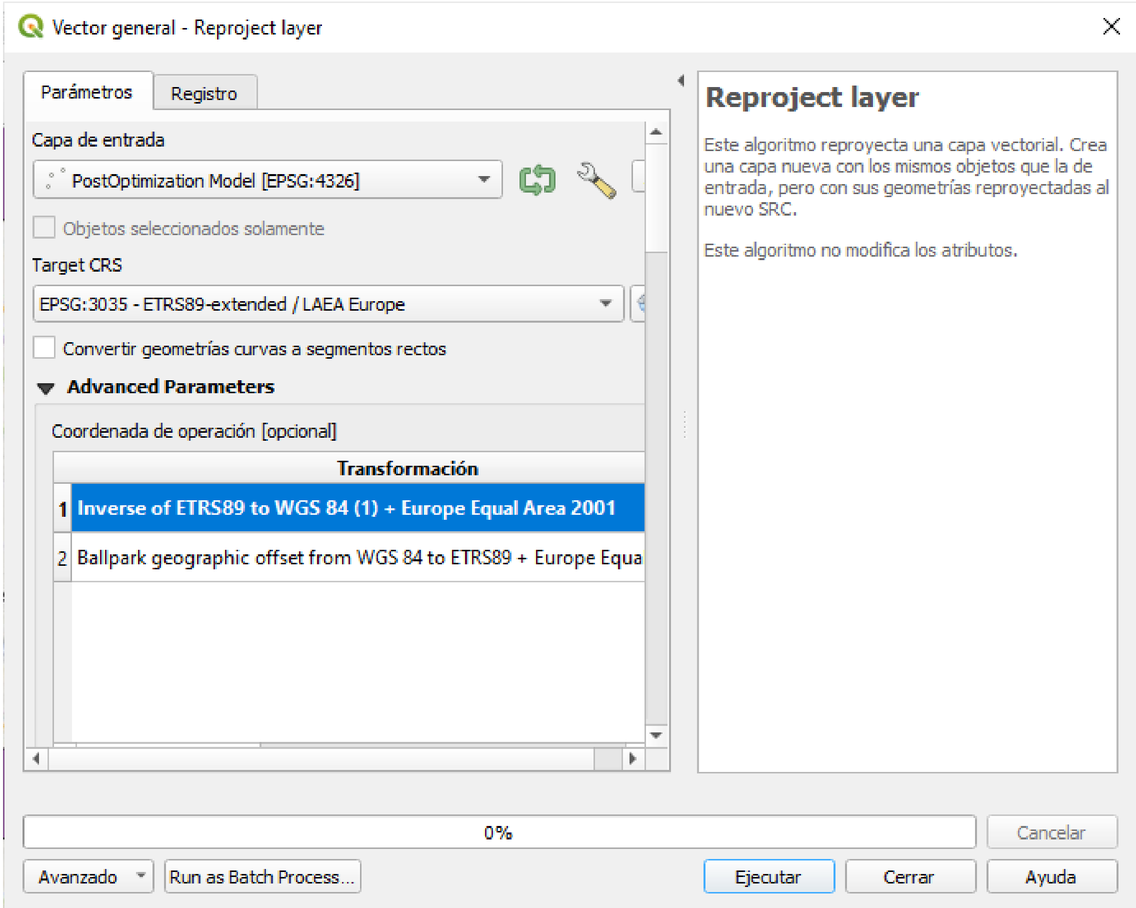


Figure 16. Reproject layer settings

The new layer will now be named “Reprojected” by QGIS and assigned a random color. To avoid confusion, rename this layer to PostOptimizationModel and delete the original one. You should also apply the same color that was previously assigned to maintain visual consistency. This updated layer now uses metric units (meters) and is fully compatible for geoprocessing operations such as intersection.

Step 2:

- Top Menu and select: Vector → Geoprocessing Tools→ Cut.

Step 3:

- In the pop-up window, configure the following settings:

- Input layer: select the reprojected Fraunhofer layer ("PostOptimizationModel")
- Overlay layer: select the buffer layer ("Buffer_MapasAcea")
- Output file: specify a file path and name for the resulting layer (e.g., "Fraunhofer_within_Buffer.shp")
- Click on Execute.

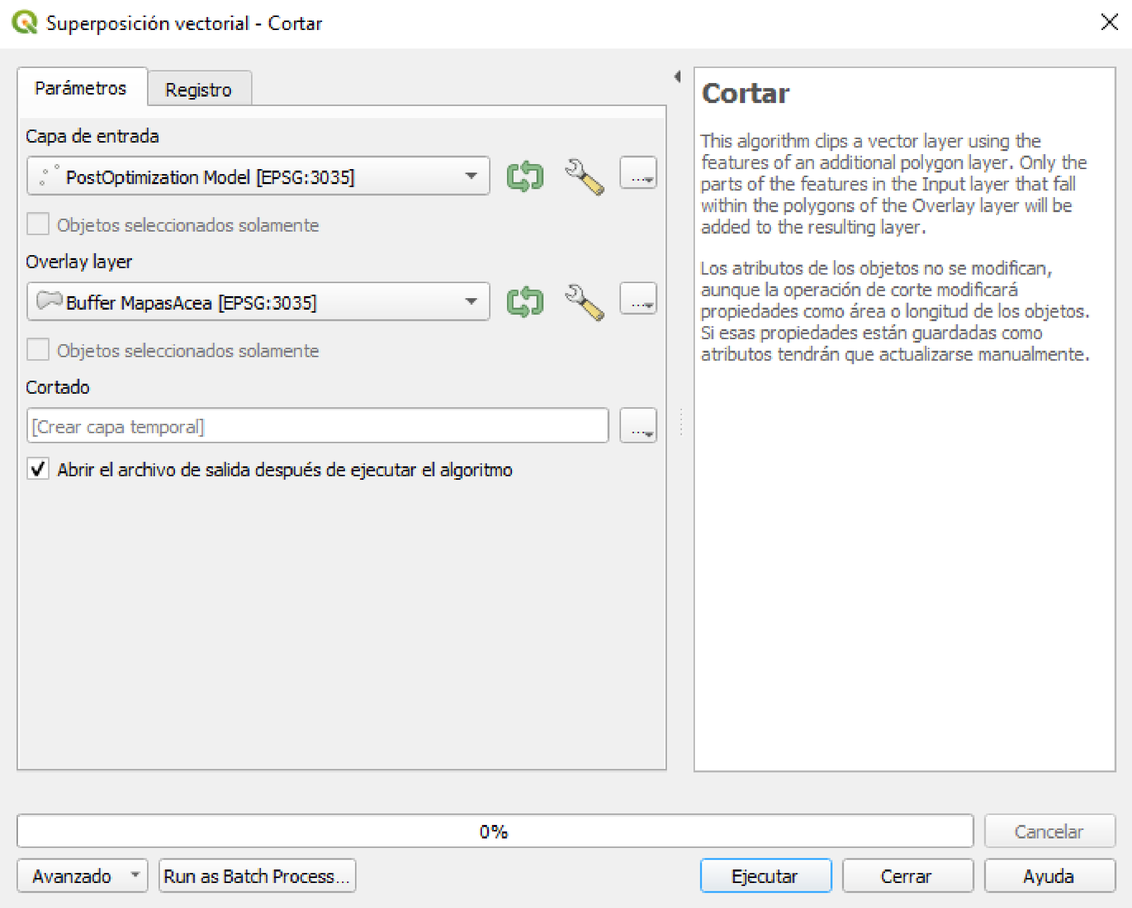


Figure 17. Cut settings

The result will be a new layer containing only the points from the Fraunhofer study that fall within the 5-kilometer radius around ACEA stops. These points will be the only ones used in the subsequent sizing of electric truck charging stations.

The following three figures illustrate the spatial analysis process carried out in QGIS to identify the strategic points from the Fraunhofer study that fall within the 5-kilometer area of influence surrounding current diesel truck stop locations, as indicated by the ACEA interactive map.

Figure 18. Zoom in of Acea spots and buffers

In Figure 18. Zoom in of Acea spots and buffers, the layer corresponding to the ACEA points is shown in red, along with the 5-kilometer-radius buffers generated around each of them, represented as purple circles. These buffers define the area within which it is assumed that diesel and electric trucks could exhibit similar stopping behavior in terms of stop type.

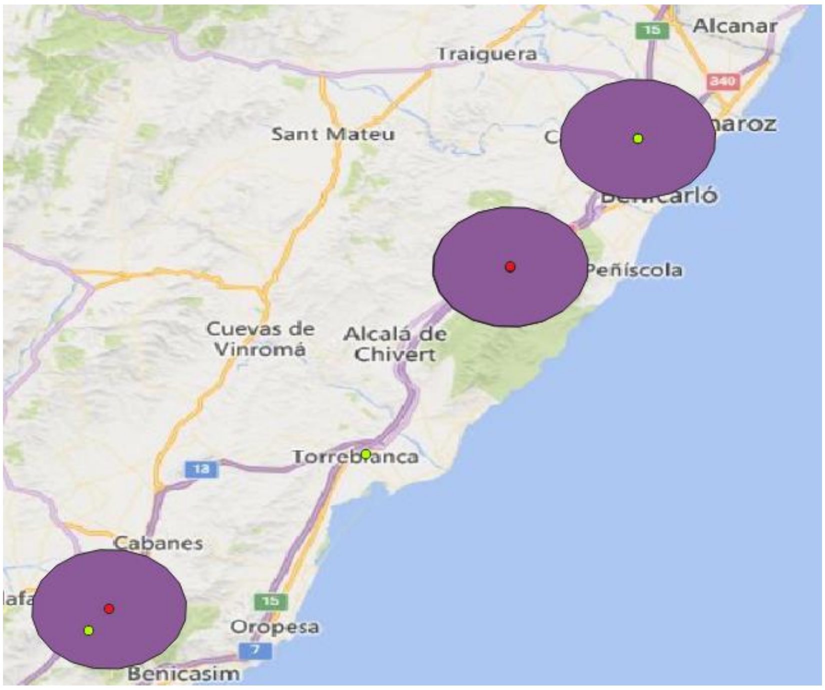


Figure 19. Zoom in of Acea spots, Fraunhofer spots and buffers

In Figure 19. Zoom in of Acea spots, Fraunhofer spots and buffers, the strategic locations from the Fraunhofer study have been added and are shown in yellow. It can be observed that some of these points fall within the buffers generated around the ACEA locations, with some even coinciding exactly. These points will be the only ones considered in the subsequent analysis, as their presence within the area of influence suggests that electric trucks are likely to stop in a manner similar to current diesel truck behavior according to ACEA data.

Figure 20. Zoom in of Fraunhofer spots within ACEA area

Finally, Figure 20. Zoom in of Fraunhofer spots within ACEA area shows the result after applying the Clip tool in QGIS. Only the Fraunhofer study points that fall within the ACEA buffers remain—that is, the locations for which precise infrastructure sizing is possible, based on the predominant stop type observed at each site.

This analysis allows for refining the initial set of locations proposed by Fraunhofer, focusing exclusively on those backed by real-world truck behavior data. In doing so, it ensures greater accuracy when planning what type of chargers to install (fast or slow) and how many, according to the expected usage at each site.

3.2.5 ADDING TRUCK FLOW DATA

A large number of potential locations have been identified for the installation of electric truck charging stations. However, this abundance poses a challenge in terms of optimization and efficiency. Since charging demand is not uniformly distributed along the TEN-T network, it is necessary to filter these locations to focus on the most strategic ones. Those will provide the best access and service to electric trucks.

To perform this selection, there will be taken into account two key factors: the distance of each location to the TEN-T network and the truck flow in the road segments closest to those locations.

Truck flow data reveals the areas of highest traffic density along the TEN-T network, allowing us to identify the routes with the greatest demand for charging infrastructure. Meanwhile, proximity to the TEN-T network ensures that charging stations are located at easily accessible points for trucks, minimizing detours and charging-related downtime. By combining both factors, it can be determined the most cost-effective and efficient locations for installing charging stations.

The article "Synthetic European Road Freight Transport Flow Data" (Fraunhofer ISI, 2022) provides a detailed analysis of heavy truck flows in Europe, including estimates of truck traffic on the TEN-T network. This dataset is essential for understanding freight flows and truck movement across major European transport corridors.

The article is based on official transport data sources, such as the ETISplus project (European commission, 2013) and Eurostat (Eurostat, 2025), which are used to update model road freight flows across Europe. In the ETISplus study, growth factors are applied internally to adjust traffic volumes to 2019 levels and to project them forward to 2030. These adjusted flows are then assigned to minimum-cost routes on the European road network using Dijkstra's algorithm, resulting in a synthetic dataset of truck traffic.

The purpose of this dataset is to provide an accurate and representative view of truck flows between Europe's major cities and logistics hubs. This helps identify high-traffic areas and, consequently, those most in need of charging infrastructure such as electric truck charging stations.

It will be use the truck flow data from the "Synthetic European Road Freight Transport Flow Data (January 2022)" along with four Excel files containing key information on the TEN-T network and the candidate locations for charging stations. These files provide the following data:

- 04_network-edges.csv: Contains information about the segments of the TEN-T network, including the ID of each segment, start and end coordinates, and the length of each road segment. This file is essential for calculating the distance between charging stations and segments of the TEN-T network.
- 03_network-nodes.csv: Provides the geographic coordinates of the TEN-T network nodes. Each node represents a connection point between segments, which is fundamental for defining the geometry of the network and calculating distances from charging stations to the TEN-T network.
- 02_NUTS-3-Regions.csv: Contains data on NUTS-3 regions, which are administrative divisions in Europe. This file is used to organize and classify charging stations by region and facilitate spatial analysis of the locations.
- 01_network-nodes.csv: Contains the coordinates of the proposed charging station locations. This file provides the geographic information necessary to represent and calculate the distance between charging stations and road segments on the TEN-T network.

These files provide the essential data needed to calculate distances and truck flows accurately, thereby identifying the most suitable locations for charging station deployment.

3.2.5.1 Loading the Data into QGIS

The first step is to load the TEN-T network nodes, which contain the coordinates of the connection points between road segments. This is essential because the nodes define the start and end of each segment, enabling the calculation of distances from charging stations to the TEN-T network.

- In QGIS, go to: Layer → Add Layer → Add delimited Text Layer

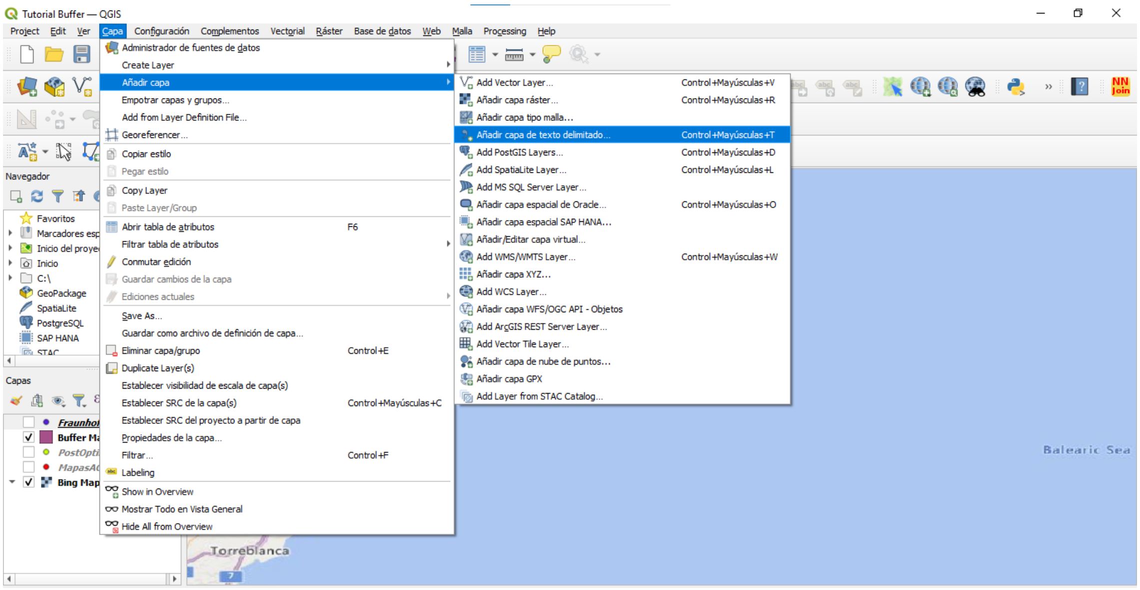


Figure 21. Adding a layer

- Load 03_network-nodes.csv, which contains coordinates of the nodes.
- In the import dialog window, assign the following fields: For X coordinate select the column Network_Node_X and for Y coordinate, select the column Network_Node_Y

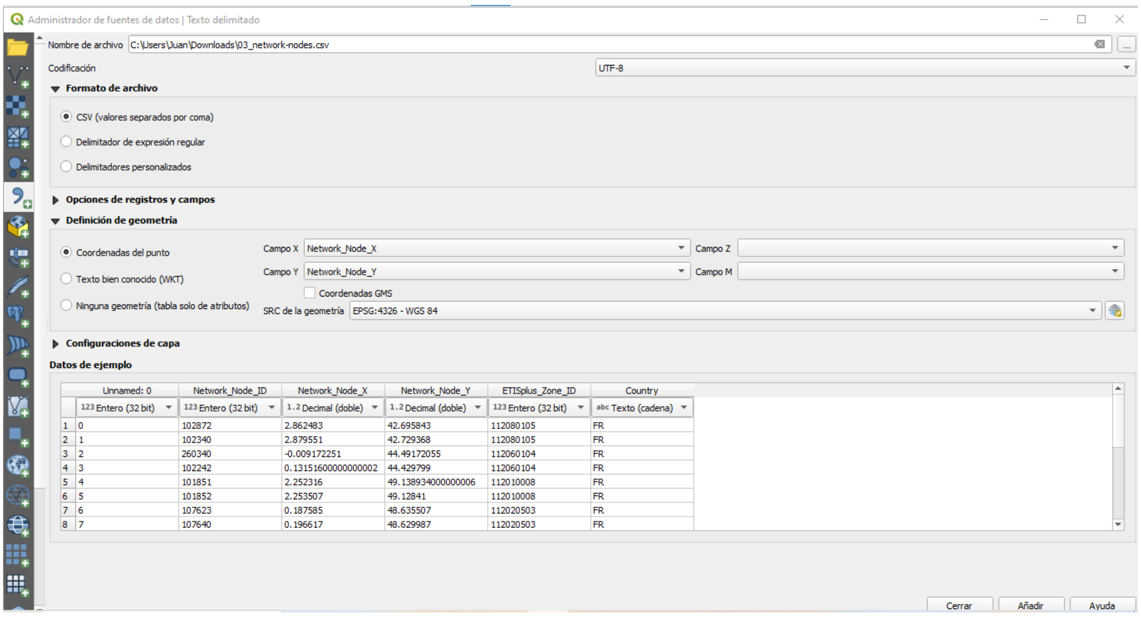


Figure 22. Layer import settings

- Finally, set the CRS to EPSG:4326 (WGS 84), which is the standard geographic coordinate system. This ensures that the coordinates are interpreted correctly and that the points are accurately placed on the map.Una vez cargados los nodos, se ven los puntos en el mapa, que representarán los lugares donde los tramos de carretera de la red TEN-T se conectan.

Once the nodes have been loaded, they will appear as points on the map, representing the locations where the segments of the TEN-T road network connect.

Next, it is needed to load the TEN-T road segments, which represent the actual stretches of road connecting the nodes. This file contains the segment IDs and the IDs of the start and end nodes, but does not include geographic coordinates. Therefore, it cannot be loaded directly as a geometry layer.

- In QGIS, go to: Layer → Add Layer → Add Delimited Text Layer.

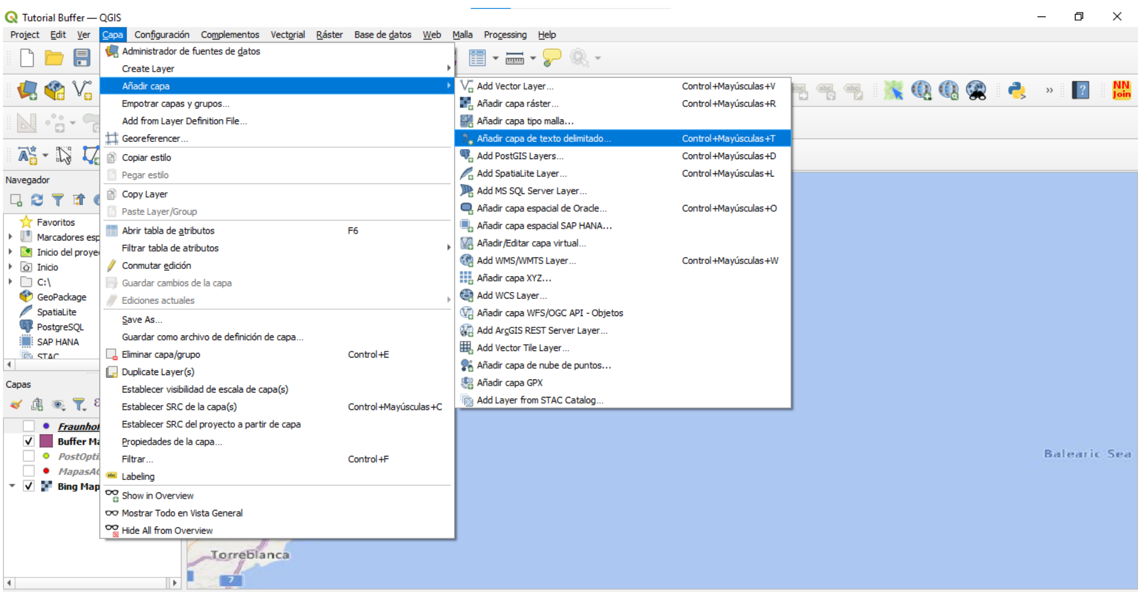


Figure 23. Adding a layer

  - Load the file 04_network-edges.csv, which contains information about the road segments.
  - Since this file does not include geographic coordinates, it must be imported as a non-spatial table. Therefore, in the import dialog window, do not select any fields for the X or Y coordinates—this will ensure the file is loaded as a simple attribute table without geometry.

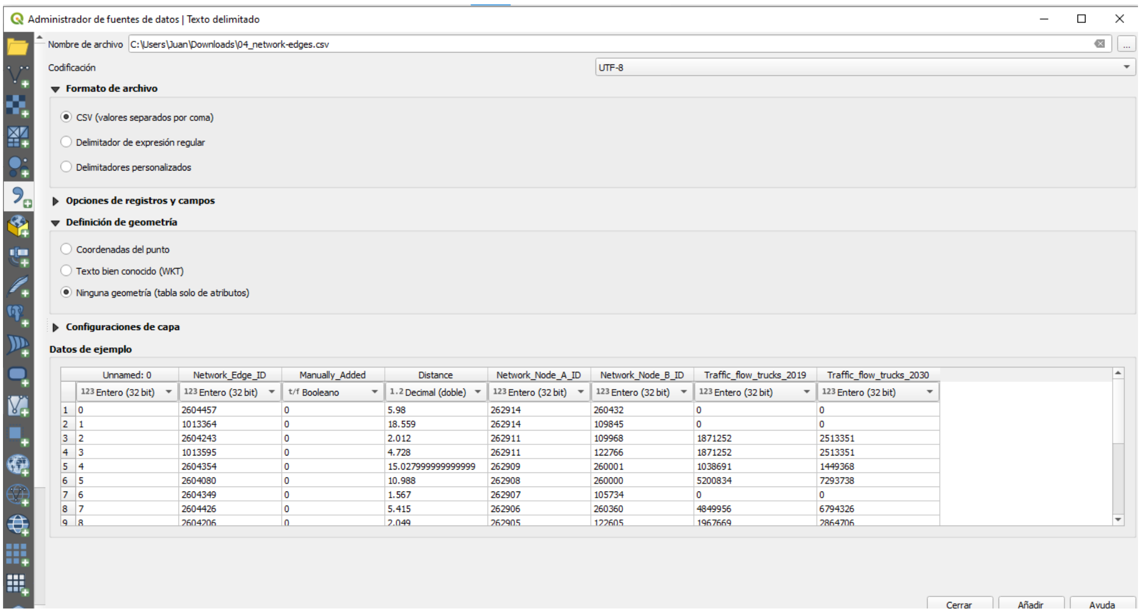


Figure 24. Layer import settings

The table is containing the road segments, but it still lacks geometry—only the segment IDs and references to the start and end nodes of each TEN-T segment are available.

3.2.5.2 Joining Attributes Between Nodes and Segments

Next, it will use the "Join attributes by field value" tool to add the coordinates of the nodes to the segments table. This step is essential because it is needed for both the start and end coordinates of each segment in order to construct the line geometries of the TEN-T network.

3.2.5.2.1 Join the Origin Nodes (Node A)

- In QGIS, go to: View → Panels → Toolbox
- On the right side of the screen, a toolbox panel will appear with various processing tools. The number and type of tools available can vary depending on the plugins you have installed. (Some tools may be different or additional if plugins are activated.)

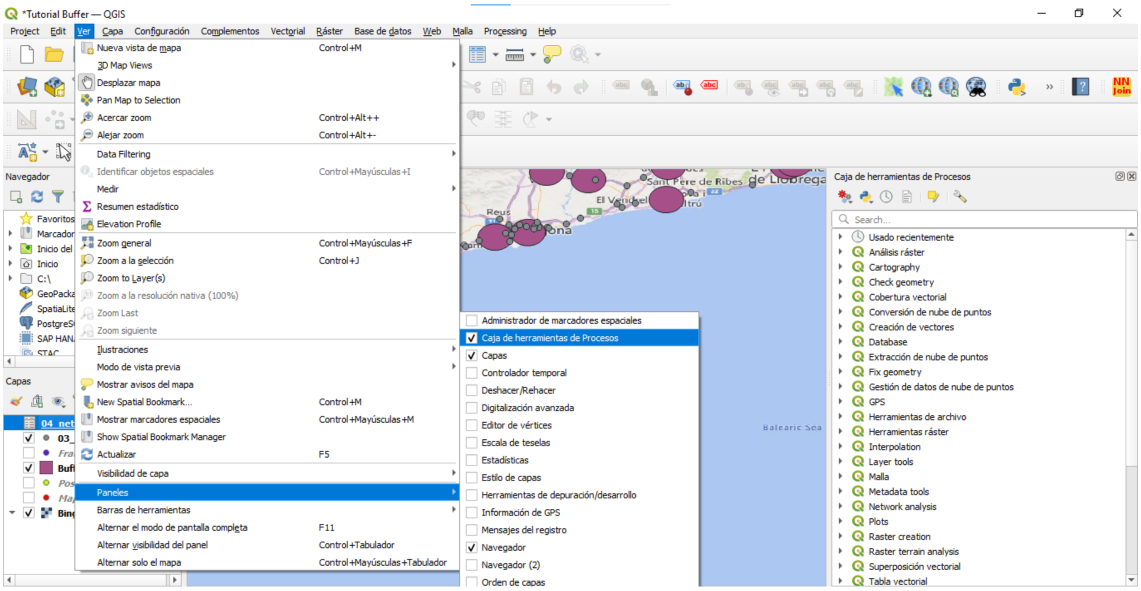


Figure 25. QGIS' Toolbox

- In the Processing Toolbox panel, search for the tool “Unir atributos por valor de campo” (Join attributes by field value).

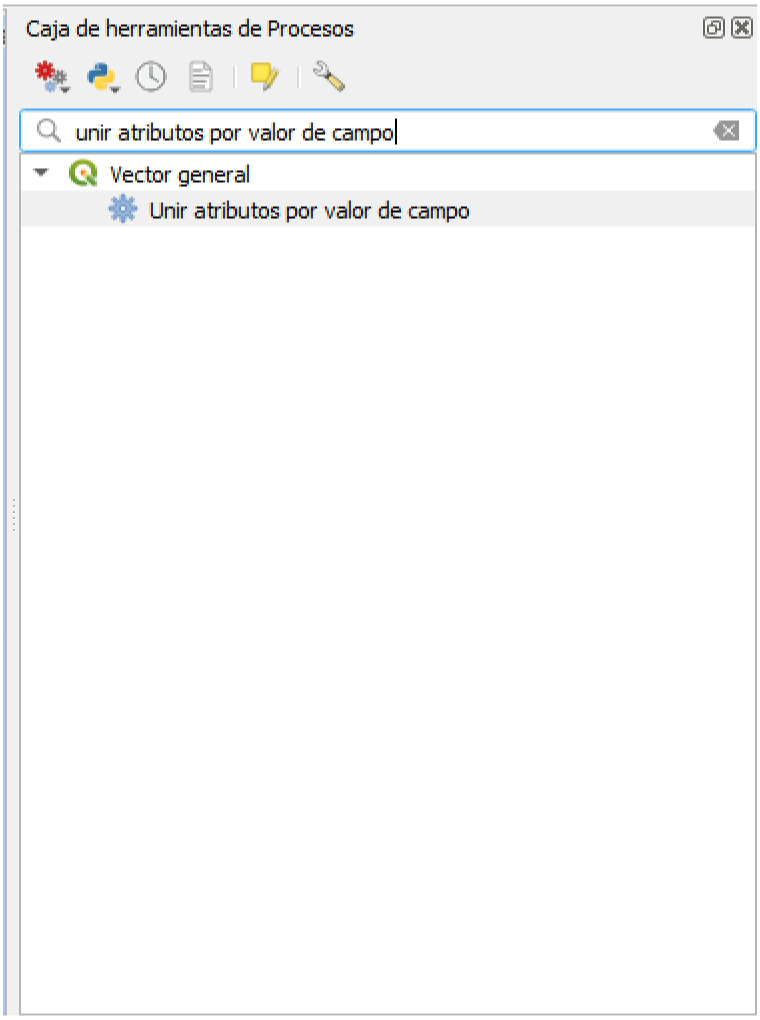


Figure 26. Selecting Join attributes by field value (Unir atrributos por valor de campo) tool

- Configure the parameters as follows:
  - Input Layer: 04_network-edges.csv (the TEN-T road segments table).
  - Join Layer: 03_network-nodes (the TEN-T nodes layer).
  - Field in Join Layer Network_Node_A_ID (the unique ID of each node).
  - Under Fields to add, select only Network_Node_X and Network_Node_Y to include the coordinates of the origin node for each segment.

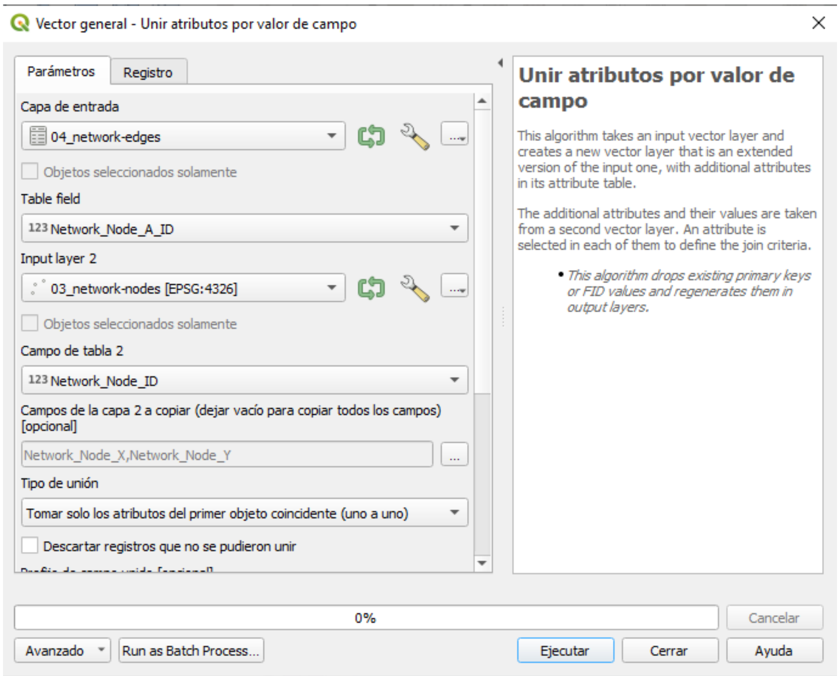


Figure 27. Join attributes by field value (Unir atrributos por valor de campo) tool

- Rename the resulting table as “Nodos A” for clarity.
- Create two new columns named X_A and Y_A in this table. These fields will store the X and Y coordinates of the origin nodes.
- To do this: Right-click on the “Nodos A” layer and select “Open Attribute Table”.

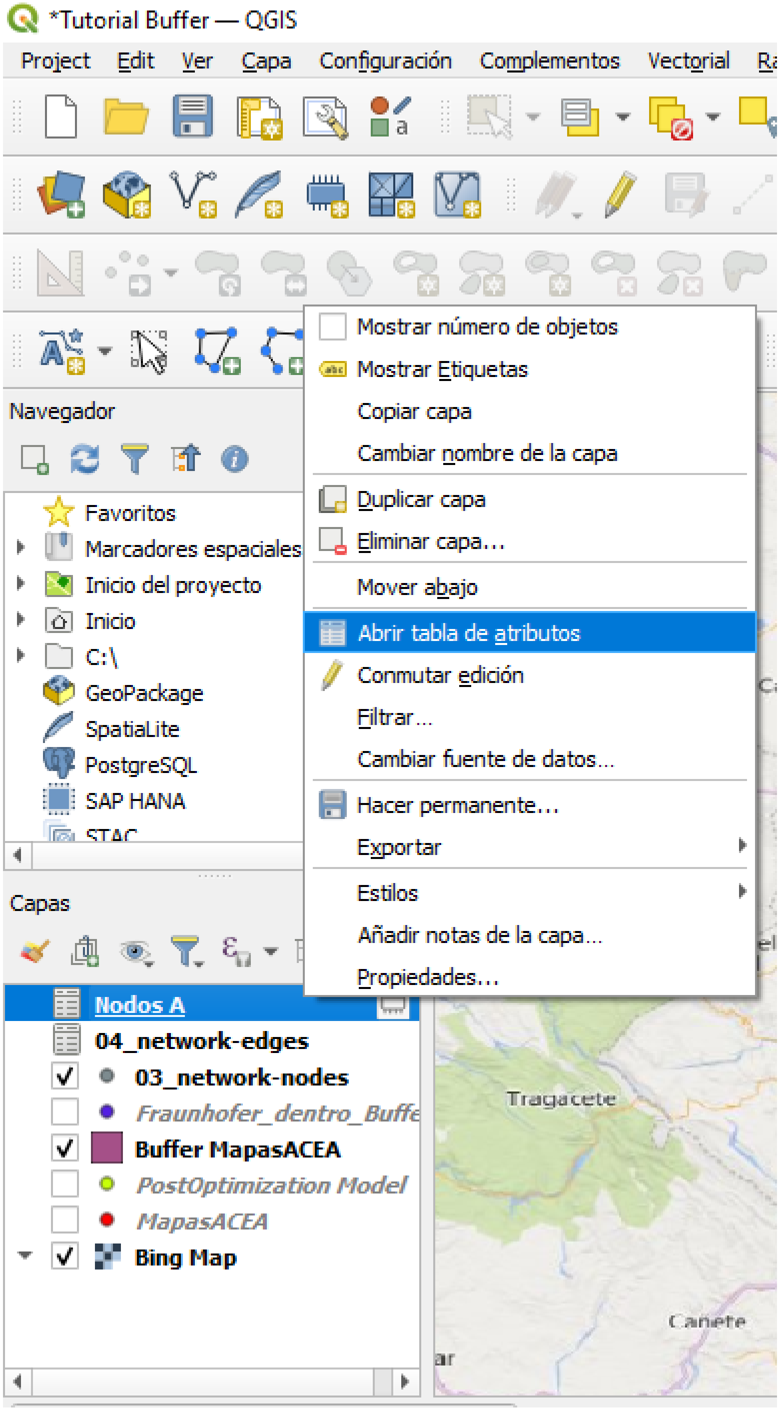


Figure 28. Opening attributes table

Then, in the table, select the pencil icon at the top left, and then click on the "Add Field" icon. Use the same number type as the column or field being copied, in this case, decimal.

Here, it is chosen 10 decimal places for length and 10 for precision to ensure no information is lost.

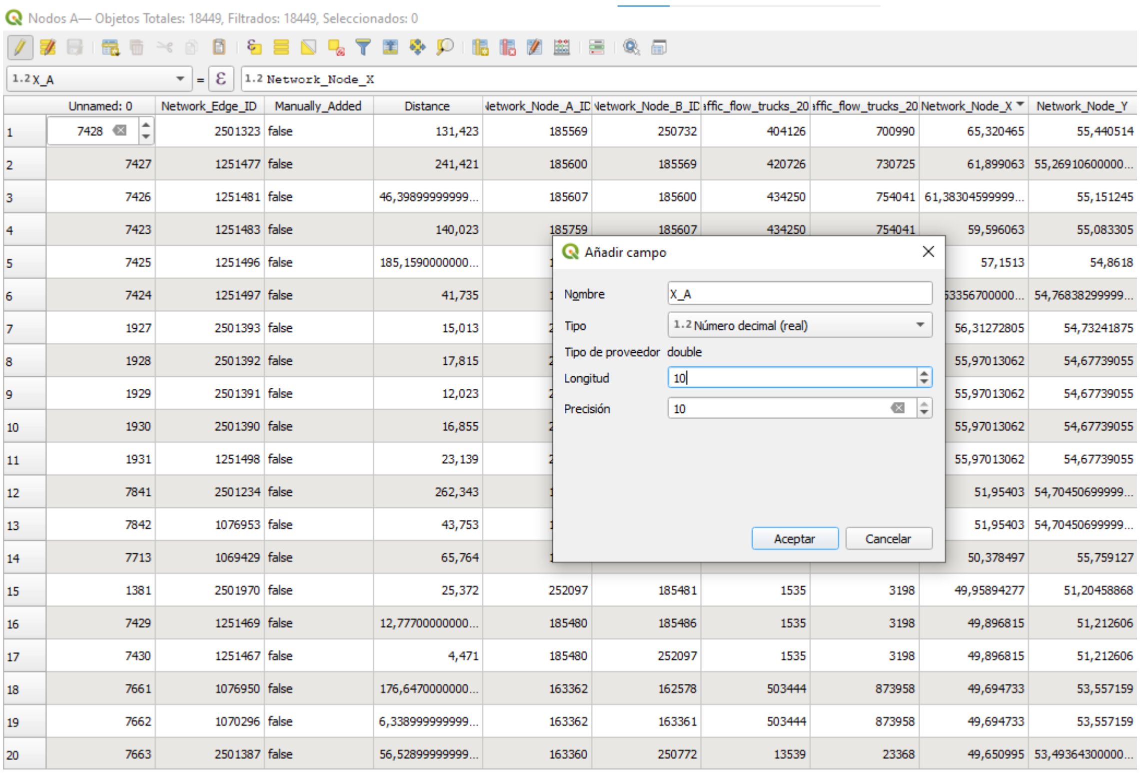
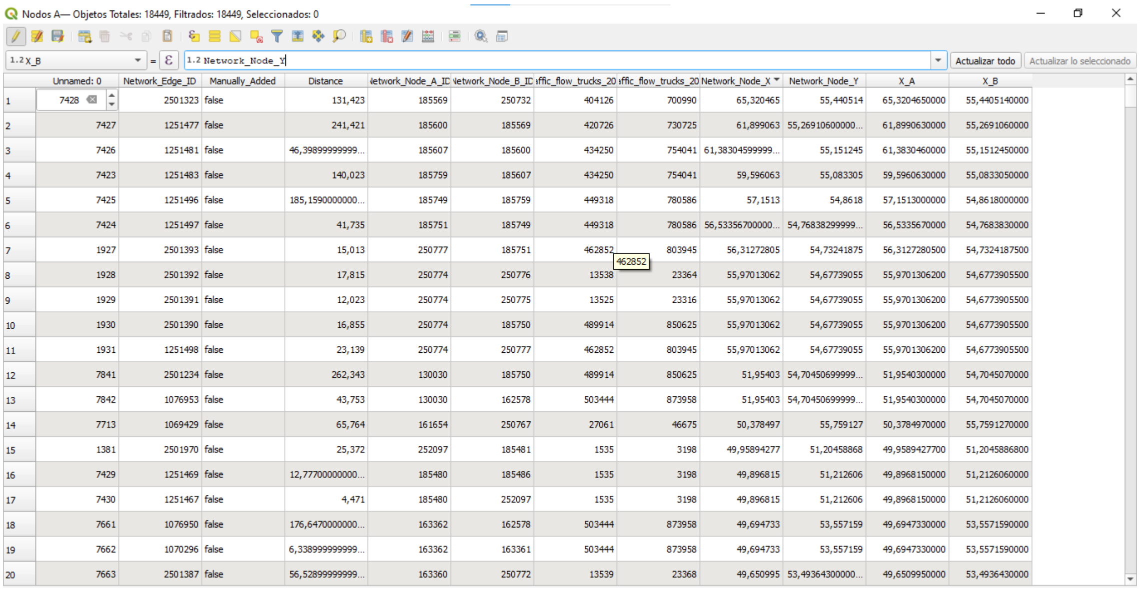


Figure 29. Adding field settings

Then, as shown in Figure 29. Adding field settings, in the upper left section of the attribute table, select the target field X_A, and on the right side, choose the source field Network_Node_X. The X_A field has now been successfully created. Next, repeat the same process for the Y_A field.



	Unnamed: 0	Network_Edge_ID	Manually_Added	Distance	letwork_Node_A_ID	letwork_Node_B_ID	affic_flow_trucks_20	affic_flow_trucks_20	Network_Node_X	Network_Node_Y	X_A	X_B
1	7428	2501323	false	131,423	185569	250732	404126	700990	65,320465	55,440514	65,3204650000	55,4405140000
2	7427	1251477	false	241,421	185600	185569	420726	730725	61,899063	55,26910600000...	61,8990630000	55,2691060000
3	7426	1251481	false	46,39899999999...	185607	185600	434250	754041	61,38304599999...	55,151245	61,3830460000	55,1512450000
4	7423	1251483	false	140,023	185759	185607	434250	754041	59,596063	55,083305	59,5960630000	55,0833050000
5	7425	1251496	false	185,1590000000...	185749	185759	449318	780586	57,1513	54,8618	57,1513000000	54,8618000000
6	7424	1251497	false	41,735	185751	185749	449318	780586	56,53356700000...	54,76838299999...	56,5335670000	54,7683830000
7	1927	2501393	false	15,013	250777	185751	462852	803945	56,31272805	54,73241875	56,3127280500	54,7324187500
8	1928	2501392	false	17,815	250774	250776	13538	23364	55,97013062	54,67739055	55,9701306200	54,6773905500
9	1929	2501391	false	12,023	250774	250775	13525	23316	55,97013062	54,67739055	55,9701306200	54,6773905500
10	1930	2501390	false	16,855	250774	185750	489914	850625	55,97013062	54,67739055	55,9701306200	54,6773905500
11	1931	1251498	false	23,139	250774	250777	462852	803945	55,97013062	54,67739055	55,9701306200	54,6773905500
12	7841	2501234	false	262,343	130030	185750	489914	850625	51,95403	54,70450699999...	51,9540300000	54,7045070000
13	7842	1076953	false	43,753	130030	162578	503444	873958	51,95403	54,70450699999...	51,9540300000	54,7045070000
14	7713	1069429	false	65,764	161654	250767	27061	46675	50,378497	55,759127	50,3784970000	55,7591270000
15	1381	2501970	false	25,372	252097	185481	1535	3198	49,95894277	51,20458868	49,9589427700	51,2045886800
16	7429	1251469	false	12,77700000000...	185480	185486	1535	3198	49,896815	51,212606	49,8968150000	51,2126060000
17	7430	1251467	false	4,471	185480	252097	1535	3198	49,896815	51,212606	49,8968150000	51,2126060000
18	7661	1076950	false	176,6470000000...	163362	162578	503444	873958	49,694733	53,557159	49,6947330000	53,5571590000
19	7662	1070296	false	6,338999999999...	163362	163361	503444	873958	49,694733	53,557159	49,6947330000	53,5571590000
20	7663	2501387	false	56,52899999999...	163360	250772	13539	23368	49,650995	53,49364300000...	49,6509950000	53,4936430000

Figure 30. Nodes A table

The result is a new layer with the segments of the TEN-T network and the starting coordinates (X_A, Y_A) of each segment.

3.2.5.2.2 Join Node B (Destination)

Repeat the same process for the destination node of each segment:

- Use the "Join attributes by field value" tool again.
- Configure the parameters as follows:
  - Input layer: Nodos A (the layer containing the segments with the origin node coordinates)
  - Join layer: 03_network-nodes (the node layer)
  - Field in Input Layer: Network_Node_B_ID
  - Field in join layer: Network_Node_ID (the ID of each node)
  - Select the fields Network_Node_X and Network_Node_Y to obtain the coordinates of the destination node for each segment.

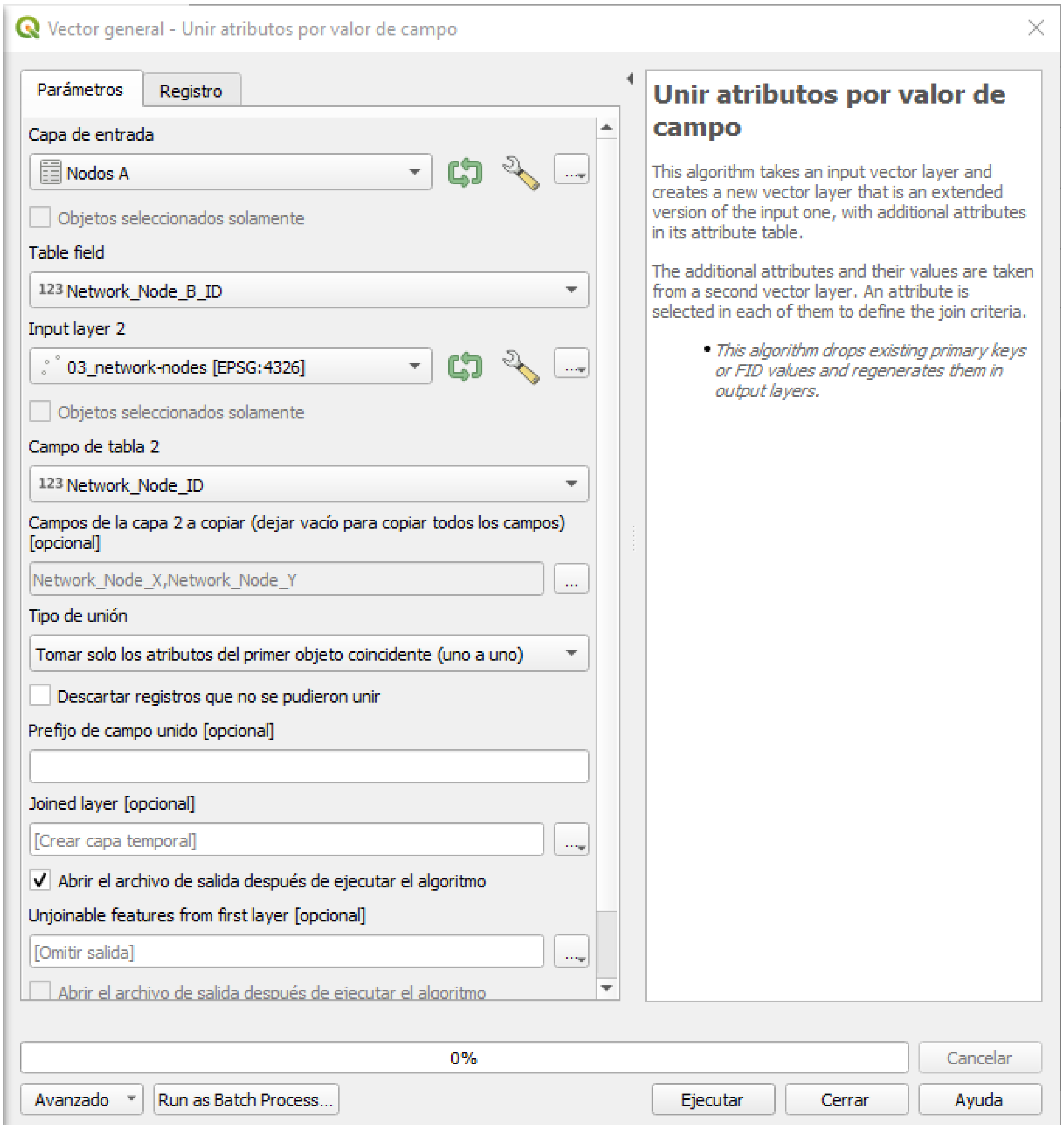


Figure 31. Join attributes by field value (Unir atrributos por valor de campo) tool

- The table is renamed to “Nodos”.
- New columns named X_B and Y_B are created in the new table. These columns will contain the X and Y coordinates of the destination nodes.

Nodos— Objetos Totales: 18449, Filtrados: 18449, Seleccionados: 0

	Distance	Network_Node_A_ID	Network_Node_B_ID	affic_flow_trucks_20	affic_flow_trucks_20	Network_Node_X	Network_Node_Y
1	5,98	262914	260432	0	0	-1,09522481	47,12448684
2	18,559	262914	109845	0	0	-1,09522481	47,12448684
3	2,012	262911	109968	1871252	2513351	-2,612827587	48,47615009
4	4,728	262911	122766	1871252	2513351	-2,612827587	48,47615009
5	15,02799999999...	262909	260001	1038691	1449368	2,687793909	43,17568329
6	10,988	262908	260000	5200834	7293738	-0,618955666	45,47647456
7	1,567	262907	105734	0	0	-0,86569552700...	45,95873537
8	5,415	262906	260360	4849956	6794326	0,403096227	46,74665531
9	2,049	262905	122605	1967669	2864706	6,972826838	43,56597105
10	3,228	262905	260477	1967669	2864706	6,972826838	43,56597105
11	1,501	262904	260473	1967669	2864706	6,724630669	43,46616035
12	2,8	262903	262904	1967669	2864706	6,694086613	43,45950646
13	0,129	262903	260475	1967669	2864706	6,694086613	43,45950646
14	1,444	262902	102973	0	0	5,36255949	43,36539323
15	6,494	262896	260076	0	0	6,274586516	48,6182723
16	4,085	262895	260028	6037959	7997395	2,921898673000...	50,4323817
17	1,906999999999...	262894	260010	162278	293698	1,783163407	50,91646082
18	1,565999999999...	262892	120502	4903691	5917864	12,30231807	55,60248654
19	1,548	262891	116146	4903691	5917864	12,27526297	55,59220774
20	2,053	262891	262892	4903691	5917864	12,27526297	55,59220774

	X_A	Y_A	Network_Node_X_2	Network_Node_Y_2	X_B	Y_B
1	-1,0952248100	47,1244868400	-1,17001803400...	47,14175585	-1,1700180340	47,1417558500
2	-1,0952248100	47,1244868400	-0,904254	47,030301	-0,904254	47,0303010000
3	-2,6128275870	48,4761500900	-2,639767	48,478893	-2,6397670000	48,4788930000
4	-2,6128275870	48,4761500900	-2,552441	48,465552	-2,5524410000	48,4655520000
5	2,6877939090	43,1756832900	2,869198573000...	43,16007197	2,8691985730	43,1600719700
6	-0,618955666	45,4764745600	-0,599637419	[illegible]499	-0,599637419	45,5741849900
7	-0,865695527	45,9587353700	-0,885601	45,95753300000...	-0,885601	45,9575330000
8	0,403096227	46,7466553100	0,463514951	46,77229015	0,463514951	46,7722901500
9	6,9728268380	43,5659710500	6,952764999999...	43,558129	6,9527650000	43,5581290000
10	6,9728268380	43,5659710500	6,99769291	43,58610169	6,9976929100	43,5861016900
11	6,7246306690	43,4661603500	6,740260552000...	43,47321514	6,7402605520	43,4732151400
12	6,6940866130	43,4595064600	6,724630669	43,46616035	6,7246306690	43,4661603500
13	6,6940866130	43,4595064600	6,692638949	43,45998902	6,6926389490	43,4599890200
14	5,3625594900	43,3653932300	5,35677	43,377009	5,3567700000	43,3770090000
15	6,2745865160	48,6182723000	6,349362694	48,59997174	6,3493626940	48,5999717400
16	2,9218986730	50,4323817000	2,865306578	50,43378156	2,8653065780	50,4337815600
17	1,7831634070	50,9164608200	1,805312788	50,92641223	1,8053127880	50,9264122300
18	12,3023180700	55,6024865400	12,32167	55,611322	12,3216700000	55,6113220000
19	12,2752629700	55,5922077400	12,258699	55,581952	12,2586990000	55,5819520000
20	12,2752629700	55,5922077400	12,30231807	55,60248654	12,3023180700	55,6024865400

Figure 32. Geometry table of TEN-T network

This provides the complete geometry of the TEN-T network segments, with the starting coordinates (X_A, Y_A) and destination coordinates (X_B, Y_B).

3.2.5.2.3 Create Lines Between Coordinates

Once the start and end node coordinates of each segment are available, these can be used to create the lines that represent the road segments of the TEN-T network.

To do this, a script must be written in Python using a text editor (e.g., Notepad). Then, the script will be executed in QGIS using the integrated Python console. When the script is run, it will automatically generate the line geometries—i.e., the roads—by connecting the start and end node coordinates for each segment.

The script to generate the lines between origin and destination nodes is as follows. To run the Python script in QGIS, follow these steps:

First, activate the Python Console. Then, you must give the command to execute the script file. This is done by entering the following command:

- exec(open(r"C:\Users\Juan\Documents\TFM\PythonFlujo.py").read())

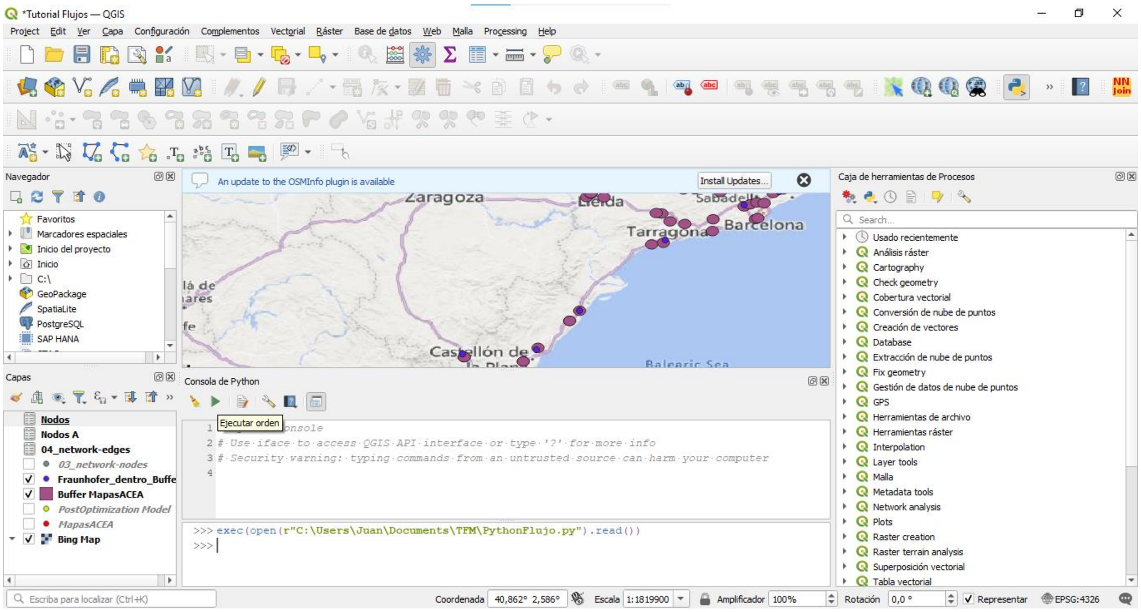


Figure 33. Python console

It is important to note that after open, you must enter the file path where the script is located, which will vary in each case. The example provided corresponds to the location and file name used in this case: “PythonFlujo”.

- Press the Play button (Run Command) :A new layer called Flujo camiones is generated. To view it more clearly, you can temporarily deactivate the Bing Map layer.

It can be observed that some lines cross over the sea to reach islands such as Corsica. This occurs because the dataset also accounts for trucks that travel by ferry, which are integrated into the model as part of the overall freight flow.

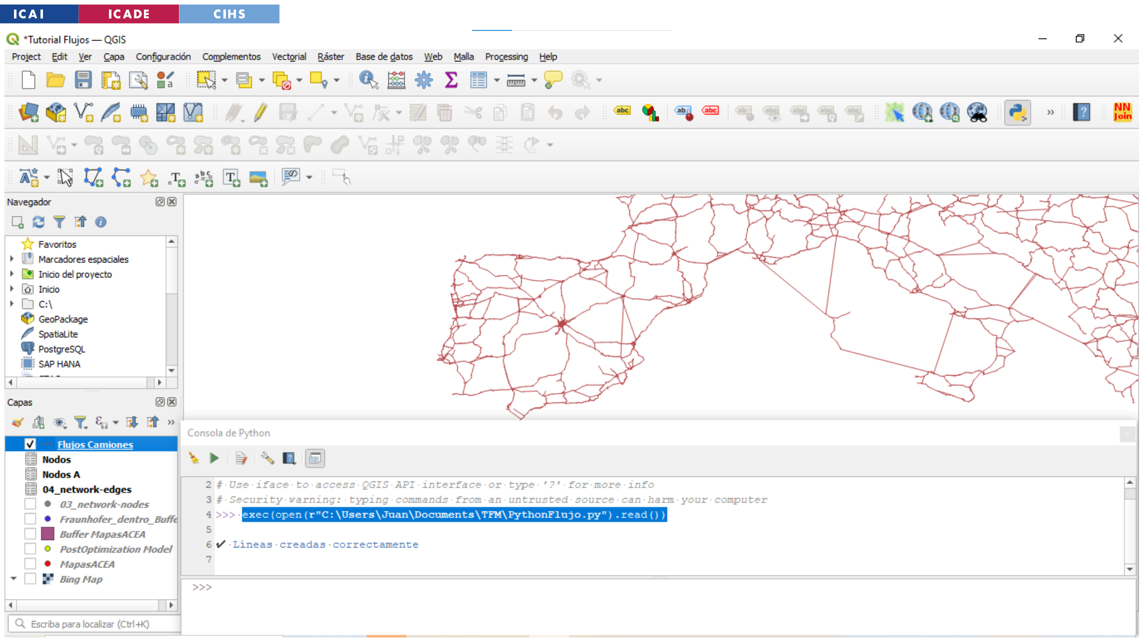


Figure 34. Visual representation of TEN-T network

The content of the Python file can be found in this document at the appendix I.

3.2.5.3 Distance from Potential Locations to the TEN-T Network

Among the main advantages of measuring the distance to the TEN-T network is the optimization of accessibility, since the closer a charging station is to this network, the easier it will be for trucks to reach it without significant detours. It also leads to reduced travel time, minimizing the distance between charging stations and TEN-T road segments shortens waiting times and improves transport efficiency. Finally, it helps ensure coverage, since placing stations near the busiest segments guarantees access to charging points without requiring long diversions.

The "Shortest line between objects" tool in QGIS is the most suitable option for calculating the minimum distance between charging stations and TEN-T road segments. It allows precise calculation of the shortest distance between a point (charging station) and a line segment (road section) in the network.

This tool offers several advantages for the analysis. First, it provides accurate measurements, calculating the minimum distance between charging station locations and road segments, which results in more precise outputs than a simple straight-line distance. Additionally, it helps optimize station placement by allowing visual identification and prioritization of stations closer to the TEN-T network, thus ensuring accessibility. Lastly, it enables efficient analysis by automating distance calculations, streamlining the decision-making process.

In addition to distance, truck traffic flow is another key factor used to prioritize charging station locations. By integrating both data—distance to the TEN-T network and truck traffic flow—it is possible to identify the optimal locations to install charging stations along the most heavily used routes, ensuring higher demand and more efficient use of infrastructure.

To use the "Shortest line between objects" tool, follow these steps:

- Open the Processing Toolbox:
  - Go to Processing → Toolbox in QGIS.
- Search for the tool:
  - In the search bar, type "Shortest line between objects" (or in English: "Shortest path between objects").
  - Select the tool
- Configure the parameters:
  - Input Layer: Select the charging stations layer (e.g., 01_network-nodes.csv or the layer containing charging station locations).
  - Reference Layer: Select the TEN-T segments layer (e.g., 04_network-edges.csv).
  - Join field of the input layer: If necessary, select the field representing the TEN-T node IDs.

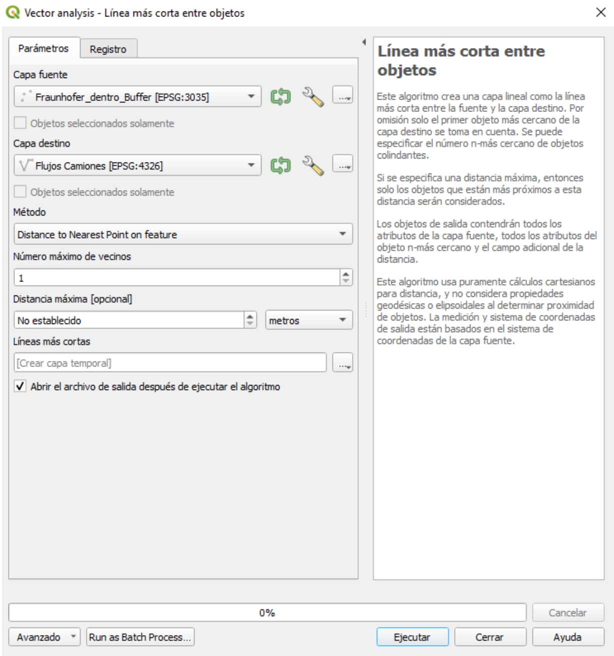


Figure 35. Shortest line between objects tool

- Run the tool.
- Export the resulting layer, as it contains all the information about the generated lines. This includes the location of the charging station and the connected TEN-T segment. Additionally, a column named “distance” is created, indicating the length of the line — that is, the distance from the charging station to the TEN-T network.

3.2.6 Export information

When analyzing charging stations and the TEN-T network, the user encounters a large number of potential locations, making it necessary to conduct a selection process to identify the most suitable ones.

The required layers are exported to analyze and select the 12 best charging station locations. These 12 sites are chosen because they are considered strategic for ensuring efficient coverage of the TEN-T network and greater accessibility for electric trucks.

The "Shortest line between objects" tool in QGIS has been used to calculate the distance between each charging station and the nearest segment of the TEN-T network. By exporting this data, it is obtained essential information that enables us to efficiently choose the best locations. The exported layer includes:

- Charging station points: The geographic coordinates of the potential charging station locations.
- The nearest flow segment to each station: Information about the closest TEN-T network segment to each station.
- The distance from each station to the nearest segment: This metric is crucial to evaluate the accessibility of each station to the TEN-T network.

The "Shortest line between objects" layer contains a large amount of additional information that is not relevant to this part of the study, such as the coordinates of the road segments or the presence of nearby hotels. The only required columns for selecting the 12 best charging station locations are:

- QGIS-assigned code for each location, referred to as fyd by the software.
- Coordinates of the potential charging station locations: Latitude and Longitude.
- Information from ACEA-identified points within 5 km: Coordinates (Latitude and Longitude), type of stop, and stop frequency.
- Truck flow in 2019 and projected for 2030 on the closest segment. This helps prioritize locations with higher charging infrastructure demand.
- Distance between charging stations and the nearest TEN-T segment.

3.3 SELECTION OF THE 12 BEST LOCATIONS

To carry out the final selection of the 12 charging stations that will form part of the long-distance electric truck charging network, a prioritization model based on the gravitational approach has been applied. This model, widely used in studies on optimal infrastructure placement, allows for the estimation of the attractiveness of each candidate point by considering both the heavy truck traffic flow in its surroundings and its distance to those flows.

3.3.1 FOUNDATION OF THE GRAVITATIONAL MODEL

The gravitational model is inspired by Newton's law of gravity, according to which the attractive force between two bodies is proportional to their masses and inversely proportional to the square of the distance between them. In the context of transport and location planning, this logic is translated as follows:

To select the 12 most strategic charging stations within the long-distance electric truck charging network, a prioritization model based on the gravitational model has been applied. This approach, commonly used in territorial planning studies, estimates the attractiveness of a location as a function of the heavy vehicle traffic flow in its surroundings and the distance to the nearest traffic flow.

The model is based on the following expression:

$$\widehat{A_\iota} = \frac{\widehat{F_\jmath}}{\widehat{d_{\iota\jmath}^{\beta}} + \varepsilon} \qquad (E1)$$

$\boldsymbol{\widehat{A_\iota}}$**:** Total attraction or score of charging i.

$\boldsymbol{\widehat{F_\jmath}}$**:** Normalized truck flow on segment j .

$\boldsymbol{\widehat{d_{\iota\jmath}}}$**:** Normalized distance between charging station i and segment j.

β: Distance penalization parameter, set in this study to 2.

ε: Regularization constant, in this case ε=0,01 which prevents division by values close to zero.

3.3.2 NORMALIZATION OF VARIABLES

Both truck flow, F_j, and distance, d_{ij}, were normalized before being used in the model in order to:

- Ensure that both variables are on the same numerical scale.
- Prevent one variable from artificially dominating the other.
- Facilitate the relative interpretation of the results.

Min-max normalization was applied, defined by the following expressions:

$$\widehat{F_j} = \frac{F_j - F_{min}}{F_{max} - F_{min}} \ y \ \widehat{d_{ij}} = \frac{d_j - d_{min}}{d_{max} - d_{min}} \qquad (E2\ y\ E3)$$

F_{max} and F_{min} are the maximum and minimum truck flow values among the considered segments.

d_{max} y d_{min} are the maximum and minimum observed distances between charging stations and road segments.

3.3.3 Proximity Penalty for Charging Stations

The gravitational model assigns each location a base score that reflects, on one hand, the intensity of truck traffic passing through the nearest TEN-T segment and, on the other, the exact distance between the charging station and that segment (the shorter the distance, the greater the accessibility, and therefore the higher the score). However, it may happen that two locations with very high scores are so close to each other that, in practice, they end up capturing the same potential demand: trucks stopping at one will barely travel a few hundred meters to refuel at the other. To avoid this redundancy — that is, multiple charging stations "eating" the same market — it is introduced a proximity penalty that reduces the value of the combination when two selected stations are too close; this penalty increases rapidly as the distance between them decreases, discouraging concentration and favoring a more balanced territorial coverage.

The model starts with a set of 18 candidate locations identified for their individual attractiveness; the final goal is to select exactly 12 of them to form the initial charging network. To make the decision, a spreadsheet was programmed in Excel with a VBA module that exhaustively generates the 48,620 possible combinations. In each iteration, the algorithm (i) adds the base score of the 12 charging stations involved — a value that depends, as indicated, on the truck flow on the adjacent TEN-T segment and the actual access distance — and (ii) calculates, one by one, the penalty terms linking each charging station to the other eleven in the same combination. The penalty accumulated for a specific pair increases rapidly as the separation between the two points decreases, reflecting the loss of efficiency in placing two stations very close to each other and "competing" for the same demand. In this way, the algorithm assigns each combination a final score that results from subtracting all the internal penalties from the aggregated benefits, and selects, as optimal, the combination of 12 locations whose final value is the highest.

Each charging station i receives a penalty based on how close it is to the other selected stations. Specifically, its penalty is defined as:

$$pen_i = \lambda \, x \, \frac{1}{\sum_{j \neq i}^{j \in s} d_{ij}^2} \qquad (E4)$$

where the denominator is the sum of the squared distances between the charging station i and the other eleven j in the combination S. The interpretation is that if i has very close neighbors (small distances), the sum becomes low, and the fraction — therefore the penalty — increases significantly. However, if it is reasonably far apart, the sum grows, and the penalty is diluted.

λ is the coefficient that balances between maximizing captured demand and minimizing spatial redundancy, so it directly influences the final network selected. This coefficient is recalculated for each iteration, adapting automatically to the average quality (mean score) of the 12 charging stations being evaluated at that moment.

The coefficient is calculated as:

$$\lambda = f \, x \, \frac{\sum_{i \in s} \widehat{A_i}}{12} \, x \, R^2 \qquad (E5)$$

f: Coverage factor (from 0 to 1) that controls the strength of the penalty.

$\frac{\sum_{i \in s} A_i}{12}$: Average score of the 12 charging stations in combination S.

R: Radius of influence, the distance at which two stations begin to overlap.

In summary, the formula for λ takes the average score of the 12 stations in the current iteration and scales it by the square of the radius of influence. Thus, it is setted a coverage factor f=1 and an influence radius R=10 km.

R=10 km, the model indicates that when two stations are exactly 10 km apart, the penalty applied to each equals their average score — effectively nullifying the utility of that station due to overlap. This reflects a decision to fully penalize redundancy at that distance.

Aggregate penalty of the combination is obtained by summing the twelve individual penalties:

$$PEN = \sum_{i \in s} pen_i \qquad (E6)$$

Ultimately, the score of each iteration is calculated using the following expression, and the selected combination is the one that yields the highest value of Z.

$$Z = \sum_{i \in s} \widehat{A_i} - PEN \qquad (E7)$$

To avoid a manual calculation, which is impractical with 48,620 combinations, a VBA macro was implemented in Excel. The script is provided in Appendix I. This macro generates all possible combinations of 12 charging stations, recalculates λ in each iteration, computes the benefit and penalty, and retains only the list with the highest Z.

3.3.4 The Best 12 Locations

Once the attractiveness index for each of the candidate locations was calculated, they were sorted in descending order based on the value obtained. This ranking reflects the relative capacity of each charging station to attract charging demand, simultaneously considering the projected traffic intensity for 2030 and geographical accessibility.

Based on this ranking, the 12 locations with the highest gravitational scores were selected to form the priority network of charging stations for electric trucks. These locations represent the best strategic options, as they maximize long-distance freight coverage with a limited number of installations. The 12 points where the charging stations will be placed can be seen in

Figure 36. Final 12 locations for truck electric chargers

3.3.5 GRAVITACIONAL MODEL RESULTS

The application of the gravitational model has made it possible to identify the 12 optimal locations for deploying high-capacity charging stations aimed at heavy-duty traffic by 2030. As shown in the Figure 36, most of the selected locations are concentrated along the Mediterranean coastal corridor, connecting major logistics and urban hubs from the region of Murcia to the French border.

This pattern directly reflects the model's results, which integrated both the projected truck flow intensity and the geographic accessibility of each point. The selected charging stations tend to be located:

- In proximity to major interchange hubs (València, Barcelona).
- Near key logistics borders (La Jonquera, Port of Cartagena).
- Along the TEN-T network and the EU's priority transport corridors.

It is also worth highlighting the inclusion of strategic intermediate locations that ensure homogeneous coverage over long stretches. These allow compliance with electric truck range limitations and promote the operational continuity of long-distance freight transport.

3.4 ELECTRIC CHARGERS

Following the identification of the 12 optimal locations for the implementation of electric truck charging stations, the next step is to determine the necessary capacity at each site—specifically, the number and type of chargers required to adequately serve the expected volume of electric trucks.

Two types of chargers are distinguished:

- Fast chargers (MCS), designed for on-the-go charging during working hours.
- Slow chargers, intended for overnight or prolonged charging, typically at rest areas or logistics centers.

3.4.1 CHARGERS TYPES

To efficiently and cost-effectively meet charging needs, the selected model is the Power Electronics MCS 1440 kW charger, with a cost of €394,000 per unit. Already deployed in Spain, this charger offers a key operational advantage: it includes four outputs and can function either as a single ultra-fast charger or as multiple lower-power chargers, thanks to its dynamic power distribution capability.

At each location, a number of these chargers will be installed equivalent to the number of fast chargers previously calculated. During the day, each unit will operate as a single 1440 kW ultra-fast charger, aimed at satisfying in-transit charging demand. At night, these same units will switch to multi-outlet mode, enabling up to four trucks to be charged simultaneously.

Power distribution is not fixed; instead, it dynamically adjusts based on the specific demand of each connected vehicle. For example, if several trucks are connected, the system can allocate the total available power across the outputs depending on each vehicle's needs, ensuring flexible and efficient use of capacity. This operational flexibility allows the infrastructure to adapt to different scenarios without compromising performance or requiring oversizing.

This solution optimizes infrastructure use by avoiding the need to duplicate equipment for different time slots, representing a significant reduction in both installation and operational costs.

In cases where projected overnight charging demand exceeds the capacity of the installed MCS units (i.e., if more slow chargers are needed than the available MCS outlets can provide), additional 100 kW chargers, such as the Hypercharger HYC200, will be installed at a cost of €50,820 per unit. These units are more affordable and suitable for prolonged overnight charging, effectively meeting the needs of trucks during rest periods.

3.4.2 SIZING OF FAST CHARGERS USING QUEUEING THEORY

The dimensioning of fast chargers will be carried out using an M/M/s queueing model, widely employed in infrastructure planning where there is stochastic (random) demand and variable service times. To apply the model, two key parameters need to be known: the average charging time of an electric truck on this type of charger and the number of trucks requiring recharging at each station per hour. To properly determine the necessary number of chargers at each of the charging stations, queueing theory will be used, specifically the M/M/s model. This method is particularly suitable for this task due to the random nature of both the arrival of trucks at the station and the time needed to charge each truck.

The M/M/s model is based on the following assumptions:

- Truck arrivals follow a Poisson distribution, meaning trucks arrive independently and at random intervals.
- Service time (charging time) follows an exponential distribution. This reflects the natural variability in charging durations—some trucks charge slightly faster, others slower. The exponential distribution is well-suited for representing such processes,

where time between events (in this case, full charges) is variable but statistically regular.

- Multiple servers (chargers) are available (s servers), which aligns with the real-world scenario of having several charging points operating simultaneously at each station.

The three key parameters in the model are:

λ: The number of trucks arriving per hour at the station. This value has been calculated previously.

μ: The number of charges a single charger can perform per hour, derived from the assumed average charging time per truck.

S: The number of chargers available — this is the variable to be determined.

3.4.2.1 Average charging time

According to EU Regulation No. 561/2006, professional drivers are required to take a minimum 45-minute rest after a maximum of 4.5 hours of continuous driving. For long-haul trucks traveling at average highway speeds (around 75 km/h), this corresponds to approximately 335 km between mandatory stops.

In line with this regulation, our study considers that electric trucks should ideally be able to drive up to 335 km before requiring a charge. Covering this distance is estimated to consume approximately 600 kWh, based on projected 2030 energy consumption rates for heavy-duty battery electric trucks.

Assuming the use of 1.440 kW ultra-fast chargers, compliant with future MCS standards, the time required to charge 600 kWh is 25 minutes.

$$25\,\frac{min}{charge} = 0{,}412\,\frac{h}{charge}$$

$$\mu = \frac{1}{0{,}4167} = 2.4 \frac{charges}{hora} \qquad (E8)$$

This value will be used as the service rate in the M/M/s model.

3.4.2.2 Demand Calculation

To accurately size the number of chargers at each of the 12 selected charging stations, it is necessary to estimate the number of trucks per hour under a representative high-demand scenario. However, the available data from the file "Traffic Flow Trucks 2030" only provides the total annual truck flow. Therefore, a rigorous procedure is needed to estimate the daily and subsequently the hourly flow realistically.

The method followed consists of several clearly defined stages:

3.4.2.2.1 Identification of nearby permanent stations

First, the nearest permanent station from the Ministry of Transport, Mobility and Urban Agenda (MITMA) will be identified for each of the 12 selected charging locations. To do so, the official map viewer available at: https://mapatrafico.transportes.gob.es/2022/ (Ministerio de Transportes y Movilidad Sostenible, 2022)

These permanent stations provide reliable data on the actual temporal distribution of heavy vehicle traffic throughout the year.

3.4.2.2.2 Actual anual traffic distribution

From the same official viewer of the Ministry of Transport, Mobility and Urban Agenda access is gained to the files associated with each permanent traffic counting station. By clicking on a station, a set of documents is displayed, including a PDF that breaks down the number of heavy vehicles by day of the week and month.

Using this information, a complete 2022 calendar was recreated in Excel. For each of the 365 days of the year, the following was identified:

- The exact date (January 1, January 2, ..., December 31),

- The corresponding day of the week (Monday, Tuesday, etc.),
- The month to which it belongs.

Next, each date was assigned the corresponding number of trucks based on its month and day of the week, using the values extracted from the PDF table of the selected station.

This procedure enabled the construction of a daily database with realistic estimates of the number of heavy vehicles passing through the station on each day of 2022.

3.4.2.3 Identification of the 100th Highest Demand Day

Once the daily traffic assignment was completed, a time series of 365 values was obtained, representing the estimated number of trucks that circulated each day through the permanent station closest to each candidate charging location.

Using this series, the daily traffic values were sorted from highest to lowest to identify the 100th busiest day. This day is considered representative of a high—though not extreme—demand scenario, and serves as a practical reference for the infrastructure sizing at each of the 12 selected charging locations.

3.4.2.4 Projection of the Highest Demand Day to 2030

The traffic flow identified for the 100th highest demand day corresponds to empirical data from 2022. However, in order to correctly size the charging stations for the 2030 horizon, this value must be projected to reflect future expectations aligned with the anticipated growth in freight transport by road.

To do this, the projection developed by Fraunhofer ISI (2024) is used. This study estimates the evolution of heavy vehicle traffic on the European TEN-T network through 2030. It provides expected annual truck volumes on strategic routes, allowing the estimation of traffic increase compared to the base year.

The approach consists of calculating the percentage that the 100th day represents in relation to the total annual volume recorded in 2022 for each permanent station. This daily proportion (e.g., 3.1% of the annual total) is considered relatively stable under the assumption that temporal traffic patterns will remain largely unchanged over time.

Once this percentage is determined, it is applied to the projected annual volume for 2030 (according to Fraunhofer's model). This yields an estimated number of heavy vehicles circulating on the 100th day of 2030, providing a reliable baseline for technical dimensioning of the charging infrastructure at each selected location.

3.4.2.5 Estimated Share of Electric Trucks

Before calculating hourly flow, an estimate is made of the percentage of trucks expected to be electric. In this study, it is assumed that 7% of heavy traffic will be electric by 2030. However, there are several studies on this topic, with some suggesting a 5% and others pointing to 10%-11%. In this study, it has been used 7%, as it seems to be the most widely agreed-upon scenario.

3.4.2.6 Estimation of Hourly Flow and Peak Hour Selection

The official MITMA viewer provides, for each permanent traffic counting station, the hourly distribution of heavy vehicle traffic broken down by day of the week. This allows for a precise understanding of how truck traffic is distributed across 24 hours, distinguishing for example a Monday from a Friday or a Sunday.

From this detailed station and day-specific distribution, the peak hour for the previously determined 100th highest demand day was identified. This hour represents the time of highest truck concentration, and is therefore the most demanding scenario from the perspective of station sizing on that day.

The hourly value obtained will be used as a reference to calculate the number of fast chargers required at each location, thereby ensuring that the infrastructure can adequately serve the maximum expected demand.

3.4.2.7 Calculating potential customers

Therefore, to determine the number of trucks per hour that will pass through the road segment where the charging station is located, the following formula is used:

$$\frac{trucks}{hour} =$$
$$= Day\ 100\ with\ highest\ demand\ in\ 2030\ x\ \%\ Electric\ Trucks\ x\ \%\ Peak\ hours\ trucks\ \ (E9)$$

3.4.2.8 Stopping probability

Now it must be obtained the estimated number of electric trucks that could stop at each charging station during the peak hour. However, not all of these trucks will actually stop; the actual stopping probability will depend on the distance to the next available charging station.

It is initially assumed that the flow of electric trucks is evenly divided, with 50% heading in one direction and the other 50% in the opposite direction. To calculate how many trucks will stop in each direction, the following formula is applied to each direction:

$$Proportion\ stop = \frac{Distance\ to\ the\ next\ electric\ charging\ station\ in\ \ direction\ \ "x"}{335}\ \ (E10)$$

The choice of 335 km as a reference is based on the typical projected range for electric trucks, assuming that each truck will need to recharge at least once every 335 km. Therefore, if the distance to the next charging station is exactly 335 km, the stopping probability would be 100%. This means all trucks in that direction would stop at this charging station. For example, if the distance is 200 km, the stopping probability would be estimated at 60% (200 km / 335 km). This approach allows for precise dimensioning, tailored to the specific characteristics of the projected charging network.

Once the flow of electric trucks per hour is obtained, it is assumed that half of the total flow travels in each direction. Then, the flow in each direction is weighted by the previously calculated stopping proportion, resulting in a realistic number of electric trucks that will actually stop at each charging station. This approach allows for precise and tailored dimensioning based on the specific characteristics of the projected charging network.

3.4.2.9 Formulas of the M/M/S model based on the obtained parameters

3.4.2.9.1 System Utilization Rate:

$$p = \frac{\lambda}{s\ x\ \mu} \qquad (E11)$$

It represents the percentage of time the chargers are occupied. If it approaches 1, it means the system is heavily loaded, and queues will form. If it exceeds 1, the system is unstable, meaning more trucks are arriving than the chargers can handle. In this case, the queues would grow indefinitely, and the charging station would collapse operationally.

3.4.2.9.2 Probability of a Truck Having to Wait:

$$P_q = \frac{\frac{(sp)^s}{s!\,(1-p)}}{\sum_{k=0}^{s-1}\frac{(sp)^k}{k!} + \frac{(sp)^s}{s!\,(1-p)}} \qquad (E12)$$

.

The probability, P_q, that a truck will have to wait when arriving, as all chargers are occupied, is given by Erlang-C's formula.

3.4.2.9.3 Average Waiting Time in the Queue

$$W_q = \frac{P_q}{s\mu - \lambda} \qquad (E13)$$

This value indicates how much time, on average, a truck will wait before it can begin charging. The higher the utilization rate or the fewer the chargers, the higher this time will be. This metric is key to ensuring a good service level and avoiding logistical delays.

3.4.2.9.4 Total Time in the System:

$$W_T = W_q + \frac{1}{\mu} \qquad (E14)$$

This value represents the total time a truck spends from arrival to the end of the charging process.

3.4.2.10 Fundamental design conditions:

The total time in the system (waiting time plus charging time) should not exceed 50 minutes to guarantee an adequate level of service.

The utilization rate (the proportion of time the chargers are occupied) should not exceed 0.95 to avoid station saturation and to allow for operational margin.

3.4.2.11 Calculation in Excel

The parameter that is calculated in the context of the M/M/s queueing model is "s," which represents the number of servers (chargers) needed at each electric charging station. In this case, "s" is the number of chargers required to meet the specified design conditions. These conditions are a utilization rate below 95%, ensuring that the chargers are not overloaded, which would lead to long waiting times and decreased service efficiency. A high utilization rate could result in long queues and delays for the trucks. Additionally, the total time in the system must be below 50 minutes, which guarantees that the time a truck spends at the charging station, including both waiting time and charging time, does not exceed the 50-minute limit. This condition is critical for maintaining operational efficiency.

The process involves evaluating different values for "s" (the number of chargers) until both of these conditions are met. This iterative approach allows for the optimal number of chargers to be determined based on the expected traffic and the system's design constraints. Essentially, the goal is to find the "s" value that ensures the system can handle the expected demand without exceeding the capacity or causing excessive delays.

3.4.3 SIZING OF SLOW CHARGERS

Once the number of fast chargers required has been determined using the M/M/s queueing theory model, it is also necessary to calculate the number of slow chargers required at each charging station. These chargers are primarily intended to address needs other than immediate transit, mainly:

- Trucks that make prolonged stops, such as overnight rests or technical stops.
- Vehicles that park for several hours and do not require immediate charging.

For this case, queueing theory cannot be used, as the nature of the use of slow chargers is fundamentally different. Unlike fast chargers, where there is a continuous flow of arrivals and departures, in the case of slow chargers, vehicles remain parked for long periods, especially overnight, without significant turnover.

Consequently, a static occupancy approach is adopted. This model assumes that:

- The arrivals of trucks requiring slow charging are concentrated within a specific time interval during the day.
- Each truck that stops for overnight rest occupies a charging point for the entire night.

No queues or significant waiting times occur, as there is no rotation of use during this period.

This behavior does not correspond to a dynamic service system but rather to a stationary and simultaneous usage pattern. Therefore, the sizing is based on estimating how many trucks regularly overnight at the station and ensuring an equivalent number of slow chargers, guaranteeing coverage without relying on rotations or service shifts.

This approach allows for precise sizing of the nighttime charging capacity, adapting to the real needs of heavy transport during extended rest hours.

To estimate how many slow chargers are needed at each charging station, the following procedure is followed:

1. Start with the daily flow of electric trucks that will pass through the section of road where the charging station is located.
2. From this daily flow, only 16.67% is considered, corresponding to trucks that will travel between 21:00 and 06:00, assuming these are the vehicles that have the potential to make an overnight stop.
3. As with the fast chargers, it is assumed that the truck flow is evenly split between both directions (50% in each direction).

4. To estimate how many trucks will actually stop at the charging station, a stop proportion is calculated based on the distance to the next charging station in each direction, using the same logic as in the fast charger sizing.

$$Proportion\ stop = \frac{Distance\ to\ the\ next\ electric\ charging\ station\ in\ \ direction\ \text{"}x\text{"}}{335} \quad (E15)$$

5. The estimated number of trucks stopping in each direction is added together. The result represents the total number of trucks that will overnight at the station, and therefore, the number of charging points needed.
6. Finally, the number of fast chargers already sized for that location is subtracted from this total number, as these chargers could also be used by trucks during prolonged rest. The difference represents the number of additional slow chargers needed.

Chapter 4. RESULTS ANALYSIS

As a result of the application of the gravitational model, a total of 12 optimal sites have been selected for the installation of electric truck charging stations along the Spanish Mediterranean Corridor. The selection was based on a maximization of the attractiveness index, which was calculated considering the projected truck flow for 2030 and geographic accessibility, while simultaneously penalizing excessive proximity between stations using a corrective term in the objective function. The optimal solution corresponds to the set that maximizes demand coverage, avoids unnecessary overlap, and balances the infrastructure along the road axis.

4.1 GEOGRAPHICAL DISTRIBUTION

The selected charging stations are distributed along the main segments of the AP-7, A-2, A-31, A-7, V-23, and C-17 roads, with a special concentration on the most critical points of the Mediterranean Corridor. This network spans from the Murcia region to the French border, passing through key logistics hubs such as Valencia, Tarragona, Barcelona, Castellón, and Girona.

A balance has been achieved between stations near major urban centers and others located in intermediate segments to ensure the operational continuity of the vehicles. The average distance between stations is around 160 km, which ensures compatibility with the expected autonomy of electric trucks and compliance with the European regulations on rest periods.

Code	*Province*	*Road*	*Exit*	*Permanent station*
9		AP-7	594	B-42-0
7		C-17	13	B-28-0
3		A-2	708	GI-20-0
17		AP-7	11	B-26-0
1		AP-7	3	GI-13-0
29		A-31	220	A-536-0
13		A-3	337	V-385-0

14	A-2	517	L-200-0
10	A-7	1153	T-61-0
11	V-23	2	V-83-0
2	AP-7	42	CS-145-0
24	AP-7	45	CS-113-0

Table 2. Geographical information of the 12 electric charger station locations

4.2 TECHNICAL SIZING OF CHARGERS

At each of the 12 selected stations, the sizing of fast and slow chargers has been carried out based on the estimated hourly flow, the probability of a stop, and the distance to the next available station in both directions. The estimation of electric trucks in 2030 in this study has been 7%, as it is the scenario which most studies agree and therefore, the one with the highest probability to occur. Nevertheless, in section 4.6 a sensitivity analysis has been conducted in order to see how the penetration of electric trucks affect to the total cost. For fast chargers, the M/M/s queueing theory model has been applied, with the goal of ensuring a total station pass-through time of less than 50 minutes and a maximum utilization rate of 95%. For slow chargers, aimed at overnight stops or prolonged rests, a static occupancy model has been adopted.

The result is a differentiated allocation by station, with between 2 and 8 fast chargers and up to 4 slow chargers at locations with the highest nighttime presence. This differentiation helps to optimize resource use, avoid over-sizing, and adapt to the expected usage patterns.

4.3 ECONOMIC COST OF THE INFRAESTRUCTURE

Based on the number of chargers sized at each location and the unit installation costs (€50,820 per slow charger and €394,000 per fast charger), the total deployment cost has been estimated. These values are based on discussions with experts from the project team and reflect current market conditions and installation standards. The result is summarized in table 3:

Electric charging station code	*Chargers (Units)*		*Price (€)*		
	Slow	Fast (MCS)	Slow	Fast (MCS)	Total
9	4	8	203.280	3.152.000	3.355.280
7	0	4	0	1.576.000	1.576.000
3	2	7	101.640	2.758.000	2.859.640
17	0	6	0	2.364.000	2.364.000
1	0	3	0	1.182.000	1.182.000
29	0	7	0	2.758.000	2.758.000
13	0	7	0	2.758.000	2.758.000
14	0	3	0	1.182.000	1.182.000
10	0	4	0	1.576.000	1.576.000
11	0	2	0	788.000	788.000
2	2	2	101.640	788.000	889.640
24	0	2	0	788.000	788.000
					22.076.560

Table 3.Breakdown of the total price per electric truck charging station

The average cost per station is €1.83 million, and the average cost per charger (combining both types) is approximately €183,250. These figures confirm the economic viability of the proposed deployment plan, especially considering its capacity to cover most of the expected heavy electric transport flows for 2030.

4.4 CRITICAL EVALUATION OF THE APPLIED MODEL

The proposed prioritization model has proven effective in identifying optimal charging station locations based on projected demand, geographic accessibility, and spatial distribution. Unlike simplistic distance-based approaches, this method integrates empirical data (MITMA, ACEA), demand forecasts (Fraunhofer), and spatial optimization techniques to develop a realistic and operationally coherent network.

One of the key strengths of the model lies in its balance between coverage and redundancy avoidance. By including a corrective term that penalizes excessive proximity between stations, the model avoids inefficient clustering and promotes territorial continuity.

Another relevant feature is its flexibility. The model can be updated as new data becomes available—such as real-world electric truck adoption rates, local energy grid constraints, or changes in traffic flows—without needing to restart the entire analysis.

It is worth noting that while the model performs well under the assumptions used, future scenarios may introduce uncertainties. For example, a significant increase in demand at a specific station may challenge the queueing-based sizing, requiring dynamic adjustments or local reinforcements. Nonetheless, the modular and data-driven nature of the methodology makes it highly adaptable to future expansion phases or policy changes.

4.5 ALIGNMENT WITH EUROPEAN REGULATIONS

The AFIR regulation, adopted in 2023, stipulates that by 2030, member states must ensure the presence of charging stations for heavy-duty vehicles every 60 kilometers in both directions along the core TEN-T network, with a minimum total power of 3,600 kW per area. While this requirement sets systematic deployment, the approach developed in this work allows for prioritizing locations with higher logistical appeal and anticipated demand, facilitating a phased and efficient implementation of the national plan.

In this context, the points selected by the proposed model largely coincide with the most trafficked sections of the TEN-T network and, therefore, are suitable to be considered as the initial phases of the mandatory deployment envisioned by the EU. In particular, the following locations stand out as priorities due to their traffic volume, connectivity, and strategic value.

4.6 COST SENSITIVITY ANALYSIS ACCORDING TO THE PENETRATION RATE OF ELECTRIC TRUCKS

Given the current uncertainty surrounding the future adoption rate of electric heavy-duty vehicles, a sensitivity analysis has been conducted to estimate how different market penetration scenarios would affect infrastructure needs and investment requirements.

Although projections suggest that a 7% penetration rate is a likely scenario by 2030, the exact rate remains uncertain. Therefore, it is useful to assess the implications of alternative adoption levels. The following table summarizes the total infrastructure cost for different penetration rates:

% of electric trucks	*Total Cost*
5%	16.357.280
7%	22.076.560
10%	29.587.680
15%	42.983.100

Table 4.Cost sensitivity analysis according to the penetration rate of electric trucks

As seen in Table 4.Cost sensitivity analysis according to the penetration rate of electric trucks, infrastructure costs rise proportionally to the increase in electric truck penetration. While a 5% adoption rate would entail a total cost of approximately €16.36 million, expanding this figure to a 15% penetration scenario would nearly triple the investment, surpassing €42.98 million.

These costs reflect the scenario in which the charging station network was optimally sized and placed to meet demand effectively while preventing oversizing and redundant infrastructure overlap. Therefore, the economic feasibility and efficiency remain robust even at higher levels of adoption, making the proposed plan scalable and economically sustainable for anticipated future growth scenarios.

Further detailed information, including the specific breakdown per station and the number of chargers required at each station according to each penetration scenario (5%, 7%, 10%, and 15%), is provided in the Annexes.

Chapter 5. CONCLUSIONS AND FUTURE WORK

This Master's Thesis has addressed the challenge of planning an electric charging infrastructure for heavy-duty trucks in the Mediterranean Corridor, one of the most important freight routes in Spain and Europe. The methodology developed throughout the project integrates spatial data analysis, optimization models, and technical dimensioning, resulting in a proposal that is both robust and practical for real-world implementation.

One of the key conclusions is that effective infrastructure planning requires prioritization. Rather than attempting to deploy stations everywhere at once, the use of demand-driven models allows for the identification of the most strategic locations. This approach ensures that resources are invested where they will have the greatest impact in terms of coverage, operational efficiency, and regulatory compliance.

Another important lesson is the need for flexibility and scalability. The sensitivity analysis performed in this study shows that the network can be deployed in phases, beginning with an initial investment to meet a 5% electric truck penetration rate, and scaling up as adoption increases. This incremental approach reduces the risk of overinvestment and allows for the integration of new data as the sector evolves.

The integration of technical, regulatory, and economic considerations from the outset has proven essential. By aligning the proposal with AFIR requirements and incorporating detailed cost analysis, the study ensures that the resulting plan is not only technically feasible, but also financially realistic and compliant with European policy.

The results demonstrate that with careful planning, it is possible to design a charging network that covers the most critical logistics segments, minimizes unnecessary overlaps, and provides a solid foundation for the electrification of road freight transport. In total, 12 optimal charging stations were selected along the Mediterranean Corridor. Under a 7% electric truck adoption scenario, the network would require 55 fast chargers and 8 slow chargers, with an estimated total infrastructure cost of €22,076,560. The proposed methodology—combining spatial analysis, optimization, and technical modeling—can be adapted for other corridors or regions, serving as a reference for future infrastructure projects.In summary, this project confirms that the transition to electric heavy-duty vehicles is achievable if supported by rigorous analysis, phased investments, and coordination between public and private stakeholders. The experience gained during this research highlights the value of using open data, advanced modeling tools, and clear regulatory guidelines to support effective decision-making in transport infrastructure.

As freight transport continues to evolve, ongoing monitoring and adaptation will be required. Future updates to the model could include real-time data, more detailed grid constraints, or varying consumption rates depending on route characteristics. What is clear is that a well-planned, adaptable, and demand-driven infrastructure will be key to meeting both national and European sustainability goals.

5.1 FUTURE LINES OF WORK

Looking ahead, there are several directions in which this work can be expanded and improved to provide even greater value to decision-makers and industry stakeholders. One important avenue is the integration of real-world electrical grid constraints into the planning model. By considering the actual capacity and connection possibilities of the power grid at each selected location, future studies could ensure that proposed stations are not only optimal in terms of logistics, but also feasible from an energy supply perspective.

Another area for further research is the refinement of demand estimation methods. Incorporating more detailed data on truck energy consumption—accounting for factors such as route topography, average loads, and different driving cycles—would make it possible to adjust infrastructure sizing more accurately to real operational needs. This would help to avoid both under-dimensioning, which could result in bottlenecks, and over-dimensioning, which would increase costs unnecessarily.

Additionally, the current model assumes fixed adoption rates for electric trucks, but the reality is likely to be more dynamic. Developing a framework to simulate the progressive growth of the electric truck fleet over time would enable planners to forecast when and where additional charging capacity will be needed, and to schedule investments accordingly. This type of dynamic modeling would also be useful for assessing the resilience of the network to sudden changes in demand or market conditions.

There is also significant potential for enhancing the user experience at charging stations. Future work could explore the integration of additional services, such as overnight rest facilities, maintenance, or logistics support, transforming charging stations into comprehensive hubs for drivers and operators. Finally, aligning the prioritization of station deployment with available funding mechanisms and broader sustainability policies at the national and European levels will be crucial for ensuring the financial viability and long-term success of the infrastructure.

Importantly, the approach and tools developed here are not limited to the Mediterranean Corridor. The methodology can be readily expanded and adapted to other logistics corridors, regions, or even countries, both within Spain and across Europe. By following the same principles, combining empirical traffic data, spatial modeling, and economic analysis, planners can identify optimal locations and size infrastructure to support the wider transition to zero-emission freight transport.

In conclusion, this work provides not only a roadmap for deploying electric truck charging stations in one of Spain's main freight corridors, but also a replicable framework that can inform similar efforts in other territories. Success in this transition will depend on rigorous planning, coordination among stakeholders, and ongoing adaptation as technologies and market conditions change.

Chapter 6. BIBLIOGRAPHY

ACEA. (March, 2025). *Interactive maps: electric trucks stop locations in southern europe.* https://www.acea.auto/figure/interactive-maps-electric-trucks-stop-locations-southern-europe/

ACEA. (2025). *Report – Vehicles on European roads 2025.* https://www.acea.auto/publication/report-vehicles-on-european-roads-2025/

European Comission. (2025). *Alternative Fuels Infrastructure Directive (AFID). Directiva 2014/94/UE.* https://eur-lex.europa.eu/eli/dir/2014/94/oj/eng

European Comission. (2025*). Fit for 55: El paquete legislativo climático de la UE. Bruselas: Unión Europea.* https://www.consilium.europa.eu/es/policies/fit-for-55/

European Comission. (2023). *Reglamento (UE) 2023/1804 del Parlamento Europeo y del Consejo relativo a la implantación de una infraestructura para los combustibles alternativos y por el que se deroga la Directiva 2014/94/UE.* https://www.boe.es/buscar/doc.php?id=DOUE-L-2023-81310

European Comission. (s.f.). *Red Transeuropea de Transporte (TEN-T). Unión Europea.*

European Commission. (2013). ETISplus – European Transport policy Information System Plus (Project No. 233596). CORDIS. https://cordis.europa.eu/project/id/233596

Eurostat. (2025). *Road freight transport statistics*. https://ec.europa.eu/eurostat

Fraunhofer ISI. (2022). *Synthetic European Road Freight Transport Flow Data.* https://www.sciencedirect.com/science/article/pii/S235234092101060X

Fraunhofer ISI (2024). *Optimized demand-based charging networks for long-haul trucking in Europe.* https://www.isi.fraunhofer.de/en/presse/2024/presseinfo-20-e-lkw-schnellladestationen-europa.html

Bloomberg. (March, 2025). *Cheaper Truck Batteries Usher in Dawn of Emissions-Free Rigs*. *McKerracher, C.* https://www.bloomberg.com/news/newsletters/2024-09-24/cheaper-truck-batteries-usher-in-dawn-of-emissions-free-rigs

Ministerio de Transportes y Movilidad Sostenible. (April, 2025). *Mapa de tráfico*. https://mapatrafico.transportes.gob.es/2022/

Ministerio para la Transición Ecológica y el Reto Demográfico. (2020). *Plan Nacional Integrado de Energía y Clima.* https://www.miteco.gob.es/es/energia/estrategia-normativa/pniec-23-30.html

International Council on Clean Transport. (March, 2025). *A total cost of ownership comparison of truck decarbonization pathways in Europe. Rodríguez, H. B.* https://theicct.org/publication/total-cost-ownership-trucks-europe-nov23/

Volvo. (February, 2025). *Towards zero emissions*. https://www.volvotrucks.com/en-en/about-us/how-we-drive-progress/towards-zero-emissions.html

APPENDIX I

ELECTRIC TRUCK CHARGING STATION INFRASTRUCTURE SUMMARY

Code	**9**
Coordinates	41.4668,1.9781
Road	AP-7
Exit	594
Permanent monitoring station	B-42-0

[1]

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	6	2.364.000	Fast chargers	8	3.152.000
Slow chargers	2	101.640	Slow chargers	4	203.280
		2.465.640			**3.355.280**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	11	4.334.000	Fast chargers	16	6.304.000
Slow chargers	8	406.560	Slow chargers	14	711.480
		4.740.560			**7.015.480**

Code	**7**
Coordinates	41.5923,2.3115
Road	C-17
Exit	13
Permanent monitoring station	B-28-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	3	1.182.000	Fast chargers	4	1.576.000
Slow chargers	0		Slow chargers	0	
		1.182.000			**1.576.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	5	1.970.000	Fast chargers	7	2.758.000
Slow chargers	0		Slow chargers	3	152.460
		1.970.000			**2.910.460**

Code	**3**
Coordinates	41.9292,2.7845
Road	A-2
Exit	708
Permanent monitoring station	GI-20-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	5	1.970.000	Fast chargers	7	2.758.000
Slow chargers	2	101.640	Slow chargers	2	101.640
		2.071.640			**2.859.640**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	9	3.546.000	Fast chargers	13	5.122.000
Slow chargers	7	355.740	Slow chargers	13	660.660
		3.901.740			**5.782.660**

Code	17
Coordinates	41.6479,2.4253
Road	AP-7
Exit	11
Permanent monitoring station	B-26-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	4	1.576.000	Fast chargers	6	2.364.000
Slow chargers	0		Slow chargers	0	
		1.576.000			**2.364.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	8	3.152.000	Fast chargers	11	4.334.000
Slow chargers	0		Slow chargers	4	203.280
		3.152.000			**4.537.280**

Code	**1**
Coordinates	42.2989,2.9374
Road	AP-7
Exit	3
Permanent monitoring station	GI-13-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	2	788.000	Fast chargers	3	1.182.000
Slow chargers	0	0	Slow chargers	0	
		788.000			**1.182.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	4	1.576.000	Fast chargers	5	1.970.000
Slow chargers	0		Slow chargers	2	101.640
		1.576.000			**2.071.640**

Code	**29**
Coordinates	38.3695,-0.7045
Road	A-31
Exit	220
Permanent monitoring station	A-536-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	5	1.970.000	Fast chargers	7	2.758.000
Slow chargers	0		Slow chargers	0	
		1.970.000			**2.758.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	9	3.546.000	Fast chargers	14	5.516.000
Slow chargers	4	203.280	Slow chargers	4	203.280
		3.749.280			**5.719.280**

Code	13
Coordinates	39.4715,-0.6455
Road	A-3
Exit	337
Permanent monitoring station	V-385-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	5	1.970.000	Fast chargers	7	2.758.000
Slow chargers	0		Slow chargers	0	
		1.970.000			**2.758.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	9	3.546.000	Fast chargers	13	5.122.000
Slow chargers	2	101.640	Slow chargers	6	304.920
		3.647.640			**5.426.920**

Code	**14**
Coordinates	41.6669,1.2112
Road	A-2
Exit	517
Permanent monitoring station	L-200-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	2	788.000	Fast chargers	3	1.182.000
Slow chargers	0		Slow chargers	0	
		788.000			**1.182.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	3	1.182.000	Fast chargers	4	1.576.000
Slow chargers	0		Slow chargers	0	0
		1.182.000			**1.576.000**

Code	**10**
Coordinates	41.1367,1.2219
Road	A-7
Exit	1153
Permanent monitoring station	T-61-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	3	1.182.000	Fast chargers	4	1.576.000
Slow chargers	0		Slow chargers	0	
		1.182.000			**1.576.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	5	1.970.000	Fast chargers	7	2.758.000
Slow chargers	1	50.820	Slow chargers	3	152.460
		2.020.820			**2.910.460**

Code	11	
Coordinates	39.6501,-0.3016	
Road	V-23	
Exit	2	
Permanent monitoring station	V-83-0	

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	2	788.000	Fast chargers	2	788.000
Slow chargers	0		Slow chargers	0	
		788.000			**788.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	3	1.182.000	Fast chargers	4	1.576.000
Slow chargers	0		Slow chargers	0	
		1.182.000			**1.576.000**

Code	**2**
Coordinates	40.4592,0.4065
Road	AP-7
Exit	42
Permanent monitoring station	CS-145-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	2	788.000	Fast chargers	2	788.000
Slow chargers	0		Slow chargers	2	101.640
		788.000			**889.640**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	3	1.182.000	Fast chargers	4	1.576.000
Slow chargers	2	101.640	Slow chargers	6	304.920
		1.283.640			**1.880.920**

Code	**24**
Coordinates	40.089,-0.0074
Road	AP-7
Exit	45
Permanent monitoring station	CS-113-0

Charging Infrastructure and Cost under Different EV Truck Penetration Scenarios for this station					
5% EV truck share			7% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	2	788.000	Fast chargers	2	788.000
Slow chargers	0		Slow chargers	0	
		788.000			**788.000**
10% EV truck share			15% EV truck share		
	Units	Cost (€)		Units	Cost (€)
Fast chargers	3	1.182.000	Fast chargers	4	1.576.000
Slow chargers	0		Slow chargers	0	
		1.182.000			**3.355.280**

PYTHON SCRIPT TO CREATE LINES BETWEEN COORDINATES

```
# QGIS script to create line geometry from coordinates X_A, Y_A, X_B, Y_B
# Runs in QGIS Python Console
from qgis.core import (
    QgsProject,
    QgsVectorLayer,
    QgsFeature,
    QgsGeometry,
    QgsPointXY,
    QgsField,
    QgsFields,
    QgsVectorFileWriter,
    QgsWkbTypes,
    QgsCoordinateReferenceSystem
)
from PyQt5.QtCore import QVariant

# Path of the loaded CSV file (without geometry)
layer = iface.activeLayer()  # select the active layer

# Create a new line-type layer
output_path = "C:/Users/Juan/Documents/TruckFlows.shp"  # change this path if
necessary
crs = QgsCoordinateReferenceSystem("EPSG:4326")
fields = layer.fields()

new_fields = QgsFields()
for field in fields:
    new_fields.append(field)

writer = QgsVectorFileWriter(
    output_path,
    "UTF-8",
    new_fields,
    QgsWkbTypes.LineString,
    crs,
    "ESRI Shapefile"
)

for feat in layer.getFeatures():
    x1 = feat["X_A"]
    y1 = feat["Y_A"]
    x2 = feat["X_B"]
    y2 = feat["Y_B"]

    if None in (x1, y1, x2, y2):
        continue  # skip if there are null values

    point1 = QgsPointXY(float(x1), float(y1))
    point2 = QgsPointXY(float(x2), float(y2))
    geom = QgsGeometry.fromPolylineXY([point1, point2])
```

```
    new_feat = QgsFeature()
    new_feat.setFields(new_fields)
    new_feat.setAttributes(feat.attributes())
    new_feat.setGeometry(geom)
    writer.addFeature(new_feat)

QgsProject.instance().addMapLayer(QgsVectorLayer(output_path, "Truck Flows",
"ogr"))
print("✔ Lines created successfully")
```

VBA SCRIPT THAT IDENTIFIES THE 12 OPTIMAL LOCATIONS

```
'================ CONFIGURATION ====================================
Const NUM_SELECT        As Long   = 12
Const RANGE_SCORE       As String = "Calculo!B2:B19"
Const RANGE_IDS         As String = "Calculo!A2:A19"
Const RANGE_DIST        As String = "Sheet1!B2:S19"    ' distances in meters
Const OUTPUT_SHEET      As String = "Selected"

' Parameters for dynamic λ
Const LAMBDA_FACTOR     As Double = 1         ' 1 → full penalty
Const RADIUS_KM         As Double = 10        ' radius of influence (km)
Const RADIUS_M          As Double = RADIUS_KM * 1000
'====================================================================



'============ MAIN MACRO: finds the optimal combination =============
Sub Optimal_12_Stations()

    '--- load data ---------------------------------------------------
    Dim vScore As Variant: vScore = Range(RANGE_SCORE).Value
    Dim vIDs   As Variant: vIDs   = Range(RANGE_IDS).Value
    Dim vDist  As Variant: vDist  = Range(RANGE_DIST).Value

    '--- preparations for enumeration --------------------------------
    Dim idx(1 To 18) As Long, i As Long
    For i = 1 To 18: idx(i) = i: Next i          ' indices 1…18

    Dim sel(1 To NUM_SELECT) As Long             ' current combination
    Dim bestSel(1 To NUM_SELECT) As Long         ' best combination
    Dim bestZ As Double: bestZ = -1E+99

    Enumerate 1, 1, sel, idx, vScore, vDist, bestZ, bestSel, NUM_SELECT

    '--- output result to sheet --------------------------------------
    Dim ws As Worksheet: Set ws = EnsureSheet(OUTPUT_SHEET)
    ws.Cells.Clear
    ws.Range("A1").Value = "Optimal ID"
    For i = 1 To NUM_SELECT
        ws.Cells(i + 1, 1).Value = vIDs(bestSel(i), 1)
    Next i
    ws.Range("C1").Value = "Optimal Score": ws.Range("C2").Value = bestZ
End Sub


'============= RECURSIVE ROUTINE WITH DYNAMIC λ =====================
Private Sub Enumerate(pos As Long, startIdx As Long, _
                      sel() As Long, idx() As Long, _
                      vScore As Variant, vDist As Variant, _
                      ByRef bestZ As Double, bestSel() As Long, _
                      N As Long)

    Dim i&, j&, k&, benefit#, totalPen#, lambdaVal#, d#
```

```
    If pos > N Then
        '-- 1) benefit and λ for combination ---------------------
        For i = 1 To N: benefit = benefit + vScore(sel(i), 1): Next i
        lambdaVal = LAMBDA_FACTOR * (benefit / N) * (RADIUS_M ^ 2)

        '-- 2) accumulated penalty --------------------------------
        For i = 1 To N - 1
            For j = i + 1 To N
                d = vDist(sel(i), sel(j))
                If d <= 0 Or Not IsNumeric(d) Then d = 1E+99
                totalPen = totalPen + lambdaVal / (d * d)
            Next j
        Next i

        '-- 3) final score and optimal update ---------------------
        Dim Z#: Z = benefit - totalPen
        If Z > bestZ Then
            bestZ = Z
            For k = 1 To N: bestSel(k) = sel(k): Next k
        End If

    Else
        '-- build the combination ---------------------------------
        For i = startIdx To UBound(idx) - (N - pos)
            sel(pos) = idx(i)
            Enumerate pos + 1, i + 1, sel, idx, vScore, vDist, bestZ, bestSel, N
        Next i
    End If
End Sub


'==================== MINIMAL UTILITY (create sheet) ==================
Private Function EnsureSheet(name As String) As Worksheet
    On Error Resume Next
    Set EnsureSheet = Worksheets(name)
    If EnsureSheet Is Nothing Then
        Set EnsureSheet = Worksheets.Add
        EnsureSheet.Name = name
    End If
    On Error GoTo 0
End Function
```

ALIGNMENT WITH THE SUSTAINABLE DEVELOPMENT GOALS (SDGS)

This project is closely aligned with several of the Sustainable Development Goals (SDGs) established by the United Nations' 2030 Agenda, as it addresses the transition toward a cleaner, more efficient, and more resilient freight transport model (United Nations, 2015). In particular, it contributes to the following SDGs:

SDG 7 – Affordable and Clean Energy

The planning of a charging network for electric trucks promotes the use of electricity as an energy source in heavy transport, facilitating the gradual replacement of fossil fuels with cleaner and more sustainable alternatives. Although the project does not focus on energy generation, it contributes to ensuring access to modern and efficient energy systems.

SDG 9 – Industry, Innovation and Infrastructure

The project supports the development of sustainable and technologically advanced infrastructure, such as charging stations for heavy electric vehicles. It also applies optimization models and spatial analysis, fostering innovation in territorial planning.

SDG 11 – Sustainable Cities and Communities

The reduction in emissions resulting from the use of electric trucks has a direct impact on improving air quality and the urban environment. This contributes to creating healthier and more sustainable environments for populations located near logistics corridors.

SDG 12 – Responsible Consumption and Production

The project promotes more efficient use of energy resources and more streamlined logistics by proposing a charging network optimized according to actual demand. This planning supports more sustainable mobility and a reduced environmental impact across the supply chain.

SDG 13 – Climate Action

By facilitating the transition to electric heavy transport, the project directly contributes to climate change mitigation, reducing greenhouse gas emissions from the logistics sector and aligning with European commitments to climate neutrality.