ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

GRADO EN INGENIERÍA ELECTROMECÁNICA

TRABAJO FIN DE GRADO

INTEGRATION OF THE URBAN DELIVERY VEHICLES IN THE GRID AND OPTIMIZATION OF THE RECHARGING PROCESS

Autor: Marta García-Borregón Castañeda

Director: Francisco Javier Ponce Cintas

Co-Director: Pablo Frías Marín

Madrid

22 de julio de 2019

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

INTEGRATON OF THE URBAN ELECTRIC VEHICLE IN THE GRID AND OPTIMITATIONOF THE RECHARGING PROCCESS

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

curso académico 2018/19 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.: Marta García-Borregón Fecha: 22/ 07/ 2019

Autorizada la entrega del proyecto

EL DIRECTOR DEL PROYECTO

Fdo.: Francisco Javier Ponce Cintas Fecha:22/07/ 2019

EL CO-DIRECTOR DEL PROYECTO

Fdo.: Pablo Frías Marín Fecha: 22/07/ 2019

AUTORIZACIÓN PARA LA DIGITALIZACIÓN, DEPÓSITO Y DIVULGACIÓN EN RED DE PROYECTOS FIN DE GRADO, FIN DE MÁSTER, TESINAS O MEMORIAS DE BACHILLERATO

1º. Declaración de la autoría y acreditación de la misma.

El autor DÑA. MARTA GARCÍA-BORREGÓN

DECLARA ser el titular de los derechos de propiedad intelectual de la obra: __INTEGRATION OF THE URBAN DELIVERY VEHICLES IN THE GRID AND OPTIMIZATION OF THE RECHARGING PROCCESS, que ésta es una obra original, y que ostenta la condición de autor en el sentido que otorga la Ley de Propiedad Intelectual.

2º. Objeto y fines de la cesión.

Con el fin de dar la máxima difusión a la obra citada a través del Repositorio institucional de la Universidad, el autor **CEDE** a la Universidad Pontificia Comillas, de forma gratuita y no exclusiva, por el máximo plazo legal y con ámbito universal, los derechos de digitalización, de archivo, de reproducción, de distribución y de comunicación pública, incluido el derecho de puesta a disposición electrónica, tal y como se describen en la Ley de Propiedad Intelectual. El derecho de transformación se cede a los únicos efectos de lo dispuesto en la letra a) del apartado siguiente.

3º. Condiciones de la cesión y acceso

Sin perjuicio de la titularidad de la obra, que sigue correspondiendo a su autor, la cesión de derechos contemplada en esta licencia habilita para:

a) Transformarla con el fin de adaptarla a cualquier tecnología que permita incorporarla a internet y hacerla accesible; incorporar metadatos para realizar el registro de la obra e incorporar “marcas de agua” o cualquier otro sistema de seguridad o de protección.
b) Reproducirla en un soporte digital para su incorporación a una base de datos electrónica, incluyendo el derecho de reproducir y almacenar la obra en servidores, a los efectos de garantizar su seguridad, conservación y preservar el formato.
c) Comunicarla, por defecto, a través de un archivo institucional abierto, accesible de modo libre y gratuito a través de internet.
d) Cualquier otra forma de acceso (restringido, embargado, cerrado) deberá solicitarse expresamente y obedecer a causas justificadas.
e) Asignar por defecto a estos trabajos una licencia Creative Commons.
f) Asignar por defecto a estos trabajos un HANDLE (URL *persistente)*.

4º. Derechos del autor.

El autor, en tanto que titular de una obra tiene derecho a:

a) Que la Universidad identifique claramente su nombre como autor de la misma
b) Comunicar y dar publicidad a la obra en la versión que ceda y en otras posteriores a través de cualquier medio.
c) Solicitar la retirada de la obra del repositorio por causa justificada.
d) Recibir notificación fehaciente de cualquier reclamación que puedan formular terceras personas en relación con la obra y, en particular, de reclamaciones relativas a los derechos de propiedad intelectual sobre ella.

5º. Deberes del autor.

El autor se compromete a:

a) Garantizar que el compromiso que adquiere mediante el presente escrito no infringe ningún derecho de terceros, ya sean de propiedad industrial, intelectual o cualquier otro.
b) Garantizar que el contenido de las obras no atenta contra los derechos al honor, a la intimidad

y a la imagen de terceros.

c) Asumir toda reclamación o responsabilidad, incluyendo las indemnizaciones por daños, que pudieran ejercitarse contra la Universidad por terceros que vieran infringidos sus derechos e intereses a causa de la cesión.

d) Asumir la responsabilidad en el caso de que las instituciones fueran condenadas por infracción de derechos derivada de las obras objeto de la cesión.

6º. Fines y funcionamiento del Repositorio Institucional.

La obra se pondrá a disposición de los usuarios para que hagan de ella un uso justo y respetuoso con los derechos del autor, según lo permitido por la legislación aplicable, y con fines de estudio, investigación, o cualquier otro fin lícito. Con dicha finalidad, la Universidad asume los siguientes deberes y se reserva las siguientes facultades:

- La Universidad informará a los usuarios del archivo sobre los usos permitidos, y no garantiza ni asume responsabilidad alguna por otras formas en que los usuarios hagan un uso posterior de las obras no conforme con la legislación vigente. El uso posterior, más allá de la copia privada, requerirá que se cite la fuente y se reconozca la autoría, que no se obtenga beneficio comercial, y que no se realicen obras derivadas.
- La Universidad no revisará el contenido de las obras, que en todo caso permanecerá bajo la responsabilidad exclusive del autor y no estará obligada a ejercitar acciones legales en nombre del autor en el supuesto de infracciones a derechos de propiedad intelectual derivados del depósito y archivo de las obras. El autor renuncia a cualquier reclamación frente a la Universidad por las formas no ajustadas a la legislación vigente en que los usuarios hagan uso de las obras.
- La Universidad adoptará las medidas necesarias para la preservación de la obra en un futuro.
- La Universidad se reserva la facultad de retirar la obra, previa notificación al autor, en supuestos suficientemente justificados, o en caso de reclamaciones de terceros.

Madrid, a 22 de 07 de 2019

ACEPTA

Fdo………………………………………………

Motivos para solicitar el acceso restringido, cerrado o embargado del trabajo en el Repositorio Institucional:

ESCUELA TÉCNICA SUPERIOR DE INGENIERÍA (ICAI)

GRADO EN INGENIERÍA ELECTROMECÁNICA

TRABAJO FIN DE GRADO

INTEGRATION OF THE URBAN DELIVERY VEHICLES IN THE GRID AND OPTIMIZATION OF THE RECHARGING PROCESS

Autor: Marta García-Borregón Castañeda

Director: Francisco Javier Ponce Cintas

Co-Director: Pablo Frías Marín

Madrid

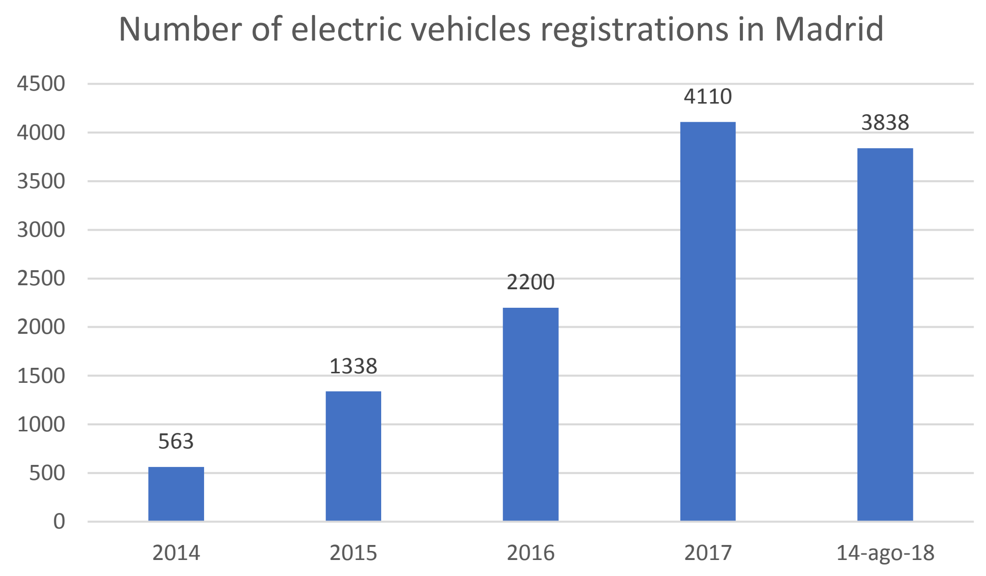
22 de julio de 2019

PROJECT SUMMERY

A. INTRODUCTION

The **European Union** is **constantly promoting the growth of the electric car**, that is why, the manufacturer industry has reacted with a target of getting 25% of their fleet electric or hybrid by 2025. Moreover, the EU has stablished the prohibition of selling combustion vehicles in 2035 [1].

In Spain, the growth of the electric vehicle is not as remarkable as in the rest of Europe. However, in the las two years the number of electric vehicle registrations experimented a sustainable raised. As it is indicated in the table below in the city of Madrid it has ascended to 4110 new vehicles in 2017:



GRAPHIC 1. NUMBER OF ELECTRIC VEHICLES REGISTRATIONS IN MADRID [2]

This increase of electric vehicles owners is because the EV models in the market are lowering their prices and increasing their ranges. However, the **doubts of an emerging technology** make potential customers want to have no risk.

This explains why the introduction of the electric vehicle in the freight business is not consolidated yet. The low confidence of the companies in this technology is due to the restricted range and the high investment required. In a general overview, incorporating electric vehicles to the fleet demands to build a recharging installation and to pay higher prices for electric vehicles than for conventional ones with similar features.

This work aims to offer a **solid business model** to show that an electric fleet can be a profitable, solid and competitive alternative to perform the deliveries. Besides, in the practise it has been already proved by the FREVUE Project[1] [3] that electric vehicles represent a viable solution in the delivery business.

Therefore, the main goal of this project is to propose an **optimal method** to introduce this new technology in pattern of the above-mentioned business as well as obtaining the confidence of the market.

B. PROBLEM STATEMENT

The Spanish Government has revealed its intention of energy decarbonization and therefore the target of getting fuel light vehicles extinctic by 2050 [4]. That is why arises the necessity of carrying out a deep analysis of the electric transportation technology and the new variables that appear in the equation, such as: the range of the vehicles and therefore the delivering time frame; the batteries and their recharging power needed; the recharging installation design and the optimal tariff to hire in order to minimize the electricity bill.

Furthermore, electric vans are an up-to-date technology with a very low background in the freight business, making meaningful to introduce them slightly in their fleet in order to **monitoring and controlling** to get enough experience.

Finally, the main objective of the project is to show that incorporating electric vehicles to freight fleet is economically viable. For that purpose, a **comparison between electric and combustion vehicles** costs will be done.

C. CASE OF STUDY

The case of study aim is to evaluate the integration of electric vehicle in a company that needs **60 fuel light fright vehicles** with the C DGT label [5] to perform all the deliveries in "Madrid Central". The logistics company owns three warehouses in the outskirts of Madrid, located in Coslada, Fuenlabrada and Alcobendas.

Due to the "*Madrid Central"* new requirements, vehicles are classified with a label based on the type of main power source used, issued by DGT. In accordance with the classification, the city centre has different time restriction for freight vehicles. Electric

[1] The **FREVUE Project** (Validating Freight Electric Vehicles in Urban Europe) is a European initiative with the objective of showing if electric vehicles can substitute fuel and diesel vehicles in the delivery distribution sector. Eight cities with very different climates participated in the project (Amsterdam, Lisbon, London, Madrid, Milan, Oslo, Rotterdam and Stockholm) that ends up with a positive outcome, **positioning electric vans as a viable solution for urban delivery**.

vehicles belong to the ZERO label, Hybrid technologies to the ECO label, fossil fuel vehicles with B or C label depending on the CO_X emissions.

Vehicles with the zero label emissions has no time restrictions. For the first evaluation process, this project will consider the same amount of daily hours for delivery in both cases, fuel and electric vans. Due to the restrictions of "*Madrid Central"* each C label vehicle will be allowed to circulate only for 8 hours per day in 2020 while electric vehicles have no restrictions [5]. In a nutshell, **for the same number of deliveries it should be needed a smaller number of electric vehicles,** but they will deliver during more hours each.

D. <u>METHODOLOGY</u>

Firstly, it would be **selected the optimal vehicle** for this case. Due to the distance between the recharging installations the vehicle selected must have at least a range of 200km. Besides, the vehicle should be able to reach a speed of 120km/h in order to perform the deliveries as fast as possible.

The second step is to establish the **number of electric vehicles** needed to perform the same deliveries as the conventional vans and the **timeframe** that there would spend **delivering and recharging** in order to minimize the electricity expenses. This optimization problem will be solved with GAMS.

Moreover, the **power of the installations** needed will be calculated depending on the capacity of the batteries and the time needed to complete a full recharge. Once the installation power is state, the recharging installation will be design in accordance with ITC-BT [6] as well as a cost breakdown.

Furthermore, it should be calculated whether to connect the installation to **Medium or Low Voltage**. For that purpose, it is required to estimate the electricity bill of each tariff considering the initial investment needed for each case. Connecting the recharge installation to the medium voltage requires the erection of a Transformation Substation, which in not needed if the installation is connected to the low voltage but in this case, should be calculated whether it is necessary to change the power rate of the grid transformer or not. In the cost evaluation shall be introduced that, the current regulation stablishes that the customer shall pay the replacement of grids elements if the required power exceeds the 20% of the power capacity of the saturated equipment in the grid.

Finally, bearing in mind all the outcomes of the previous section, it will be estimated the set of CAPEX and OPEX costs that incorporating the electric vehicles into the light freight fleets requires. As well as making a **comparison between the electric and fuel vehicles expenses.**

E. <u>OUTCOMES</u>

In compliance with the requirements designated in the previous section it has been selected the **Renault Kangoo Z.E.** as the most suitable van for this case.

According to the new legislation of "*Madrid Central"*, C label vehicles will be allowed to deliver for 8 hours in 2020 [5]. In order to minimize the number of electric vans needed to perform the same number deliveries, each electric vehicle should deliver for more than 8 hours a day. After analysing the tariff rates, it has been stated that delivering for 11 hours generally avoid recharging the vehicles during peak-hours (although sometimes it is required) and drop the **electric vehicles needed to 42**.

On the other hand, if the vehicles are delivering for 11 hours a day, there are 13 remaining hours to recharge them. However, the analysis departs from 11 recharging hours with the purpose of leaving 2 free hours to prevent possible incidents.

Besides, the power needed to recharge a battery with a capacity of 22kWh in 3 hours is **7.4kW.** Meaning that each installation will require a power of **104 kW** to recharge 14 vehicles each.

In order to avoid big initial investment and re-analyse the liability of such a recent technology in the market, it is a good practise to increase the number of electric vans moderately during time. Therefore, by the beginning the investment shall be focused on the installations recharge, while the wallboxes will be bought only when they are required.

The next step is to decide whether to connect the recharging installation to low or medium voltage. Connecting to **medium voltage will require a Transformer Substation with a cost of 59.902, 50 € for each of the 3 installation**, while low voltage will not have additional costs. The toll differences will make not worth it, in fact it would take 59.3 years to recover medium voltage installation costs versus low voltage development.

Finally, the major goal of this project is to form a contrast between the electric and fuel transportation technology focussing on the expenses. Note that to make a comparison on equal basis, for this section it has been state that the whole investment required to introduce the 42 electric vehicles in freight fleets is payed at the beginning. The outcomes show that the OPEX (Operational Expenditures) costs of an electric fleet represent a 7.2% of the variable costs of a fuel fleet. Besides, it will take 4 months to depreciate the initial investment with an IRR (Internal Rate of Return) of 76% in the case of hiring the low voltage tariff. The expenses of the recharging installation are 119.064,75€ and the adding costs of purchasing the vehicles are 134.115,00€ while the saving of using electricity instead of fuel are 786.170,86€.

F. CONCLUSION

As an overview, incorporating electric vehicles to delivery companies is a nice way to contribute to the **environmental care** as well as brilliant idea to get **free positive advertising**.

The introduction of the electric vehicle requires **accuracy in timeliness** so that each vehicle is effectively recharging when it is estimated. Although, this is not very predictable it should be considered that electric vehicles are allowed to circulate in HOV [2]lanes, so traffic jams can be avoided.

Furthermore, monitoring the vehicles can make a practical feedback to make realistic delivering routes as well as drivers should be trained to use this up-to-date technology.

It is true that for the implementation of the electric vehicle, a **high investment** is needed due to the high prices of this technology as well as the recharging installation needed. Precisely, the initial investment would be of **119.064,75 €** for the three recharging installations and **the price of the vehicles are nearly two times higher.** Notwithstanding, the **OPEX costs of an electric fleet represent a 7.2% of the variable costs of a fuel fleet**. Besides, it will take **4 months to depreciate the initial** investment with a **IRR of 76%** in the case of hiring the low voltage tariff. However, note that this outcome is very optimistic due to the huge distance and fleet state for delivering only in *"Madrid Central"*. That is why this outcome will turn out to be more reasonable when the requirements of *"Madrid Central"* extends to other areas of Madrid. Besides, it will take 4 months to depreciate the initial investment only in the case that all the vehicles are bought in the first year.

It is important to point out that fuel vehicles with the C label will be allowed to deliver in the centre of Madrid for 8 hours in 2020, while according to the calculations made in this paper the electric vans may circulate for 11 hours. Meaning that to make the same number of deliveries, it would be necessary to count with **42 electric vehicles** while there would be necessary **60 fuel vehicles** with the B label.

Furthermore, it has been considered that the **Renault Kangoo Z.E can be circulating for 3** hours due to its 260 km range and to be able to deliver for 11 hours it is necessary to recharge the vehicles completely in 3 hours. That is why it is needed a **power of recharging of 7.4 kW per vehicle and 104 kW for each of the 3 recharging installations.**

On the other hand, it should be decided whether to connect or not the 3 recharging installations to medium or low voltage. Connecting to **medium voltage will require a Transformer Substation with a cost of 59.902, 50 € for each of the 3 installation**, while low voltage will not have additional costs. The toll differences will make not worth it, it would take **59.3 years** to recover medium voltage installation costs versus low voltage development. Besides, if the vehicles are slightly introduced in the fleet, it will take 10 more years to depreciate it.

To conclude**, environmentally friendly vehicles are a viable and economically competitive** alternative to the currently delivery business that state a change in the business model because it is required changes in the schedule, routes and smart energy

[2] High Occupancy Vehicle

management. Turning the electric vehicle into the new up-to-date technology which surely will conquer the market.

INTEGRATION OF THE URBAN DELIVERY VEHICLES IN THE GRID AND OPTIMITATION OF THE RECHARGING PROCESS

Author: García-Borregón, Marta.
Supervisor: Ponce Cintas, Francisco Javier.
Collaborating Entity: ICAI

ABSTRACT

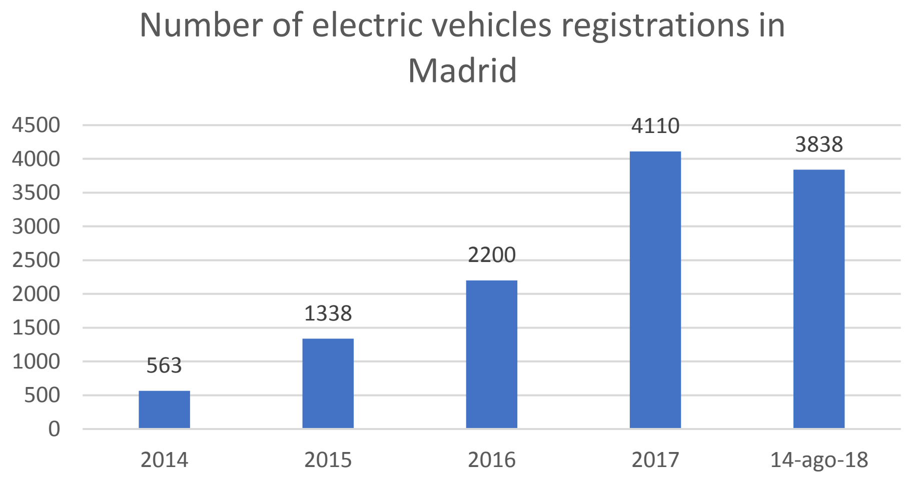
El objetivo principal del proyecto es realizar un análisis principalmente económico sobre la viabilidad de la inserción del vehículo eléctrico en el negocio del transporte de mercancías urbano. Así como hacer una comparación del transporte eco-friendly con el convencional.

Keywords: Vehículo, Eléctrico, Cargar, Distribución.

A. INTRODUCCIÓN

La **Unión Europea** está constantemente **promoviendo el crecimiento del vehículo eléctrico,** por esta razón la industria automovilística ha reaccionado poniéndose como meta conseguir que el 25% de su flota sea híbrida o eléctrica para el 2025. Además, la UE ha establecido la prohibición de vender vehículos de combustión en 2035 [1].

En España este crecimiento no es tan notable como en el resto de Europa. No obstante, en los últimos dos años el número de matriculaciones de vehículos eléctricos ha experimentado un crecimiento considerable. Tal y como se indica en la siguiente tabla, el número de matriculaciones en Madrid de vehículos no contaminantes es de 4110 en 2017:



GRAPHIC 2. NUMBER OF ELECTRIC VEHICLES REGISTRATIONS IN MADRID [2]

El aumento de la popularidad del coche eléctrico es debido a que los nuevos modelos del mercado cuentan cada vez con mayor autonomía a un precio más razonable. Sin embargo, las **dudas sobre una tecnología incipiente** provocan que los potenciales compradores no quieran correr riesgos.

Esto explica por qué la inserción del vehículo eléctrico en las flotas de reparto de mercancías no se ha consolidado todavía. La poca confianza de las empresas en esta tecnología se debe a su restringida autonomía y a la gran inversión inicial requerida. Como visión general, incorporar vehículos eléctricos a las flotas requiere construir instalaciones de recarga y pagar precios mayores por vehículos con características similares.

Es por ello, que el objeto principal de este proyecto es ofrecer un **método óptimo** para introducir esta nueva tecnología en el mencionado negocio, así como obtener la confianza del mercado.

B. <u>CASO DE ESTUDIO</u>

El caso de estudio tiene como meta evaluar la integración del vehículo eléctrico en una compañía que cuenta con **60 furgonetas de combustión** con el distintivo C de la DGT [5] para realizar todos los pedidos de "*Madrid Central*". La compañía posee 3 almacenes en la periferia de Madrid, localizados en Coslada, Fuenlabrada y Alcobendas.

Debido a los nuevos requisitos de "*Madrid Central*", los vehículos se clasifican con una etiqueta emitida por la DGT dependiendo del tipo de la fuente de energía que utilizan. De acuerdo con esta clasificación, el centro de la ciudad tiene diferentes restricciones horarias para los vehículos de reparto de mercancías. Los vehículos eléctricos tienen la etiqueta ZERO, los híbridos la etiqueta ECO y los vehículos de combustión tienen la etiqueta B o C dependiendo de las emisiones de COx.

Los vehículos con la etiqueta ZERO emisiones no tienen restricciones horarias. Para una primera evaluación del proceso, se considerará la misma cantidad de horas diarias dirigidas al reparto de mercancías para el caso de vehículos de combustión y eléctricos. No obstante, debido a las restricciones de "*Madrid Central*" los vehículos con la etiqueta C solo podrán circular durante 8 horas en 2020 [5]. En resumidas cuentas, **para el mismo número de repartos se necesitará un número menor de furgonetas eléctricas** pero cada una de ellas realizará repartos durante un mayor número de horas.

C. <u>METODOLOGÍA</u>

En primer lugar, se **seleccionará la mejor furgoneta del mercado para el caso propuesto**. Debido a las distancias que se deben cubrir entre las instalaciones, se requiere una autonomía mínima de 200km. Además, para realizar los pedidos lo más rápido posible se exigirá también que las furgonetas alcancen una velocidad de al menos 120 km/h.

Una vez se haya seleccionado la furgoneta, se establecerá el **número de vehículos eléctricos necesarios** para cubrir el servicio, así como el **horario de carga y descarga de las baterías**.

El segundo paso es calcular la **potencia de carga** en función de la autonomía y de la capacidad de carga de vehículo seleccionado. Todo ello, con el objetivo de minimizar la factura de electricidad dentro de un rango razonable a la vez que se procura disminuir la cantidad de vehículos eléctricos necesarios. Este proceso de ha realizado con la ayuda de GAMS.

Además, la potencia de la instalación necesaria se calcula en función de la capacidad de las baterías y el tiempo necesario para completar una carga. Una vez se establezca la potencia necesaria, se diseñará la instalación de recarga de acuerdo con la ITC-BT [6] así como un desglose de costes.

Por otro lado, es necesario analizar la posibilidad de conectar las instalaciones de recarga a media o baja tensión. Con esta finalidad, se requiere estimar el coste de electricidad para cada tarifa. La conexión de la instalación de recarga a media tensión requiere la construcción de un centro de transformación, que no es necesario en caso de que se conecte la instalación de recarga a baja tensión, pero en este caso se debe calcular si es necesario o no cambiar la tasa de potencia del transformador de la red. En esta evaluación de costes se debería tener en cuenta que la regulación actual establece que el consumidor debe pagar la sustitución de los elementos de la red si la potencia requerida excede el 20% de la capacidad de potencia del equipo saturado en la red.

Además, teniendo en cuenta todos los resultados anteriores se debe estimar los costes CAPEX y OPEX necesarios al incorporar vehículos eléctricos a las flotas ligeras de reparto. Así como llevar a cabo una comparación entre los vehículos eléctricos y de combustión.

D. RESULTADOS

En relación, a los requisitos previamente establecidos para la elección del vehículo eléctrico. Se ha considerado el **Renault Kangoo Z.E** como el óptimo para el caso de estudio.

De acuerdo con la nueva legislación de Madrid Central, los vehículos con el distintivo C tendrán acceso restringido a un total de 8 horas en 2020[5]. Con el objeto de disminuir el número de vehículos eléctricos se aumentan el número de horas que cada uno realizará repartos. Después de analizar las tasas por horas de las tarifas eléctricas se ha llegado a la conclusión de que lo óptimo es repartir 9 horas durante el día y dos por la noche con **42 vehículos** para evitar en la medida de lo posible las tasas más altas, quedando así 13 horas para cargar. No obstante, en el análisis se ha establecido que las baterías **cargarán durante 11 horas**, de forma que se puedan cargar en 3 horas para así prevenir posibles accidentes.

Además, la potencia requerida para cargar una batería con una capacidad de 22kWh en 3 horas es de al menos **7.4kW.** Lo que significa que cada instalación tendrá una potencia destinada a la recarga de vehículos de **104kW** para recargar un total de 14 vehículos simultáneamente.

Con el propósito de evitar grandes inversiones iniciales y reanalizar la fiabilidad de una tecnología tan reciente en el mercado, se incorporarán los vehículos eléctricos a la flota paulatinamente. Por lo tanto, aunque el primer año habrá que realizar un gasto más elevado para construir las instalaciones hasta el punto de recarga, solo comprarán los wallaboxes [3] una vez sean necesarios.

El siguiente paso es decidir si conectarse a baja o a media tensión. “Pinchar” en media tensión requerirá la construcción de un Centro de Transformación de un coste de 59.602,50€ para cada una de las tres instalaciones de recarga, mientras conectarse a baja tensión no tendrá costes adicionales. La diferencia de peajes hace que no valga la pena conectarse a media tensión, de hecho, se necesitarían 59.3 años para recuperar la inversión de la media tensión frente al crecimiento de la baja tensión. Además, si se considera una inserción paulatina del vehículo eléctrico en la flota dicha amortización aumentará en 10 años.

Finalmente, la meta principal de este proyecto es formular un contraste entre los vehículos eléctricos y de combustión focalizado en los costes. Se debe remarcar que, para realizar una comparación en igualdad de condiciones, se establece que toda la inversión requerida para introducir los 42 vehículos a la flota de reparto se realiza el primer año. Los resultados muestran que los costes OPEX del vehículo eléctrico representan el 7.2% de los costes OPEX del de combustión. Además, se necesitarán solo cuatro meses para amortizar la inversión inicial con un TIR de 76% en el caso de contratar la tarifa de baja tensión.

E. <u>CONCLUSIONES</u>

En general, la incorporación del vehículo eléctrico en las flotas de las compañías de transporte de mercancías es una adecuada forma de favorecer el **cuidado del medio ambiente**, así como de conseguir **publicidad gratuita.**

El uso de vehículos eléctricos en el sector de la distribución requerirá **de exactitud y puntualidad** en los tiempos establecidos de reparto y recarga. Aunque esto no es del todo previsible y está sujeto a posibles incidentes, la autorización del uso del carril VAO puede evitar retrasos debidos a atascos. Por todo esto, se hace necesario monitorizar y controlar los vehículos en todo momento, para poder así establecer rutas realistas.

Para la implementación del vehículo eléctrico es necesaria una **elevada inversión inicial** debido a los elevados precios de esta tecnología, así como el pago de la instalación requerida para la recarga de las baterías. En concreto, **el coste de las tres instalaciones será de 119.064,75€ y** el **precio de los vehículos eléctricos** será de aproximadamente el **doble**. No obstante, los costes OPEX del vehículo eléctrico representa el 7.2% de los

[3] Cargadores

costes variables de los vehículos de combustión. Además, se necesitarán solo dos meses para amortizar la inversión inicial con un TIR de 76% en el caso de contratar la tarifa de baja tensión.

Por otro lado, se debe decidir si conectar las instalaciones de recarga a **media o baja tensión**. Al conectarse a media tensión se necesita adquirir un centro de transformación con un coste de 59.902.50€ para cada una de las 3 instalaciones de recarga, mientras que conectarse a baja tensión no supondrá costes adicionales. Esto unido a que la diferencia de peajes es muy pequeña, hace que no valga la pena conectarse a media tensión. Además, si se considera una inserción paulatina del vehículo eléctrico en la flota dicha amortización aumentará en 10 años.

Tal y como se expone en este documento, la inserción del vehículo eléctrico en las flotas de reparto puede suponer grandes rentabilidades debido a que se requieren menos vehículos y los costes OPEX son menores. Siendo en el caso de estudio amortizadas las inversiones necesarias para eléctrico en menos de un año.

Para concluir, **los vehículos eléctricos representan una alternativa viable y económicamente competitiva** para el negocio de distribución urbano que requiere un cambio en el modelo de negocio debido a la necesidad de seguir un horario puntual y preciso y de gestionar la energía de manera inteligente. Convirtiéndose así, en una moderna tecnología que con total seguridad acabará dominando el mercado.

table of contents

FIGURE INDEX

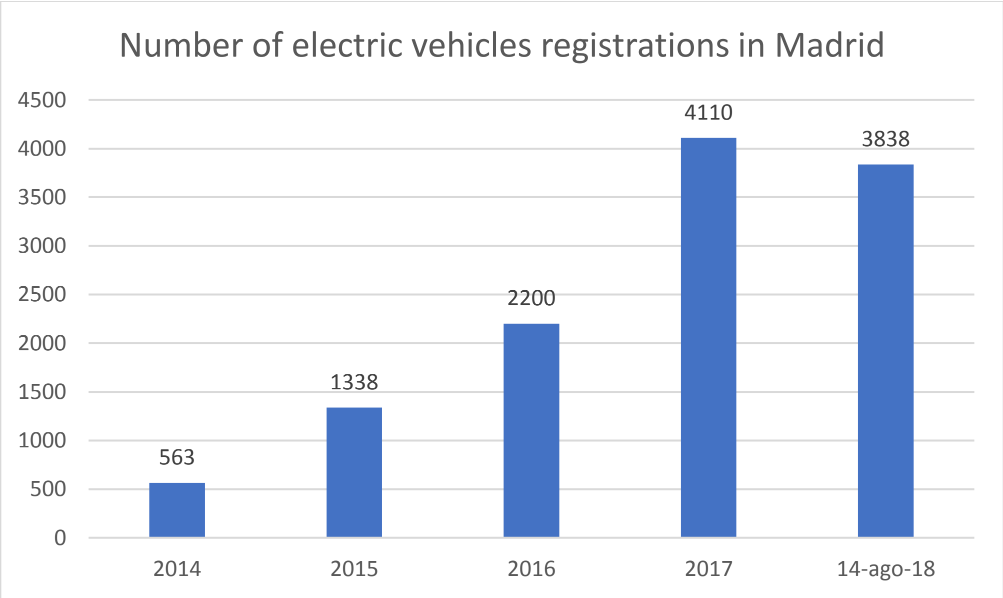
TABLES INDEX

1. INTRODUCTION

1.1.PROJECT MOTIVATION

The European Union is promoting the growth of the electric vehicles. 25% of the car's manufacturers fleet is expected to be electric or hybrid in 2025. Besides, the UE has established the prohibition of selling combustion vehicles in 2035. [1]

In Spain, the growth of the electric vehicle is not as remarkable as in the rest of Europe. However, in the last two years the number of electric vehicle registrations experimented a sustainable raised. As it is indicated in the table below the registration of electric vehicles in the city of Madrid in 2017 ascended to 4110:



GRAPHIC 3. NUMBER OF ELECTRIC VEHICLES REGISTRATIONS IN MADRID [2]

This increased of electric vehicles owners is because the models in the market are lowering their prices and increasing their autonomies. However, the unknown of an uncertain technology make some possible customers feel uncomfortable with it.

The introduce of the electric vehicle in the delivering business is not consolidated yet. The main reason is the low confidence of the companies in this technology due to the restricted autonomy and the high investment required. In a general overview, incorporating electric vehicles to the fleet requires to build a recharging installation and to pay higher prices for electric vehicles than conventional ones with similar features.

This paper aims to offer a solid business model to show that an electric fleet can be a profitable, solid and competitive option to make the delivery services. In the practise it has been already proved by the FREVUE Project [4][3] that electric vehicles represent a viable solution in the delivery business.

There are several economic advantages which might be taken into account when deciding to buy or not an electric vehicle. Due to all those advantages, the city council of Madrid is supporting electric vehicles with some **incentives** to make them more attractive from an economical point of view. Those incentives are the following:

1. **Indefinite 75% bonus on the tax of mechanic** traction vehicle since the first year. [8] However, it is not a very high bonus in comparison with the price of the vehicle.

2. **Free parking in green and blue places without time limitation in Regulated Parking Service (SER)**. It is necessary to own a Cero Emission Permission (free of recharge) [9].

3. **Free Access to Priority Residential Areas owning the Cero Emission Permission during the entire day** [5]. This feature makes electric transportation a very attractive option in the delivering business because it allows to circulate at any time.

4. Permission to use **HOV lanes without restrictions [10].** This feature makes a green-transportation desirable to the business of delivering because there is not an extra waste of time depending of the external factors which cannot be controlled. Furthermore, the peak hours of traffic jams coincide with the hours the non-green alternatives transportation are allowed to deliver in "Madrid Central".

5. **The Register Vehicle Tax varies** its recharge depending of the CO_2 emissions. Meaning a cero recharge for electric vehicles.

6. Government **grants** for electric transport transition such as "Plan MOVES", with amounts up to 5500 € per vehicle [11].

7. Each day **more insurance companies are lowering prices** for electric vehicles. That is due to the lower costs of maintenance necessary for electric vehicles.

8. The introduction of electric vehicles into the delivery urban service requires a deep analysis of the recharging batteries process. Moreover, owning a large number of vans add the possibility of making a **parallel trading energy business**.

[4] The **FREVUE Project** (Validating Freight Electric Vehicles in Urban Europe) is a European initiative with the objective of showing if electric vehicles can substitute fuel and diesel vehicles in the delivery distribution sector. Eight cities with very different climates participated in the project (Amsterdam, Lisbon, London, Madrid, Milan, Oslo, Rotterdam and Stockholm) that ends up with a positive outcome, **positioning electric vans as a viable solution for urban delivery**.

However, to be able to return energy into the grid it is necessary to recharge the vehicles in a very little period of time. Recharging completely a battery in 15-30 minutes will suppose enormous investment quantities so at the present it is not worthy to return energy into the grid.

9. The batteries should be recharged during off-peak hours. In the official site of “Red Eléctrica de España” [12] is showed the demand curve of electricity in real time giving a global idea of when it should be the best time to recharge the batteries. In a general overview it can be seen an off-peak at night and on-peak about 11:00h and also another on-peak around 21:00h.

1.2. OBJECTIVE

The **law in Madrid is each day harder with the care of the environment**. Some of the initiatives such as the “Madrid Central” [5] or the limitation speed in some roads during high pollution days [9] seem to indicate a certain change in the transport technology.

Notwithstanding, it is not only a matter of legacy but also of health hence the **rates of CO_X and CO_2 are high** in Madrid among other cities [13].

The situation right now is of inexperience in the new electric technology transportation and the need of a deep analysis is undeniable due to the new variables that appear in the equation. Some of them are:

- The **power to recharge the vehicles**, directly related with the time needed for a battery to complete a recharge.
- The **best period of the day to recharge** in order to reduce the electric tariffs costs to the minimum as possible.
- The maintenance needed for a technology with very low feedback.

Besides, after all the delivery business aimed to make the most benefits as possible in addition to make the best service as possible. And that is why it is so necessary to came up with a solution that make possible to:

- **Increase the delivery schedule**. Legally only the Zero pollutants will be allowed to circulate at night in Madrid [5].
- **Reduced the energy costs**. Specially because the price of fuel is high and the government merely can do to slow it down, because it depends on foreign countries.
- Make the deliveries faster by using HOV lanes, which during rush hours can **avoid losing much time in traffic jams**.
- **Improve the work conditions for the drivers** by reducing the stress due to traffic jams. It should also be pointed out the fact that electric vans do not make the characteristic annoying noise of combustion engines.

One of the targets of the project is to decide the power of recharging to make it as fast as possible but with a reasonable price.

In the paper "FREVUE Results and Guidelines for Vehicle Suppliers v_09" [17] is indicated that the delivery companies are not convinced to move to the electric transportation due to:

1. The **large trucks are very expensive**, although the Low Freight vehicles are favourable in comparison with conventional vans, and Medium Freight vehicles are challenging but possible to be depreciated in a reasonable period of time.
2. In order to get more autonomy, **the payload of electric vehicle is very low**. This feature does not convince the customers.
3. Some customers claimed that the autonomy is not enough. However, 100 km is enough for most of urban deliveries requirement. This is probably an issue of **mistrust of an unknown new technology**.

However, some of the benefits of the electric transportation gather in the "FREVUE Results and Guidelines for Vehicle Suppliers v_09" [17] are the following:

1. The visibility given to a company the fact of using such an up-to-date technology, which basically is having **free advertisement.** Furthermore, it gives a very good impression of being modern company.
2. Repair and maintenance agreements have cheaper rates. Notwithstanding, **the batteries are the most expensive component of the electric vehicles, and the most also the most vulnerable.**

In order to achieve the minimum costs of recharging batteries, the **electric demand curve** should be considered as well as the long term and spot prices. Thus, it will be more profitable to consume electricity from the grid whenever the prices are lower due to low demand or high RE production periods. Also, would be suitable to study PPAs in order to state a long-term use.

Furthermore, it will be required a **comparison between the different electric tariffs** as well as the research of the possibility of allowing to return power into the grid (using self-switching rectifiers or switched by dual network rectifiers). However, returning power into the grid seem to be unrealistic these days due to the high power needed to be able to recharge, deliver the products and then have spare time to return power into the grid. That would be therefore a problem of the future and not of the current present.

The connection to the power network shall be establishes **in Low or Medium Voltage** according to the simultaneous power needs of the set of batteries which should be recharged at the same time and the duration of it's plug-in. It should be established the depreciation time of medium voltage to see if it is feasible to be connected to medium voltage. Due to the high power which seem reasonable to think that the installations should have.

The aim of this paper is to see if electric vehicles can be a realistic option nowadays to fuel vehicles. It is true that the price of an electric van is twice a conventional one with similar features, but it is also certain that the price of electricity is lower than fuel or diesel. Besides, the electricity prices can be somehow controlled by the Spanish government while the prices of fuel or diesel are established by other countries.

Furthermore, it is a good thought to try to **get the most experience as possible of this technology** in order to **optimize the routes and prevent incidences** that may occur.

This project shows a resolution to a problem in the **city of Madrid.** And all the considerations are made for its regulations. However, it can be extended to other cities in the case of similar laws.

Note that the resolution of the problem will be based on the idea that Madrid Central is restricted during certain hours to delivering vehicles with high or medium pollute rates. This means, that the project is focused in delivering that should be perform inside the restricted are of Madrid Central [5]. Notwithstanding, **the restrictions for contaminating transportation is predicted to be extended to all the area inside the M-30 in the near future**. Although, there still no official documents that support it.

Furthermore, it is important to remark that dominating such a new transportation technology will be essential for the business because the trend is to finish with non-green energies.

On the other hand, it is uncertain how the electricity market will operate in the future. In Spain, it is now possible to return power into the grid and get a compensation for it in the electricity bill [15]. This means that the energy will not be only produce by companies but also by the consumers, contributing to flatten the demand curve and therefore, therefore the rates of the electricity bill may decrease.

Therefore, **the introduction of the electric vehicle in the delivery business would mean a change in the business model** due to the new variables incorporated to the equation of optimal delivering. In this new situation, monitoring and controlling will be totally necessary to perform the deliveries in time an avoid delays. Timeliness will be much more important now because it is very important to recharge the vans when stablished to minimize the energy costs.

1.3.PROJECT SCOPE

The first step is to select the optimal electric van for our case basing the decision on the range, maximum speed and the price.

Once the van is selected, it will be stablished **how many hours the electric vans will deliver, the number of electric vehicles needed and the delivering-recharging frame**. This will be done bearing in mind that the total deliveries would be the same for electric and conventional vans. The next step would be to **calculate the power needed for each**

vehicle to be recharge completely in the time defined to be able to meet the delivering-recharging frame.

There are three installations around Madrid, where the vans can stop and be recharged. **The recharging installations power will be calculated, as well as the cost of its extension due to the power need to recharge the batteries**. For that, it is required to draw a single line diagram and choose the specific devices from the market and indicate their prices.

Furthermore, it is important to decide **whether to connect the recharging installations to medium or low voltage.** Medium voltage has lower energy rates but higher power rates. Besides it is required to pay for a Transformation Substation in the case of connecting the installation to medium voltage.

The following scheme shows the order carried out:

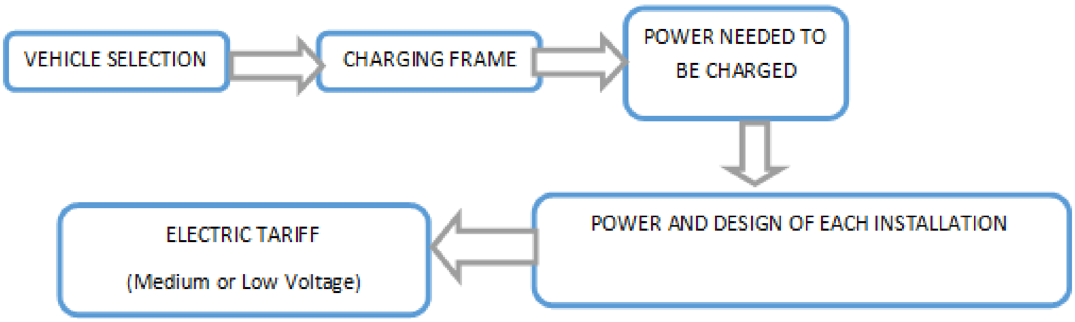


IMAGE 1. SCHEME OF THE PROJECT STRUCTURE

Finally, the main objective is to **make a comparison between the Zero Emissions and the polluting transportation**. The idea is to see if it is a realistic competence and show some other advantages that electric vehicles may offer.

2. METHODOLOGY

In order to stablish an understandable project structure, it will be firstly explained the case of study. So that the departing variables could be settle and therefore clarify the model propose.

2.1.CASE OF STUDY

The case of study is considering that a company need **60 fuel light fright vehicles** with the C DGT label [5] to perform all the deliveries in Madrid Central. For the storage of the products it already owns **3 buildings located in Coslada, Fuenlabrada and Alcobendas.**

Due to the "*Madrid Central*" new requirements, vehicles are classified with a label based on the type of main power source used, issued by DGT. In accordance with de classification, the city centre has different time restriction for freight vehicles. Electric vehicles belong to the ZERO label, Hybrid technologies to the ECO label, fossil fuel vehicles with B or C label depending on the CO_X emissions.
Vehicles with the zero label emissions has no time restrictions. For the first evaluation process, this project will consider the same amount of daily hours for delivery in both cases, fuel and electric vans. Due to the restrictions of "*Madrid Central*" each C label vehicle will be allowed to circulate only for 8 hours in 2020 while electric vehicles have no restrictions [5]. In a nutshell, **for the same number of deliveries it should be needed a smaller number of electric vehicles,** but they will deliver during more hours each.

2.2.PROJECT STRUCTURE

Firstly, it would be selected the optimal vehicle for this case. Due to the distance between the recharging installations the vehicle selected must have at least a range of 200km. Besides, the vehicle should be able to reach a speed of 120km/h in order to perform the deliveries as fast as possible.

The second step is to establish the **number of electric vehicles** needed to perform the same deliveries as the conventional vans and the **timeframe** that their would spend **delivering and recharging** in order to minimize the electricity bill. This optimization problem will be solved with GAMS.

Moreover, the **power of the installations** needed will be calculated depending on the recharging time, the capacity of the batteries and the time needed to complete a recharge. Once the installation power is state, the recharging installation will be design in accordance with ITC-BT [6] as well as a cost breakdown.

Furthermore, it should be calculated whether to connect the installation to **Medium or Low Voltage**. For that purpose, it is required to estimate the electricity bill of each tariff as well as the initial investment needed for each case. Connecting the recharge installation to medium voltage requires paying for a Transformation Substation, while if the installation is connected to low voltage it should be calculated whether it is necessary to change the grid transformer or not. The requirement to avoid changing it is that the installation power do not exceed the 20 % capacity of the grid transformer.

Finally, bearing in mind all the outcomes of the previous section, it will be estimated the set of CAPEX and OPEX costs that incorporating the electric vehicles into the light freight fleets requires. As well as making a **comparison between the electric and fuel vehicles expenses.**

2.3.RESOURCES

The resources needed to come up with a solution to the problem state are:

- **GAMS** will be used to calculate de optimal recharging and delivering timeframe to recharge the vehicles in order to minimize electricity costs.
- **Amikit Ormazabal** as a tool to calculate the price of the Substation Centre.
- **EXCEL** will be required as a tool to make easily varying calculations such as the electricity bill, the costs of the fuel and the total cost of the recharging installations.
- **Electronic Headquarter Land Registry** to see the specific features of the recharging buildings.

3. TECHNICAL ANALYSIS

This section aims to solve the logistic and technical challenges that this case may demand, such as explaining how the deliveries will be perform, the forecast of the delivering model and carrying out a legal analysis of the freight urban business in the city of Madrid.

3.1.ELECTRIC VAN SELECTION

This paper aims to reach the optimum conditions to make an environmentally friendly urban delivery as well as viable from an economic view. This entails to make a study of the available vans in the market and choose the best one for this case **based on the autonomy, capacity and price**.

To make a reselection of all the vans available in the market, it is a good practise to see which of those vehicles have been previously use with success in a similar situation. That is why the following models of vehicles with presence in the FREVUE project [3] will be include in this study:

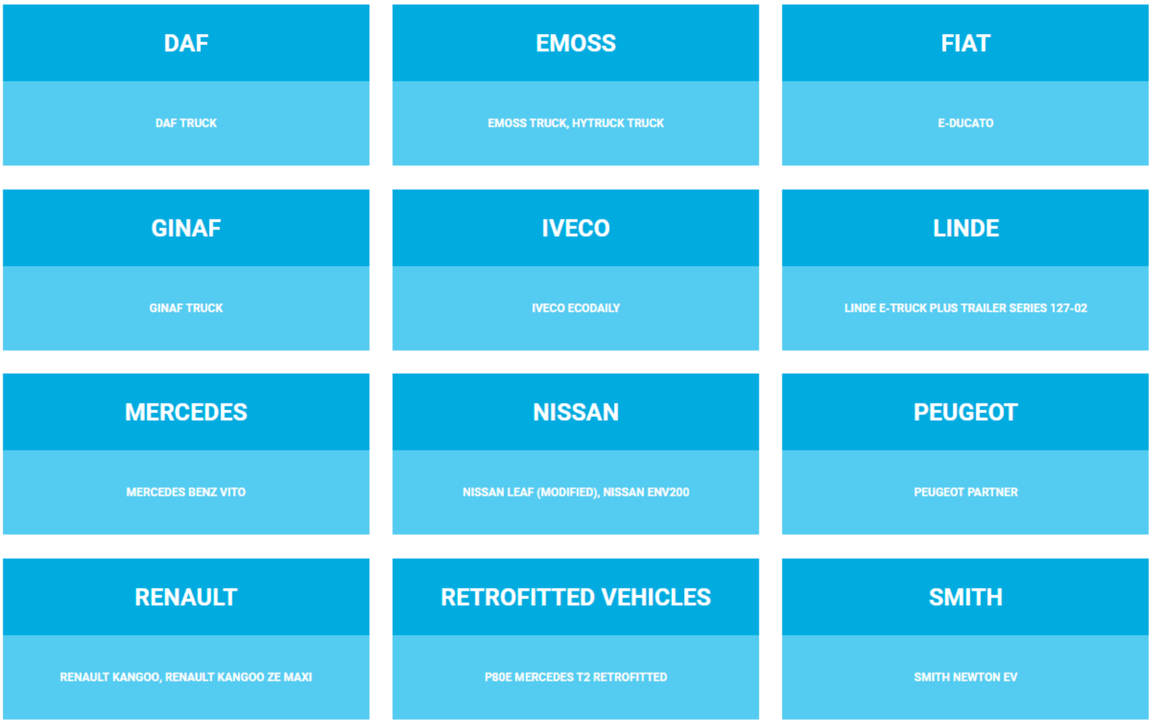


IMAGE 2 .VEHICLES WITH PRESENCE IN THE FREVUE PROJECT. [3]

The proposal is made with the aim of being able to make deliveries in the city of Madrid. There will be 3 locations with equally number of recharging points each, situated in Fuenlabrada, Coslada and Alcobendas. **The zone covered by the delivery service is shown in the following image painted in red**. In the present, the vehicles should deliver inly in Madrid Central, but with the scope of delivering in the area painted in red when "Madrid Central" restrictions will be extended to the rest of the city of Madrid:

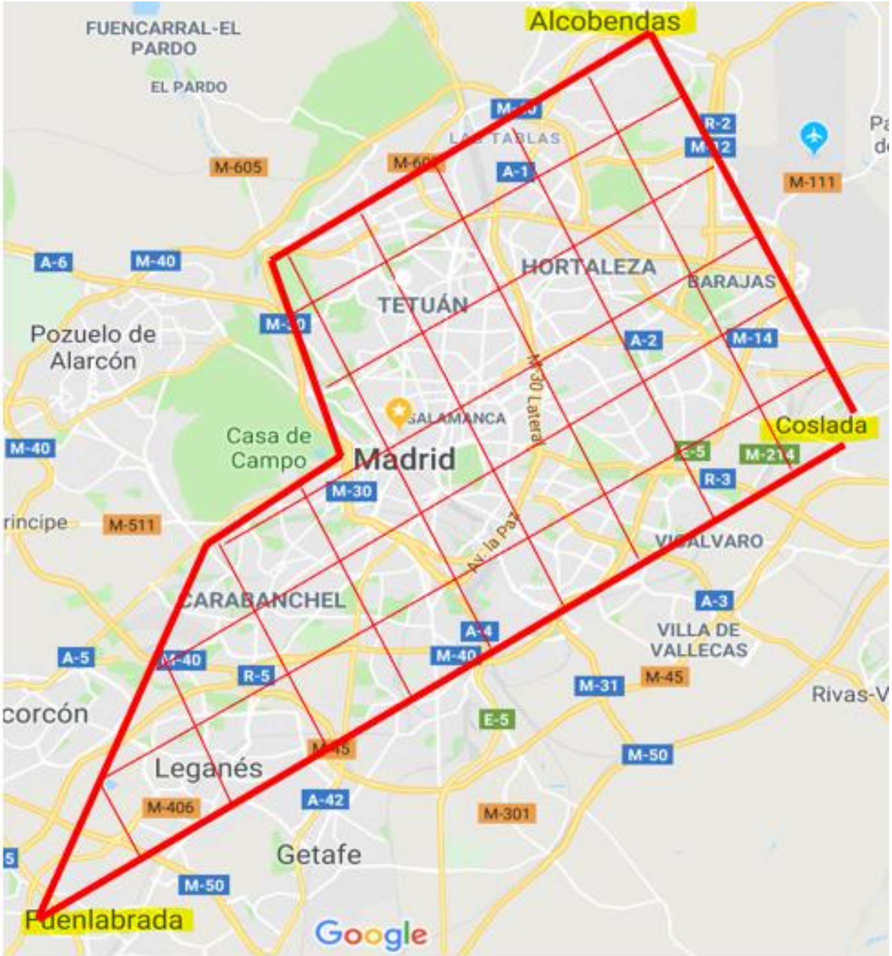


IMAGE 3. ZONE COVERED BY THE DELIVERY SERVICE.

The proposal is to drive the vans from one installation to another, making stops to recharge when necessary and delivering the products during route. It is not analysed in this paper, but it is supposed that the routes will be daily calculated to perform the necessary deliveries in the time stablished.

The idea is that the deliveries are made in the city centre. In order to benefit from the regulation indicated above that allows electric transportation to circulate inside Madrid Central" [5] at any time of the day.

According to Google Maps, the distance and timing between the recharging sites are the following:

	Distance (Km)		
	Fuenlabrada	Coslada	Alcobendas
Fuenlabrada	0	38	45
Coslada	38	0	19
Alcobendas	45	19	0

	Time (min)		
	Fuenlabrada	Coslada	Alcobendas
Fuenlabrada	0	30	35
Coslada	30	0	16
Alcobendas	35	16	0

TABLE 1. DISTANCE AND TIMING BETWEEN THE RECHARGING LOCATIONS

As it is indicated in the table above, the distance form Alcobendas to Coslada is the lowest. This means that more deliveries can be made in between, but it is not necessary to stop if it is not necessary to recharge the vehicles.

To select the optimal van for the case stated, the following requirements should be met:

- At least an **Autonomy of 200 km.**
- Minimum maximum **speed of 120km/h**.
- Recharging time of less than 8 hours with standard recharging point.
- The minimum price as possible.

The following table shows the Light Freight Vehicles with presence in the FREVUE project and with the most suitable features for the case of study:

BRAND	MODEL	ELECTRIC MOTOR (kW)	CAPACITY BATERIES (kWh)	TORQUE (Nm)	RANGE (km)	PRICE [€]	Maximum velocity (km/h)	
MERCEDES VENZ	MERCEDES VENZ VITO	70	36	300	150	39.900,00 €	80	
NISSAN	ENV 200	80	40	254	170	28.900,00 €	123	
PEUGEOT	PARTNER TEPEE ELECTRIC	49	22,5	200	170	24.500,00 €	110	
RENAULT	KANGOO ZE	44	22	226	260[5]	16.000,00 €	135	

TABLE 2 .DISTANCE AND TIMING BETWEEN THE RECHARGING LOCATIONS [18][19][20][21]

The previous table show the minimum prices of the vans without any extra, but it is enough to make a comparison between them.

Finally, due to the requirements establish before, the most suitable van for the case of study is the **Renault Kangoo Z.E**. The next image this vehicle:

[5] NEDC cycle

IMAGE 4. RENAULT KANGOO Z.E.

3.2.INSTALLATION SITE

As it is indicated in the previous section, there will be three different recharging premises located in Fuenlabrada, Coslada and Alcobendas, with the specific addresses included in the Annex A. As it was indicated before, the three building are already own by the company, so it will be only necessary to invest on the extension of the electric installations needed to recharge the vehicles.

The extensions of each installation are very different, but this is only due to the capacity of storage of each one. Meaning that **the number of vehicles able to recharge at the same in all of them**.

As it was said before, the idea is to go from one installation to the next one and perform the deliveries in-between. Each installation would be capable to recharge a third of the total fleet, meaning that at the beginning of the day the fleet would be distributed by the three sites. All of them could be recharged at the same time in order to minimize the electricity costs.

3.3.COMPARISON BETWEEN ELECTRIC AND FUEL VEHICLES

The aim of this project is to check the feasibility to perform the service of delivering and making similar benefits to the actual technology. In a general overview seems to be less profitable due to the initial high investments. Variable costs are lower in electric vehicles than in fuel ones. Thus, it will be depreciated during time and the invest shall be recovered.

There are many incentives to promote the use of electric vehicles which might be considered when deciding whether to buy or not an electric van for a delivering use. The legal advantages are the following:

1. **Free Access to Priority Residential Areas** owning the Zero Emission Permission (free) during the entire day. However, this is an uncertain advantage due to the new government in Madrid [5]. In the next table are indicated the frames where each type of vehicle is allowed to deliver in “Madrid Central”:

		Cero Emissions	ECO	C	B	A
Light Vehicles ≤3500Kg	Since 30/11/2018 to 31/12/2019	24 hours	7:00-23:00	7:00-21:00	7:00-15:00	7:00-13:00
	Since 01/01/2020	24 hours	7:00-21:00	7:00-15:00	7:00-13:00	NO ACCESS

TABLE 3. TIME FRAME OF ACCESS TO PRIORITY RESIDENTIAL AREAS

IMAGE 2. PRIORITY RESIDENTIAL [22]

2. Permission to circulate on **HOV lanes without restrictions [10].** The permission of using this lane makes the electric vehicles very attractive to avoid losing time in traffic jams converting this new transportation technology into an appealing option.

Due to the “*Madrid Central*” new requirements, vehicles are classified with a label based on the type of main power source used, issued by DGT. In accordance with de classification, the city centre has different time restriction for freight vehicles. Electric vehicles belong to the ZERO label, Hybrid technologies to the ECO label, fossil fuel vehicles with B or C label depending on the CO_X emissions.

Vehicles with the zero label emissions has no time restrictions. For the first evaluation process, this project will consider the same amount of daily hours for delivery in both cases, fuel and electric vans. Due to the restrictions of "*Madrid Central*" each C label vehicle will be allowed to circulate only for 8 hours in 2020 while electric vehicles have no restrictions [5]. In a nutshell, **for the same number of deliveries it should be needed a smaller number of electric vehicles,** but they will deliver during more hours each.

If the C label vehicles deliver for 8 hours during the day, the statement for electric vehicles would be to deliver for 9 hours from 7:00h to 0:00h because during the night the electricity prices are always the lowest.

According to Google Maps, in 2.7 hours a vehicle will make 200 km (the real autonomy of the Renault Kangoo Z.E.) but in the practise, there is time needed to unload the products, so it is considered that the time delivering as maximum can be of 3 continued hours without recharging. That consideration will be bear in mind in the next section in order to calculate the optimal frames to recharge and deliver.

4. ECONOMIC ANALYSIS

In order to make a deep and accurate analysis, it is vital to make a clear difference between the CAPEX[6], referred to the fixed costs such as the recharge installations and the prices of the vehicles, and the OPEX[7] costs, referred to variable expenses such as the energy costs. Besides, it is vital to calculate the amortization period and the IRR[8] in order to see if the investment needed to introduce the electric vehicle in the fleet is reasonable.

4.1.RECHARGING-DELIVERING FRAME TO MINIMIZE ELECTRICITY COSTS

In order to calculate the optimal frame to recharge the batteries it is necessary to take notice to the tariff rates (Annex B).
In this section, it will be discussion over when the vehicles should be recharged in order to pay for the minimum costs in electricity. The following considerations have been taken:

1. Due to the autonomy of the batteries, **it is not possible to deliver for more than 3 consecutive hours**.
2. **All the vehicles are plug in at the same time**.
3. All the vehicles must **deliver for 9 hours during the day and 2 at night.**
4. **The vans can be plug in or not during a whole hour.** Therefore, the minimum time to recharge is 1 hour once the vehicle is plug in.
5. The cases of study are:

$$\begin{cases} CASE\ II: Tariff\ 6.1 \rightarrow Different\ charging\ frame\ for\ each\ month \\ CASE\ I: Tariff\ 3.1 \rightarrow Different\ charging\ frame\ for\ each\ month \end{cases}$$

To minimize the expenses on electricity each month would have a different routine in recharging due to the different rates per hour in each month.

4.1.1. MATLAB CODE

The objective is to calculate when it is more likely to recharge the vehicles in order to get the lowest electricity bill.

The idea is to generate a matrix M that indicates with a 0 if the vehicle is delivering and with a 1 if the vehicle is recharging at a specific hour. In fact, the M matrix is a truth matrix and therefore:

- The M matrix would have an extension of $2^{24}x24 \rightarrow 16777216x24$
- For each column, the number of consecutives ones or ceros is 2^x. X is 1 in the last column and is increased by one in each column to the left.
- Each row of the matrix M represents a possibility of recharging or delivering for each hour.

[6] Capital Expenditure
[7] Operational Expenditure
[8] Internal Rate of Return

In the following Image is indicated how a truth Matrix structure is:

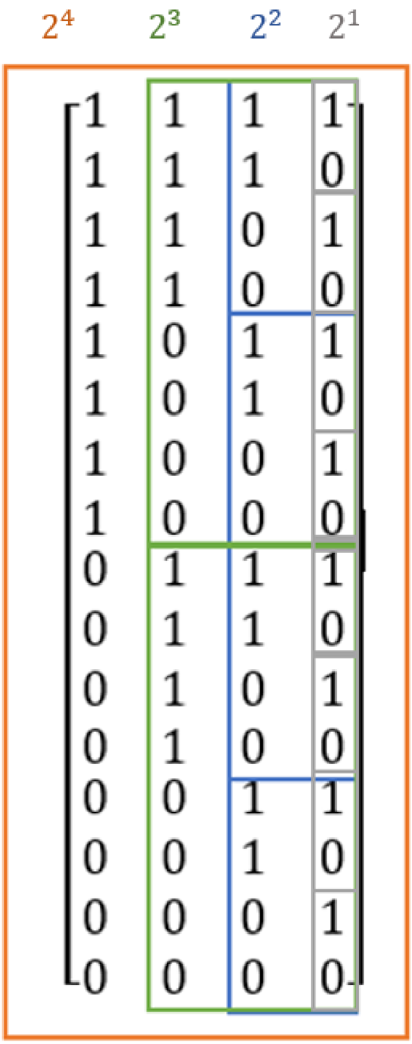


IMAGE 5. MATRIX M

The code that build the truth matrix is included in Annex A.

However, running this code would take long time and shall not be operative, also its formulation may not be so precise as a no-lineal programming.

4.1.2. GAMS CODE

GAMS is an optimization software able to design and solve lineal and non-lineal problems. In this case, it can be a very helpful tool to calculate the optimal timeframe to recharge the vans.

The objective is to calculate when it is more likely to recharge the vehicles in order to get the lowest electricity bill. The code is based on building a Matrix call Recharge(i) that indicates with a 0 if the vehicles are delivering and with a 1 if they are recharging. Besides, the following restrictions have been made:

- $\sum_{i}^{i+3} charge(i) \geq 1$
- $\sum_{i}^{i+3} charge(i) \leq 4$
- $\sum_{i}^{24} charge(i) = 15$

On the other hand, the Objective function is the following:

- $\min(\sum_{i}^{24} tariff(i) * charge(i))$

In the GAMS code is indicated to recharge during 9 hours during the day and then it is state that during the night all the months will be recharging for at least two hours.

The codes and **outcomes form GAMS are included in annex A.** The following tables indicated with a cero when the vehicles are delivering and with a 1 when they are recharging:

		TARIFF 6.1												
		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUN		JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	1:00	1	1	1	1	1	1	1	1	1	1	1	1	1
1:00	2:00	1	1	1	1	1	1	1	1	0	1	1	1	1
2:00	3:00	1	1	0	1	1	1	1	1	0	1	1	1	1
3:00	4:00	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00	5:00	0	0	0	0	0	0	0	0	1	0	0	0	0
5:00	6:00	1	1	1	1	1	1	1	1	1	1	1	1	1
6:00	7:00	1	1	1	1	1	1	1	1	0	1	1	1	1
7:00	8:00	1	1	1	1	1	1	1	1	0	1	1	1	1
8:00	9:00	0	0	0	0	0	0	0	0	1	0	1	0	0
9:00	10:00	1	1	0	0	0	0	1	1	1	0	0	0	1
10:00	11:00	0	0	0	0	0	0	1	1	0	0	0	0	0
11:00	12:00	0	0	1	1	1	1	0	0	1	1	0	1	0
12:00	13:00	0	0	1	1	1	1	0	0	0	1	1	1	0
13:00	14:00	1	1	1	1	1	0	0	0	1	0	1	1	1
14:00	15:00	1	1	0	0	0	0	1	1	1	0	1	0	1
15:00	16:00	0	0	1	0	0	1	1	1	0	1	0	1	0
16:00	17:00	1	1	0	1	1	1	0	0	1	1	0	0	1
17:00	18:00	1	1	0	1	1	0	0	0	0	0	1	0	1
18:00	19:00	0	0	1	0	0	1	1	1	1	1	0	1	0
19:00	20:00	0	0	1	0	0	1	0	0	1	1	0	0	0
20:00	21:00	0	0	0	1	1	1	1	1	0	1	1	0	0
21:00	22:00	1	1	0	1	1	0	1	1	0	0	1	1	1
22:00	23:00	1	1	1	0	0	0	0	0	1	0	0	1	1
23:00	0:00	0	0	1	0	0	0	0	0	1	0	0	0	0

TABLE 4. RECHARGE MATRIX FROM JANUARY TO DECEMBER FOR ELECTRIC THE TARIFF 6.1

		TARIFF 3.1													
		JANUARY	FEBRUARY	MARCH		APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER		NOVEMBER	DECEMBER
0:00	1:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
1:00	2:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
2:00	3:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
3:00	4:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
4:00	5:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
5:00	6:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
6:00	7:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
7:00	8:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
8:00	9:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
9:00	10:00	0	0	0	1	1	1	1	1	1	1	1	0	0	0
10:00	11:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
11:00	12:00	1	1	1	0	0	0	0	0	0	0	0	1	1	1
12:00	13:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
13:00	14:00	1	1	1	0	0	0	0	0	0	0	0	1	1	1
14:00	15:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
15:00	16:00	0	0	0	1	1	1	1	1	1	1	1	1	1	1
16:00	17:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
17:00	18:00	0	0	0	1	1	1	1	1	1	1	1	0	0	0
18:00	19:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
19:00	20:00	1	1	1	1	1	1	1	1	1	1	1	0	0	0
20:00	21:00	1	1	1	1	1	1	1	1	1	1	1	1	1	1
21:00	22:00	0	0	0	0	0	0	0	0	0	0	0	1	1	1
22:00	23:00	0	0	0	0	0	0	0	0	0	0	0	0	0	0
23:00	0:00	1	1	1	0	0	0	0	0	0	0	0	0	0	0

TABLE 5. RECHARGE MATRIX FROM JANUARY TO DECEMBER FOR ELECTRIC THE TARIFF 3.1

As it has been already stated, the electric vehicles will deliver for 11 hours, which means that they should complete a recharge in 3 hours, leaving 2 extra recharging hours in case of any incident that may occur.

To complete a recharge in 3 hours with a battery capacity of 22kWh it is required a power of 22kWh/3h= **7.4 kW**. Note that if a vehicle is delivering for 3 hours it does not mean that is circulating during all the time (because there is time required to load and unload).

Once the Recharge Matrix has been built and therefore it is state when the vehicles are going to be recharge, the costs of electricity can be calculated by multiplying the recharge matrix and the tariff rates. Finally, **the costs of electricity are of 59.924,75€ with tariff 6.1 and 59.954,35€ for tariff 3.1.** The details are included in Annex A.

If the electric vehicles are delivering for 11 hours per day and the combustion vans for 8 hours, the number of electric vehicles needed are the following:

$$\frac{11 hours}{8 hours} = 1.4 \rightarrow \frac{60\ vehicles}{1.4} = \mathbf{42\ vehicles}$$

$$\begin{cases} Coslada: 14\ vehicles \\ Fuenlabrada: 14\ vehicles \\ Alcobendas 14\ vehicles \end{cases}$$

The following step is to calculate the power needed for each recharging installation.

- Alcobendas (14 vehicles):
$$P_{installation}(kW) = \frac{nº\ vehicles * kWh_{vehicle}}{t_{charge}} = \frac{14 * 22}{3} = \mathbf{104kW}$$
- Coslada (14 vehicles):
$$P_{installation}(kW) = \frac{nº\ vehicles * kWh_{vehicle}}{t_{charge}} = \frac{14 * 22}{3} = \mathbf{104kW}$$
- Fuenlabrada (14 vehicles):
$$P_{installation}(kW) = \frac{nº\ vehicles * kWh_{vehicle}}{t_{charge}} = \frac{14 * 22}{3} = \mathbf{104kW}$$

4.2.POWER CONTRACT

In the following section will be calculated the power needed for each installation to recharge 14 vans. The calculations in this section will be done in accordance with Low Voltage Regulation [3].

In the previous section, it was calculated a required installation of **104 kW to recharge the vehicles**. However, a higher installation might be needed due to other electric consumption such as illumination, ventilation, etc.

The estimated load will be assessed according to the ITC-BT-52.

$$P_{Building} = (P_1 + P_2 + P_3 + P_4) + C_s * P_5$$

$$\boxed{P_{Building} = (13.5kW + 7.2kW) + 1 * 104kW = \mathbf{124.7kW}}$$

$$\begin{cases} P_1 \equiv charge\ corresponding\ to\ the\ group\ of\ housing\ (C_s) \\ P_2 \equiv Charge\ correspoding\ to\ general\ services \\ P_3 \equiv Charge\ corresponding\ to\ comercial\ premises \\ P_4 \equiv charge\ corresponding\ to\ garage\ different\ from\ electric\ vehicle\ charges. \\ P_5 \equiv Charge\ estimated\ for\ electric\ vehicle\ charge. \end{cases}$$

The simultaneous factor (Cs) is 1 in this case because the SPL system will not be installed due to the fact that the installation should be prepared to plug in all the vehicles at the same time.

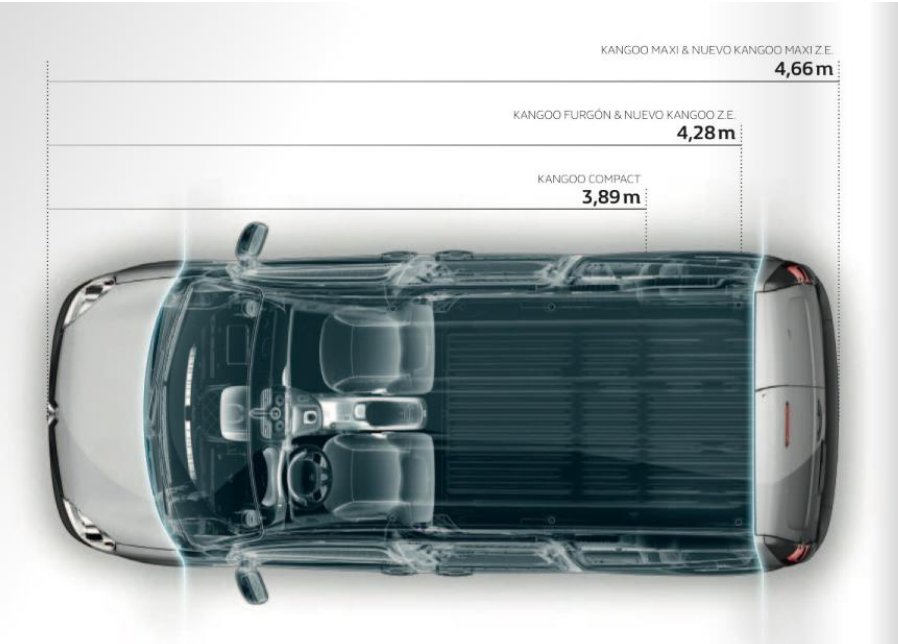


IMAGE 6. RENAULT KANGOO Z.E DIMENSIONS

The parking area dimensions would be:

$$A_{parking} = 120m^2$$

Due to corridors needed to manoeuvre the total dimensions of the garage are $12x30\ m^2$ and $9x30m^2$ of warehouse.

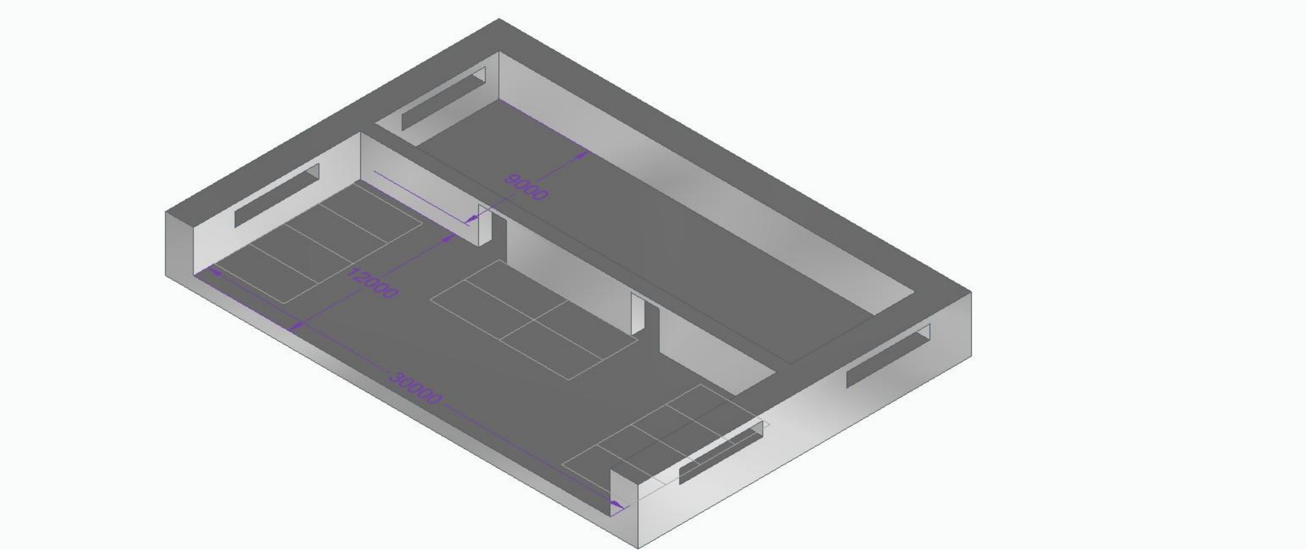


IMAGE 7. 3D VIEW OF INSTALLATION

The estimated load of the building is calculated according to ITC-BT-10:

$$P_{warehause} = 100\frac{W}{m^2} * (9 * 30)m^2 = 27kW\ \ \&\, P \geq 3450W\ with\ 230V$$

However, in logistic warehouse it is possible to request an Exception for the Quality Law that allow to design with a power of $50\frac{W}{m^2}$.

$$\boxed{P_{warehouse} = 50\frac{W}{m^2} * (9 * 30)m^2 = 13.5kW}$$

$$P_{garage}\begin{cases} 10\frac{W}{m^2} * (30 * 12)m^2 = 3.6\ kW \rightarrow natural\ ventilation \\ \boxed{20\frac{W}{m^2} * (30 * 12)m^2 = 7.2\ kW \rightarrow \textbf{forced ventilation}} \end{cases}$$

According to the Technical Building Code natural ventilation is allowed if there are ventilation slots with a maximum distance of 25m. Due to the dimensions of the building that is not possible, so there will be force ventilation.

On the other hand, the connection to the power network shall be establishes **in Low or Medium Voltage** according to the simultaneous power needs of the set of batteries which should be recharged at the same time and the duration of it's plug-in. It should be established the depreciation time of medium voltage to see if it is feasible to be connected to medium voltage. Due to the high power which seem reasonable to think that the installations should have.

Furthermore, the electric rate hired will be determined relying on the voltage and power of the installation.

In Annex B are indicated the prices, power and voltage delimitated for each tariff. In the following subsections are indicated the CAPEX costs for each case:

4.2.1. MEDIUM VOLTAGE

In the north of Madrid the Medium Voltage available is 20kV and 15kV in the south. **Meaning that only tariffs 3.1A and 6.1A can be selected**.

The installation will be design for 20kV both for the north and the south equally, because the devices available in the market are design for 20kV.

Each Substation Centre will cost 59.902,56€. The disaggregation of the expenses is indicated in Annex C.

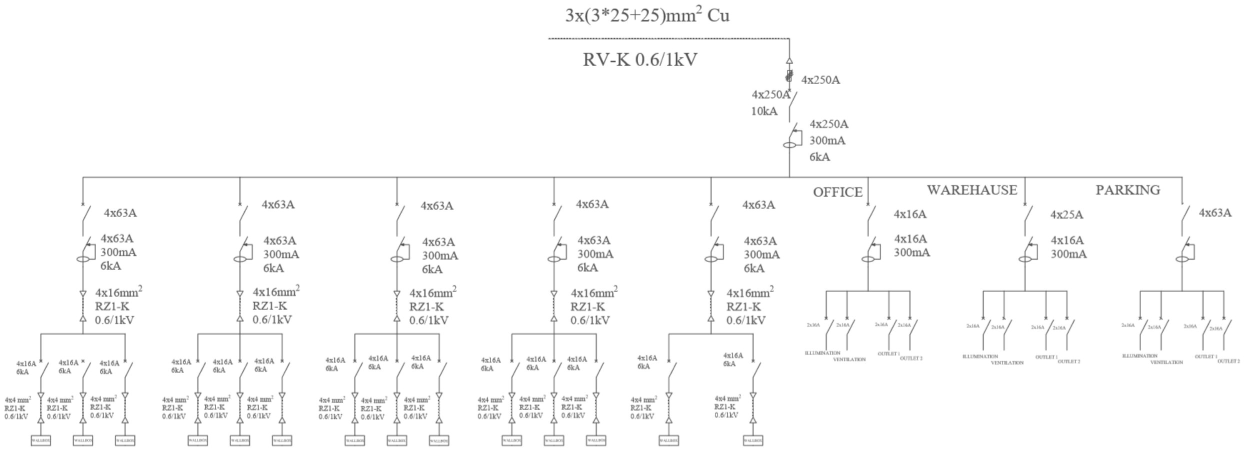
4.2.2. LOW VOLTAGE

The transformer substation in the low voltage case belongs to the electric company, so it is not necessary to perform any additional payment for it unless the installation requires a higher capacity transformer. Nevertheless, the electrical installation can be scalable into a Medium Voltage by the erection of a new Client Transformer substation.

The surrender transformer substations in all cases are equipped with a 630 kVA transformer, in case of overloading with the new supplies the replacement of grids elements if the required power exceeds the 20% of the power capacity of the saturated equipment in the grid. **As it is calculated in the Power Contract section, the simultaneous power required will never exceed 124.7 kW, which represents 19.8%** of the installed capacity **thus, it is plausible to consider it will not be required make an additional payment**. However, the cost of the required modifications in the transformer substation shall be defrayed by the distribution company.

4.3.INSTALLATION DESIGN

The target of this section is to design the recharging installations and make the pertinent calculations to recharge 14 vehicles each with a power of 104kW.



SCHEME 1. ONE LINE DIAGRAM FROM THE SUPPLY LINE TO WALLBOX

The installation design will meet the requirements of ITC-BT [6].

The maximum admissible currents are the following:

$$I_1 = \frac{P_{building}}{\sqrt{3} * U * \cos\varphi} = \frac{124.7kW}{\sqrt{3} * 400V * 0.85} = 211.7A$$

$$I_2 = \frac{P_{vehicle}}{\sqrt{3} * U * \cos\varphi} = \frac{\left(\frac{104kW}{14}\right)}{\sqrt{3} * 400V * 0.85} = 12.61A$$

$$I_3 = \frac{P_{building} - P_{vehicles}}{\sqrt{3} * U * \cos\varphi} = \frac{124.7kW - 104kW}{\sqrt{3} * 400V * 0.85} = 35.15A$$

*NOTE: $\cos(\varphi) = 0.85$ *because is the worst case contemplated*

4.3.1. ELECTRICITY SUPPLY

For the design it will be necessary to the following characteristics:

- Estimated Load: $P_{Building} = 124.7kW$
- Voltage supply: 400V (triphasic circuit)
- Maximum admissible voltage drops:1%

1. Type of supply line selection:

   The supply line will be underground, so the ITC-BT-06 determines the minimum wires section defined by the maximum current admissible.

2. Type of wire selection:

The insulation of the wires will able to bear a voltage of 0.6/1kV (section 1.2.1, paragraph 3, ITC-BT-11).

The stretches with a distance to the floor lower than 2.5m should be cover by tubes or flutes that should have the following requirements:

The correction factors will be considered 1 in every case, because there is no information available. The tables in Annex D indicate the correcting factors.

3. Section selection according to overheating of the electrical conductors:

$$I_{adm} * F_c \geq I_c$$

The maximum admissible temperature due to the type of isolation is reflected in the annex D.

Therefore, the isolation type will be XLPE, with a maximum conductor temperature of 90ºC in permanent service and 250ºC during a short-circuit of less than 5 seconds.

The maximum current admissible will defined according with the following tables in Annex D:

$$I_1 = 211.7A \begin{cases} S_{Cu} = 3\text{x}50mm^2 \\ S_{Al} = 3\text{x}95\ mm^2 \end{cases}$$

4. Section selection according to the maximum admissible voltage drops:

$$S = \frac{P * L}{\gamma * e * U} \begin{cases} \gamma_{Cu(90)} = 44 \left[\frac{m\Omega}{mm^2}\right] \\ \gamma_{Al(90)} = 28 \left[\frac{m\Omega}{mm^2}\right] \\ e \equiv voltage\ drop\ (1\%) \end{cases}$$

$$S_{Cu} = \frac{124.7kW * 30m}{44\frac{m\Omega}{mm^2} * (0.01 * 400V) * 400V} = 53.1\ mm^2$$

$$S_{Al} = \frac{124.7kW * 30m}{28\frac{m\Omega}{mm^2} * (0.01 * 400V) * 400V} = 83.5mm^2$$

Furthermore, the minimum section for supply lines must be $\begin{cases} S_{Cu} = 6mm^2 \\ S_{Al} = 16mm^2 \end{cases}$, according to ITC-BT-07.

And the normalized wires sections in this case are the same:

$$S_{Cu} = 70mm^2$$
$$S_{Al} = 95mm^2$$

As far as the cable price shall be quoted, the overall price based on density and material cost shows that aluminium is cheaper than copper in this section. However, a higher section is needed for aluminium wires which lead to a difficulty during the cable laying (bend radius is higher). Therefore, the optimal global solution will be to use copper wires.

4.3.2. INDIVIDUAL DERIVATION

- Three phase circuit (400V)
- Multiconductor wire able to bear a voltage of 0.6/1kV, wall installation.
- Isolation type: XLPE

$$I_3 = 35.15A$$

1. Section selection according to overheating of the electrical conductors:

$$S_{Cu} \geq 16mm^2$$

However, according to ITC-BT-15 the wires will be made of cooper and $S_{Cu} \geq 6mm^2$.

2. Section selection according to the maximum admissible voltage drops:

The maximum voltage drop should be 1% when there is a unique user and no General Supply Line due to ITC-BT-15.

$$S = \frac{P * L}{\gamma * e * U} \begin{cases} \gamma_{Cu(90)} = 44 \left[\frac{m\Omega}{mm^2}\right] \\ e \equiv voltage\ drop\ (1.5\%) \end{cases}$$

$$S_{Cu} \geq \frac{(124.7 - 104)kW * 200m}{44\frac{m\Omega}{mm^2} * (0.015 * 400V) * 400V} \geq 39.2mm^2$$

The normalized wire required is:

$$S_{Cu} = 50mm^2$$

The remaining cable lines, for illumination, climatization, differential protections, etc. Purposes will be made of copper $2.5mm^2$.

4.3.3. GENERAL PROTECTION AND MEASURMENT BOX

SUPPLY LINE

In accordance with the ITC-BT-13, ‘’In the case of supplying a unique consumer, the installation could be simplified by placing a unique element, the General Protection Box and Measurement Equipment’’

Furthermore, a PLC filter should be installed with the purpose of eliminating the noise produced by the recharging installation. (section 5, paragraph 15, ITC-BT-52).

1. Differential protection:

$$I_c \leq I_N \leq I_{adm}$$

$$S_{supply\ line} = 70mm^2 \dashrightarrow I_{adm} = \frac{S * V_L}{\rho_{Cu} * L * cos\varphi} = \frac{70 * 0.01 * 400}{\left(\frac{1}{44}\right) * 30 * 0.85} = 4831.37A$$

$$I_c = I_1 = 211.7A$$

- I_N: 250A
- Tripping characteristic C

In Annex D is indicated the Differential protection and break circuit selected.

RECHARGING POINTS

All the recharging points should be able to admit the following current due to **fast recharging.** Although it does not mean that it would be the usual current they would bare.

1. Differential protection:

$$I_c \leq I_N \leq I_{adm}$$

$$S_{recharging\ point} = 16mm^2 \rightarrow I_{adm} = \frac{S * V_L}{\rho_{Cu} * L * cos\varphi} = \frac{35 * 0.04 * 400}{\left(\frac{1}{44}\right) * 200 * 0.85} = 66.26A$$

- $I_2 = 37.45A$
- I_N: Calibration according to UNE-EN 60898: 6A, 10A ,16A, 20A ,25A, 32A, 40A, 50A, 63A, 80A, 100A, 125A.
- Tripping characteristic C (According to section 6.3, ITC-BT-52)

In Annex D is indicated the Differential protection and break circuit selected.

INDIVIDUAL DERIVATION

$$I_c \leq I_N \leq I_{adm}$$

$$S_{supply\ line} = 50mm^2 \rightarrow I_{adm} = \frac{S * V_L}{\rho_{Cu} * L * cos\varphi} = \frac{50 * 0.015 * 400}{\left(\frac{1}{44}\right) * 200 * 0.85} = 77.65A$$

$$I_c = I_3 = 35.15A$$

- I_N: Calibration according to UNE-EN 60898: 6A, 10A ,16A, 20A ,25A, 32A, 40A, 50A, 63A, 80A, 100A, 125A.
- Tripping characteristic C

In Annex D is indicated the Differential protection and break circuit selected.

4.3.4. RECHARGE POINTS WIRES

There will be 14 recharging points, with the same characteristics. The section of the cable will be calculated below:

$$I_2 = 12.61A$$

- Triphasic circuit, U=400V
- The insulation of the wires will able to bear a voltage of 0.6/1kV (section 5.3, paragraph 3, ITC-BT-52)

The wire in recharge of supplying energy to the **fast recharge point**, will have a different section, which is calculated below:

$$I_2 = \frac{P_{recharge}}{\sqrt{3} * U * \cos\varphi} = \frac{22kW}{\sqrt{3} * 400V * 0.85} = 37.45A$$

1. Section selection according to overheating of the electrical conductors:

$$S_{Cu} \geq 4mm^2$$

However, according to section 5, paragraph 15, ITC-BT-52 the wires will be made of cooper and $S_{Cu} \geq 2{,}5mm^2$.

2. Section selection according to the maximum admissible voltage drops:

The maximum voltage drop from the top of the installation to the recharging point will not exceed 5% according to section 5, paragraph 15, ITC-BT-52. In the supply line, it was already considered a maximum voltage drop of 1%, so the recharge points wire would not exceed 4% drop voltage.

$$S = \frac{P * L}{\gamma * e * U} \begin{cases} \gamma_{Cu(90)} = 44 \left[\frac{m\Omega}{mm^2}\right] \\ e \equiv voltage\ drop\ (4\%) \end{cases}$$

$$S_{Cu} \geq \frac{22kW * 200m}{44\frac{m\Omega}{mm^2} * (0.04 * 400V) * 400V} \geq 15.63mm^2$$

Therefore, the section of the wire should be higher than $15.63mm^2$. The normalized section is:

$$\boxed{S_{Cu} = 16mm^2}$$

The idea is that all the recharging points could be able to make a fast recharge in case of an emergency. That is why all of the should have a section of $16mm^2$

4.3.5. WALLBOX

In order to recharge the batteries, it is necessary to place a Wallbox at the end of each recharge point cable. For each recharging installation 14 Wallaboxes are necessary to recharge 14 vehicles at a time. The power of the Wallaboxes should be of at least **7.4kW**. Furthermore, each Wallbox has incorporated a digital counter.

In Annex D is indicated the wallbox selected.

4.3.6. INSTALLATION PRICES

The table below indicate the prices disaggregated of the recharge installation:

		GENERAL PROTECTION AND MEASURMENT BOX
	Switchgear 1x(4x250A)	171,20 €
	circuit breaker 1x(4x250A)	11,86 €
	Switchgear 5x(4x63A)	476,00 €
	circuit breaker 5x(4x63A)	21,05 €
	circuit breaker 14x(4x16A)	58,94 €
		WIRES
SUPPLY LINE	3x30m x(3X25+25) mm^2	961,20 €
RECHARGING POINTS (x14)	14x200m x(3x16)mm^2	17.416,00 €
INDIVIDUAL DERIVATION	4x200m x(1x50)mm^2	3.800,00 €
		WALLBOX 14x7,4kW
		16.772,00 €
	COST INSTALLATION	39.688,25 €
	COST INSTALLATIONS (x3)	119.064,75 €

TABLE 6. INSTALLATIONS COSTS

All the devices selected are indicated in Annex D and their prices.

As it is indicated in the table above it will cost **119.064,75€ the extension of all installations.**

5. DISCUSSION AND CONCLUSIONS

In this section, it will be discussed the outcomes of the project as well as developing a model plan during the years in order to introduce the electric vehicle in a solid and secure way.

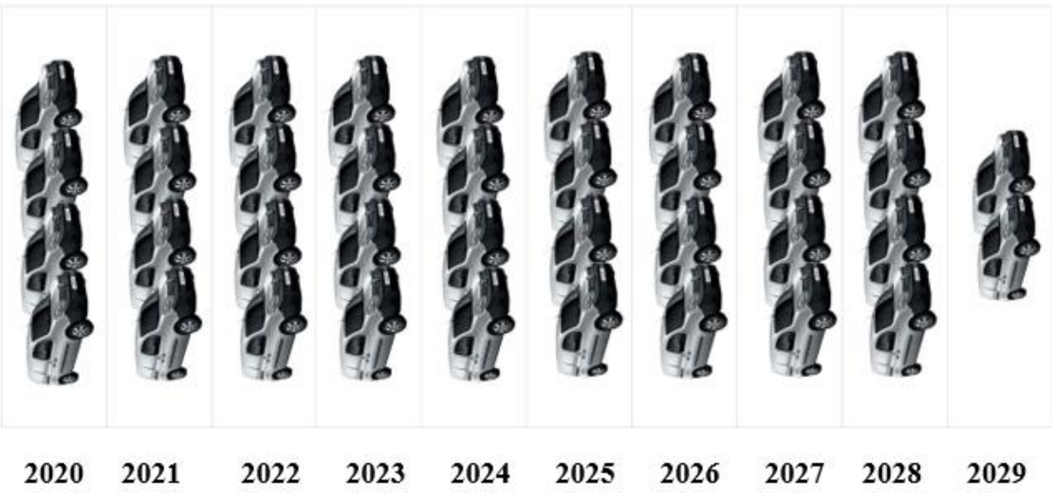
5.1.ESCALABILITY ANALYSIS

With the aim of avoiding a very big investment initially and **receive feedback** of a such a recent technology in the market. It is a good practise to increase the number of electric vans moderately during time.

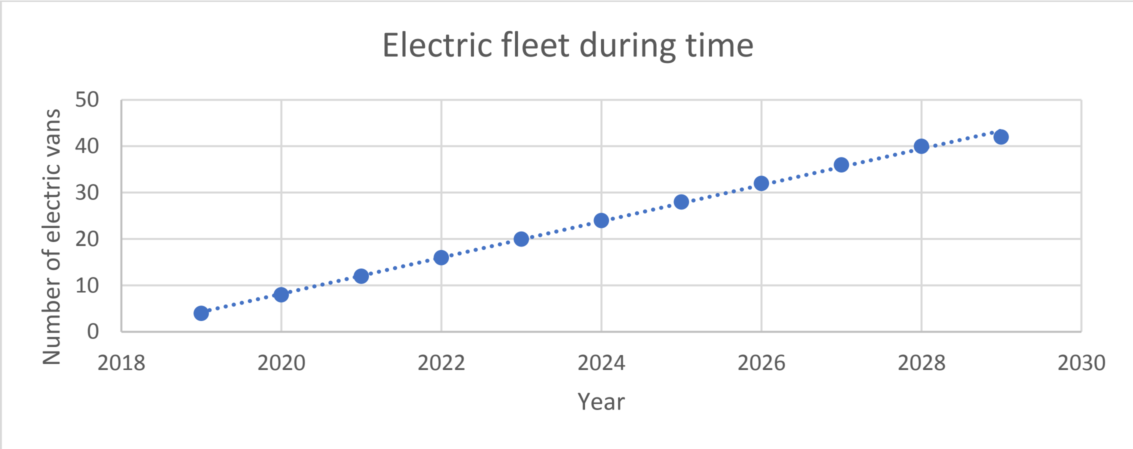
This practise would give the company experience in the field, and the feedback given will be an advantage to calculate the optimal routes and prevent incidents.

In the case of study, it will be required 10 years to complete the fleet with all the electric vehicles.

A good option might be to increase each year the electric fleet with 4 new vehicles as it is show in the following chronogram:



GRAPHIC 4.CHRONOGRAM OF THE NUMBER OF VEHICLES INCREASED EACH YEAR.



GRAPHIC 5. NUMBER OF VEHICLES DURING TIME

The number of recharging points that increase in each installation for a specific year is indicated below, the point is to increase the power of the installations equally.

	Number of electric vehicles		
Year	Coslada	Fuenlabrada	Alcobendas
2019	2	1	1
2020	1	2	1
2021	1	1	2
2022	2	1	1
2023	1	2	1
2024	1	1	2
2025	2	1	1
2026	1	2	1
2027	1	1	2
2028	2	1	1
2029	0	1	1

TABLE 7. NUMBER OF RECHARGING POINTS THAT INCREASE IN EACH INSTALLATION

In the following table is indicated the power needed for each installation in each year as well as the expenses that each year should be paid due to the extension of the installations:

Year	Number of vehicles	P_installations (kW)	P_Coslada(kW)	P_Fuenlabrada (kW)	P_Alcobendas(kW)	Costs
2019	4	28,8	14,4	7,2	7,2	73.540,75 €
2020	8	58	21,7	21,8	14,5	4.792,00 €
2021	12	87,2	29	29,1	29,1	4.792,00 €
2022	16	116,4	43,6	36,4	36,4	4.792,00 €
2023	20	145,6	50,9	51	43,7	4.792,00 €
2024	24	174,8	58,2	58,3	58,3	4.792,00 €
2025	28	204	72,8	65,6	65,6	4.792,00 €
2026	32	233,2	80,1	80,2	72,9	4.792,00 €
2027	36	262,4	87,4	87,5	87,5	4.792,00 €
2028	40	291,6	102	94,8	94,8	4.792,00 €
2029	42	306,2	102	102	102	2.396,00 €

TABLE 8. POWER AND COSTS DURING TIME

For the first year, it is necessary to pay for all the expenses of the recharge installations. Although, the wallaboxes will be bought simultaneously with the growth of the electric vehicles incorporated in the fleet. Besides, it has not been included the construction work prices.

5.2.MEDIUM OR LOW VOLTAGE

The connection to the power network shall be establishes **in Low or Medium Voltage** according to the simultaneous power needs of the set of batteries which should be recharged at the same time and the duration of it's plug-in. It should be stablished the depreciation time of medium voltage to see if it is feasible to be connected to medium voltage due to the high power which seem reasonable to think that the installations should have.
The next step will be therefore to decide whether to connect the installation to low or medium voltage. In the next table is shown the price breakdown for each case:

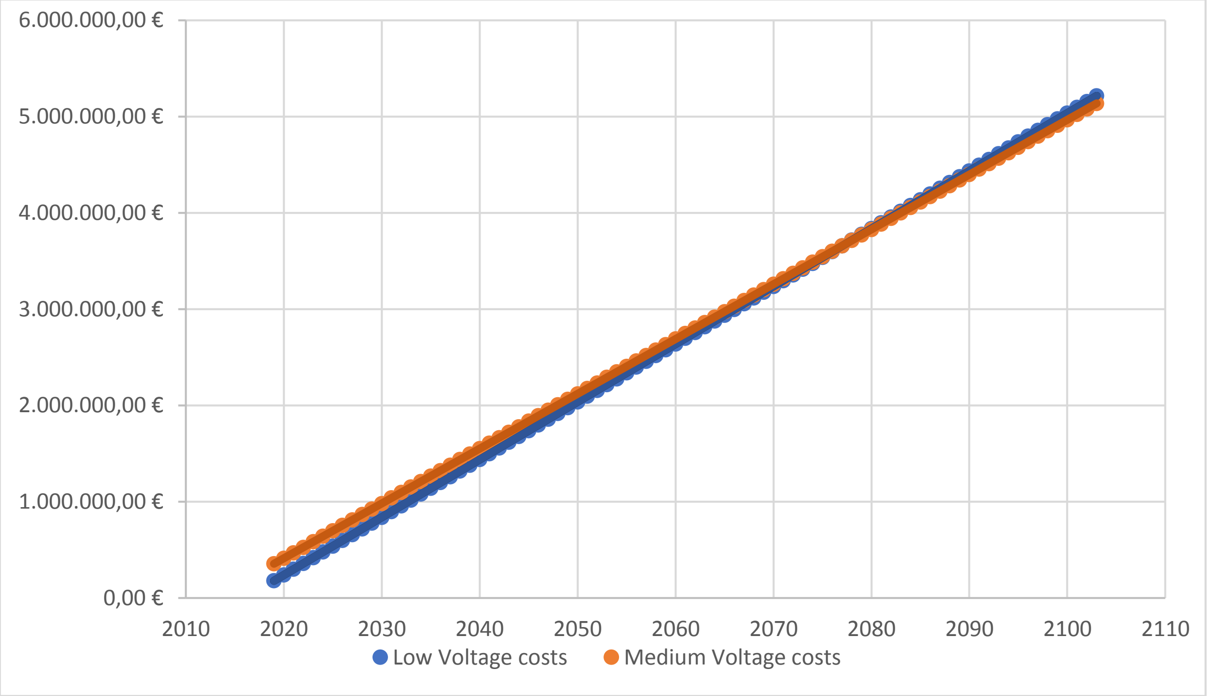
	MEDIUM VOLTAGE		LOW VOLTAGE	
CAPEX	Transfomer Substation	59.902,50 €	New transformer	0,00 €
	Installation	39.688,25 €	Installation	39.688,25 €
	Number of installations	3	Number of installations	3
	Total	298.772,25 €	Total	119.064,75 €
OPEX	Fixed power costs (kW/year)	39853,74234	Fixed power costs (kW/year)	38294,13797
	Energy price [Tariff 6.1A]	17.071,01 €	Energy price [Tariff 3.1A]	21.660,21 €
	Total	56.924,75 €	Total	59.954,35 €

TABLE 9. COSTS MEDIUM VOLTAGE VS LOW VOLTAGE

The Substation Centre costs have been calculated with Amikit and it is detailed shown in Annex C.

It is necessary to decide whether to connect the recharging installation to low or medium voltage. Connecting to **medium voltage will require a Transformer Substation with a cost of 59.902, 50 € for each of the 3 installation**, while low voltage will not have additional costs. The toll differences will make not worth it, in fact it would take 59.3 years to recover medium voltage installation costs versus low voltage development. Besides, it will take 10 more years to depreciate it due to the slightly introduction of the electric vehicle in the fleet.

The following graphic shows the cost of electricity during time:



GRAPHIC 6. ELECTRIC VS MEDIUM VOLTAGE COSTS DURING TIME

5.3. ELECTRIC VS CONVENTIONAL VEHICLES

There are several advantages in incorporating electric vehicles to the fleets such as avoiding traffic jams by using HOV lanes [10]. , be allowed to circulate at any time of the day in "Madrid Central" [5], low expenses in insurance and maintenance and free positive advertisement and some others like reducing stress to the drivers due to the silence of electric engines.

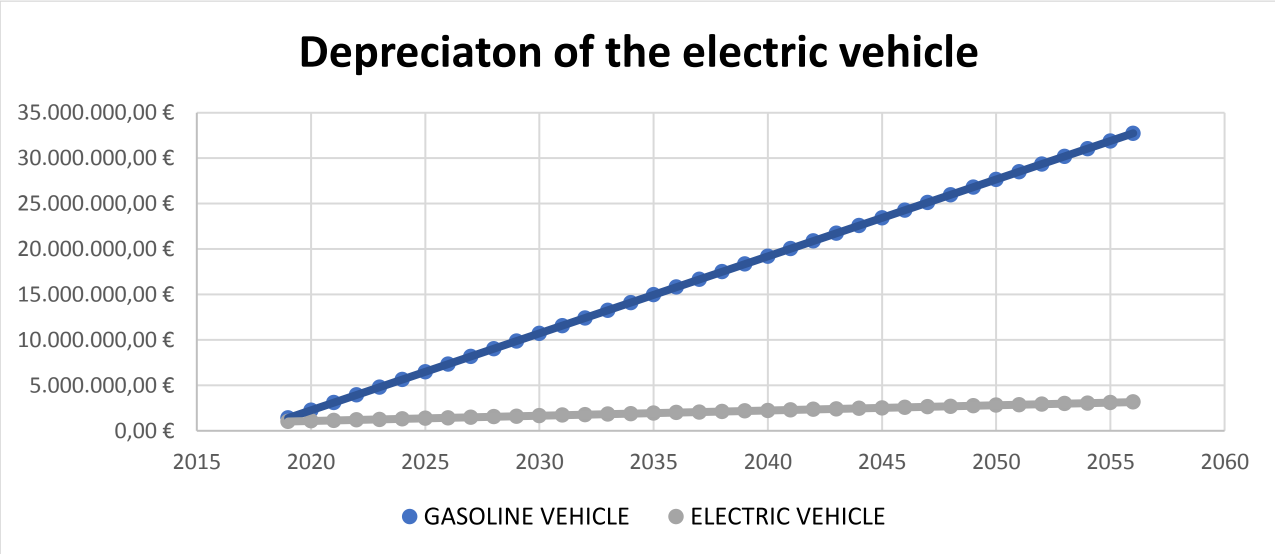
For the case of study, it has been assumed the following:

- **The over cost of the electric installation is only due to the recharging vehicle costs**. The building is also necessary for non-electric vans for storage.
- The three recharging installations would have the same cost.

- **The prices of the vans are the lowest available in the market**. Notwithstanding, as it is a comparison between both the prices are valid.
- **60 Fuel vehicles required (635 km each per day) vs 42 electric vehicles (950km per day each). And all of them are bought in the first year.**
- **3 installations required with 104 kW each one**.
- There is no problem with delivering at night.

In annex E are shown the comparison tables of the vehicles and energy prices for electric and conventional vehicles.

As it is shown, **the fleet price would be 134.115,00 €** more expensive with electric vehicles than with conventional. This cost represents only a 17 % of the difference between the OPEX costs of the electric and the gasoline fleet.
In Annex D are the tables that compare the costs of electricity (for tariff 3.1 and 6.1) vs fuel.



GRAPHIC 7. DEPRECIATION OF ELECTRIC VAN DURING TIME

The initial investment would be of **119.064,75 €** for the three recharging installations and **the price of the vehicles are nearly two times higher.** Notwithstanding, the **OPEX costs of an electric fleet represent a 7.2% of the variable costs of a fuel fleet**. Besides, it will take **4 months to depreciate the initial** investment with an **IRR of 76%** in the case of hiring the low voltage tariff. The expenses of the recharging installation are 119.064,75€ and the adding costs of purchasing the vehicles are 134.115,00€ while the saving of using electricity instead of fuel are 786.170,86€. However, note that this outcome is very optimistic due to the huge distance and fleet state for delivering only in *"Madrid Central"*. That is why this outcome will turn out to be more reasonable when the requirements of *"Madrid Central"* extends to other areas of Madrid. Besides, it will take 4 months to depreciate the initial investment only in the case that all the vehicles are bought in the first year.

Although the outcomes are too positive, it is only due to the fact that the case of study contemplate a huge fleet that cover many kilometres each day. This seems very unrealistic if the fleet is delivering only in the centre of Madrid, notwithstanding as it was said in the introduction, it is predicted that the "*Madrid Central*" requirements will be extended to more Areas of Madrid.

5.4.CONCLUSION

As an overview, incorporating electric vehicles to delivery companies is a nice way to contribute to the **environmental care** as well as brilliant idea to get **free positive advertising**.

The introduction of the electric vehicle requires **accuracy in timeliness** so that each vehicle is effectively recharging when it is estimated. Although, this is not very predictable it should be considered that electric vehicles are allowed to circulate in HOV lanes, so traffic jams can be avoided.

Furthermore, monitoring the vehicles can make a practical feedback to make realistic delivering routes as well as drivers should be trained to use this up-to-date technology.

It is important to point out that fuel vehicles with the B label will be allowed to deliver in the centre of Madrid for 8 hours in 2020, while according to the calculations made in this paper the electric vans may circulate for 11 hours. Meaning that to make the same number of deliveries, it would be necessary to count with **42 electric vehicles** while there would be necessary 60 fuel vehicles with the B label.

Furthermore, it has been considered that the **Renault Kangoo Z.E can be circulating for 3** hours due to its 200 km real range and to be able to deliver for 11 hours it is necessary to recharge the vehicles completely in 3 hours. That is why it is needed a **power of recharging of 7.4 kW per vehicle and 104 kW for each of the 3 recharging installations.**

On the other hand, it should be decided whether to connect or not the 3 recharging installations to medium or low voltage. Connecting to **medium voltage will require a Transformer Substation with a cost of 59.902, 50 € for each of the 3 installation**, while low voltage will not have additional costs. The toll differences will make not worth it, it would take **59.3 years** to recover medium voltage installation costs versus low voltage development. Besides, if the vehicles are slightly introduced in the fleet, it will take 10 more years to depreciate it.
It is true that for the implementation of the electric vehicle, a **high investment** is needed due to the high prices of this technology as well as the recharging installation needed. Precisely, the initial investment would be of **119.064,75 €** for the three recharging installations and **the price of the vehicles are nearly two times higher.** Notwithstanding, the **OPEX costs of an electric fleet represent a 7.2% of the variable costs of a fuel fleet**. Besides, it will take **4 months to depreciate the initial** investment with an **IRR of 76%** in the case of hiring the low voltage tariff. However, note that this outcome is very

optimistic due to the huge distance and fleet state for delivering only in *"Madrid Central"*. That is why this outcome will turn out to be more reasonable when the requirements of *"Madrid Central"* extends to other areas of Madrid. Besides, it will take 4 months to depreciate the initial investment only in the case that all the vehicles are bought in the first year.

To conclude**, environmentally friendly vehicles are a viable and economically competitive** alternative to the currently delivery business that state a change in the business model because it is required changes in the schedule, routes and smart energy management. Turning the electric vehicle into the new up-to-date technology which surely will conquer the market.

6. REFERENCES

[1] DIRECTIVA 2009/33/CE DEL PARLAMENTO EUROPEO Y DEL CONSEJO de 23 de abril de 2009

[2] El Pais. Madrid 20 August 2018

[3] FREVUE Fright Electric Vehicles in Urban Europe. https://frevue.eu/ https://www.boe.es/eli/es/rdl/2018/12/28/28/dof/spa/pdf

[4] Real Decreto 958/2018, de 27 de julio, por el que se crea y regula la Comisión Interministerial para el Cambio Climático y la Transición Energética. «BOE» núm. 182, de 28 de julio de 2018.

[5] Acuerdo de 29 de octubre de 2018 de la Junta de Gobierno de la Ciudad de Madrid por el que se desarrolla el régimen de gestión y funcionamiento de la Zona de Bajas Emisiones "Madrid Central"

[6] Real Decreto 842/2002, de 2 de agosto, por el que se aprueba el Reglamento electrotécnico para baja tensión.

[7] Ley del cambio climático y transición energética

[8] Ordenanza Fiscal Reguladora del Impuesto sobre Vehículos de Tracción Mecánica. (BO. Ayuntamiento de Madrid 22/11/2001 núm. 547 pág. 3825)

[9] Articule 49-55 "Ordenanza de movilidad sostenible". (BO. Comunidad de Madrid 23/10/2018 núm. 253 pág. 130 – 251).

[10] Resolución de 13 de abril de 2016, de la Dirección General de Tráfico, por la que se modifica el apartado C.1 del punto primero y los anexos I, II y VIII de la de 8 de enero de 2016, por la que se establecen medidas especiales de regulación del tráfico durante el año 2016.

[11] Extracto de la resolución 11 de Julio de 2019, por la que se inicia el procedimiento de concesión directa por razones de interés público de las subvenciones del programa de incentivos a la movilidad eficiente y sostenible (Programa MOVES)

[12] RED ELECTRICA DE ESPAÑA Oficial website.

[13] Informe calidad del aire en la ciudad de Madrid en el 2018 por ecologistas en acción. Hecho público el 9 de enero de 2019

[14] Royal Decree published in «BOE» núm. 83, de 06/04/2019. Reference: BOE-A-2019-5089

[15] «BOE» núm. 46, 21/02/2018. Reference: BOE-A-2018-2400

[16] «BOE» núm. 41, de 16 de febrero de 2019.Reference: BOE-A-2019 2148

[17] "FREVUE Results and Guidelines for Vehicle Suppliers v_09". September 2017

[18] RENAULT, https://www.renault.es/electricos/kangoo-ze/bateria.html

[19] NISSAN official Website: https://www.nissan.es/vehiculos/nuevos-vehiculos/e-nv200.html

[20] PEUGOT official Website http://www.peugeot.com/es

[21] MERCEDES VENZ: https://www.mercedes-benz.es/vans/es/mercedes-benz-vans/wltp-rde

[22] Telemadrid 27/11/2018: http://www.telemadrid.es/madrid-central/Madrid-Central-cronologia-fechas-clave-0-2070092975--20181123024819.html

[23] Informe de precios energéticos regulados octubre 2018. IDEA (Instituto para la diversificación y ahorro de la energía)

7. ANNEXES

7.1. ANNEX A: DEVELOPMENT PROJECT

7.1.1. INSTALLATION SITE

As it is indicated in the previous section, there will be three different recharging locations situated in Fuenlabrada, Coslada and Alcobendas with the specific directions included in the Annex A.

IMAGE 8. LOCALIZATION INSTALLATION COSLADA [ELECTRONIC HEADQUARTERS LAND REGISTRY]

IMAGE 9. LOCALIZATION INSTALLATION ALCOBENDAS [ELECTRONIC HEADQUARTERS LAND REGISTRY]

IMAGE 10. LOCALIZATION INSTALLATION FUENLABRADA [ELECTRONIC HEADQUARTERS LAND REGISTRY]

7.1.2. OUTCOME OF RECHARGING FRAME

7.1.2.1.MATLAB CODE

The following code purpose is to make a matrix M, with a 0 value if it is delivering and 1 for recharging:

```
%CREACION DE LA MATRIZ CHARGE

%iniciating variables
control1=0
control2=0

for c=0:1:23
for m=1:2^c:8388608
    for i=1:1:16777216


        if control1<m  %m is the number of consecutives ceros or ones
         M(i,c+1)=1
         control1=control1+1;

        else

            M(i,c+1)=0
            control2=control2+1;
                if control2==m
                    control2=0
                    control1=0
                end

        end
        %charge(i,c)=transpose(M(i));
    end
end
end
```

IMAGE 11. CODE TO CREATE MATRIX M

7.1.2.2.GAMS CODE

For the following cases it has been used GAMS, the purpose is to find the best moment to recharge in order to pay for the minimum electricity prices.

<u>CASE I: Tariff 6.1- Different recharging frame for each month</u>

- JANUARY

The following code is an example of the GAMS code. All the months has the same code but with different vector tariff(i) representing the rate of electricity for each hour and each month.

Due to GAMS limitation the tariff rates has been multiplied by 1000, so it must be corrected after in the calculations of the costs.

```
SETS

i hours/a,b,c,d,e,f,g,h,i,j,k,l,m,n,o,p,q,r,s,t,u,v,w,y/
  ;
SCALARS

charging_time time needed per day to charge each van /15/
   ;
PARAMETER

tariff(i) Matrix of the prices of electricity during hour i
/a        2.137
b        2.137
c        2.137
d        2.137
e        2.137
f        2.137
g        2.137
h        2.137
i        19.921
j        19.921
k        26.674
l        26.674
m        26.674
n        19.921
o        19.921
p        19.921
q        19.921
r        19.921
s        26.674
t        26.674
u        26.674
v        19.921
w        19.921
y        19.921
```

```
/
   ;
VARIABLES
Costs(i) cost of electricity during hour i
charge(i) 1 if it is charging during hour i
VFO Objective function value
         ;
BINARY VARIABLES charge(i)
EQUATIONS
FO Total cost of electricity
Cost_frame(i) Cost per frame
C1 Condition that requires each van to be conected
C2 Condition that requires a maximum of 3 consecutives hours delivering
C3
C4
C5
C6
C7
C8
C9
C10
C11
C12
C13
C14
C15
C16
C17
C18
C19
C20
C21
C22
C23
```

```
C24
C25
          ;
          ;

C1.. SUM[(i),Charge(i)]=E=15;
C2.. Charge('a')+Charge('b')+Charge('c')+Charge('d')=G=1;
C3.. Charge('b')+Charge('c')+Charge('d')+Charge('e')=G=1;
C4.. Charge('c')+Charge('d')+Charge('e')+Charge('f')=G=1;
C5.. Charge('d')+Charge('e')+Charge('f')+Charge('g')=G=1;
C6.. Charge('e')+Charge('f')+Charge('g')+Charge('h')=G=1;
C7.. Charge('f')+Charge('g')+Charge('h')+Charge('i')=G=1;
C8.. Charge('g')+Charge('h')+Charge('i')+Charge('j')=G=1;
C9.. Charge('h')+Charge('i')+Charge('j')+Charge('k')=G=1;
C10.. Charge('i')+Charge('j')+Charge('k')+Charge('l')=G=1;
C11.. Charge('j')+Charge('k')+Charge('l')+Charge('m')=G=1;
C12.. Charge('k')+Charge('l')+Charge('m')+Charge('n')=G=1;
C13.. Charge('l')+Charge('m')+Charge('n')+Charge('o')=G=1;
C14.. Charge('m')+Charge('n')+Charge('o')+Charge('p')=G=1;
C15.. Charge('n')+Charge('o')+Charge('p')+Charge('q')=G=1;
C16.. Charge('o')+Charge('p')+Charge('q')+Charge('r')=G=1;
C17.. Charge('p')+Charge('q')+Charge('r')+Charge('s')=G=1;
C18.. Charge('q')+Charge('r')+Charge('s')+Charge('t')=G=1;
C19.. Charge('r')+Charge('s')+Charge('t')+Charge('u')=G=1;
C20.. Charge('s')+Charge('t')+Charge('u')+Charge('v')=G=1;
C21.. Charge('t')+Charge('u')+Charge('v')+Charge('w')=G=1;
C22.. Charge('u')+Charge('v')+Charge('w')+Charge('y')=G=1;
C23.. Charge('v')+Charge('w')+Charge('y')+Charge('a')=G=1;
C24.. Charge('w')+Charge('y')+Charge('a')+Charge('b')=G=1;
C25.. Charge('y')+Charge('a')+Charge('b')+Charge('c')=G=1;

Cost_frame(i).. Costs(i)=E=tariff(i)*charge(i);
FO.. VFO=E=SUM[(i),Costs(i)];

MODEL recarga_enero/all/

SOLVE recarga_enero USING MIP MINIMIZING VFO
```

IMAGE 12 .CODE TO GET THE OPTIMUM RECHARGE MATRIX FOR JANUARY WITH TARIFF 6.1

The following image shows the matrix of recharge that indicate when in this month should the vehicles be recharged. To these images follows all the outcomes for each month and from each tariff.

---- VAR Costs cost of electricity during hour i

	LOWER	LEVEL	UPPER	MARGINAL
a	-INF	2.137	+INF	.
b	-INF	2.137	+INF	.
c	-INF	2.137	+INF	.
d	-INF	2.137	+INF	.
e	-INF	2.137	+INF	.
f	-INF	2.137	+INF	.
g	-INF	2.137	+INF	.
h	-INF	2.137	+INF	.
i	-INF	.	+INF	.
j	-INF	19.921	+INF	.
k	-INF	.	+INF	.
l	-INF	.	+INF	.
m	-INF	.	+INF	.
n	-INF	19.921	+INF	.
o	-INF	19.921	+INF	.
p	-INF	19.921	+INF	.
q	-INF	19.921	+INF	.
r	-INF	19.921	+INF	.
s	-INF	.	+INF	.
t	-INF	.	+INF	.
u	-INF	.	+INF	.
v	-INF	19.921	+INF	.
w	-INF	.	+INF	.
y	-INF	.	+INF	.

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000     2.137
b      .       1.000     1.000     2.137
c      .       1.000     1.000     2.137
d      .       1.000     1.000     2.137
e      .       1.000     1.000     2.137
f      .       1.000     1.000     2.137
g      .       1.000     1.000     2.137
h      .       1.000     1.000     2.137
i      .         .       1.000    19.921
j      .       1.000     1.000    19.921
k      .         .       1.000    26.674
l      .         .       1.000    26.674
m      .         .       1.000    26.674
n      .       1.000     1.000    19.921
o      .       1.000     1.000    19.921
p      .       1.000     1.000    19.921
q      .       1.000     1.000    19.921
r      .       1.000     1.000    19.921
s      .         .       1.000    26.674
t      .         .       1.000    26.674
u      .         .       1.000    26.674
v      .       1.000     1.000    19.921
w      .         .       1.000    19.921
y      .         .       1.000    19.921

                      LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO           -INF    156.543    +INF        .


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED


EXECUTION TIME       =        0.000 SECONDS      2 MB  25.1.1 r66732 WEX-WEI


USER: GAMS Development Corporation, USA              G871201/0000CA-ANY
      Free Demo, +1 202-342-0180, support@gams.com, www.gams.com DC0000


**** FILE SUMMARY

Input      E:\TFG_Final\recarga_enero.gms
Output     C:\Users\stic\Documents\gamsdir\projdir\recarga_enero.lst
```

IMAGE 13 .OUTOME FOR JANUARY WITH TARIFF 6.1

The variable costs of electricity in January would be:

$$Electricty\ Costs_{JANUARY} = \frac{156.543}{1000} * nº\ vehicles * workdays$$

$$Electricty\ Costs_{JANUARY} = \frac{156.543}{1000} * 42 * 22 = 144.64€$$

- FEBRUARY

```
---- VAR charge  1 if it is charging during hour i

      LOWER     LEVEL     UPPER    MARGINAL

a       .       1.000     1.000     2.137
b       .       1.000     1.000     2.137
c       .       1.000     1.000     2.137
d       .       1.000     1.000     2.137
e       .       1.000     1.000     2.137
f       .       1.000     1.000     2.137
g       .       1.000     1.000     2.137
h       .       1.000     1.000     2.137
i       .         .       1.000    19.921
j       .       1.000     1.000    19.921
k       .         .       1.000    26.674
l       .         .       1.000    26.674
m       .         .       1.000    26.674
n       .       1.000     1.000    19.921
o       .       1.000     1.000    19.921
p       .       1.000     1.000    19.921
q       .       1.000     1.000    19.921
r       .       1.000     1.000    19.921
s       .         .       1.000    26.674
t       .         .       1.000    26.674
u       .         .       1.000    26.674
v       .       1.000     1.000    19.921
w       .         .       1.000    19.921
y       .         .       1.000    19.921
```

```
                         LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO             -INF    156.543     +INF       .

  VFO  Objective function value


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED


EXECUTION TIME       =        0.000 SECONDS      2 MB  25.1.1 r66732 WEX-WEI


USER: GAMS Development Corporation, USA              G871201/0000CA-ANY
      Free Demo, +1 202-342-0180, support@gams.com, www.gams.com DC0000
```

IMAGE 14. OUTOME FOR FEBRUARY WITH TARIFF 6.1

$$Electricty\ Costs_{FEBRUARY} = \frac{156.543}{1000} * 42 * 22 = 144.64€$$

- MARCH

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	2.137
b	.	1.000	1.000	2.137
c	.	1.000	1.000	2.137
d	.	1.000	1.000	2.137
e	.	1.000	1.000	2.137
f	.	1.000	1.000	2.137
g	.	1.000	1.000	2.137
h	.	1.000	1.000	2.137
i	.	.	1.000	5.283
j	.	.	1.000	5.283
k	.	.	1.000	5.283
l	.	1.000	1.000	5.283
m	.	1.000	1.000	5.283
n	.	1.000	1.000	5.283
o	.	.	1.000	5.283
p	.	1.000	1.000	5.283
q	.	.	1.000	10.615
r	.	.	1.000	10.615
s	.	1.000	1.000	10.615
t	.	.	1.000	10.615
u	.	.	1.000	10.615
v	.	.	1.000	10.615
w	.	1.000	1.000	5.283
y	.	1.000	1.000	5.283

```
                        LOWER      LEVEL      UPPER     MARGINAL

---- VAR VFO             -INF     59.409      +INF        .

  VFO  Objective function value


**** REPORT SUMMARY :          0     NONOPT
                               0 INFEASIBLE
                               0  UNBOUNDED


EXECUTION TIME       =        0.000 SECONDS      2 MB  25.1.1 r66732 WEX-WEI


USER: GAMS Development Corporation, USA              G871201/0000CA-ANY
      Free Demo, +1 202-342-0180, support@gams.com, www.gams.com DC0000
```

IMAGE 15. OUTOME FOR MARCH WITH TARIFF 6.1

$$Electricty\ Costs_{MARCH} = \frac{59.409}{1000} * 42 * 22 = 54.89€$$

- APRIL

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	2.137
b	.	1.000	1.000	2.137
c	.	1.000	1.000	2.137
d	.	1.000	1.000	2.137
e	.	1.000	1.000	2.137
f	.	1.000	1.000	2.137
g	.	1.000	1.000	2.137
h	.	1.000	1.000	2.137
i	.	.	1.000	3.411
j	.	1.000	1.000	3.411
k	.	1.000	1.000	3.411
l	.	1.000	1.000	3.411
m	.	1.000	1.000	3.411
n	.	1.000	1.000	3.411
o	.	.	1.000	3.411
p	.	.	1.000	3.411
q	.	1.000	1.000	3.411
r	.	.	1.000	3.411
s	.	.	1.000	3.411
t	.	.	1.000	3.411
u	.	1.000	1.000	3.411
v	.	.	1.000	3.411
w	.	.	1.000	3.411
y	.	.	1.000	3.411

```
                      LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO           -INF     40.973     +INF        .

  VFO  Objective function value


**** REPORT SUMMARY :        0     NONOPT
                             0 INFEASIBLE
                             0  UNBOUNDED


EXECUTION TIME       =        0.000 SECONDS      2 MB  25.1.1 r66732 WEX-WEI
```

IMAGE 16 .OUTOME FOR APRIL WITH TARIFF 6.1

$$Electricty\ Costs_{APRIL} = \frac{40.973}{1000} * 42 * 22 = 37.859€$$

- MAY

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000     2.137
b      .       1.000     1.000     2.137
c      .       1.000     1.000     2.137
d      .       1.000     1.000     2.137
e      .       1.000     1.000     2.137
f      .       1.000     1.000     2.137
g      .       1.000     1.000     2.137
h      .       1.000     1.000     2.137
i      .         .       1.000     3.411
j      .       1.000     1.000     3.411
k      .       1.000     1.000     3.411
l      .       1.000     1.000     3.411
m      .       1.000     1.000     3.411
n      .       1.000     1.000     3.411
o      .         .       1.000     3.411
p      .         .       1.000     3.411
q      .       1.000     1.000     3.411
r      .         .       1.000     3.411
s      .         .       1.000     3.411
t      .         .       1.000     3.411
u      .       1.000     1.000     3.411
v      .         .       1.000     3.411
w      .         .       1.000     3.411
y      .         .       1.000     3.411

                       LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO            -INF     40.973    +INF        .

  VFO  Objective function value
```

IMAGE 17. OUTOME FOR MAY WITH TARIFF 6.1

$$Electricty\ Costs_{MAY} = \frac{40.973}{1000} * 42 * 22 = 37.86€$$

- JUNE1

```
---- VAR charge  1 if it is charging during hour i

      LOWER     LEVEL     UPPER    MARGINAL

a       .       1.000     1.000     2.137
b       .       1.000     1.000     2.137
c       .       1.000     1.000     2.137
d       .       1.000     1.000     2.137
e       .       1.000     1.000     2.137
f       .       1.000     1.000     2.137
g       .       1.000     1.000     2.137
h       .       1.000     1.000     2.137
i       .         .       1.000     5.283
j       .         .       1.000    10.615
k       .         .       1.000    10.615
l       .       1.000     1.000    10.615
m       .         .       1.000    10.615
n       .         .       1.000    10.615
o       .         .       1.000    10.615
p       .       1.000     1.000     5.283
q       .       1.000     1.000     5.283
r       .       1.000     1.000     5.283
s       .       1.000     1.000     5.283
t       .       1.000     1.000     5.283
u       .       1.000     1.000     5.283
v       .         .       1.000     5.283
w       .         .       1.000     5.283
x       .         .       1.000     5.283
```

IMAGE 18. OUTOME FOR JUNE 1 WITH TARIFF 6.1

```
                      LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO           -INF     59.409     +INF        .

  VFO  Objective function value
```

$$Electricty\ Costs_{JUN1} = \frac{59.409}{1000} * 42 * 22 = 54.89€$$

- JUNE 2

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	2.137
b	.	1.000	1.000	2.137
c	.	1.000	1.000	2.137
d	.	1.000	1.000	2.137
e	.	1.000	1.000	2.137
f	.	1.000	1.000	2.137
g	.	1.000	1.000	2.137
h	.	1.000	1.000	2.137
i	.	.	1.000	19.921
j	.	1.000	1.000	19.921
k	.	1.000	1.000	19.921
l	.	.	1.000	26.674
m	.	.	1.000	26.674
n	.	.	1.000	26.674
o	.	1.000	1.000	26.674
p	.	1.000	1.000	26.674
q	.	.	1.000	26.674
r	.	.	1.000	26.674
s	.	.	1.000	26.674
t	.	1.000	1.000	19.921
u	.	1.000	1.000	19.921
v	.	1.000	1.000	19.921
w	.	.	1.000	19.921
y	.	.	1.000	19.921

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR VFO	-INF	170.049	+INF	.

IMAGE 19. OUTOME FOR JUNE 2 WITH TARIFF 6.1

$$Electricty\ Costs_{JUN2} = \frac{170.049}{1000} * 42 * 22 = 157.13€$$

- JULY

```
---- VAR charge  1 if it is charging during hour i

         LOWER      LEVEL      UPPER     MARGINAL

a          .        1.000      1.000      2.137
b          .        1.000      1.000      2.137
c          .        1.000      1.000      2.137
d          .        1.000      1.000      2.137
e          .        1.000      1.000      2.137
f          .        1.000      1.000      2.137
g          .        1.000      1.000      2.137
h          .        1.000      1.000      2.137
i          .          .        1.000     19.921
j          .        1.000      1.000     19.921
k          .        1.000      1.000     19.921
l          .          .        1.000     26.674
m          .          .        1.000     26.674
n          .          .        1.000     26.674
o          .        1.000      1.000     26.674
p          .        1.000      1.000     26.674
q          .          .        1.000     26.674
r          .          .        1.000     26.674
s          .          .        1.000     26.674
t          .        1.000      1.000     19.921
u          .        1.000      1.000     19.921
v          .        1.000      1.000     19.921
w          .          .        1.000     19.921
y          .          .        1.000     19.921

                           LOWER      LEVEL      UPPER     MARGINAL

---- VAR VFO                -INF     170.049      +INF          .
```

IMAGE 20. OUTOME FOR JULY WITH TARIFF 6.1

$$Electricty\ Costs_{JULY} = \frac{170.049}{1000} * 42 * 22 = 157.13€$$

- AUGUST

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	2.137
b	.	.	1.000	2.137
c	.	1.000	1.000	2.137
d	.	.	1.000	2.137
e	.	1.000	1.000	2.137
f	.	1.000	1.000	2.137
g	.	.	1.000	2.137
h	.	.	1.000	2.137
i	.	1.000	1.000	2.137
j	.	1.000	1.000	2.137
k	.	1.000	1.000	2.137
l	.	1.000	1.000	2.137
m	.	.	1.000	2.137
n	.	1.000	1.000	2.137
o	.	1.000	1.000	2.137
p	.	.	1.000	2.137
q	.	1.000	1.000	2.137
r	.	.	1.000	2.137
s	.	1.000	1.000	2.137
t	.	1.000	1.000	2.137
u	.	.	1.000	2.137
v	.	.	1.000	2.137
w	.	1.000	1.000	2.137
y	.	1.000	1.000	2.137

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR VFO	-INF	32.055	+INF	.

IMAGE 21. OUTOME FOR AUGUST WITH TARIFF 6.1

$$Electricty\ Costs_{AUGUST} = \frac{32.055}{1000} * 42 * 22 = 29.61€$$

- SEPTEMBER

```
---- VAR charge  1 if it is charging during hour i

        LOWER      LEVEL      UPPER     MARGINAL

a         .        1.000      1.000      2.137
b         .        1.000      1.000      2.137
c         .        1.000      1.000      2.137
d         .        1.000      1.000      2.137
e         .        1.000      1.000      2.137
f         .        1.000      1.000      2.137
g         .        1.000      1.000      2.137
h         .        1.000      1.000      2.137
i         .          .        1.000      5.283
j         .          .        1.000     10.615
k         .          .        1.000     10.615
l         .        1.000      1.000     10.615
m         .          .        1.000     10.615
n         .          .        1.000     10.615
o         .          .        1.000     10.615
p         .        1.000      1.000      5.283
q         .        1.000      1.000      5.283
r         .        1.000      1.000      5.283
s         .        1.000      1.000      5.283
t         .        1.000      1.000      5.283
u         .        1.000      1.000      5.283
v         .          .        1.000      5.283
w         .          .        1.000      5.283
y         .          .        1.000      5.283

                         LOWER      LEVEL      UPPER     MARGINAL

---- VAR VFO              -INF      59.409      +INF         .
```

IMAGE 22. OUTOME FOR SEPTEMBER WITH TARIFF 6.1

$$Electricty\ Costs_{SEPTEMBER} = \frac{59.409}{1000} * 42 * 22 = 54.89€$$

- OCTOBER

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	2.137
b	.	1.000	1.000	2.137
c	.	1.000	1.000	2.137
d	.	1.000	1.000	2.137
e	.	1.000	1.000	2.137
f	.	1.000	1.000	2.137
g	.	1.000	1.000	2.137
h	.	1.000	1.000	2.137
i	.	1.000	1.000	3.411
j	.	.	1.000	3.411
k	.	1.000	1.000	3.411
l	.	1.000	1.000	3.411
m	.	1.000	1.000	3.411
n	.	1.000	1.000	3.411
o	.	.	1.000	3.411
p	.	.	1.000	3.411
q	.	.	1.000	3.411
r	.	1.000	1.000	3.411
s	.	.	1.000	3.411
t	.	.	1.000	3.411
u	.	1.000	1.000	3.411
v	.	.	1.000	3.411
w	.	.	1.000	3.411
y	.	.	1.000	3.411

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR VFO	-INF	40.973	+INF	.

IMAGE 23. OUTOME FOR OCTOBER WITH TARIFF 6.1

$$Electricty\ Costs_{OCTOBER} = \frac{40.973}{1000} * 42 * 22 = 37.86€$$

- NOVEMBER

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000      2.137
b      .       1.000     1.000      2.137
c      .       1.000     1.000      2.137
d      .       1.000     1.000      2.137
e      .       1.000     1.000      2.137
f      .       1.000     1.000      2.137
g      .       1.000     1.000      2.137
h      .       1.000     1.000      2.137
i      .         .       1.000      5.283
j      .         .       1.000      5.283
k      .         .       1.000      5.283
l      .       1.000     1.000      5.283
m      .       1.000     1.000      5.283
n      .       1.000     1.000      5.283
o      .         .       1.000      5.283
p      .       1.000     1.000      5.283
q      .         .       1.000     10.615
r      .         .       1.000     10.615
s      .       1.000     1.000     10.615
t      .         .       1.000     10.615
u      .         .       1.000     10.615
v      .         .       1.000     10.615
w      .       1.000     1.000      5.283
y      .       1.000     1.000      5.283

                       LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO            -INF     59.409     +INF        .
```

IMAGE 24. OUTOME FOR NOVEMBER WITH TARIFF 6.1

$$Electricty\ Costs_{NOVEMBER} = \frac{59.409}{1000} * 42 * 22 = 54.89€$$

- DECEMBER

```
---- VAR charge  1 if it is charging during hour i

       LOWER     LEVEL     UPPER    MARGINAL

a        .       1.000     1.000     2.137
b        .       1.000     1.000     2.137
c        .       1.000     1.000     2.137
d        .       1.000     1.000     2.137
e        .       1.000     1.000     2.137
f        .       1.000     1.000     2.137
g        .       1.000     1.000     2.137
h        .       1.000     1.000     2.137
i        .         .       1.000    19.921
j        .       1.000     1.000    19.921
k        .         .       1.000    26.674
l        .         .       1.000    26.674
m        .         .       1.000    26.674
n        .       1.000     1.000    19.921
o        .       1.000     1.000    19.921
p        .       1.000     1.000    19.921
q        .       1.000     1.000    19.921
r        .       1.000     1.000    19.921
s        .         .       1.000    26.674
t        .         .       1.000    26.674
u        .         .       1.000    26.674
v        .       1.000     1.000    19.921
w        .         .       1.000    19.921
y        .         .       1.000    19.921

                          LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO               -INF    156.543     +INF        .
```

IMAGE 25. OUTOME FOR DECEMBER WITH TARIFF 6.1

$$Electricty\ Costs_{DECEMBER} = \frac{156.543}{1000} * 42 * 22 = 144.645€$$

CASE II: Tariff 3.1- Different recharging frame for each month

- JANUARY

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000     7.805
b      .       1.000     1.000     7.805
c      .       1.000     1.000     7.805
d      .       1.000     1.000     7.805
e      .       1.000     1.000     7.805
f      .       1.000     1.000     7.805
g      .       1.000     1.000     7.805
h      .       1.000     1.000     7.805
i      .         .       1.000    12.754
j      .         .       1.000    12.754
k      .       1.000     1.000    12.754
l      .       1.000     1.000    12.754
m      .       1.000     1.000    12.754
n      .       1.000     1.000    12.754
o      .         .       1.000    12.754
p      .         .       1.000    12.754
q      .       1.000     1.000    12.754
r      .         .       1.000    14.335
s      .         .       1.000    14.335
t      .       1.000     1.000    14.335
u      .         .       1.000    14.335
v      .         .       1.000    14.335
w      .         .       1.000    14.335
y      .       1.000     1.000    12.754

                       LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO           -INF    153.299     +INF        .

  VFO  Objective function value
```

IMAGE 26. OUTOME FOR JANUARY WITH TARIFF 3.1

$$Electricty\ Costs_{JANUARY} = \frac{153.299}{1000} * 42 * 22 = 141.65€$$

- FEBRUARY

```
---- VAR charge  1 if it is charging during hour i

        LOWER      LEVEL      UPPER     MARGINAL

a         .        1.000      1.000      7.806
b         .        1.000      1.000      7.806
c         .        1.000      1.000      7.806
d         .        1.000      1.000      7.806
e         .        1.000      1.000      7.806
f         .        1.000      1.000      7.806
g         .        1.000      1.000      7.806
h         .        1.000      1.000      7.806
i         .          .        1.000     12.755
j         .          .        1.000     12.755
k         .        1.000      1.000     12.755
l         .        1.000      1.000     12.755
m         .        1.000      1.000     12.755
n         .        1.000      1.000     12.755
o         .          .        1.000     12.755
p         .          .        1.000     12.755
q         .        1.000      1.000     12.755
r         .          .        1.000     14.336
s         .          .        1.000     14.336
t         .        1.000      1.000     14.336
u         .          .        1.000     14.336
v         .          .        1.000     14.336
w         .          .        1.000     14.336
y         .        1.000      1.000     12.755

                          LOWER      LEVEL      UPPER     MARGINAL

---- VAR VFO               -INF     153.314     +INF         .
```

IMAGE 27. OUTOME FOR FEBRUARY WITH TARIFF 3.1

$$Electricty\ Costs_{FEBRUARY} = \frac{153.314}{1000} * 42 * 22 = 141.66€$$

- MARCH 1

```
---- VAR charge  1 if it is charging during hour i

          LOWER     LEVEL     UPPER    MARGINAL

a          .        1.000     1.000     7.807
b          .        1.000     1.000     7.807
c          .        1.000     1.000     7.807
d          .        1.000     1.000     7.807
e          .        1.000     1.000     7.807
f          .        1.000     1.000     7.807
g          .        1.000     1.000     7.807
h          .        1.000     1.000     7.807
i          .         .        1.000    12.756
j          .         .        1.000    12.756
k          .        1.000     1.000    12.756
l          .        1.000     1.000    12.756
m          .        1.000     1.000    12.756
n          .        1.000     1.000    12.756
o          .         .        1.000    12.756
p          .         .        1.000    12.756
q          .        1.000     1.000    12.756
r          .         .        1.000    14.337
s          .         .        1.000    14.337
t          .        1.000     1.000    14.337
u          .         .        1.000    14.337
v          .         .        1.000    14.337
w          .         .        1.000    14.337
y          .        1.000     1.000    12.756

                            LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO                 -INF    153.329     +INF        .
```

IMAGE 28. OUTOME FOR MARCH 1 WITH TARIFF 3.1

$$Electricty\ Costs_{MARCH1} = \frac{153.329}{1000} * 42 * 22 = 141.68€$$

- MARCH 2

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000      7.808
b      .       1.000     1.000      7.808
c      .       1.000     1.000      7.808
d      .       1.000     1.000      7.808
e      .       1.000     1.000      7.808
f      .       1.000     1.000      7.808
g      .       1.000     1.000      7.808
h      .       1.000     1.000      7.808
i      .         .       1.000     12.757
j      .       1.000     1.000     12.757
k      .         .       1.000     14.335
l      .         .       1.000     14.335
m      .       1.000     1.000     14.335
n      .         .       1.000     14.335
o      .         .       1.000     14.335
p      .         .       1.000     14.335
q      .       1.000     1.000     12.750
r      .       1.000     1.000     12.751
s      .       1.000     1.000     12.752
t      .       1.000     1.000     12.753
u      .       1.000     1.000     12.754
v      .         .       1.000     12.755
w      .         .       1.000     12.756
y      .         .       1.000     12.757

                     LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO          -INF    153.316     +INF        .
```

IMAGE 29. OUTOME FOR MARCH 2 WITH TARIFF 3.1

$$Electricty\ Cost_{MARCH2} = \frac{153.316}{1000} * 42 * 22 = 141.66€$$

- APRIL

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000     7.809
b      .       1.000     1.000     7.809
c      .       1.000     1.000     7.809
d      .       1.000     1.000     7.809
e      .       1.000     1.000     7.809
f      .       1.000     1.000     7.809
g      .       1.000     1.000     7.809
h      .       1.000     1.000     7.809
i      .         .       1.000    12.758
j      .       1.000     1.000    12.758
k      .         .       1.000    14.336
l      .         .       1.000    14.336
m      .       1.000     1.000    14.336
n      .         .       1.000    14.336
o      .         .       1.000    14.336
p      .         .       1.000    14.336
q      .       1.000     1.000    12.751
r      .       1.000     1.000    12.752
s      .       1.000     1.000    12.753
t      .       1.000     1.000    12.754
u      .       1.000     1.000    12.755
v      .         .       1.000    12.756
w      .         .       1.000    12.757
y      .         .       1.000    12.758

                      LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO           -INF    153.331     +INF        .
```

IMAGE 30. OUTOME FOR APRIL WITH TARIFF 3.1

$$Electricty\ Costs_{APRIL} = \frac{153.331}{1000} * 42 * 22 = 141.67€$$

- MAY

```
---- VAR charge  1 if it is charging during hour i

          LOWER     LEVEL     UPPER    MARGINAL

a           .       1.000     1.000     7.810
b           .       1.000     1.000     7.810
c           .       1.000     1.000     7.810
d           .       1.000     1.000     7.810
e           .       1.000     1.000     7.810
f           .       1.000     1.000     7.810
g           .       1.000     1.000     7.810
h           .       1.000     1.000     7.810
i           .         .       1.000    12.759
j           .       1.000     1.000    12.759
k           .         .       1.000    14.337
l           .         .       1.000    14.337
m           .       1.000     1.000    14.337
n           .         .       1.000    14.337
o           .         .       1.000    14.337
p           .         .       1.000    14.337
q           .       1.000     1.000    12.752
r           .       1.000     1.000    12.753
s           .       1.000     1.000    12.754
t           .       1.000     1.000    12.755
u           .       1.000     1.000    12.756
v           .         .       1.000    12.757
w           .         .       1.000    12.758
y           .         .       1.000    12.759

                          LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO              -INF    153.346     +INF        .
```

Image 31. Outome for May with tariff 3.1

$$Electricty\ Costs_{MAY} = \frac{153.346}{1000} * 42 * 22 = 141.69€$$

- JUNE

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	7.811
b	.	1.000	1.000	7.811
c	.	1.000	1.000	7.811
d	.	1.000	1.000	7.811
e	.	1.000	1.000	7.811
f	.	1.000	1.000	7.811
g	.	1.000	1.000	7.811
h	.	1.000	1.000	7.811
i	.	.	1.000	12.760
j	.	1.000	1.000	12.760
k	.	.	1.000	14.338
l	.	.	1.000	14.338
m	.	1.000	1.000	14.338
n	.	.	1.000	14.338
o	.	.	1.000	14.338
p	.	.	1.000	14.338
q	.	1.000	1.000	12.752
r	.	1.000	1.000	12.753
s	.	1.000	1.000	12.754
t	.	1.000	1.000	12.755
u	.	1.000	1.000	12.756
v	.	.	1.000	12.757
w	.	.	1.000	12.758
y	.	.	1.000	12.759

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR VFO	-INF	153.356	+INF	.

IMAGE 32. OUTOME FOR JUNE WITH TARIFF 3.1

$$Electricty\ Costs_{JUNE} = \frac{153.356}{1000} * 42 * 22 = 141.7€$$

- JULY

```
---- VAR charge  1 if it is charging during hour i

     LOWER      LEVEL      UPPER     MARGINAL

a      .        1.000      1.000      7.812
b      .        1.000      1.000      7.812
c      .        1.000      1.000      7.812
d      .        1.000      1.000      7.812
e      .        1.000      1.000      7.812
f      .        1.000      1.000      7.812
g      .        1.000      1.000      7.812
h      .        1.000      1.000      7.812
i      .          .        1.000     12.761
j      .        1.000      1.000     12.761
k      .          .        1.000     14.339
l      .          .        1.000     14.339
m      .        1.000      1.000     14.339
n      .          .        1.000     14.339
o      .          .        1.000     14.339
p      .          .        1.000     14.339
q      .        1.000      1.000     12.752
r      .        1.000      1.000     12.753
s      .        1.000      1.000     12.754
t      .        1.000      1.000     12.755
u      .        1.000      1.000     12.756
v      .          .        1.000     12.757
w      .          .        1.000     12.758
y      .          .        1.000     12.759

                       LOWER      LEVEL      UPPER     MARGINAL

---- VAR VFO            -INF     153.366     +INF         .

  VFO  Objective function value
```

IMAGE 33. OUTOME FOR JULY WITH TARIFF 3.1

$$Electricty\ Costs_{JULY} = \frac{153.366}{1000} * 42 * 22 = 141.7€$$

- AUGUST

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	7.813
b	.	1.000	1.000	7.813
c	.	1.000	1.000	7.813
d	.	1.000	1.000	7.813
e	.	1.000	1.000	7.813
f	.	1.000	1.000	7.813
g	.	1.000	1.000	7.813
h	.	1.000	1.000	7.813
i	.	.	1.000	12.762
j	.	1.000	1.000	12.762
k	.	.	1.000	14.340
l	.	.	1.000	14.340
m	.	1.000	1.000	14.340
n	.	.	1.000	14.340
o	.	.	1.000	14.340
p	.	.	1.000	14.340
q	.	1.000	1.000	12.752
r	.	1.000	1.000	12.753
s	.	1.000	1.000	12.754
t	.	1.000	1.000	12.755
u	.	1.000	1.000	12.756
v	.	.	1.000	12.757
w	.	.	1.000	12.758
y	.	.	1.000	12.759

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR VFO	-INF	153.376	+INF	.

IMAGE 34. OUTOME FOR AUGUST WITH TARIFF 3.1

$$Electricty\ Costs_{AUGUST} = \frac{153.376}{1000} * 42 * 22 = 141.72€$$

- SEPTEMBER

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .       1.000     1.000     7.815
b      .       1.000     1.000     7.815
c      .       1.000     1.000     7.815
d      .       1.000     1.000     7.815
e      .       1.000     1.000     7.815
f      .       1.000     1.000     7.815
g      .       1.000     1.000     7.815
h      .       1.000     1.000     7.815
i      .         .       1.000    12.764
j      .       1.000     1.000    12.764
k      .         .       1.000    14.342
l      .         .       1.000    14.342
m      .       1.000     1.000    14.342
n      .         .       1.000    14.342
o      .         .       1.000    14.342
p      .         .       1.000    14.342
q      .       1.000     1.000    12.752
r      .       1.000     1.000    12.753
s      .       1.000     1.000    12.754
t      .       1.000     1.000    12.755
u      .       1.000     1.000    12.756
v      .         .       1.000    12.757
w      .         .       1.000    12.758
y      .         .       1.000    12.759

                       LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO            -INF    153.396     +INF        .
```

IMAGE 35. OUTOME FOR SEPTEMBER WITH TARIFF 3.1

$$Electricty\ Costs_{SEPTEMBER} = \frac{153.396}{1000} * 42 * 22 = 141.74€$$

- OCTOBER 1

```
---- VAR charge  1 if it is charging during hour i

          LOWER       LEVEL       UPPER     MARGINAL

a           .         1.000       1.000       7.815
b           .         1.000       1.000       7.815
c           .         1.000       1.000       7.815
d           .         1.000       1.000       7.815
e           .         1.000       1.000       7.815
f           .         1.000       1.000       7.815
g           .         1.000       1.000       7.815
h           .         1.000       1.000       7.815
i           .           .         1.000      12.764
j           .         1.000       1.000      12.764
k           .           .         1.000      14.342
l           .           .         1.000      14.342
m           .         1.000       1.000      14.342
n           .           .         1.000      14.342
o           .           .         1.000      14.342
p           .           .         1.000      14.342
q           .         1.000       1.000      12.752
r           .         1.000       1.000      12.753
s           .         1.000       1.000      12.754
t           .         1.000       1.000      12.755
u           .         1.000       1.000      12.756
v           .           .         1.000      12.757
w           .           .         1.000      12.758
y           .           .         1.000      12.759

                        LOWER       LEVEL       UPPER     MARGINAL

---- VAR VFO             -INF     153.396       +INF         .
```

IMAGE 36. OUTOME FOR OCTOBER 1 WITH TARIFF 3.1

$$Electricty\ Costs_{OCTOBER1} = \frac{153.396}{1000} * 42 * 22 = 141.74€$$

- OCTOBER 2

	LOWER	LEVEL	UPPER	MARGINAL
a	.	1.000	1.000	7.816
b	.	1.000	1.000	7.816
c	.	1.000	1.000	7.816
d	.	1.000	1.000	7.816
e	.	1.000	1.000	7.816
f	.	1.000	1.000	7.816
g	.	1.000	1.000	7.816
h	.	1.000	1.000	7.816
i	.	.	1.000	12.765
j	.	.	1.000	12.765
k	.	.	1.000	12.753
l	.	1.000	1.000	12.753
m	.	1.000	1.000	12.753
n	.	1.000	1.000	12.753
o	.	1.000	1.000	12.753
p	.	1.000	1.000	12.753
q	.	1.000	1.000	12.753
r	.	.	1.000	14.342
s	.	.	1.000	14.342
t	.	.	1.000	14.342
u	.	1.000	1.000	14.342
v	.	.	1.000	14.342
w	.	.	1.000	14.342
y	.	.	1.000	12.765

	LOWER	LEVEL	UPPER	MARGINAL
---- VAR VFO	-INF	153.388	+INF	.

Image 37. Outome for October 2 with tariff 3.1

$$Electricty\ Costs_{OCTOBER2} = \frac{153.388}{1000} * 42 * 22 = 141.73€$$

- NOVEMBER

```
---- VAR charge  1 if it is charging during hour i

     LOWER     LEVEL     UPPER    MARGINAL

a      .        1.000     1.000      7.815
b      .        1.000     1.000      7.815
c      .        1.000     1.000      7.815
d      .        1.000     1.000      7.815
e      .        1.000     1.000      7.815
f      .        1.000     1.000      7.815
g      .        1.000     1.000      7.815
h      .        1.000     1.000      7.815
i      .          .       1.000     12.764
j      .        1.000     1.000     12.764
k      .          .       1.000     14.342
l      .          .       1.000     14.342
m      .        1.000     1.000     14.342
n      .          .       1.000     14.342
o      .          .       1.000     14.342
p      .          .       1.000     14.342
q      .        1.000     1.000     12.752
r      .        1.000     1.000     12.753
s      .        1.000     1.000     12.754
t      .        1.000     1.000     12.755
u      .        1.000     1.000     12.756
v      .          .       1.000     12.757
w      .          .       1.000     12.758
y      .          .       1.000     12.759

                      LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO           -INF    153.396     +INF        .
```

IMAGE 38. OUTOME FOR NOVEMBER WITH TARIFF 3.1

$$Electricty\ Costs_{NOVEMBER} = \frac{153.396}{1000} * 42 * 22 = 141.73€$$

- DECEMBER

```
---- VAR charge  1 if it is charging during hour i

      LOWER     LEVEL     UPPER    MARGINAL

a       .       1.000     1.000     7.815
b       .       1.000     1.000     7.815
c       .       1.000     1.000     7.815
d       .       1.000     1.000     7.815
e       .       1.000     1.000     7.815
f       .       1.000     1.000     7.815
g       .       1.000     1.000     7.815
h       .       1.000     1.000     7.815
i       .         .       1.000    12.764
j       .       1.000     1.000    12.764
k       .         .       1.000    14.342
l       .         .       1.000    14.342
m       .       1.000     1.000    14.342
n       .         .       1.000    14.342
o       .         .       1.000    14.342
p       .         .       1.000    14.342
q       .       1.000     1.000    12.752
r       .       1.000     1.000    12.753
s       .       1.000     1.000    12.754
t       .       1.000     1.000    12.755
u       .       1.000     1.000    12.756
v       .         .       1.000    12.757
w       .         .       1.000    12.758
y       .         .       1.000    12.759

                        LOWER     LEVEL     UPPER    MARGINAL

---- VAR VFO             -INF    153.396     +INF        .
```

IMAGE 39. OUTOME FOR DECEMBER WITH TARIFF 3.1

$$Electricty\ Costs_{DECEMBER} = \frac{153.396}{1000} * 40 * 22 = 141.73€$$

The following matrix indicate the **cost of electricity** with the matrix recharge calculated previously and the increment of the costs caused by the changes using the marginal column of GAMS outcome:

	VARIABLE COSTS												FIXED COSTS	TOTAL COST
	JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUNE	JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER	[€/YEAR]	[€/YEAR]
TARIFF 6.1	1025,074908	1025,074908	428,2427	247,0577	247,0577	784,2612	1161,458496	187,021692	407,063844	247,057668	407,063844	1025,074908	39853,74234	56.924,75 €
TARIFF 3.1	937,56564	937,653156	937,6969	937,7407	937,8282	937,8888	937,949364	938,009952	938,07054	938,100834	938,158056	938,245572	38294,13797	59.954,35 €

TABLE 10. ELECTRICITY COSTS

7.2. ANNEX B: ELECTRIC TARIFFS TABLES

The following table shows the electricity tariffs and their bounded power and voltage:

RATE	$P_{CONTRACTED}$	VOLTAGE
LOW VOLTAGE		
2.0	≤10 kW	≤1 kV
2.0DHA	≤10 kW	≤1 kV
2.0DHS	≤10 kW	≤1 kV
2.1A	10 kW<Pc≤15kW	≤1 kV
2.1DHA	11 kW<Pc≤15kW	≤1 kV
3.0A	≥15 kW	≤1 kV
MEDIUM VOLTAGE		
3.1A	≤450 kW	1kV a 36kV
6.1A	≤450 kW	1kV a 30kV
6.1B	≤450 kW	30kV a 36kV
6.2	≤450 kW	36kV a 72,5kV
6.3	≤450 kW	75,2kV a 145kV
6.4	≤450 kW	≥145 kV

TABLA 1.ELECTRIC TARIFFS IN SPAIN [23]

In the following table it is indicated the variable and fixed costs of the electricity in Spain for each tariff:

		TP(€/kW year)	TE(€/kWh)
TARIFF 3.1A	P1	59,173468	0,014335
	P2	36,490689	0,012754
	P3	8,367731	0,007805
TARIFF 6.1A	P1	39,139427	0,026674
	P2	19,586654	0,019921
	P3	14,334178	0,010615
	P4	14,334178	0,005283
	P5	14,334178	0,003411
	P6	6,540177	0,002137
TARIFF 6.1B	P1	31,020989	0,021822
	P2	15,523919	0,016297
	P3	11,360932	0,008685
	P4	11,360932	0,004322
	P5	11,360932	0,002791
	P6	5,183592	0,001746
TARIFF 6.2	P1	22,158348	0,015587
	P2	11,088763	0,011641
	P3	8,115134	0,006204
	P4	8,115134	0,003087
	P5	8,115134	0,001993
	P6	3,702649	0,001247
TARIFF 6.3	P1	18,916198	0,015048
	P2	9,466286	0,011237
	P3	6,92775	0,005987
	P4	6,92775	0,002979
	P5	6,92775	0,001924
	P6	3,160887	0,001206
TARIFF 6.4	P1	13,706285	0,008465
	P2	6,859077	0,007022
	P3	5,019707	0,004025
	P4	5,019707	0,002285
	P5	5,019707	0,001475
	P6	2,290315	0,001018

TABLA 2.ELECTRIC RATES AND PERIOD [23]

		TARIFF 3.1													
		JANUARY	FEBRUARY	MARCH		APRIL	MAY	JUN	JULY	AUGUST	SEPTEMBER	OCTOBER		NOVEMBER	DECEMBER
0:00	1:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
1:00	2:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
2:00	3:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
3:00	4:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
4:00	5:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
5:00	6:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
6:00	7:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
7:00	8:00	3	3	3	3	3	3	3	3	3	3	3	3	3	3
8:00	9:00	2	2	2	2	2	2	2	2	2	2	2	2	2	2
9:00	10:00	2	2	2	2	2	2	2	2	2	2	2	2	2	2
10:00	11:00	2	2	2	1	1	1	1	1	1	1	1	2	2	2
11:00	12:00	2	2	2	1	1	1	1	1	1	1	1	2	2	2
12:00	13:00	2	2	2	1	1	1	1	1	1	1	1	2	2	2
13:00	14:00	2	2	2	1	1	1	1	1	1	1	1	2	2	2
14:00	15:00	2	2	2	1	1	1	1	1	1	1	1	2	2	2
15:00	16:00	2	2	2	1	1	1	1	1	1	1	1	2	2	2
16:00	17:00	2	2	2	2	2	2	2	2	2	2	2	2	2	2
17:00	18:00	1	1	1	2	2	2	2	2	2	2	2	1	1	1
18:00	19:00	1	1	1	2	2	2	2	2	2	2	2	1	1	1
19:00	20:00	1	1	1	2	2	2	2	2	2	2	2	1	1	1
20:00	21:00	1	1	1	2	2	2	2	2	2	2	2	1	1	1
21:00	22:00	1	1	1	2	2	2	2	2	2	2	2	1	1	1
22:00	23:00	1	1	1	2	2	2	2	2	2	2	2	1	1	1
23:00	0:00	2	2	2	2	2	2	2	2	2	2	2	2	2	2

TABLE 11. ELECTRCIC RATES FOR TARIFF 3.1 [23]

		TARIFF 6												
		JANUARY	FEBRUARY	MARCH	APRIL	MAY	JUN		JULY	AUGUST	SEPTEMBER	OCTOBER	NOVEMBER	DECEMBER
0:00	1:00	6	6	6	6	6	6	6	6	6	6	6	6	6
1:00	2:00	6	6	6	6	6	6	6	6	6	6	6	6	6
2:00	3:00	6	6	6	6	6	6	6	6	6	6	6	6	6
3:00	4:00	6	6	6	6	6	6	6	6	6	6	6	6	6
4:00	5:00	6	6	6	6	6	6	6	6	6	6	6	6	6
5:00	6:00	6	6	6	6	6	6	6	6	6	6	6	6	6
6:00	7:00	6	6	6	6	6	6	6	6	6	6	6	6	6
7:00	8:00	6	6	6	6	6	6	6	6	6	6	6	6	6
8:00	9:00	2	2	4	5	5	4	2	2	6	4	5	4	2
9:00	10:00	2	2	4	5	5	3	2	2	6	3	5	4	2
10:00	11:00	1	1	4	5	5	3	2	2	6	3	5	4	1
11:00	12:00	1	1	4	5	5	3	1	1	6	3	5	4	1
12:00	13:00	1	1	4	5	5	3	1	1	6	3	5	4	1
13:00	14:00	2	2	4	5	5	3	1	1	6	3	5	4	2
14:00	15:00	2	2	4	5	5	3	1	1	6	3	5	4	2
15:00	16:00	2	2	4	5	5	4	1	1	6	4	5	4	2
16:00	17:00	2	2	3	5	5	4	1	1	6	4	5	3	2
17:00	18:00	2	2	3	5	5	4	1	1	6	4	5	3	2
18:00	19:00	1	1	3	5	5	4	1	1	6	4	5	3	1
19:00	20:00	1	1	3	5	5	4	2	2	6	4	5	3	1
20:00	21:00	1	1	3	5	5	4	2	2	6	4	5	3	1
21:00	22:00	2	2	3	5	5	4	2	2	6	4	5	3	2
22:00	23:00	2	2	4	5	5	4	2	2	6	4	5	4	2
23:00	0:00	2	2	4	5	5	4	2	2	6	4	5	4	2

TABLE 12. ELECTRIC RATES FOR TARIFF 6.1 [23]

7.3.ANNEX C: MEDIUM VOLTAGE INVESTMENT

The following Substation Centre has been calculated with Amikit:

PARÁMETROS	OPCIONES
DATOS GENERALES	
Objeto del Proyecto	
Objeto	Este proyecto tiene por objeto definir las características de un centro destinado al sumini...
Titular	Este Centro es propiedad de <propietario>
Provincia	Madrid
Emplazamiento	El Centro se halla ubicado en <localidad> y sus coordenadas geográficas son: <latitud, l...
Programa de Necesidades	Se precisa el suministro de energía a una tensión de <tensión BT> V, con una potencia ...
Red de Alimentación	La alimentación a la nueva instalación eléctrica se alimentará mediante una línea de me...
Portafirmas	El/la técnico competente, D./Dª. <técnico proyectista>
Red Eléctrica	
Compañía	Iberdrola
Tensión de Servicio (kV)	20
Frecuencia (Hz)	50 Hz
Intensidad de Bucle (A)	400 A
Potencia de Cortocircuito (MVA)	350
Intensidad de Cortocircuito Nominal (kA)	16 kA
CENTRO DE TRANSFORMACIÓN	
Centro	
Tipo de Centro	Cliente
Modelo de Centro	Centro definido completamente por el usuario
Tensión Asignada (kV)	24 kV
Tipo de Aparamenta MT	cgmcosmos modular
Clasificación IAC	Con clasificación IAC
Tipo de Control	Equipo de automatización completo
Conexión a la Red	Dos entradas / salidas
Reserva espacio celdas	No reservar espacio para celdas
Transformadores de Potencia	Con un transformador
Reserva espacio transformadores	No reservar espacio para transformadores
Datos del Transformador 1	
Potencia de Transformador 1 (kVA)	400 kVA
Tensión Primaria de Transformador 1	20 kV
Tipo de Aislamiento de Transformador 1	Aislamiento éster natural biodegradable
Celda de Protección del Transformador 1	Protección de transformador con Protección General
Protección Propia del Transformador 1	Termómetro
Tensión Secundaria del Transformador 1	420 V en vacío (B2)
Número de Salidas B2 del Transformador 1	Interruptor en carga + 1 salida con fusibles
Protección Física del Transformador 1	Protección con cerradura
Datos Protección General	
Celda de Protección General	Celda de Protección con Fusibles
Protección General	Sobreintensidad 3 Fases y Neutro
Toroidales de Protección General	Rango 5 - 100 A
Alimentación de Protección General	Alimentación Auxiliar

Medida de Energía	
Potencia Contratada (kW)	Valor desconocido en proyecto
Tipo de Cliente	Tipo 3
Tipo de Tarificador	Electrónico
Separación Compañía - Cliente	
Separación Física entre Compañía / Cliente	Separación en edificios distintos
Tipo de Seccionamiento	Seccionamiento sin Medida
Seccionamiento Compañía	Seccionamiento con interruptor y fusibles
Acometida al Centro de Transformación	Interruptor - Seccionador
Seccionamiento Cliente	Sin seccionamiento
Edificio	
Modelo Edificio Centro de Seccionamiento	cms
Tipo de Acabado Centro de Seccionamiento	Acabado Estándar
Modelo Edificio Centro de Transformación	pfu
Tipo de Acabado Centro de Transformación	Acabado Estándar
LÍNEAS DE MEDIA TENSIÓN	
Conexión de Neutro	
Tipo de Conexión	Unido a tierra a través de impedancia
Resistencia del Neutro (Ohm)	0
Reactancia del Neutro (Ohm)	25
Protecciones	
Tipo de Protecciones	Asignación automática
Red de Tierras	
Separación de Tierras	No es necesario separar
Tierras Edificio de Seccionamiento	
Tipo de Red de Tierras de Protección	Asignación automática
Tierras Edificio de Transformación	
Tipo de Red de Tierras de Protección	Asignación automática
Resistividad del Terreno (Ohm.m)	150

TABLE 13. PARAMETERS OF THE MEDIUM VOLTAGE INSTALLATION

	CAPÍTULO		SUBTOTAL €	...	...
-	OBRA CIVIL		22.225,00		
	cms.15	Edificio de Seccionamiento	13.825,00	...	...
	pfu-4	Edificio de Transformación	8.400,00	...	...
-	EQUIPO DE MEDIA TENSIÓN		16.512,50		
	cgmcosmos-2lp	E/S1,E/S2,Scia	,00	...	...
	cgmcosmos-p Protección fusibles	Protección General	5.750,00	...	...
	cgmcosmos-m Medida	Medida	6.150,00	...	...
	cgmcosmos-l Interruptor-seccionador	Remonte Cliente	3.762,50	...	...
	Cables MT 12/20 kV	Puentes MT Transformador 1	850,00	...	...
-	TRANSFORMADOR		10.126,00		
	transforma.organic 24 kV	Transformador 1	10.126,00	...	...
-	EQUIPO DE BAJA TENSIÓN		6.681,00		
	Interruptor en carga + Fusibles	Cuadros BT - B2 Transformador 1	2.700,00	...	...
	Puentes transformador-cuadro	Puentes BT - B2 Transformador 1	1.150,00	...	...
	Equipo de medida	Equipo de Medida de Energía	2.831,00	...	...
-	RED DE TIERRAS		3.200,00		
	Anillo rectangular	Tierras Exteriores Prot Seccionamiento	1.285,00	...	...
	Anillo rectangular	Tierras Exteriores Prot Transformación	1.285,00	...	...
	Picas alineadas	Tierras Exteriores Serv Transformación	630,00	...	...
	Instalación interior tierras	Tierras Interiores Prot Seccionamiento	,00	...	...
	Instalación interior tierras	Tierras Interiores Prot Transformación	,00	...	...
	Instalación interior tierras	Tierras Interiores Serv Transformación	,00	...	...
-	VARIOS		1.158,00		
	Protección física transformador	Defensa de Transformador 1	283,00	...	...
	Equipo de seguridad y maniobra	Maniobra de Seccionamiento	,00	...	...
	Equipo de iluminación	Iluminación Edificio de Transformación	600,00	...	...
	Equipo de seguridad y maniobra	Maniobra de Transformación	275,00	...	...

TOTAL PRESUPUESTO	**59.902,50 €**

TABLE 14. MEDIUM VOLTAGE INSTALLATION BUDGET MADE WITH AMIKIT

7.4. ANNEX D: INSTALLATIONS COSTS

7.4.1. ELECTRICITY SUPPLY

Hereafter are all the tables required to correct the factor of the terrain:

Característica	Grado (canales)	Código (tubos)
Resistencia al impacto	Fuerte (6 julios)	4
Temperatura mínima de instalación y servicio	-5 °C	4
Temperatura máxima de instalación y servicio	+60 °C	1
Propiedades eléctricas	Continuidad eléctrica/aislante	1 / 2
Resistencia a la penetración de objetos sólidos	∅ ≥ 1 mm	4
Resistencia a la corrosión (conductos metálicos)	Protección interior media, exterior alta	3
Resistencia a la propagación de la llama	No propagador	1

TABLE 15. REQUIREMENTS FOR TUBES AND FLUTES (ITC-BT-11)

Temperatura de servicio Θ_s (°C)	Temperatura del terreno, Θ_t ,en °C								
	10	15	20	25	30	35	40	45	50
90	**1.11**	**1.07**	**1.04**	**1**	**0.96**	**0.92**	**0.88**	**0.83**	**0.78**
70	**1.15**	**1.11**	**1.05**	**1**	**0.94**	**0.88**	**0.82**	**0.75**	**0.67**

TABLE 16. CORRECTION FACTOR DUE TO TEMPERATURE [ITC-BT-07]

Tipo de cable	Resistividad térmica del terreno, en K.m/W										
	0.80	0.85	0.90	1	1.10	1.20	1.40	1.65	2.00	2.50	2.80
Unipolar	**1.09**	**1.06**	**1.04**	**1**	**0.96**	**0.93**	**0.87**	**0.81**	**0.75**	**0.68**	**0.66**
Tripolar	**1.07**	**1.05**	**1.03**	**1**	**0.97**	**0.94**	**0.89**	**0.84**	**0.78**	**0.71**	**0.69**

TABLE 17. CORRECTION FACTOR DUE TO THERMAL GROUND RESISTIVITY [ITC-BT-07]

Factor de corrección								
Separación entre los cables o ternas	Número de cables o ternas de la zanja							
	2	3	4	5	6	8	10	12
D=0 (en contacto)	**0,80**	**0,70**	**0,64**	**0,60**	**0,56**	**0,53**	**0,50**	**0,47**
d= 0,07 m	**0,85**	**0,75**	**0,68**	**0,64**	**0,6**	**0,56**	**0,53**	**0,50**
d= 0,10 m	**0,85**	**0,76**	**0,69**	**0,65**	**0,62**	**0,58**	**0,55**	**0,53**
d= 0,15 m	**0,87**	**0,77**	**0,72**	**0,68**	**0,66**	**0,62**	**0,59**	**0,57**
d= 0,20 m	**0,88**	**0,79**	**0,74**	**0,70**	**0,68**	**0,64**	**0,62**	**0,60**
d= 0,25 m	**0,89**	**0,80**	**0,76**	**0,72**	**0,70**	**0,66**	**0,64**	**0,62**

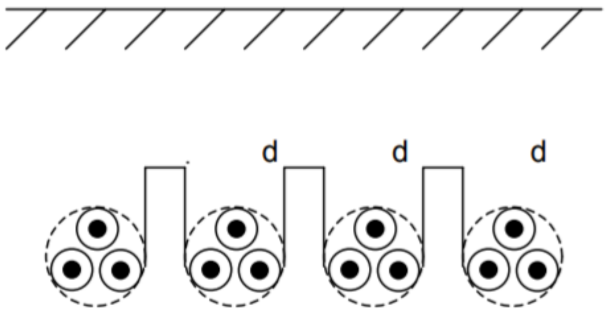


TABLE 18. CORRECTION FACTOR FOR CLUSTERS OF WIRES [ITC-BT-07]

Profundidad de instalación (m)	**0,4**	**0,5**	**0,6**	**0,7**	**0,80**	**0,90**	**1,00**	**1,20**
Factor de corrección	**1,03**	**1,02**	**1,01**	**1**	**0,99**	**0,98**	**0,97**	**0,95**

TABLE 19. CORRECTION FACTOR DUE TO INSTALLATION DEPTH

Tipo de Aislamiento seco	Temperatura máxima ºC	
	Servicio permanente	Cortocircuito t ≤ 5s
Policloruro de vinilo (PVC) S ≤ 300 mm² S > 300 mm²	 **70** **70**	 **160** **140**
Polietileno reticulado (XLPE)	**90**	**250**
Etileno Propileno (EPR)	**90**	**250**

TABLE 20. MAXIMUM TEMPERATURES IN ISOLATED WIRES WITH DRY INSULATION [ITC-BT-07]

The following table indicate the minimum section of a wire due to temperature:

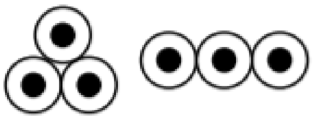
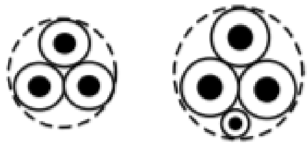
SECCIÓN NOMINAL mm^2	Terna de cables unipolares (1) (2)			1cable tripolar o tetrapolar (3)		
						
	TIPO DE AISLAMIENTO					
	XLPE	**EPR**	**PVC**	**XLPE**	**EPR**	**PVC**
6	**72**	**70**	**63**	**66**	**64**	**56**
10	**96**	**94**	**85**	**88**	**85**	**75**
16	**125**	**120**	**110**	**115**	**110**	**97**
25	**160**	**155**	**140**	**150**	**140**	**125**
35	**190**	**185**	**170**	**180**	**175**	**150**
50	**230**	**225**	**200**	**215**	**205**	**180**
70	**280**	**270**	**245**	**260**	**250**	**220**
95	**335**	**325**	**290**	**310**	**305**	**265**
120	**380**	**375**	**335**	**355**	**350**	**305**
150	**425**	**415**	**370**	**400**	**390**	**340**
185	**480**	**470**	**420**	**450**	**440**	**385**
240	**550**	**540**	**485**	**520**	**505**	**445**
300	**620**	**610**	**550**	**590**	**565**	**505**
400	**705**	**690**	**615**	**665**	**645**	**570**
500	**790**	**775**	**685**	**-**	**-**	**-**
630	**885**	**870**	**770**	**-**	**-**	**-**

TABLE 21. WIRE SECTION FOR UNDERGROUND COPPER CABLES (ITC-BT-07)

SECCIÓN NOMINAL mm^2	Terna de cables unipolares (1) (2)			1cable tripolar o tetrapolar (3)		
						
	TIPO DE AISLAMIENTO					
	XLPE	EPR	PVC	XLPE	EPR	PVC
16	97	94	86	90	86	76
25	125	120	110	115	110	98
35	150	145	130	140	135	120
50	180	175	155	165	160	140
70	220	215	190	205	220	170
95	260	255	225	240	235	210
120	295	290	260	275	270	235
150	330	325	290	310	305	265
185	375	365	325	350	345	300
240	430	420	380	405	395	350
300	485	475	430	460	445	395
400	550	540	480	520	500	445
500	615	605	525	-	-	-
630	690	680	600	-	-	-

TABLE 22. WIRE SECTION FOR UNDERGROUND ALUMINIUM CABLES (ITC-BT-07)

The company BRICOelige.com provide the following wire:

Manguera Eléctrica Flexible Color Negro 4x25 RV-K 1000V

Referencia: RVK4X25

Ficha técnica

- Cubierta Exterior : PVC tipo DMV-18
- Sección : 25 mm
- Aislamiento : Polietileno reticulado (XLPE)
- Color : Negro
- Temperatura máxima : 90 °C
- Material conductor : Cobre electrolítico flexible (Clase V)
- Nº conductores : 4

~~59,31 €~~

10,68 €

I.V.A incluido

Cantidad 1

Añadir al carro

Manguera eléctrica flexible con cubierta negra, con 4 conductores de 25 mm de sección.

Conductores de color marrón, negro, gris y azul.

Cable de fácil pelado y alta flexibilidad. Dada su gran flexibilidad es muy apropiado para instalaciones complejas y de gran dificultad. Es adecuado en trazados difíciles y puede ser enterrado o instalarse dentro de un tubo, así como a la intemperie, sin requerir protección adicional. Soporta entornos húmedos incluyendo su total inmersión en agua.

Los cables RV-K 0,6/1kV son los indicados para el transporte y distribución de energía eléctrica en baja tensión. Recomendado para conexiones industriales, acometidas, distribución interna y otras instalaciones fijas. Adecuados para instalaciones en interiores y exteriores, sobre soportes al aire, en tubos o enterrados.

Opciones de pedido:

Disponible por cortes a partir de **1 METRO** (Precio por metro de cable), introduce en 'Cantidad' la cifra exacta de metros que desees.

There are necessary three wires of this characteristics laid in parallel.

$$59.31€ * 3 * 30 = 5337.9€$$

7.4.2. RECHARGING STATIONS CABLES

The following table indicate the minimum section of a wire due to temperature:

	Conductores	1	2	3	4	5	6	7	8	9	10	11
A	Conductores aislados en tubos empotrados en paredes aislantes		3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR					
A2	Cables multiconductores en tubos empotrados en paredes aislantes	3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR						
B	Conductores aislados en tubos[2)] en montaje superficial o empotrados en obra				3x PVC	2x PVC			3x XLPE o EPR	2x XLPE o EPR		
B2	Cables multiconductores en tubos[2)] en montaje superficial o emprotrados en obra			3x PVC	2x PVC		3x XLPE o EPR		2x XLPE o EPR			
C	Cables multiconductores directamente sobre la pared[3)]					3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR		
E	Cables multiconductores al aire libre[4)]. Distancia a la pared no inferior a 0.3D[5)]						3x PVC		2x PVC	3x XLPE o EPR	2x XLPE o EPR	
F	Cables unipolares en contacto mutuo[4)]. Distancia a la pared no inferior a D[5)]							3x PVC			3x XLPE o EPR[1)]	
G	Cables unipolares separados mínimo D[5)]									3x PVC[1)]		3x XLPE o EPR
Cobre	**mm²**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**
	1,5	11	11,5	13	13,5	15	16	-	18	21	24	-
	2,5	15	16	17,5	18,5	21	22	-	25	29	33	-
	4	20	21	23	24	27	30	-	34	38	45	-
	6	25	27	30	32	36	37	-	44	49	57	-
	10	34	37	40	44	50	52	-	60	68	76	-
	16	45	49	54	59	66	70	-	80	91	105	-
	25	59	64	70	77	84	88	96	106	116	123	166
	35		77	86	96	104	110	119	131	144	154	206
	50		94	103	117	125	133	145	159	175	188	250
	70				149	160	171	188	202	224	244	321
	95				180	194	207	230	245	271	296	391
	120				208	225	240	267	284	314	348	455
	150				236	260	278	310	338	363	404	525
	185				268	297	317	354	386	415	464	601
	240				315	350	374	419	455	490	552	711
	300				360	404	423	484	524	565	640	821

TABLE 23. WIRE COOPER SECTION DEPENDING ON THE CURRENT

The company ilumitec provide the following wire:

Cable flexible 3x16 mm2 RZ1-K 0,6/1 KV EXZHELLENT GENERAL CABLE

Marca: GENERAL CABLE
Referencia: RZ1-K 3X16 mm2

Precio con iva
6,22 €
5.14 € s/iva

Envío en 24 horas

1 Añadir al Carrito

Información del Producto

Cable flexible L.H. de 3x16 mm2 de General Cable (o similar de primeras marcas).

Precio por metro lineal al corte, cantidad mínima 1 metro.

Características

Referencia:	**RZ1-K 3X16 mm2**
Aislamiento	0,6/1Kv
Material	Cobre
Sección	16 mm2
Tipo de cable	CPR Libre Halogenos

7.4.3. INDIVIDUAL DERIVATION

The following table indicate the minimum section of a wire due to temperature:

	Descripción	1	2	3	4	5	6	7	8	9	10	11
A	Conductores aislados en tubos empotrados en paredes aislantes		3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR					
A2	Cables multiconductores en tubos empotrados en paredes aislantes	3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR						
B	Conductores aislados en tubos[2] en montaje superficial o empotrados en obra				3x PVC	2x PVC			3x XLPE o EPR	2x XLPE o EPR		
B2	Cables multiconductores en tubos[2] en montaje superficial o emprotrados en obra			3x PVC	2x PVC		3x XLPE o EPR		2x XLPE o EPR			
C	Cables multiconductores directamente sobre la pared[1]					3x PVC	2x PVC		3x XLPE o EPR	2x XLPE o EPR		
E	Cables multiconductores al aire libre[4]. Distancia a la pared no inferior a 0.3D[5]						3x PVC		2x PVC	3x XLPE o EPR	2x XLPE o EPR	
F	Cables unipolares en contacto mutuo[4]. Distancia a la pared no inferior a D[5]							3x PVC			3x XLPE o EPR[1]	
G	Cables unipolares separados mínimo D[3]									3x PVC[3]		3x XLPE o EPR
Cobre	mm²	1	2	3	4	5	6	7	8	9	10	11
	1,5	11	11,5	13	13,5	15	16	-	18	21	24	-
	2,5	15	16	17,5	18,5	21	22	-	25	29	33	-
	4	20	21	23	24	27	30	-	34	38	45	-
	6	25	27	30	32	36	37	-	44	49	57	-
	10	34	37	40	44	50	52	-	60	68	76	-
	16	45	49	54	59	66	70	-	80	91	105	-
	25	59	64	70	77	84	88	96	106	116	123	166
	35		77	86	96	104	110	119	131	144	154	206
	50		94	103	117	125	133	145	159	175	188	250
	70				149	160	171	188	202	224	244	321
	95				180	194	207	230	245	271	296	391
	120				208	225	240	267	284	314	348	455
	150				236	260	278	310	338	363	404	525
	185				268	297	317	354	386	415	464	601
	240				315	350	374	419	455	490	552	711
	300				360	404	423	484	524	565	640	821

TABLE 3. WIRE COOPER SECTION DEPENDING ON THE CURRENT

The company SUMIDELEC provide the following wire:

Cable unipolar flexible 1x50mm RV-K color negro 1Kv

Referencia **MFM-1x50RVK**

4,75 € Iva incluido

Manguera de cable flexible negro 1x50mm RVK 1Kv

Cantidad 1 COMPRAR

Disponible

Manguera flexible 1000v cable de 1x50 mm RV-K.

Características:

Sección 50 mm.

Cable 1Kv negro.

El precio es por metro.

Para cortes de más de 100m consultar.

Los cables eléctricos, se utilizan principalmente para la transmisión de energía. Conducen la corriente eléctrica a través de largas distancias desde las centrales eléctricas. Los **cables RV-K** se necesitan en cada rincón del planeta donde exista población humana, ya que son una de las necesidades básicas de cada individuo.

Con una gran flexibilidad que lo hace particularmente adecuado en canalizaciones difíciles. Gracias al diseño de sus materiales, puede ser instalado en todo tipo de condiciones ambientales: zonas húmedas y secas, instalación al aire libre, enterrado subterráneo, e incluso sumergido en agua, sin que deteriore la vida útil del cable.

Nuestros **cables flexibles RVK** están diseñados para complacer los requisitos industriales más exigentes: conexiones industriales de baja tensión, redes urbanas, instalaciones en edificios de viviendas, etc.

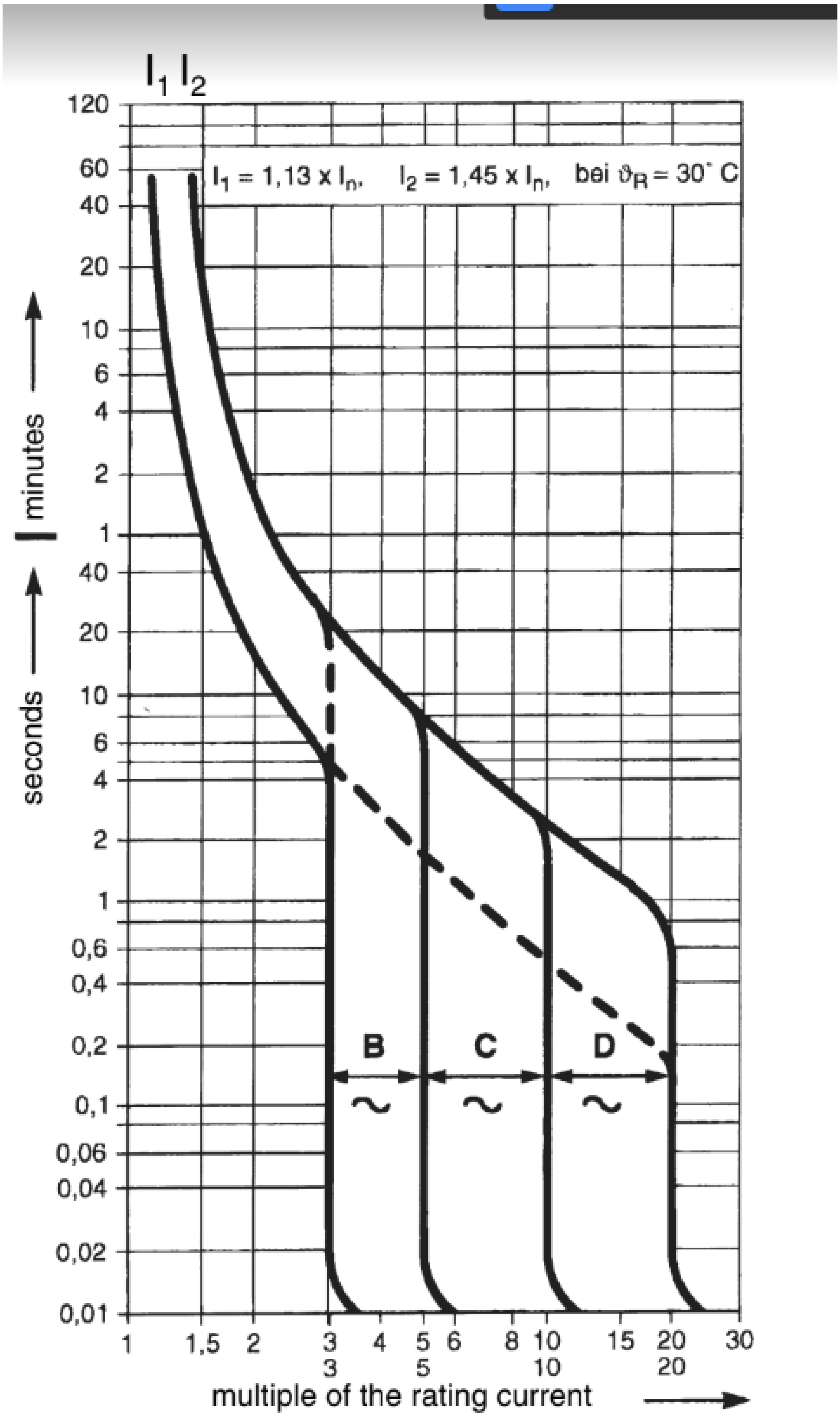
Fabricante del producto: Sumidelec

The total price would be:

$$4 * 4.75 * 200 = 3800€$$

7.4.4. GENERAL PROTECTION AND MEASURMENT BOX

The following graphic indicate the time a protection takes to perform depending on the current, in this case it has been selected the curve C:



The differential protection chosen is from the company :

Caja General de Protección Cahors trifásica 250A

Referencia **cgp-10-250/B**

171,20 € Iva incluido

Cantidad 1 – +

COMPRAR

Disponible

Caja General de Protección trifásica 250A Cahors CGP-10-250/BUC

Tensión asignada: 500V
Intensidad asignada: 250V
Tres bases seccionables en carga (BUC) tamaño 1, 250 A.
Neutro seccionable con borne puesta a tierra de 50mm
Esquema 10
Tornillos de acero inoxidable embutidos en las pletinas de entrada y salida de abonado, para el conexionado de terminales bimetálicos.
Código UNION FENOSA: cgp-10-250/BUC
-Artículo suministrado bajo encargo, no admite devolución.

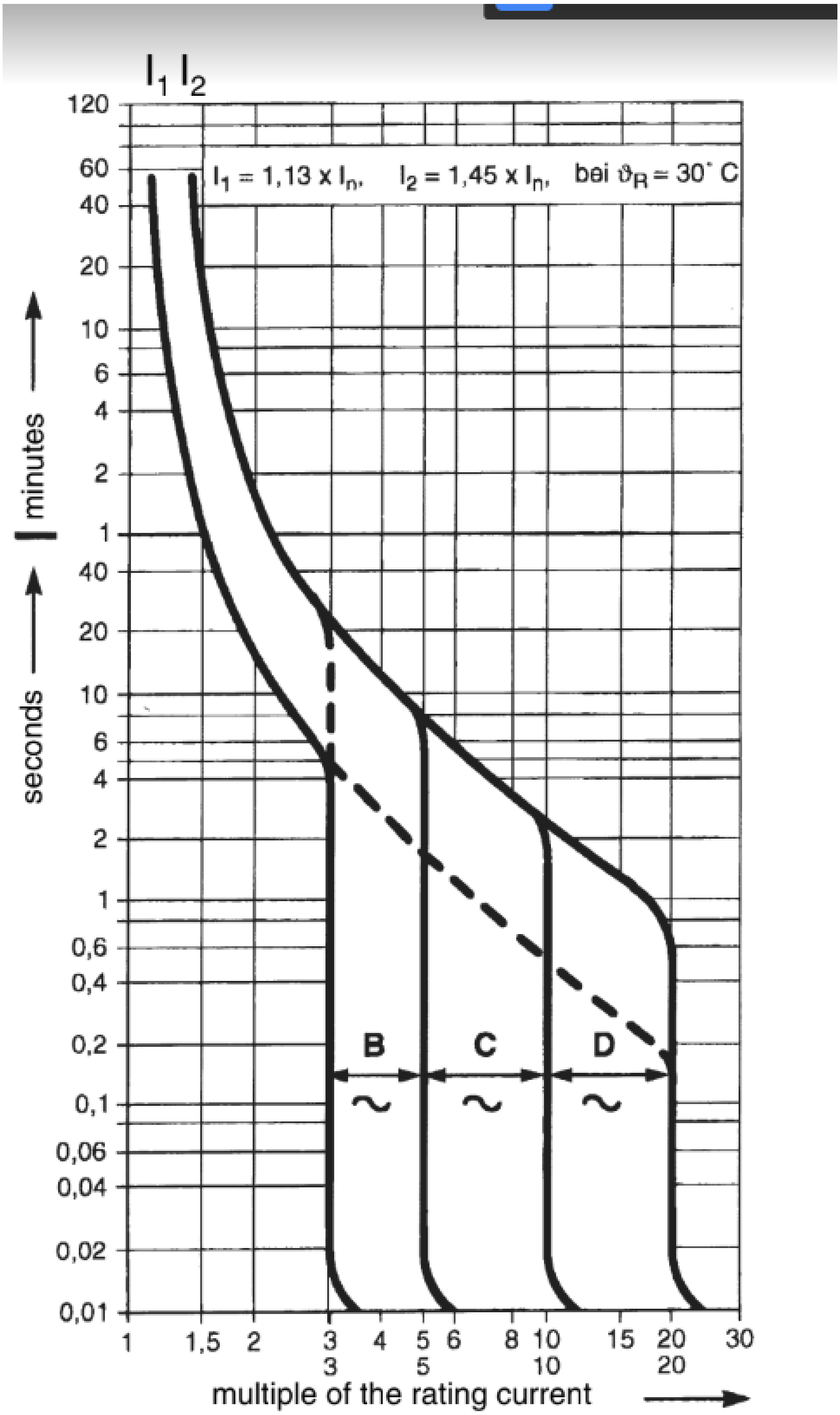
Fabricante del producto: Cahors

2. Circuit breakers:

The circuit breaker of the company ilumitec:

<u>RECHARGING POINTS</u>

The following graphic indicate the time a protection take to perform depending on the current, in this case it has been selected the curve C:



Only one Differential protection of this characteristics is needed. The one selected is from the company .

Automatico magnetotermico Schneider A9N18364 63A 3polos C120N

Referencia **A9N18364**

95,20 € Iva incluido

Cantidad 1 − +

COMPRAR

Disponible

Interruptor automático magnetotérmico C120N, gama terciario Acti 9. 3 polos 63A **A9N18364 de Schneider**.

Características:
Código curva disparo ins: C.
Calibre: 63A.
Clave A.
Número de polos: 3.
Frecuencia asignada empleo: 50/60 Hz.
Poder corte: 6000 A.
Tensión de empleo 230/400 V CA.
Tensión de aislamiento: (Ui) 500 V CA.
Doble aislamiento clase 2.
Certificados AENOR conforme a la norma UNE-EN 60898.

Fabricante del producto: Schneider Electric

The total price would be 95.20*14=1332.8€

2. Circuit breakers:
   The circuit breaker from the supplier ilumitec:

Fusible AC-00 Clase gG CRADY (de 10 a 160 A)

102038 > 63A

4.21€

3.48€ s/iva

3-7 días

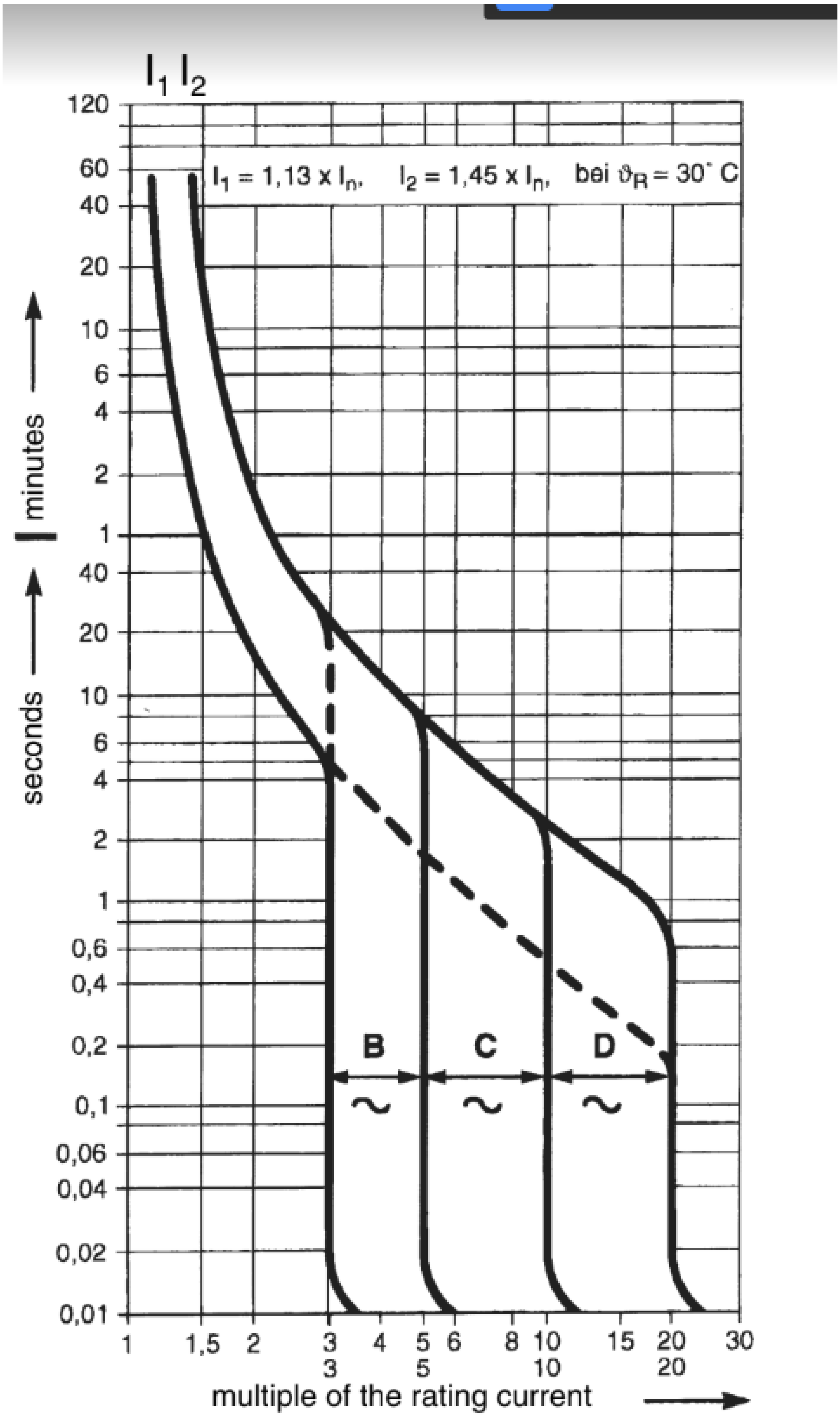
1

The total price would be 4,21*5=21.05€

The total price would be 4,21*14=58,94€

INDIVIDUAL DERIVATION

The following graphic indicate the time a protection take to perform depending on the current, in this case it has been selected the curve C:



Only one Differential protection of this characteristics is needed. The one selected is from the company SUMIDELEC Almacén de material eléctrico online.

Automatico magnetotermico Schneider A9N18364 63A 3polos C120N

Referencia **A9N18364**

95,20 € Iva incluido

Cantidad 1 COMPRAR

Disponible

Interruptor automático magnetotérmico C120N, gama terciario Acti 9. 3 polos 63A **A9N18364 de Schneider**.

Características:
Código curva disparo ins: C.
Calibre: 63A.
Clave A.
Número de polos: 3.
Frecuencia asignada empleo: 50/60 Hz.
Poder corte: 6000 A.
Tensión de empleo 230/400 V CA.
Tensión de aislamiento: (Ui) 500 V CA.
Doble aislamiento clase 2.
Certificados AENOR conforme a la norma UNE-EN 60898.

Fabricante del producto: Schneider Electric

1. Circuit breakers:

The circuit breaker from the supplier ilumitec:

Fusible AC-00 Clase gG CRADY (de 10 a 160 A)

102038 > 63A

4.21€

3.48€ s/iva

1

3-7 días

7.4.5. WALLBOX

The model selected is Commander Wallabox of the brand wallbox is the following:


wallbox
Connect to start charging

Ficha técnica

Especificaciones generales	
Cargador:	AC
Conector:	tipo 1 o tipo 2
Modo de carga::	Modo 3
Dimensiones (sin conector):	220x150x135mm
Peso:	2,4 kg
Longitud de cable:	5m (7m opcional)

Especificaciones eléctricas	
Potencia Máxima:	7,4 kW 1P / 22 kW 3P
Corriente máxima (por fase):	32A
Corriente ajustable:	de 6A a 32A

The price is of 1198€ per Wallbox.

$$1198€ * 14 = 16772€$$

7.4.6. INSTALLATION COSTS

The following table show the expenses of the installations disaggregated:

		GENERAL PROTECTION AND MEASURMENT BOX
	Switchgear 1x(4x250A)	171,20 €
	circuit breaker 1x(4x250A)	11,86 €
	Switchgear 5x(4x63A)	476,00 €
	circuit breaker 5x(4x63A)	21,05 €
	circuit breaker 14x(4x16A)	58,94 €
		WIRES
SUPPLY LINE	3x30m x(3X25+25) mm^2	961,20 €
RECHARGING POINTS (x14)	14x200m x(3x16mm^2)	17.416,00 €
INDIVIDUAL DERIVATION	4x200m x(1x50mm^2)	3.800,00 €
		WALLBOX 14x7,4kW
		16.772,00 €
	COST INSTALLATION	39.688,25 €
	COST INSTALLATIONS (x3)	119.064,75 €

TABLE 24. INSTALLATION COSTS

7.5. ANNEX E: ELECTRICITY VS FUEL VANS

The following table show a comparison of the vehicle's prices, considering that there are needed 60 for fuel vans and 42 for electric vans:

	Number of vehicles required	Vehicle price [€]	Register vehicle tax	Fleet price [€]	
Fuel	60	9.300,00 €	14,75 €	558.885,00 €	
Electric	42	16.500,00 €	- €	693.000,00 €	
				-134.115,00 €	electricity vs fuel

TABLE 25.VEHICLES PRICES.

In the next tables are indicated the expenses of fuel, fuel and diesel in a year. Both for the electric tariff 3.1 and 6.1.

- TARIFF 3.1

		Per van			
	Consumption[€/km]	[Km/day]	[€/year]	Mechanic Traction Vehicle Tax [€/year]	Total costs[€/year]
Gasoline	0,08 €	635	14.041,86 €	73,00 €	14.114,86 €
Electricity (tariff 3.1)			1.427,48 €	18,25 €	

TABLE 26. COSTS ELECTRIC VS FUEL VS FUEL FOR ONE VAN

Per Fleet				
[Km/day]	Consumption[€/year]	Mechanic Traction Vehicle Tax [€/year]	Total costs[€/year]	
635	842.511,70 €	4.380,00 €	846.891,70 €	
	59.954,35 €	766,50 €	60.720,85 €	
			786.170,86 €	electricity vs gasoline

TABLE 27. COSTS ELECTRIC VS FUEL VS FUEL FOR THE FLEET

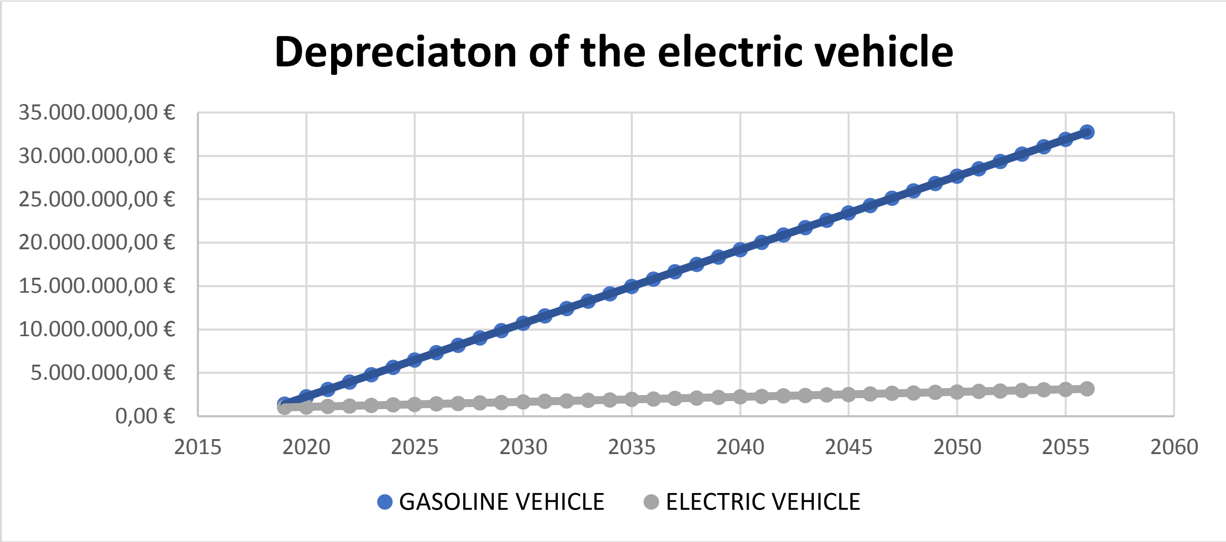
- TARIFF 6.1

		Per van				
	Consumption[€/km]	[Km/day]	[€/year]	Mechanic Traction Vehicle Tax [€/year]	Total costs[€/year]
Gasoline	0,08 €	635	14.041,86 €	73,00 €	14.114,86 €
Electricity (tariff 6.1)			1.355,35 €	18,25 €	

TABLE 28. COSTS ELECTRIC VS FUEL VS FUEL FOR ONE VAN

Fleet				
[Km/day]	Consumption[€/year]	Mechanic Traction Vehicle Tax [€/year]	Total costs[€/year]	
635	842.511,70 €	4.380,00 €	846.891,70 €	
	56.924,75 €	766,50 €	57.691,25 €	
			789.200,45 €	electricity vs gasolline

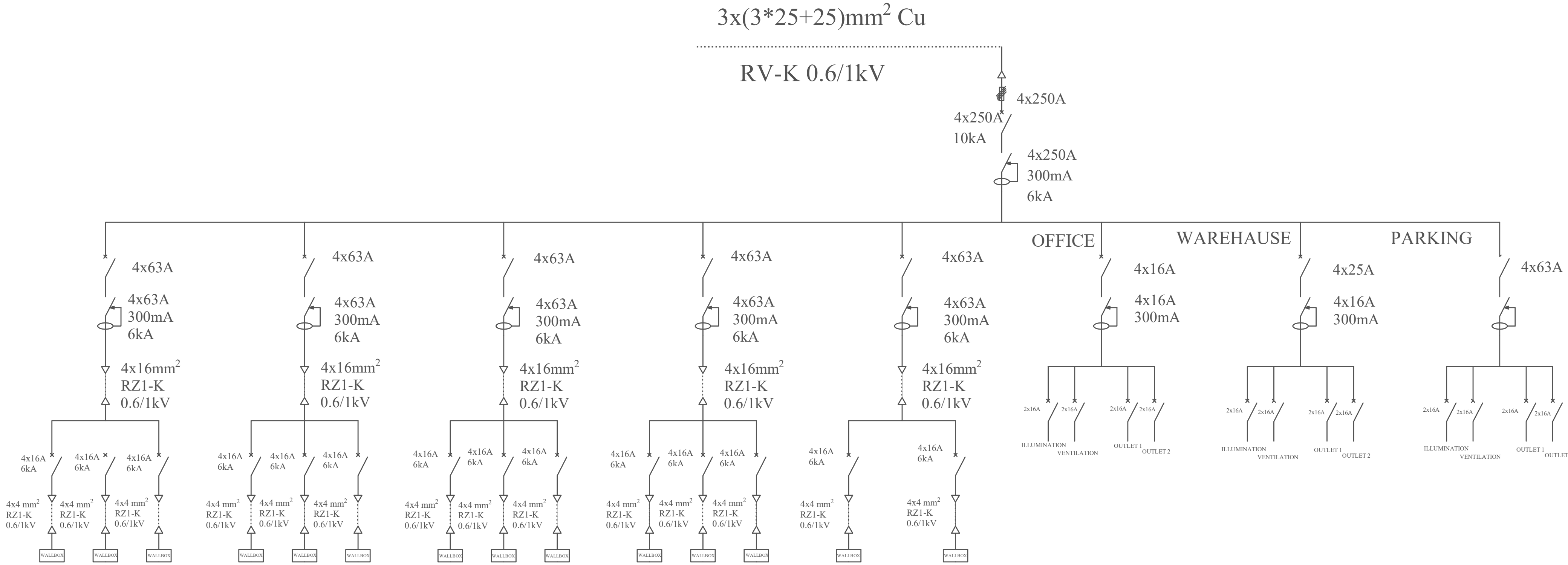
TABLE 29. COSTS ELECTRIC VS FUEL VS FUEL FOR THE FLEET



GRAPHIC 8. DEPRECIATON OF ELECTRIC VAN DURING TIME

In the graphic below can be easily seen that it takes less than a year to depreciate the investment of the electric-transport infrastructure.

8. SINGLE LINE DIAGRAM



	Date	Name		ICAI
Drawn:				
Checked:				
Id.s.norm:				
	ELECTRIC SCHEME			DRAW Nº 1: