ECOFLOTA: BUSINESS INTELLIGENCE SYSTEM FOR THE TRANSITION TOWARDS SUSTAINABLE MOBILITY FLEETS

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ABSTRACT

The lack of knowledge about the possibilities of switching to sustainable fleets and their costs lead companies to prolong the life of their fleets as much as possible. Therefore, the overall objective of ECOFLOTA is to provide arguments for companies to decide to migrate their fleets towards new ones that provide more sustainable mobility.

Within this framework, this project proposes the development of an automated analysis, planning and forecasting system consisting of i) a support tool for the optimised migration towards cleaner vehicles to achieve the objectives of zero emissions and green transport; ii) a predictive model of the useful life of these new sustainable vehicles and iii) the development of an eco-driving model to optimise the performance of these new sustainable vehicles. Hence, the project proposes the design and development of a global system at all levels for the upgrade of fleets with low emission vehicles.

The project was developed over a period of 15 months, during which time last mile delivery companies were involved in the definition, design, development and validation of the system, in order to meet the technical specifications and functional requirements of their operations. As a result, 61 use cases were simulated considering three types of routes (urban, short distance and interurban), as well as three types of low emission vehicles (electric, gas and hybrid)

1. INTRODUCTION

In recent years, local governments have adopted several urban traffic and mobility management measures based on energy efficiency and environmental sustainability. The aim is to create a more liveable and friendly environment. Simultaneously, cities face this challenge while trying to increase the operational efficiency of urban goods distribution.

In many studies, low emission vehicles are considered the right solution to meet both needs. However, currently logistics operators do not have clear information about the advantages offered by these new sustainable vehicles. Likewise, it is difficult for them to calculate the costs of replacing their current fleet with these types of vehicles and to estimate the profitability that this fact could generate in the long term.

In this context, the ECOFLOTA tool is an automated system of analysis, planning and forecasting of sustainable mobility fleets. It comprises a support module for optimised migration to low emission fleets, a predictive life model of these new sustainable vehicles and an eco-driving model to optimise the performance of these type of vehicles.

Specifically, the migration module involves a multi-objective optimisation model that allows to determine, for an established time horizon, a fleet replacement plan that minimizes the total cost to invest considering all the economic, technical, operational, environmental, and regulatory restrictions.

In addition, the predictive maintenance model is based on a genetic algorithm that allows monthly maintenance of the new fleet to be planned considering both economic and technical criteria.

Finally, the system includes an eco-driving module that contemplates and quantifies the savings in fuel consumption, pollutant emissions and maintenance costs in vehicles, derived from a more efficient and safe driving.

For its validation, more than sixty use cases were simulated taking into account different types of routes (urban, short distance and interurban), as well as low emission vehicles (electric, gas and hybrid)

2 TECHNICAL AND FUNCTIONAL REQUIREMENTS OF THE SYSTEM

The first of the tasks carried out focuses on identifying the technical requirements of the project and its functionalities. Based on this, the system architecture and all associated components were designed.

2.1 System architecture

The following figure shows the general architecture of ECOFLOTA, which identifies the three components that interact within the tool, as well as the actors involved in it:

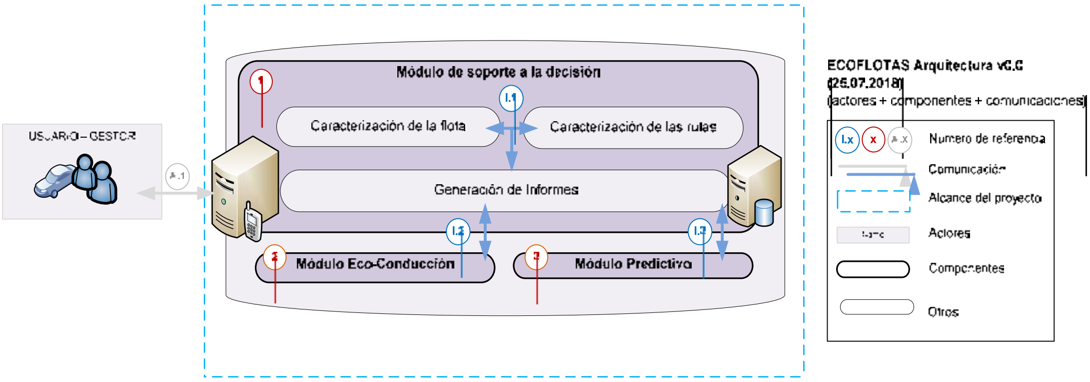

Fig. 1: ECOFLOTA architecture.

The table below identifies all system components, the communications between them and the graphical interfaces involved:

#	ECOFLOTA component	HMI	Communications
1	Decision Support module	User (Web)	I.1
2	Eco-driving Module	User (Web)	I.2
3	Predictive Module	User (Web)	I.3

Table 1: System components.

Considering both technical and economic feasibility, the aim is to obtain optimised solutions that demonstrate the benefits of the company's competitive, ecological, and sustainable development. With the use of predictive models, local regulations and standards in force or planned to be implemented, mobility patterns on historical routes, eco-driving models, among others, it will be possible to establish for the most common delivery routes where low-emission vehicles can be incorporated as a priority. This information, from the point of view of planning and logistics, is an added value of high performance of the tool.

The starting point for the definition and design of the tool, as well as its operation, is the characterisation of the company's operations, mainly related to the services provided (routes used and vehicles used). To complement the basic information of the data on its current operation and to provide a result more aligned with the company's needs, the user will also provide additional information, such as the city where it operates (to know municipal restrictions), critical mass of nearby recharging points, investment capacity and amortisation.

In order to propose an optimal development of the tool, some working sessions were held on Business Design and Lean Start-up, with the participation of companies, and in which the following objectives on their operation were identified:

- Minimising costs
- Optimising routes with mixed fleets
- Avoiding service incidents (breakdowns, accidents...)

Furthermore, some barriers relating to the different low emission vehicle typologies considered were also identified:

- Electric vehicles: high price; less autonomy; and limited recharging points
- Gas vehicles: less space and reduced power; greener, but polluting, vehicles; and limited refuelling stations
- Hybrid vehicles: high price; and not-definitive (transition to electric vehicle)

2.2 Decision Support Module

This is a support tool for logistics operators, vehicle dealerships or, in short, any company with a vehicle fleet. Its objective is to analyse the feasibility of migrating their fleets to less polluting vehicles, achieving the objectives of low emissions and green transport.

To this end, a multi-objective optimisation model has been developed that is capable of defining the optimal plan for replacing a current fleet, made up of conventional petrol or diesel vehicles, for a given time horizon of 5 to 10 years, or whatever the user estimates.

Thus, the optimisation model can define which vehicles of the current conventional fleet should be replaced by which type of more sustainable vehicle (that includes electric, hybrid or gas types)

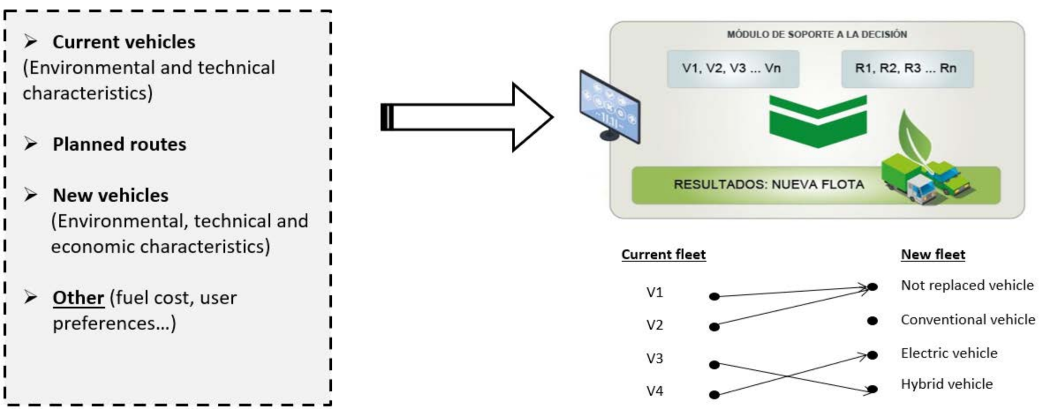

Fig. 2: Decision Support Module architecture.

With a view to define the replacement plan, the optimisation model developed considers all aspects or factors that may affect this decision to a greater or lesser extent. Specifically, all the technical, environmental, and economic characteristics of the current and new vehicles (sustainable and conventional) and the technical characteristics of the scheduled service routes. In addition, other non-economic and non-technical aspects have also been considered, such as user preferences in relation to the type of car they are willing to purchase, budget constraints, among other considerations. The table below shows all these technical, economic, and environmental aspects considered.

Current fleet	**Routes**	**New fleet**	**Other**
- Cost and maintenance - Fuel consumption - CO2 emissions	- Type - Km - Frequency - Cargo to be transported - Restriction on diesel?	- Age and km - Acquisition cost - Maximum permissible load - Range (km) - Fuel consumption - CO2 emissions	- Fuel costs - Bonuses for the purchase of sustainable vehicles - Reduction in maintenance operating cost and emissions by eco-driving - Maintenance cost - User preferences: > Car type > Car size (small, medium, and large) > Type of range (basic, mid-range and luxury)

Table 2. Economic, technical and environmental aspects considered in the substitution module.

Two different criteria, one economic and one environmental, have been considered for the optimisation model. This model seeks to minimise both the environmental impact of the new fleet and the total replacement cost. To define this cost, not only the acquisition cost but also the maintenance cost and the operating cost over the proposed horizon have been considered. The operating cost corresponds to the cost of charging the battery for hybrid and electric cars, or filling the tank in the case of gas, diesel or petrol vehicles. These two optimisation criteria can be completely opposite, i.e., the vehicle that pollutes the least, i.e., the electric vehicle, can be much more expensive than, for example, a hybrid that pollutes a little more. In this type of situation, the optimisation model will seek to minimise both criteria, but always giving greater priority to the environmental criterion, since the replacement module aims to replace the current fleet with a more sustainable one.

Through the optimisation model, the decision tool will be able to determine for each vehicle, i, in the fleet whether it needs to be replaced and if so, the type of sustainable vehicle, x, (electric, hybrid, or gas) and the corresponding range, g, (high, low and medium) by which it should be replaced.

Therefore, the decision variables of the model are the binary variables $n_{i,\,x,\,g}$ y n_i^{co}. More specifically, $n_{i,\,x,\,g}$ is a binary variable that will be equal to 1 if the vehicle i in the fleet is to be replaced by a sustainable vehicle of type x and range g:

$$n_{i,\,x,\,g} \begin{cases} 0 & \text{Vehicle i not replaced} \\ 1 & \text{Vehicle i replaced by a sustainable one of x type and g} \end{cases} \tag{1}$$

While the binary variable n_i^{co} will be equal to 1 if the vehicle i is not to be replaced and remains as a conventional type vehicle:

$$n_{i,}^{\,co} \begin{cases} 0 & \text{Vehicle i replaced by a sustainable one} \\ 1 & \text{Vehicle i not replaced} \end{cases} \tag{2}$$

For clarity, the following table specifies the indexes used in the nomenclature for the definition of both parameters and variables.

Indexes	**Description**
x $\{c, e, h, g\}$	Vehicle types {conventional, electric, hybrid, and gas}
k	Time period
i	Vehicles
r	Routes
$g=\{a, m, b\}$	Car type range {High, medium, low}

Table 3. Indexes used for the variables and parameters of the optimisation model.

The table below summarises all input parameters required for the development of the optimisation model:

Data	**Description**
T	Planning horizon
NC	Fleet size
B_x	Bonus for purchase of type *x* sustainable vehicle
β	Normalisation parameter
P	Vehicle procurement budget
$UL_{x,g}$	Lifetime (years) of type *x* vehicle and range *g*
UL_i^{co}	Useful life (years) of vehicle *i* of the original fleet
RUL_i^{co}	Remaining useful life (years) of vehicle *i* of the original fleet
Q_r	Average route load *r*
$Q_{x,g}$	Load that can be carried by type *x* vehicle and range *g*
$C_{x,g}^a$	Acquisition/replacement cost of type *x* vehicle and range *g*
$C_i^{a,co}$	Replacement cost of fleet *i* vehicle
$C_{x,g}^m$	Maintenance cost of type *x* vehicle and range *g*
$C_i^{m,co}$	Maintenance cost of fleet vehicle type *i*
$D_{i,x,g}$	Eco-driving discount factor for vehicle *i* when it is of type *x* vehicle and range *g*
D_i^{co}	Eco-driving discount factor for vehicle *i* when vehicle *i* is not replaced
l_r	Average route length *r*
$l_{x,g}$	Maximum km of type *x* vehicle and range *g*
fr_r	Route *r* frequency
$C_{k,x,g}^f$	Cost fuel of type *x* vehicle and range *g*
$C_i^{f,co}$	Fuel cost of fleet *i* vehicle
f_i^{co}	Fuel per km of fleet *i* vehicle
$f_{x,g,k}$	Fuel per km of car type *x* and range *g*
$E_{x,g}$	CO2 emission per km of vehicle type *x* and range *g*
E_i^{co}	CO2 emission per km of fleet i vehicle

Table 4. Required parameters for the optimisation model.

Finally, the following table describes parameters that are necessary for the optimisation model and that are calculated from the data defined in Table 3, i.e., fixed data, specified by the user or that can be collected from the database.

Parameter	**Description**
eco	Total emissions from existing vehicles
G	Total operating cost over the entire time horizon
$C_{i,k}^{co}$	Operational cost for original fleet vehicle *i* in period *k*
$C_{i,x,g,k}$	Operational cost of sustainable vehicle *x* of range *g* in period *k*
$k_{i,x,g}$	Total consumption on the routes by vehicle *i* of vehicle type *x* and range *g*
k_i^{co}	Total consumption on the routes by original fleet *i* vehicle

Table 5. Calculated parameters.

With the aim of defining the optimal fleet replacement plan, the optimisation model must consider the acquisition and maintenance costs of the different types of vehicles (current and those that could be acquired) as well as the future operational costs due to the energy consumption of the vehicles. Thus, the objective function of the optimisation model seeks to minimise all these costs according to the given replacement plan as well as to minimise the total emissions of the new fleet, but always giving higher priority to emission reduction. This priority is achieved by defining a very high emission cost, c.

Meanwhile the overall restrictions affecting the fleet are as follows:

- Avoiding of allocating more than one type of vehicle, sustainable or conventional (non-substituted), per vehicle.
- The total number of vehicles must be equal to that of the initial fleet
- Replacement of the current vehicle with sustainable vehicles based on the minimum weight they have be able to carry
- Replacement of the current vehicle by sustainable vehicles with the minimum autonomy required to carry out the assigned routes
- Limitation of access in certain areas due to regulations
- Load limitation for safety or danger reasons or due to regulations
- User requirements/preferences (e.g., user only wants electric and gas vehicles)
- Limitation in the budget for the acquisition of new sustainable vehicles

Additionally, another term can be added to the objective function to penalise the number of times the new fleet vehicles (sustainable and non-replaced) should be replaced over the time horizon according to their useful life. For example, if the lifetime of an electric vehicle is 8 years and the considered time horizon of the replacement plan is 10 years, the objective function should consider the cost of replacing this vehicle twice over the time horizon, in order to keep the number of vehicles in the fleet.

Many of the parameters that are considered within the optimisation model are user-defined, which can lead to infeasible solutions. In this case, the optimisation model will result in an infeasible solution. To warn the user about this type of error, in addition to the optimisation module, an error detection program has been developed to identify inconsistencies in the input parameters.

2.3 Maintenance module

The maintenance module is based on the development of the predictive maintenance tool. This consists of a genetic algorithm that allows monthly maintenance planning of the new fleet based on both economic and technical criteria of the new sustainable fleet.

For the development of the decision tool, a genetic algorithm based on metaheuristic techniques has been developed which can establish the monthly maintenance planning for the cars that make up the current sustainable fleet based on economic and technical criteria.

To do this, it has been necessary to identify, for each of the types of cars (electric, petrol, diesel, gas, hybrid), the critical elements, i.e. the elements whose breakdowns are the most frequent, most complex and, above all, most costly. In the case of petrol and diesel vehicles, the injection system and the steering system have been identified as critical elements. In the case of the injection system, its breakdowns are not the most frequent.

Specifically, it accounts for 16% of car breakdowns, but changing the injectors involves a large outlay of money. In the case of hybrid and electric cars, the car battery has been considered as a critical element, and in the case of hybrids, as an additional element, the injection system. Finally, for gas cars, only the injection system has been considered.

Based on the types of cars that make up the fleet, the genetic algorithm defines which months the user should perform the maintenance of its critical elements so that the total cost of preventive and corrective maintenance of the entire fleet over a predefined time horizon is minimal. Preventive maintenance refers to the maintenance of the element before its breakage and makes it possible to reduce the failure rate of the critical element, and therefore to avoid its replacement due to breakage, which could entail a high cost.

The only parameter defined by the user in the genetic algorithm is the time horizon (in years) to be analysed, the rest of the parameters will either be given by the substitution module or will be collected from the database. The parameters obtained from the previous module define some of the technical characteristics of the cars that make up the new sustainable fleet. In particular, the maintenance model only needs to know the type of car involved and the lifetime of the car, as it is not the same to plan the maintenance of a 10-year-old car with 1,000 km as a newly acquired one. In turn, the parameters defined in the database are those that characterise from an economic and technical point of view the critical elements of each of the types of car that may exist within the fleet.

More specifically, these parameters define the failure rate of each of the critical elements, and their corresponding preventive and corrective maintenance costs. In summary, the parameters considered are indicated in the following table.

Source	Description
User-defined	Number of years to be considered for planning purposes
Replacement module	Vehicle type
	Vehicle lifetime
Database	Failure rate of critical element of a vehicle depending on its type (petrol, diesel, gas, hybrid, or gas)
	Preventive maintenance cost of a critical element of a vehicle
	Corrective maintenance cost of a critical element of a vehicle

Table 6. Inputs to the genetic algorithm

The genetic algorithm aims to define the months of maintenance of each of the critical elements of the cars that make up the fleet given by the substitution module. In this sense, the only decision variables of the algorithm, i.e., the genomes that would compose everyone, are binary variables that will take the value equal to 1 when maintenance is scheduled for a specific critical element of a given car in a given month, and 0 otherwise.

In order to model the time evolution of the failure rate $\lambda_i^d(t)$of the critical element d of a car i, which is of petrol, diesel, electric, hybrid, gas or hybrid-electric type, based on what is suggested in the technical literature, the two-parameter Weibull function has been used, which adopts the following expression:

$$\lambda_i^d(t) = \left(\frac{\beta_i^d}{\alpha_i^d}\right)\left(\frac{t}{\alpha_i^d}\right)^{\beta_i^d - 1} \qquad (2)$$

$\lambda_i^d(t)$: Failure rate of equipment i by critical element d at time t

β_i^d, α_i^d: Weibull function coefficients

2.4 Eco-driving module

The Institute for Energy Diversification and Saving (IDAE) points out that efficient or ecological driving, compared to aggressive driving, reduces emissions of carbon dioxide (CO2), one of the main gases involved in climate change, as well as other pollutant emissions: up to 78% of carbon monoxide (CO), 63% of hydrocarbons and 50% of nitrogen oxides (NOx). Noise pollution is also reduced: one car at 4,000 revolutions per minute (rpm) makes the same noise as 32 cars at 2,000 rpm.

In this context, eco-driving is a concept associated with the new way of driving, which focuses on achieving a more economical and safer way of driving, reducing environmental pollution, and improving comfort. To this end, the concept defines and sets out a series of rules and modes of behaviour that seek to take advantage of the possibilities offered by current car engine technologies.

Driving style is influenced by a complex mix of social, psychological and cultural factors that directly affect the driver. At the same time, eco-driving is also influenced by technical factors related to the vehicle. In this area, the main driving parameters affecting the emission of pollutants are speed, engine speed, idling time, power take-off time, acceleration breaking, tyres and air-conditioning use.

In line with the above, the following are a number of guidelines and driving behaviours that can save fuel while driving, and therefore also help to reduce emissions.
With simple changes in driving habits, most drivers can save 10-15% on fuel.

- Reduce speed: For every 10 km/h over 100 km/h, fuel efficiency is reduced by 10%. Driving at 120 km/h on the highway instead of 100 km/h is equivalent to a 20% saving on fuel. In addition, maintaining a constant speed means lower fuel consumption. Using the accelerator and brake pedals smoothly: Hard starts between traffic lights can save 2.5 minutes on a one-hour journey, but it increases fuel consumption by 37%.
- Reducing idling times: As noted above, 10 seconds at idle speed means higher fuel consumption than when starting the engine. In this context, 10 minutes at idle means a consumption of half a litre of fuel
- Warming up the engine on the move: today's vehicles do not require periods of idling to warm up the engine. Gentle driving for the first few minutes after starting allows the transmission, steering and engine to warm up at the same time.
- Combining journeys: Journeys of less than 5 km are the most polluting, as the engine and pollution control system never reach maximum operating temperature. Combining several trips into one can reduce fuel use and emissions by 20-50%.
- Avoid overloading: every additional 100 kg of load reduces fuel efficiency by up to 2%, so it is recommended not to carry unnecessary items
- Make the most of your transmission: using overdrive at high speeds saves fuel and reduces engine wear. With a manual transmission, smooth but quick shifting at higher speeds allows the engine to operate more efficiently.
- Consult the vehicle's on-board computer (if available): such devices provide real-time fuel consumption information. In general, drivers who learn to adjust their driving habits according to the information available can save up to 10% in fuel consumption
- Proper maintenance of the different elements of the vehicle: Aditionally to being a safety factor, also results in lower fuel consumption.

Eco-driving offers numerous benefits: it not only saves fuel and costs, but also improves road safety and the quality of the local and global environment. In addition, eco-driving provides direct benefits to drivers and passengers, i.e., more comfort and a more relaxed environment. All of this is associated with equal or shorter travel times.

In short, the eco-driving module aims to be a tool that complements the decision module, with the objective of, on the one hand, making recommendations on the way of driving, both sustainable and conventional vehicles, and on the other hand, estimating the effects that the practice of this driving style (savings) will have on the operational scenarios of the fleet. To do this, it is based on both the type of vehicle and the type of routes that the vehicle will carry out.

Thus, and as a synthesis of the possible benefits of this driving style, the following table is taken into account, depending on the different types of vehicles (propulsion):

SAVINGS	**CONVENTIONAL**	**GAS**	**HYBRID**	**ELECTRIC**
Fuel	15%	15%	18%	20%
Emissions	15%	15%	18%	N/A
Maintenance	5%	5%	5%	5%

Table 7. Percentage savings as a result of eco-driving by vehicle type

2.5 System validation

For the validation of the integrated system, 61 different tests were proposed, whose fleet was made up of three combustion vehicles (2 petrol and 1 diesel), and their operation included three different types of routes (Urban, Interurban and Short distance).. The results showed that:

- 7 of the cases did not result in a change of fleet. In other words, there was no substitution necessary in the scenario proposed. The specific cases were:
    - Only sustainable vehicles with a current full diesel fleet and with a budget constraint of €17,000
    - No sustainable selection with no vehicle selection. At least one sustainable vehicle must be selected, when only sustainable vehicles are selected
    - No range selection. The range must be selected
    - No size selection. The size must be selected
    - With a higher bonus than the budget for electric vehicles.
    - Routes currently undertaken are not viable for sustainable vehicles (1,000,000 km)
    - The weight of the current routes cannot be covered by the current sustainable vehicles.

- 38 replacement cases 1 fleet vehicle
  - 23 electric
  - 6 gas
  - 3 hybrids
  - 3 new diesel
  - 3 new petrol
- 10 replacement cases 2 fleet vehicles
  - 5 new diesel
  - 3 new petrol
  - 1 gas
  - 1 hybrid
- 6 replacement cases all 3 vehicles in the fleet
  - 3 new diesel
  - 3 new petrol

3. WEB INTERFACE DESIGN

The web platform is designed in such a way that any user can use it intuitively following good web design practices. In addition, it is designed to be "responsive" so that no matter what device is used to view it, whether mobile, tablet or monitor, the content of the page will adapt to the resolutions of each of these screens.

In order to access the platform, registration is required. Once registered, you can log in to access the platform. It contains different sections, which are always available in a fixed sidebar. Among the sections are some designed to create and visualise the initial fleet situation, both vehicles and route types. Also, a section to perform simulations, being able to vary different input parameters to generate different results.

Finally, a screen to visualise these simulations, and to generate the prediction of the maintenance module with respect to the associated simulation.
Below are a series of screenshots of all the screens mentioned above.

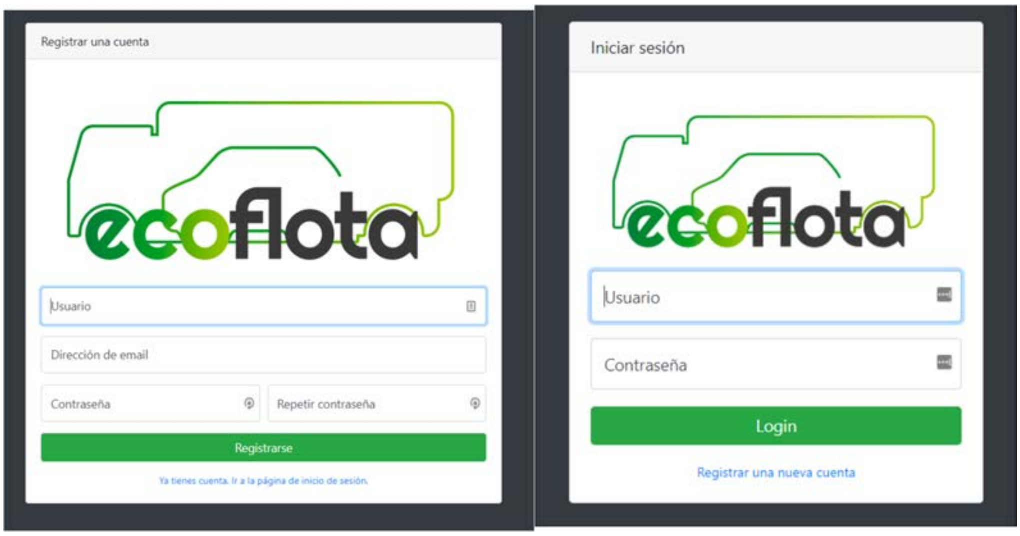

Fig. 3: Registering on the platform and logging in.

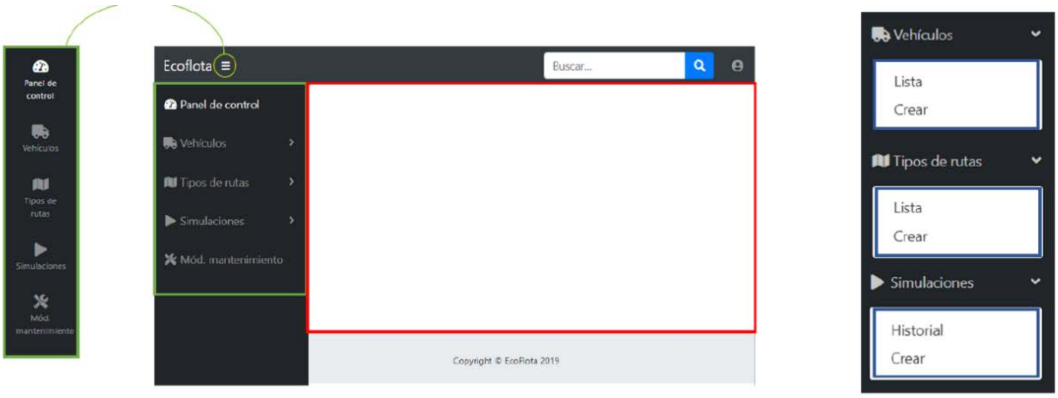

Fig. 4: Basic structure of the web platform.

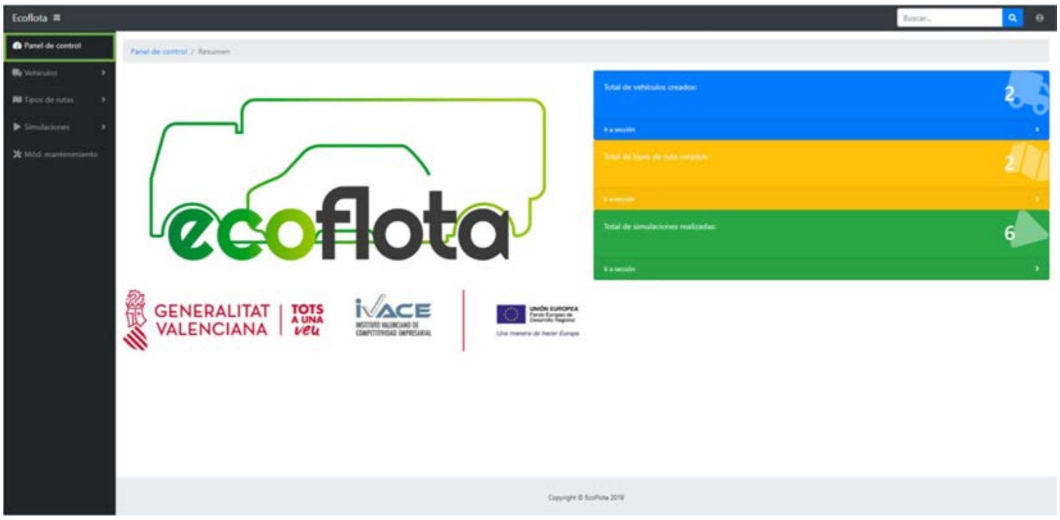

Fig. 5: Control pannel.

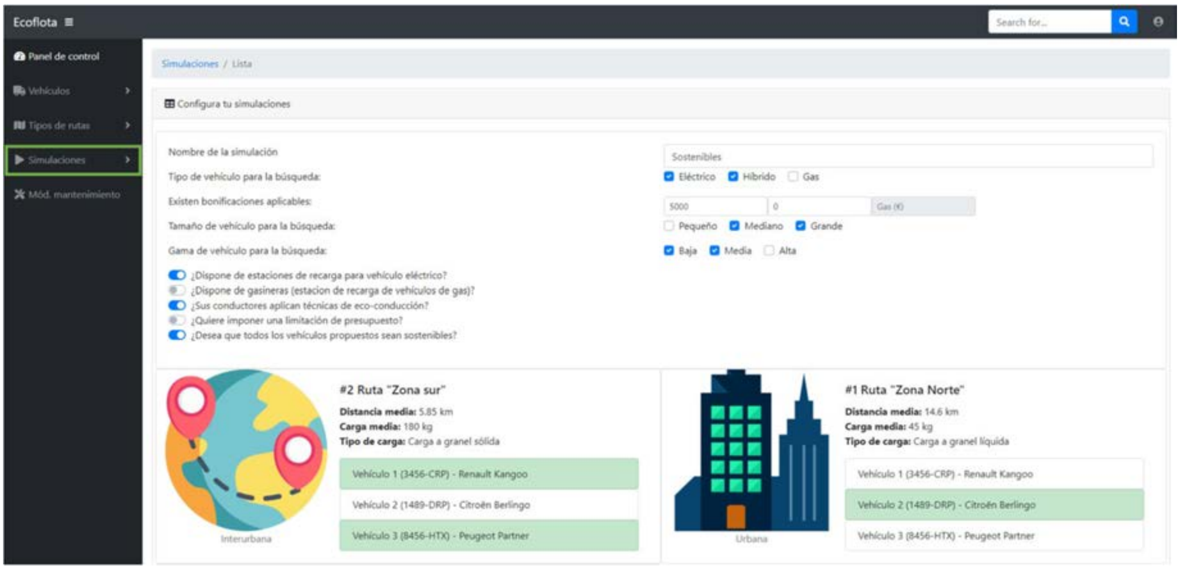

Fig. 6: Simulation creation.

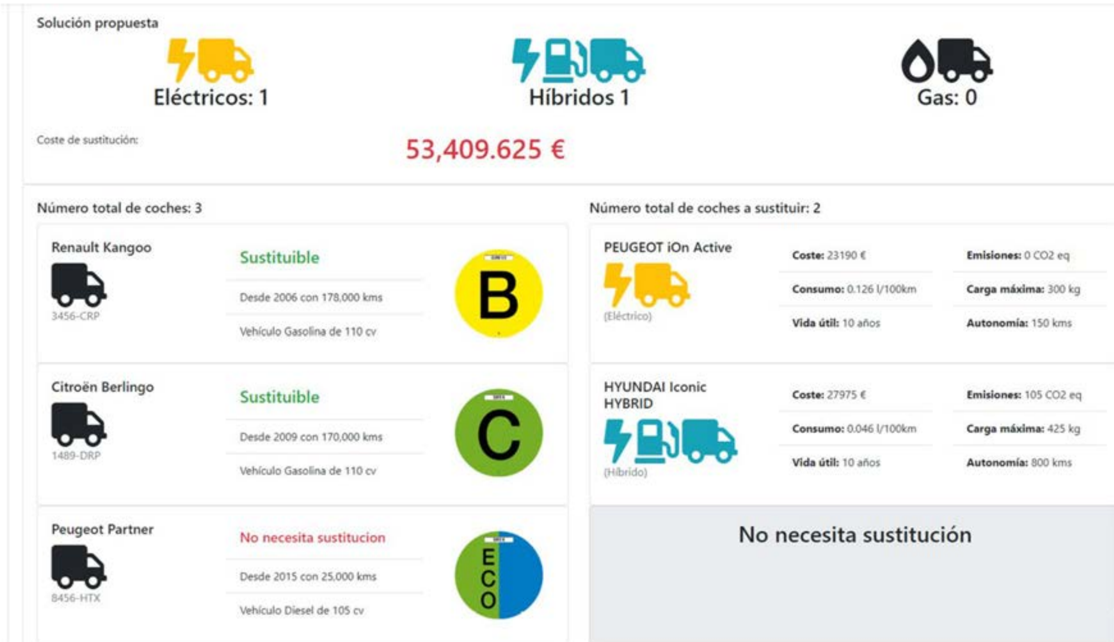

Fig. 7: Example simulation output.

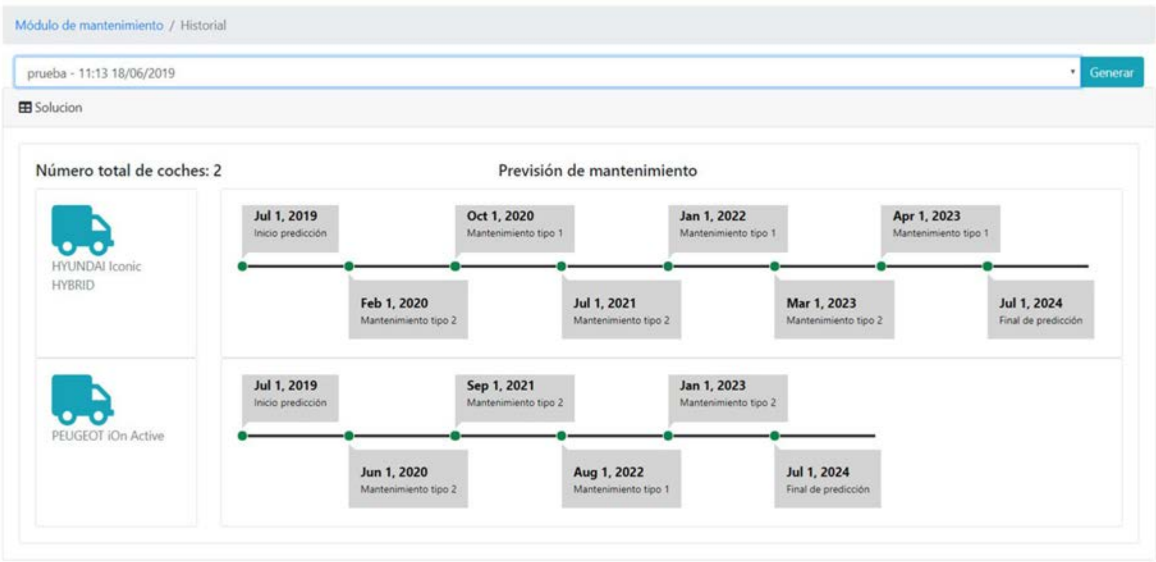

Fig. 8: Maintenance module simulation output.

4. CONCLUSION

To help the transition to a sustainable mobility model, ECOFLOTA has developed an intelligent decision support system, capable of interpreting the needs of both routes and vehicles, to provide the optimal result. In other words, the main objective is to facilitate the change from conventional fleets to sustainable fleets.

The decision has been based on the needs of the companies transferred directly to the architecture and design of the system. To this end, it has been obtained:

- Automated system for analysis, planning and forecasting of sustainable mobility fleets.
- Aimed at transport and logistics companies
- Contributes to reducing pollution and noise in cities.
-

It mainly consists of:

- A support tool for logistics companies for the optimised migration of their fleets towards cleaner vehicles to achieve zero emission and green transport objectives.
- A predictive model for the lifetime of these new sustainable vehicles.

In view of the results and feedback obtained, the tool could be further improved with:

- Include leasing and carsharing modalities in the model
- Extending the catalogue of vehicles
- Extend the topology of the vehicles. (Bicycles, motorbikes, scooters...)

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