Optimal distribution of charging stations for electric vehicles

Supervisor: Ekhine Irurozki

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Challenge Presentation

- **What is the optimal deployment of the interurban network of public charging stations?**

  With different chargers disaggregated by type

- **BASE CASE**
  Considering 65 charging stations are already available

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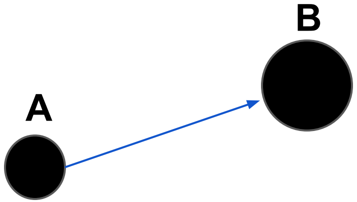
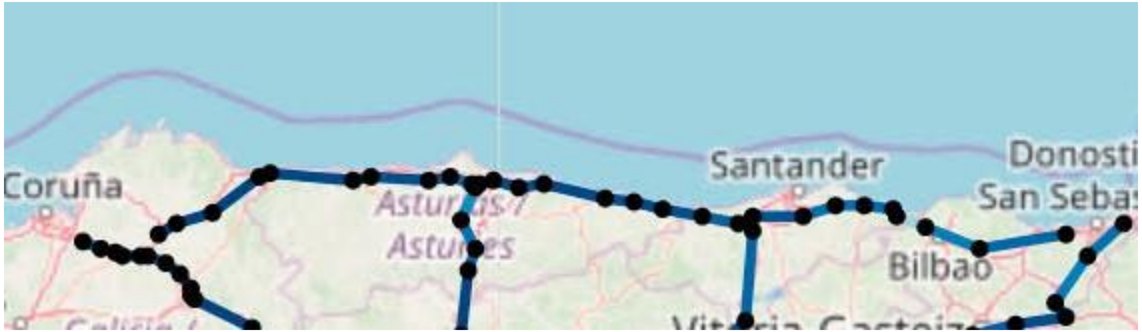
Assumptions

#A2.We focus on the interurban behavior → Road by road approach

- Cities have their own charging stations
- Commuter model, IMD based, other approach, gravity models
- IMD measurements are “dense”





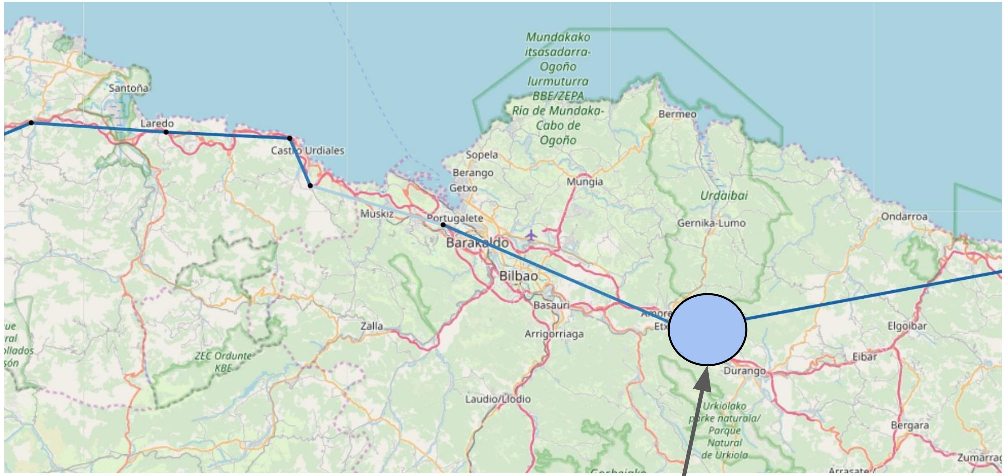
Input Data

Number EV

Battery size of the vehicles

Coordinates of IMD

#A1. Fixed Range! (100Km)



Mean Day Intensity

% of Light Vehicles

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Station information

	T1	T2	T3
Power (kW)	50	150	350
Nº vehicles simul*	2	3	6
Charging t (min/vehicle) in 2018	30	10	5
Installation cost (€)	28900	289000	578000
Charging cost (€/kWh)	0,15	3	8

Modelling?

We decided to focus on **two goals**:

A. Low total cost of building the charging stations:

Cost = (Number of stations) · (Prize per station)

Cost is easy to model and good for algorithms (Linear Optimization)!

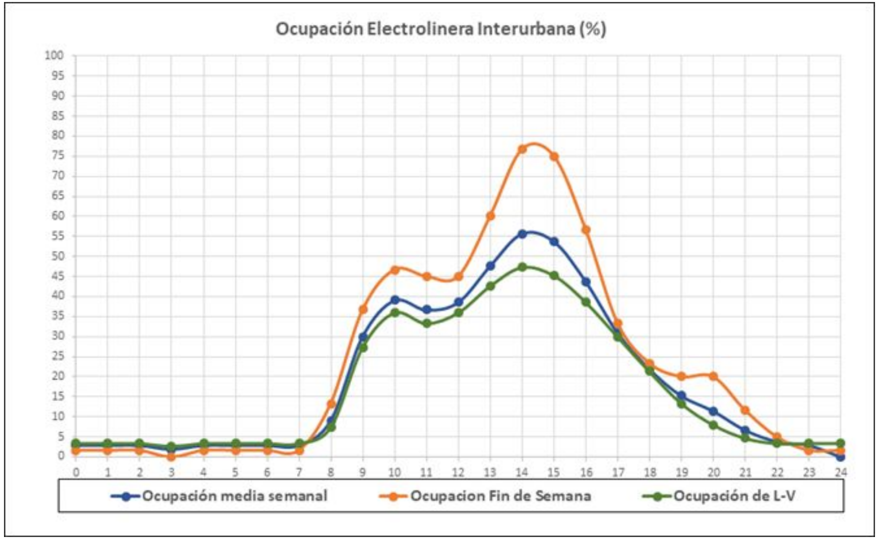
B. Low maximum waiting time at all stations:

Problem: How can we compute/model the waiting time at a station?

A detailed description requires queueing theory. We used a simpler approach!

Energetic Approach I - Peak Traffic

Traffic has two phases: Peak traffic / off-peak traffic



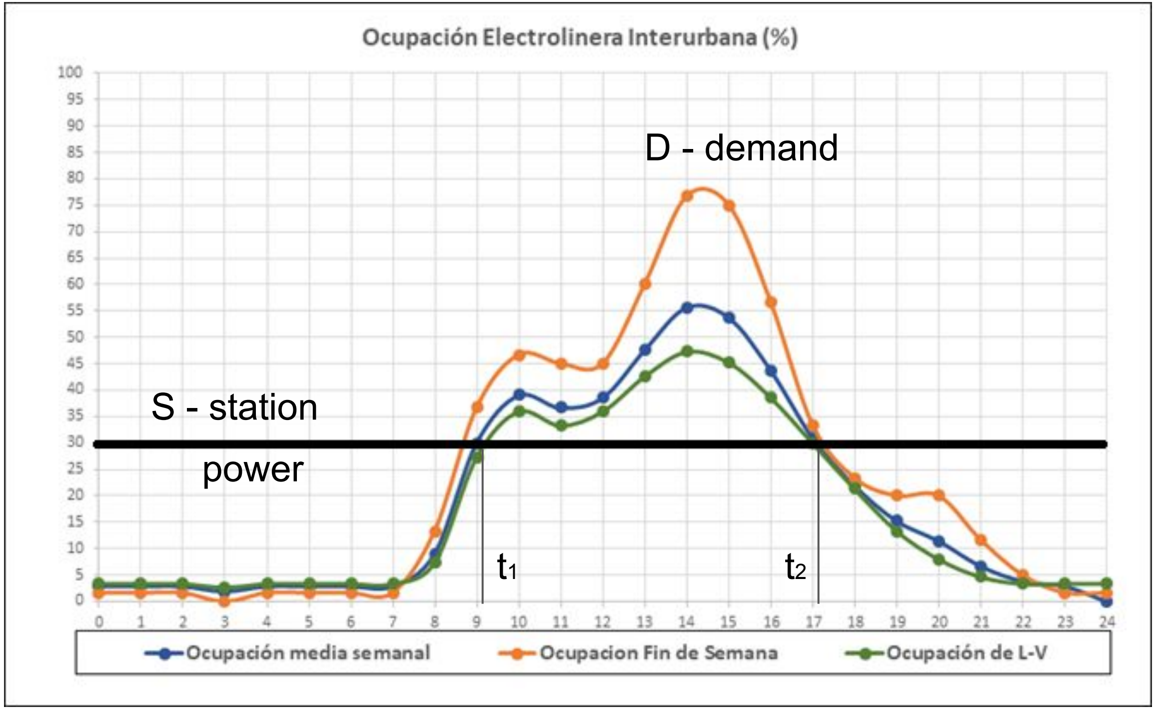
(Peak time traffic diagram by Iberdrola)

Energetic Approach II - Approximation

- We approximate waiting time with energy demand at each point

- Assumptions:
  - Energy demand at each point is proportional to the car movement density
  - Waiting time at each point depends on the power balance

Energetic Approach III - Approximation



$$Waiting\ time = t - t_2$$

$$\int_{t_1}^{t_2} D - S = \int_{t_2}^{t} S - D$$

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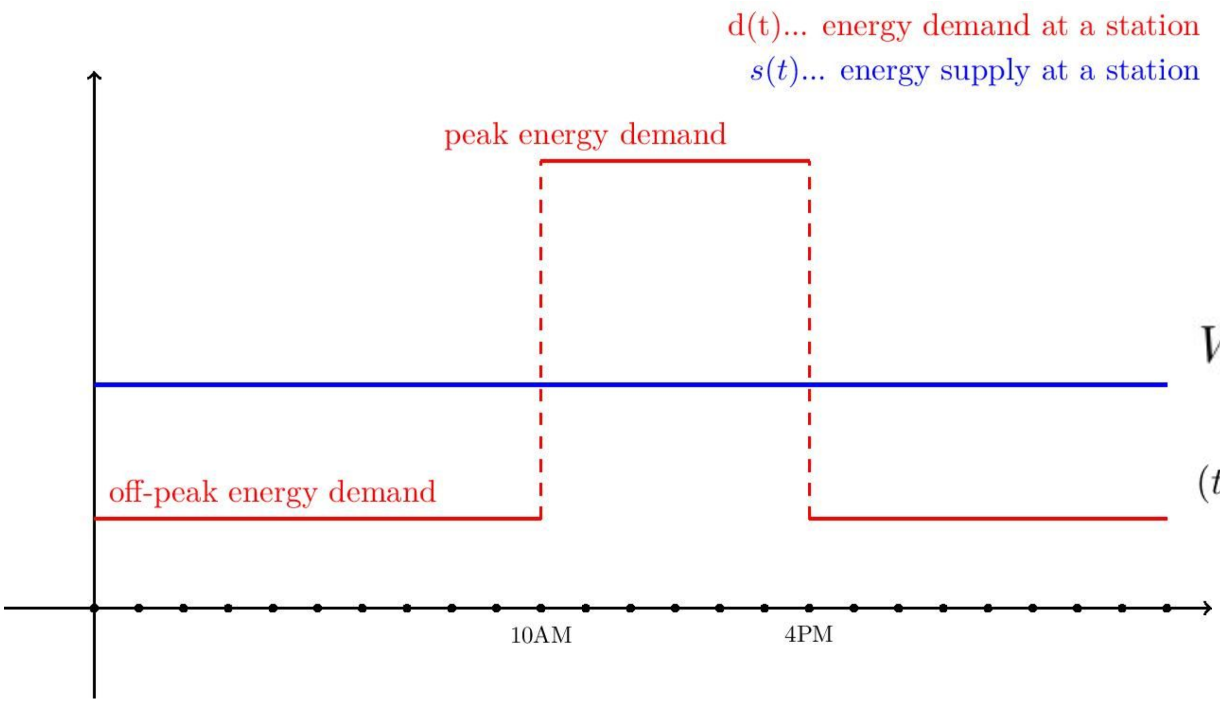
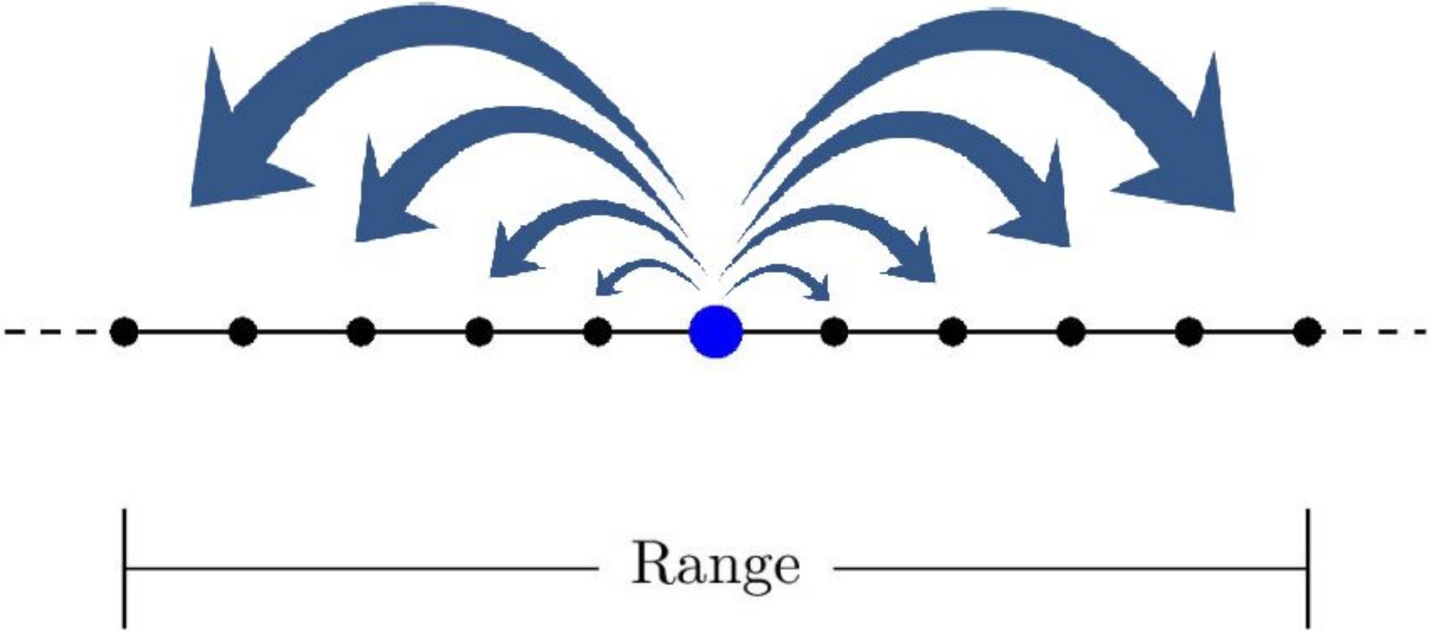
Energetic Approach III - Approximation



$$Waiting\ time = t - t_2$$

$$(t - t_2) = \frac{D^{peak} - S}{S - D^{off-peak}}(t_2 - t_1)$$

Energetic Approach III - Demand



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Energetic Approach III - Demand

- General formulation

$$\int D_k = \sum_{\substack{j \in X \\ \|j-k\| \leqslant R}} IMD(j) \cdot D_{j \to k} \cdot P_{j \to k}$$

- Application

$$\int D_k = \sum_{\substack{j \in X \\ \|j-k\| \leqslant R}} IMD(j) \cdot C_e \|j-k\| \cdot \frac{1}{NSR(j)^2}$$

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What is the genetic algorithm?

It's a particular type of evolution algorithm where an initial population of solutions is repeatedly modified, such that it evolves toward the local optimum.

Useful terminology:

- **Fitness function**: the objective function to be minimized.
- **Individual**: a specific solution.
- **Population**: array of individuals.
- **Parents and children**: parents are the individuals selected within the population to produce the next generation.

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Classic algorithm vs Genetic algorithm

Classic algorithm (ex. line search)	Genetic algorithm
At each iteration it generates one solution. The sequence then converge to the optimum.	At each iteration it generates a population The best individual (the one with the least fitness value) converges to the optimum
Points in the sequence are computed analytically	Next generations are computed using random generators.

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Three types of rules

At each step the next generation is computed according to three types of rules:

- **Selection**: It selects the parents.

- **Crossover**: combines the selected parents to form children.

- **Mutation**: Apply changes to parents to form children.

The algorithm

It begins with a random initial population.

Then at each step it creates a sequence of population as following:

- Computes the fitness values of the current population.
- Based on the values, it selects the parents.
- Children are produced from parents, with crossover or mutation.
- Replace the initial population with the new children.

Goal

The optimization problem formulated falls in the class of nonlinear integer programming (INLP) problems.

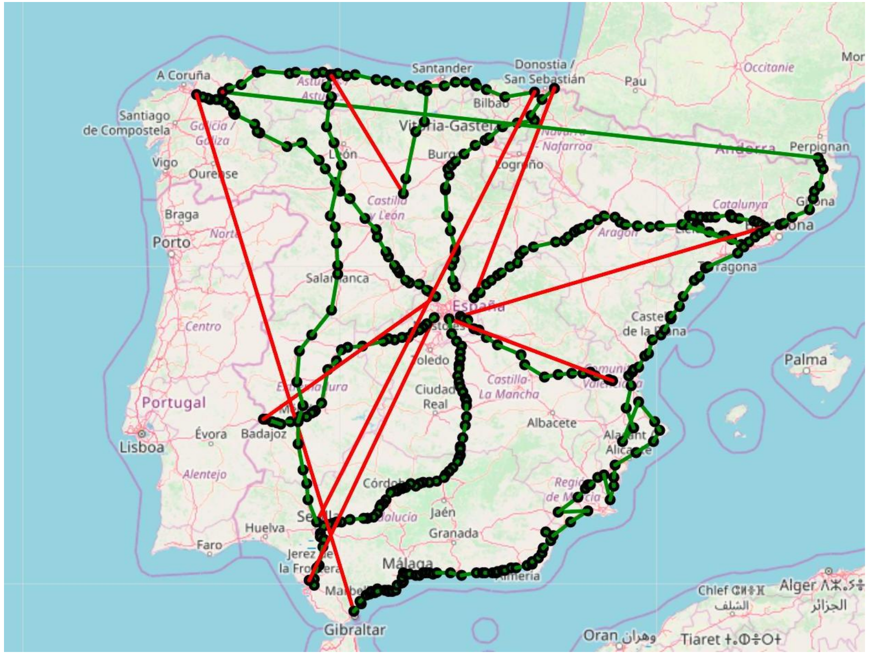
The goal is to apply the genetic algorithm to both single and multi-objective cost functions.

Data Cleaning

- One point is placed in the wrong road
- Close to Marbella the street is divided in two streets
- Loops
  - Near Barcelona
  - Near Cartagena
  - Near Lleida

➔ Clean up the data

➔ Correct and remove odd points



Pareto and Genetic algorithms

- Genetic algorithms create many solutions and filter out good ones
- With two objective functions, sometimes it is unclear what solution is “best”
- Overview over all solutions and exclude “dominated solutions”
- This creates the “Pareto Front”, solutions which are candidates for “best”
- Sometimes this produces a good picture, sometimes not

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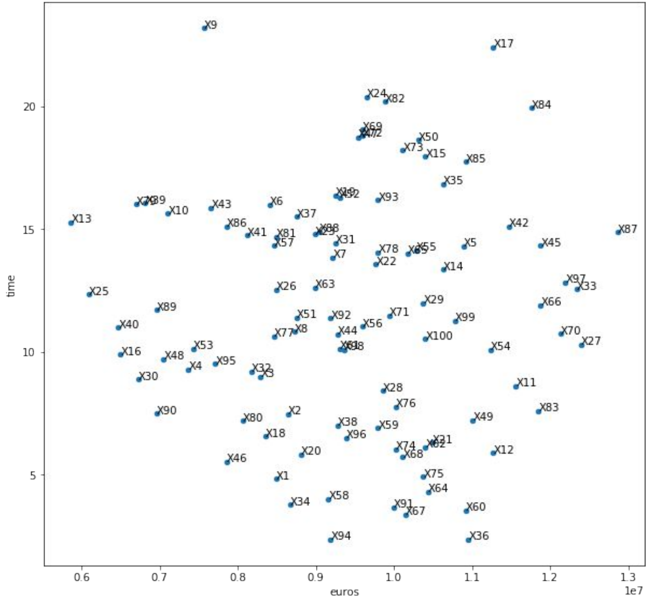
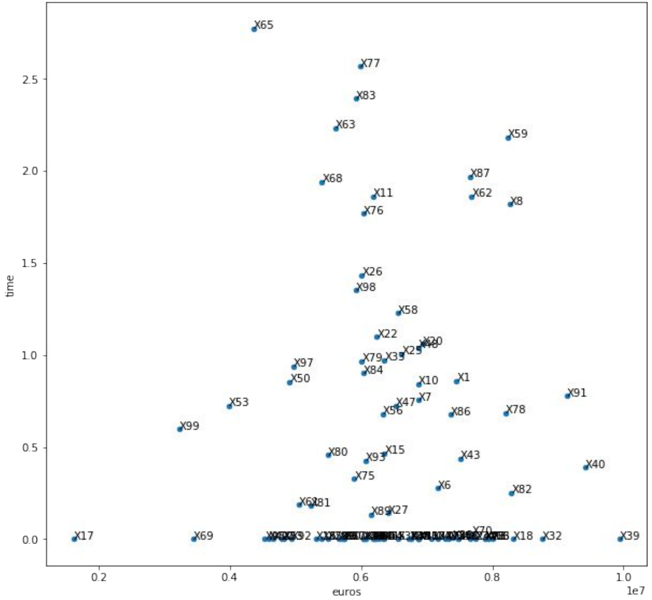
Pareto Front



Obvious Pareto Front (road A2)



Unclear Pareto Front (road A5)

Solutions for Road A2

Road A2 has a clear Pareto Front, but which solution to choose?

- Low waiting time and high cost?
- Medium waiting time and medium cost?
- High waiting time and low cost?

Note: We assume only one charging station per location.

Low waiting time, high cost

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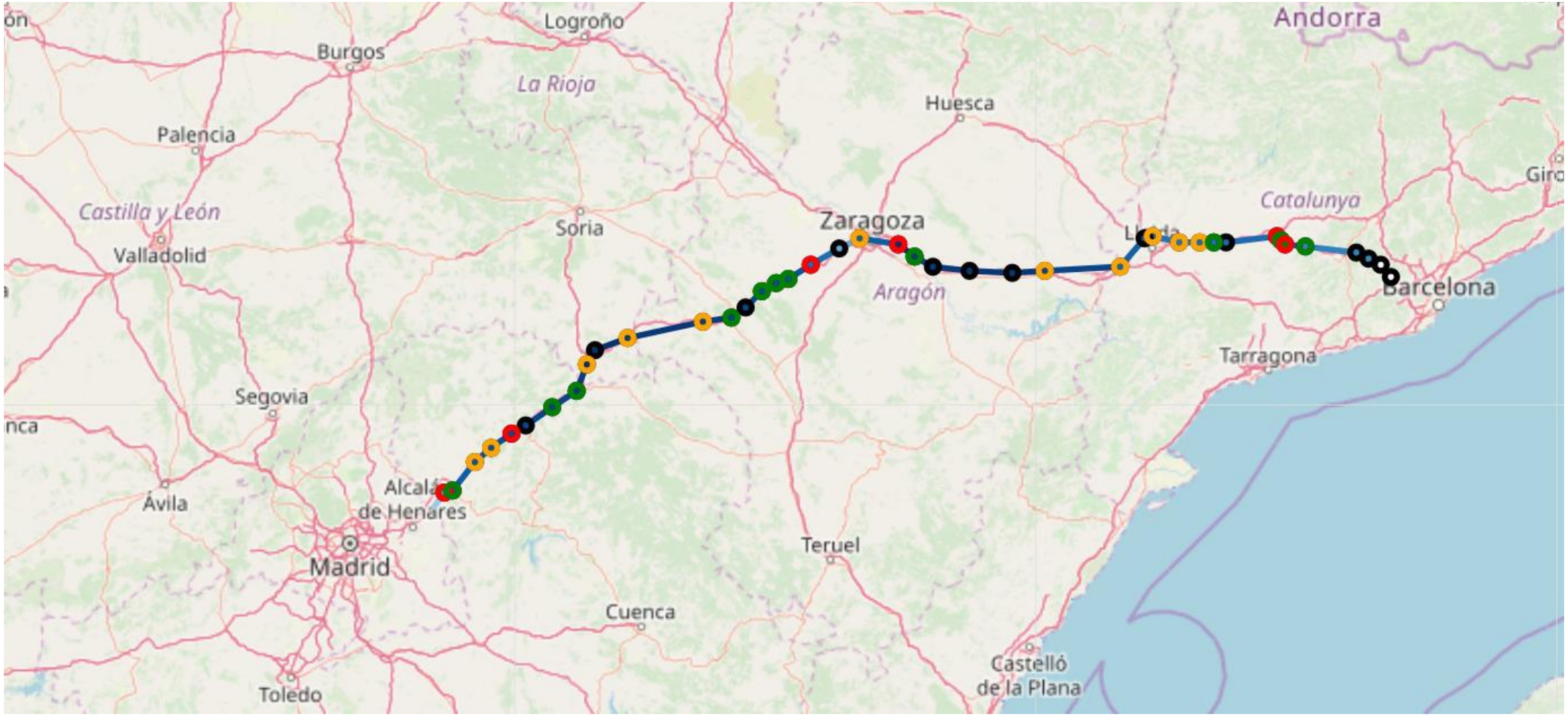
Medium waiting time, medium cost



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High waiting time, low cost

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Combined solution

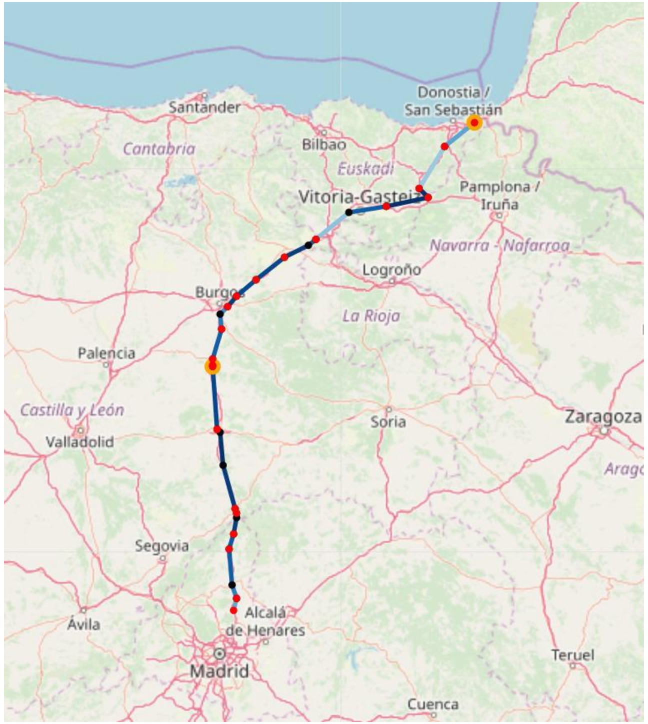
- Select **a** best solution from every individual simulation for each road
- Combine these solutions into a whole grid of stations

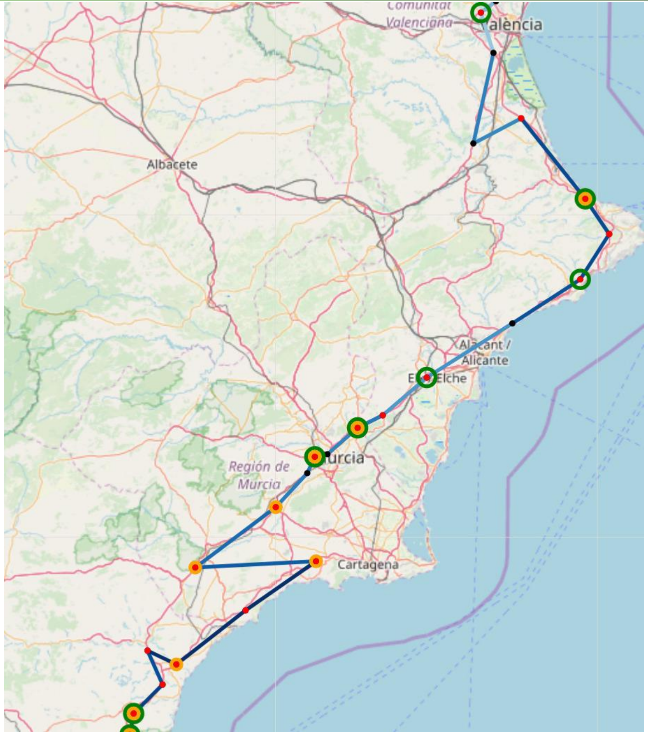
Combined solution

Multiple charging stations per location

- At one location, there can be more than one charging station
- This leads to a more difficult optimisation problem, but is closer to reality
- Very promising ideas for programming

Multiple charging stations at one location





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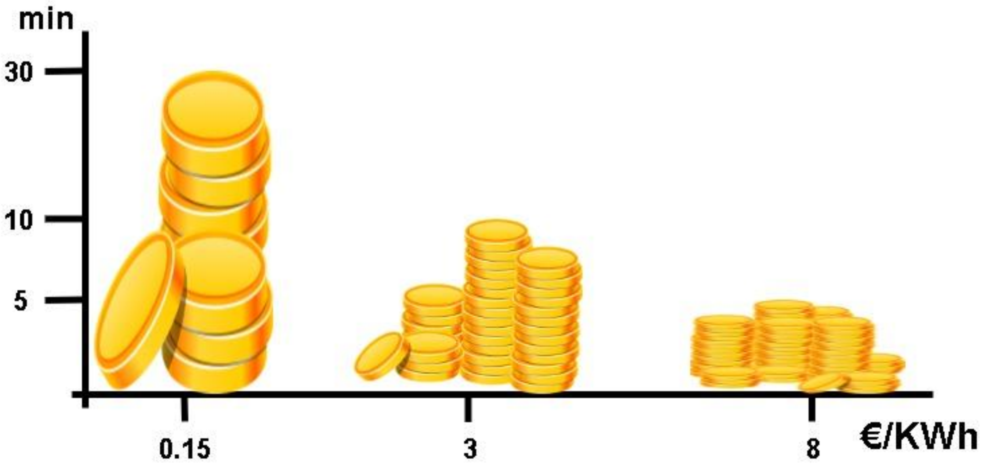
Future work

Distinguish between regions depending on

- The wealth
- Number of electric cars
- The traffic

Decrease charging time

Consider locate more than one type of charge station per place



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Thank you!