Hydrogen Trucks Charging Stations

Data Analytics for Sustainability

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TO SIZE THE H2 TRUCK CHARGING STATIONS NETWORK IN 2030 AND 2040 WE DEVELOPED A FLEXIBLE RULED-BASED MODEL

CONTEXT

- Heavy truck transportation is a major contributor to global greenhouse gas emissions in France (8% of CO2 emissions)
- Hydrogen fuel cells emit only water and do not produce harmful pollutants
- The deployment of hydrogen charging stations for heavy trucks is crucial for the widespread adoption of hydrogen fuel cell technology
- In France, there will be 10,000 hydrogen-powered trucks in 2030 and 60,000 in 2040

➔ The hydrogen charging station market will grow exponentially over the next decades and Air Liquide must position itself.

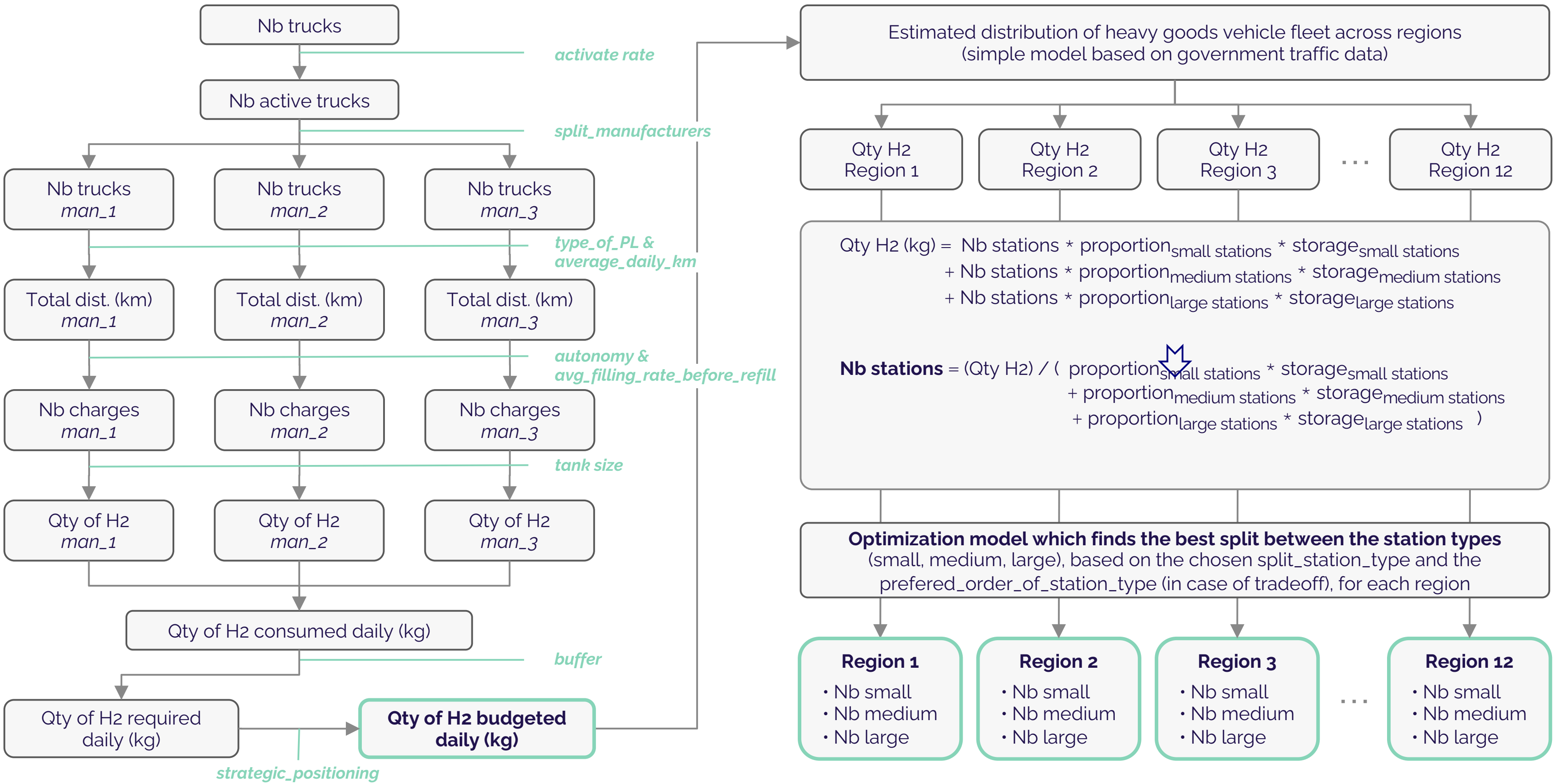
First problematic: sizing the H2 truck charging stations network in the coming decades

METHODOLOGY

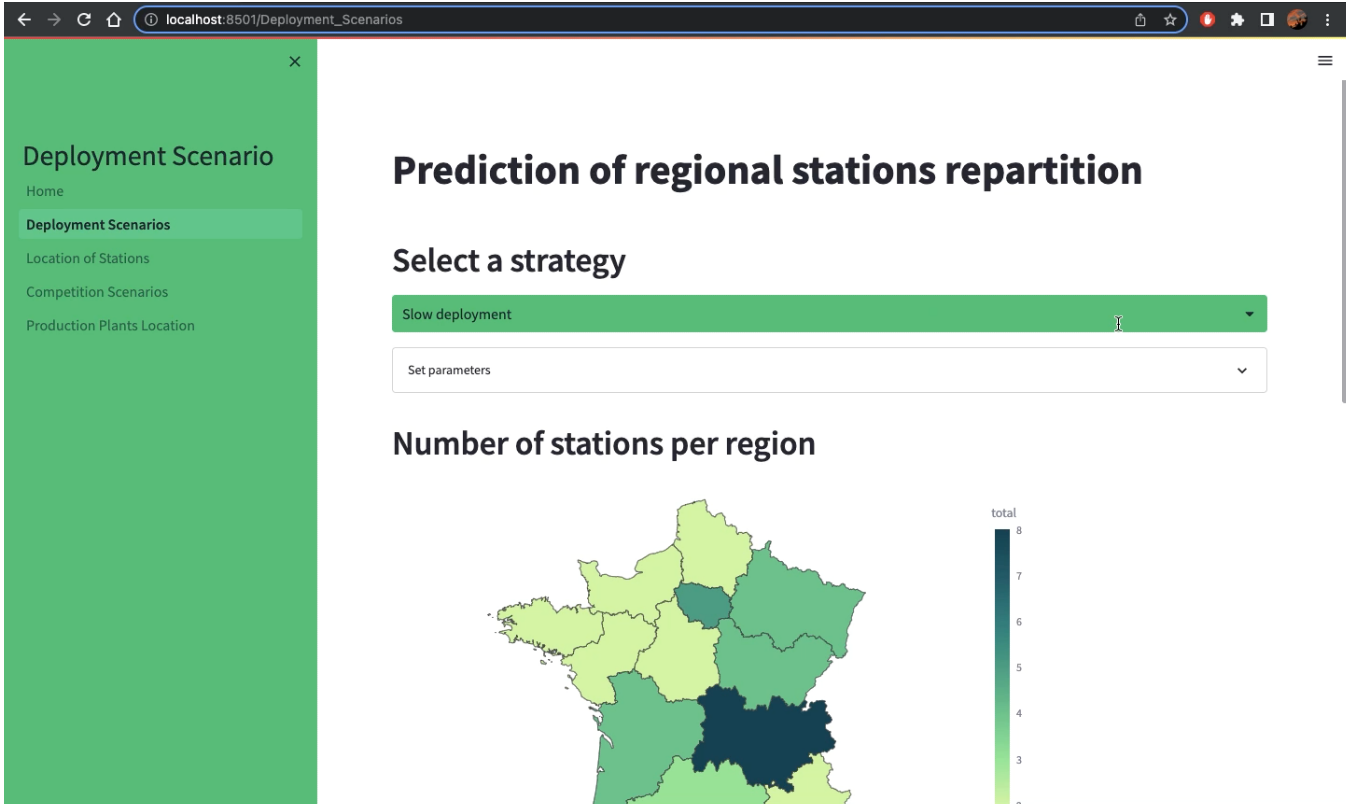
A very flexible and interpretable model which takes into account:

1. Initial assumptions/parameters:
    a. On the manufacturers: tank size, autonomy, type of PL (short or long distance), etc.
    b. On the stations: costs, storage onsite, footprint, etc.
    c. On the market: split between the manufacturers, daily average distance (for each type of PL), the security buffer, the activation rate of the fleet, the desired split between the station types (small, medium, large), etc.
2. The current distribution of trucks (based on the government traffic data)
3. The chosen positioning strategy with the strategic positioning index: 1 = meet the demand, 1.5 = get 50% ahead of the demand, etc.

H2 TRUCK CHARGING STATIONS NETWORK MODEL IN DETAILS



Visualisation of regional statistics in App



5 panels :

Description of the steps & positions taken

- Number of stations per region for the scenarios
- Optimal locations of H2 stations
- Competition strategies
- Optimal location of H2 production plants

BASED ON AIR LIQUIDIC STRATEGIC POSITIONING, WE IDENTIFIED THREE SCENARIOS

Here, we considered a setup with those parameters:

- nb_trucks: 10k (2030) and 60k (2040)
- activation_rate: 80% - security_buffer: 20%
- manufacturer_split: {'man_1': 1/3, 'man_2': 1/3, 'man_3': 1/3}
- station_split: {'small': 1/2, 'medium': 1/3, 'large': 1/6}

We get those results:

- 2030: 231,648 kg of H_2 → 93 stations (49 small, 34 medium, 10 large)
- 2040: 1,389,888 kg of H_2 → 529 stations (269 small, 178 medium, 82 large)

Conservative: Playing it Safe

Scenario description

- Low coverage of H_2 station need
  strategic_positioning_index: ***50%***
- Certainty to have high demand.
- Possible drawback : slow down of the trucks replacement.

Number of stations to build

- 2030: 47 (25 - 17 - 5)
- 2040: 265 (135 - 89 - 41)

Medium: Patiently Progressive

Scenario description

- Cover the estimated demand
  strategic_positioning_index: ***80%***
- High probability to have matching demand.
- In line with current previsions.

Number of stations to build

- 2030: 75 (40 - 27 - 10)
- 2040: 423 (215 - 142 - 66)

Chosen Scenario : reasonable, low risk

Bold: Visionary Leadership

Scenario description

- Plan to build more than needed
  strategic_positioning_index: ***120%***
- Less demand than offer.
- Expectations : accelerate trucks replacement and have higher number of trucks than predicted

Number of stations to build

- 2030: 111 (71 - 37 - 12)
- 2040: 635 (323 - 213 - 99)

Part 2 - Location Identification

- Identify what makes a good location for a H2 Station
- Find best spots for such stations across the country

Output of Part 1 on a region-to-region basis to get the number of different stations to build

↓

The data

Locations of existing Total stations

Locations of major industrial areas

Mapping of the French road network

Road traffic data throughout the years

↓

Identified locations per region

First model - Greedy Permutations

- Use “points de repères” from motorway traffic data as potential locations for stations
- Proceed on a station type basis (big then medium then small)
- Assign a “fitness” score to each PR based on profitability threshold, traffic and distance to industrial areas
- Randomly select a permutation of PRs and evaluate their total fitness, compounded by their distance to each other
- Output the “fittest” found permutation

Profitability = F (Traffic, consumption, Station type)

Point fitness = F (profitability, distance to IA)

Permutation fitness = F (point fitness, distance between points)

Greedy Permutations

Example: Say we want 1 large, 2 medium and 2 small stations in the department 66

- Explainability
- Customizability
- Large network

- Computational cost
- Simple approach
- Randomness

Big

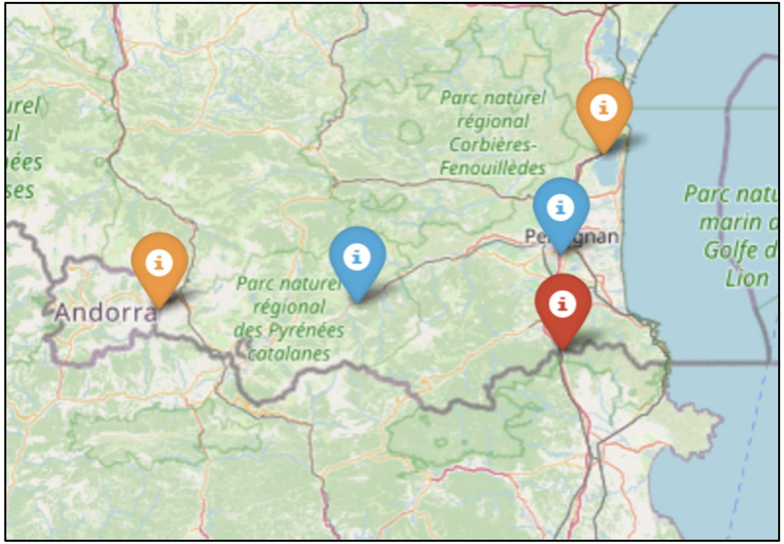
	point	coords	fitness
0	227A000911	(698585.43, 6196493.63)	1.319786

Medium

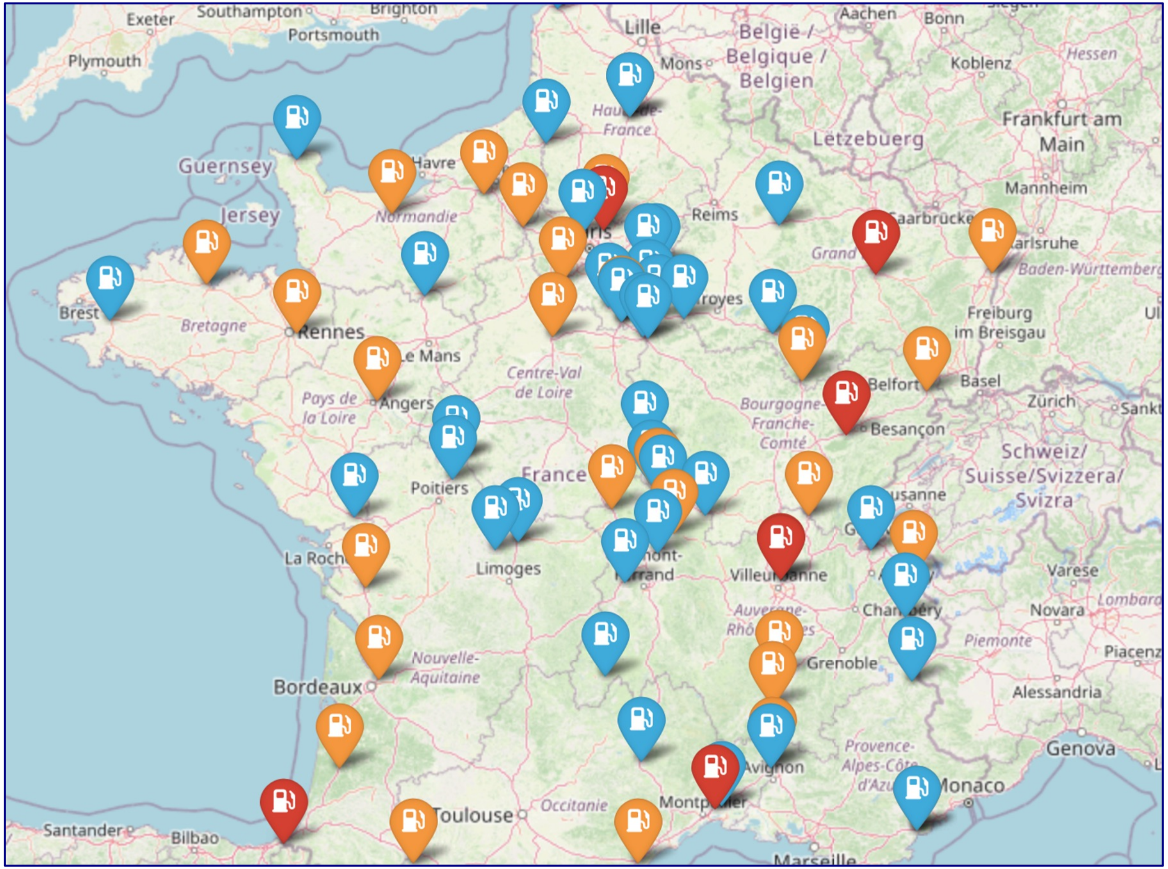
	point	coords	fitness
0	280A000966	(688911.76, 6151643.75)	1.388219
1	5N002266	(596176.86, 6161871.46)	1.855467

Small

	point	coords	fitness
0	56N011666	(641612.81, 6162697.65)	1.017484
1	255A000966	(688619.9, 6173843.4)	1.111118



Nationwide view

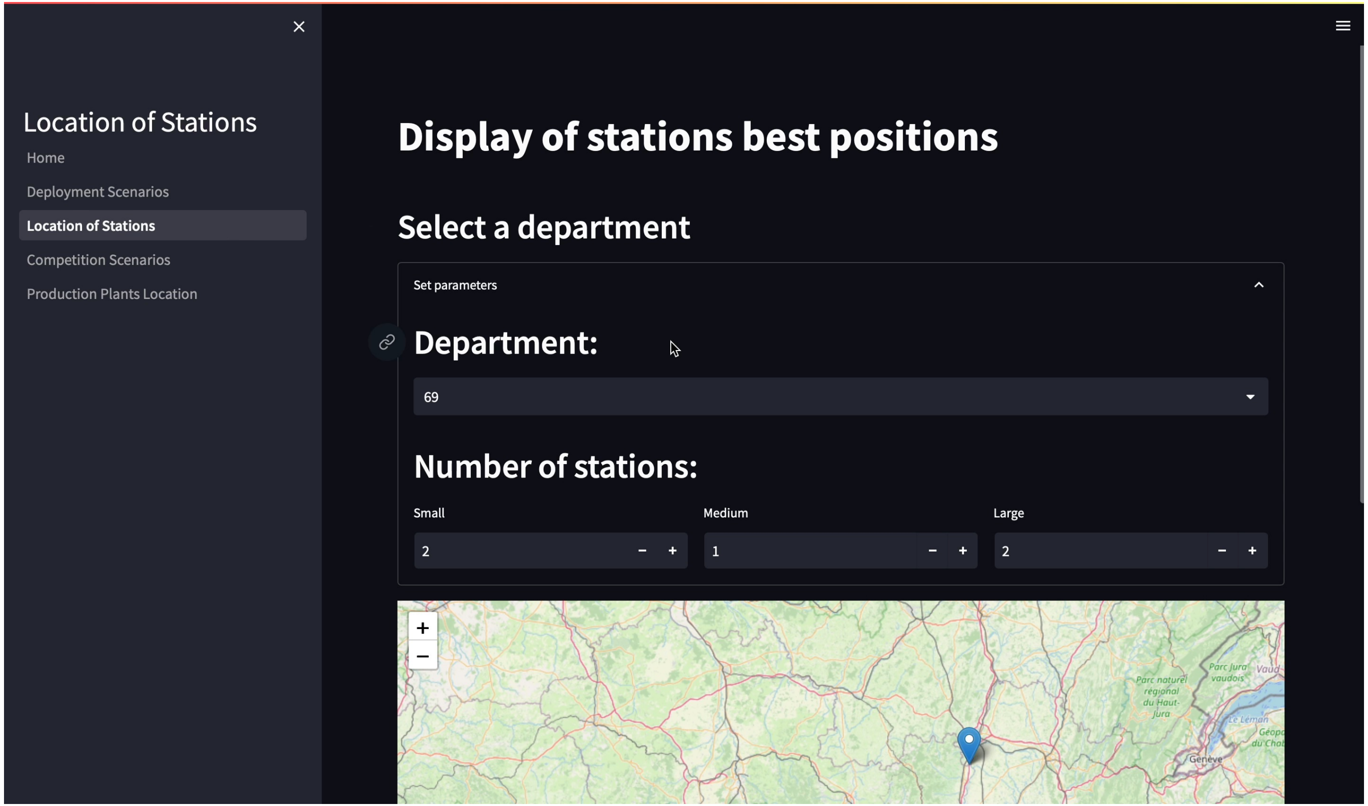


Red are big, orange medium and blue small stations

Based on 2030 predictions from part 1

Separated by region

Visualisation of regional statistics in App



Same app, different color : Background color changed since version of part 1.

Display options:

Departments (subsections of regions) : up to 101 in 2022.

Number of stations given type:

- Small
- Medium
- Big

Flexibility : change options to rerun the model & output new best locations.

Alternative model - priority based

1. Create area around each road section

Number of areas based

2. Define the number of areas you want
3. Pick the busiest road section and increase the area around it until it encompases area of france / number of areas
4. Do the same for the next busiest road section that is not in the previous area
5. Iterate until you have the number of areas you want
6. For each area, determine the center and pick the closest existing station

H2 need based

2. Define the weight of H2 you want to serve
3. Pick the busiest road section and increase the area around it until it encompases the maximum traffic servable by the chosen station size
4. Do the same for the next busiest road section that is not in the previous area
5. Iterate until all the weight can be served
6. For each area, determine the center and pick the closest existing station

Part 3 - Deployment Plan

- **Monopoly scenario**
- **Duopoly competition**
- **Late entrant**

Demand of H2 will be modelized in an exponential following the model of EV trucks deployment(1).

Find the timeline for deploying stations according to return on investment

Prioritise stations with the best score according to profitability & traffic

Adapt to the competition by maximizing relative payoff

Defined steps & strategy for deployment

(1) https://www.iea.org/data-and-statistics/data-tools/global-ev-data-explorer

Monopoly strategy

Amortization of stations (not including depreciation)

Large : 1 year and 3 month at full capacity
Medium : 1 year and 2 month at full capacity
Small : 1 year at full capacity

Set importance on mapping to incentivize growth of H2 trucks fleet

Choose location to provide H2 across France so trucks can recharge as needed

For 2030

2024

Small : 25
Medium : 24
Large : 24

Investment : 387 M€
Amortized in 2026, possible to build same amount in 2028 with no further investment

2028

Small : 24
Medium : 24
Large : 25

Investment : on payoff
Amortized in 2031

TOTAL 2030 : 148

For 2040

Same reasoning with the following steps to keep up with demand :

	2031	2033	2036	2038
Small	40	37	51	70
Medium	40	37	50	69
Large	40	37	50	69

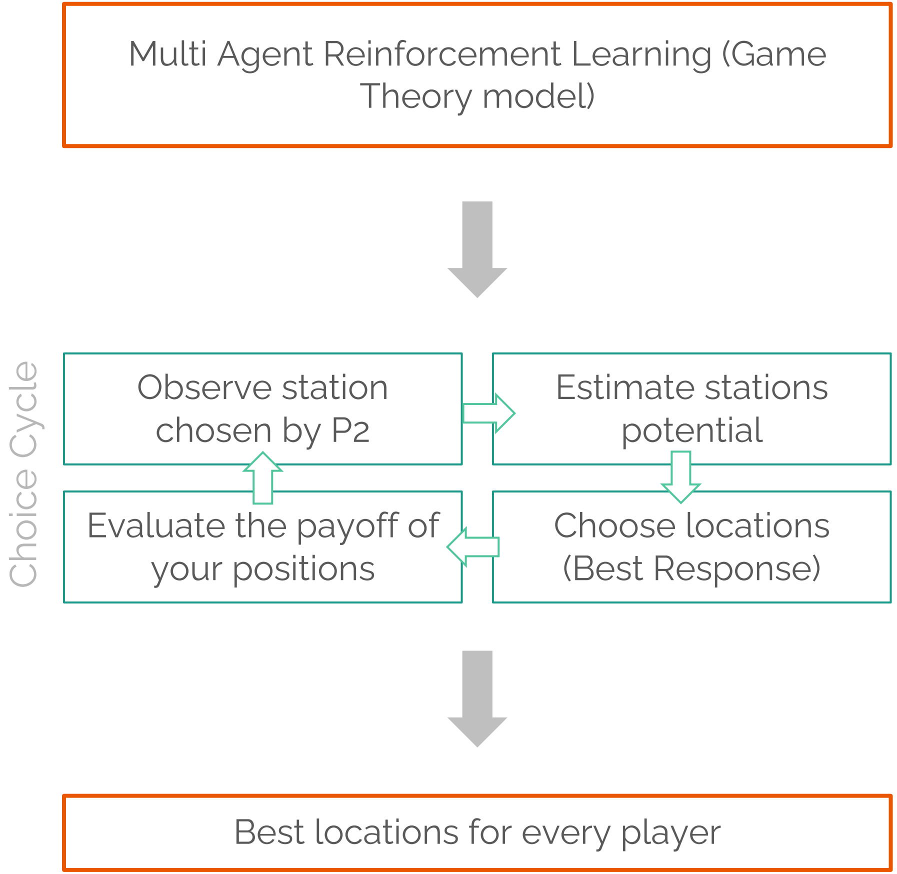
TOTAL 2040 : 740

Duopoly & Entrant Scenarios

Flexibility

Type of competition :

- Aggressive (reward if the other loses payoff)
- Pacific (reward if we are not exposed to competition)
- Number of stations chosen per round
- Learning rate



Reinforcement Learning model

Selection of stations

Explore :

Try random picking of stations

Exploit :

Select best stations according to score (best response)

Learning rate :

Balance the number of explorations / number of exploitations

Reward

Payoff of each station:

- (storage x H_2 price) if max of H_2 needed is not covered.
- Weighted distributed payoff if H_2 offered by both players in the region > H_2 needed

Final reward: payoff …

- … adjusted with a coeff of number of adverse stations in the area if strategy is safe.
- … adjusted with payoff of other player if strategy is bold

Update

Removing the stations already chosen from possibilities.

Updating the score of each station given its payoff relative to the general payoff taking closeness to opponent into account depending on strategy

Training

Choose number of batch to train the model.

Play the game as many times as batch & refine the station score through training using the update & keeping previous update in memory.

Results Duopoly for 2030

2 steps of selection

Strategy : safe

74 stations chosen per round

Batch = 10

AirLiquide

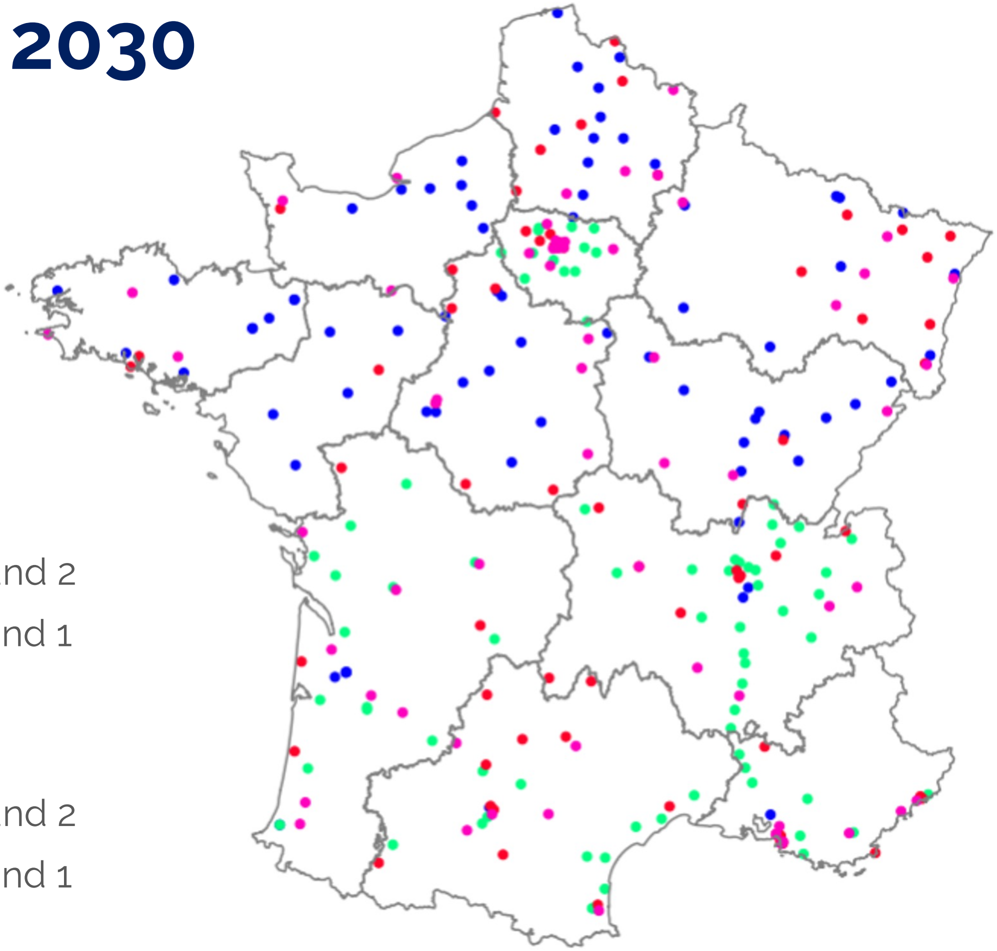
2030 - round 2

2026 - round 1

Competitor

2030 - round 2

2026 - round 1



Entrant Scenario

compute the remaining capacity to provide

Modelise the deployment of the competitor given an exponential following the deployment of trucks

Compute H2 quantity offered per region

Subtract from total needed quantity modelised per year per region (exponential too)

Find advantage threshold

When the remaining H2 need per region is too low to allow for new stations plan to be profitable → threshold to enter on the market.

After it will not be profitable to enter the market.

Deploy according to strategy game of duopoly

Given the remaining quantity to provide : compute possible number of stations per region.

Deploy these station in the same optimized framework than for the duopoly

Can be simplified by following the priority order previously defined

Deployment road map (Part 3)

Monopoly

	2025	2028	2031	2033	2036	2038
Small	25	25	40	37	51	70
Medium	24	25	40	38	50	70
Large	24	25	40	37	50	69
	73	*148*	*268*	*380*	*531*	*740*

Duopoly

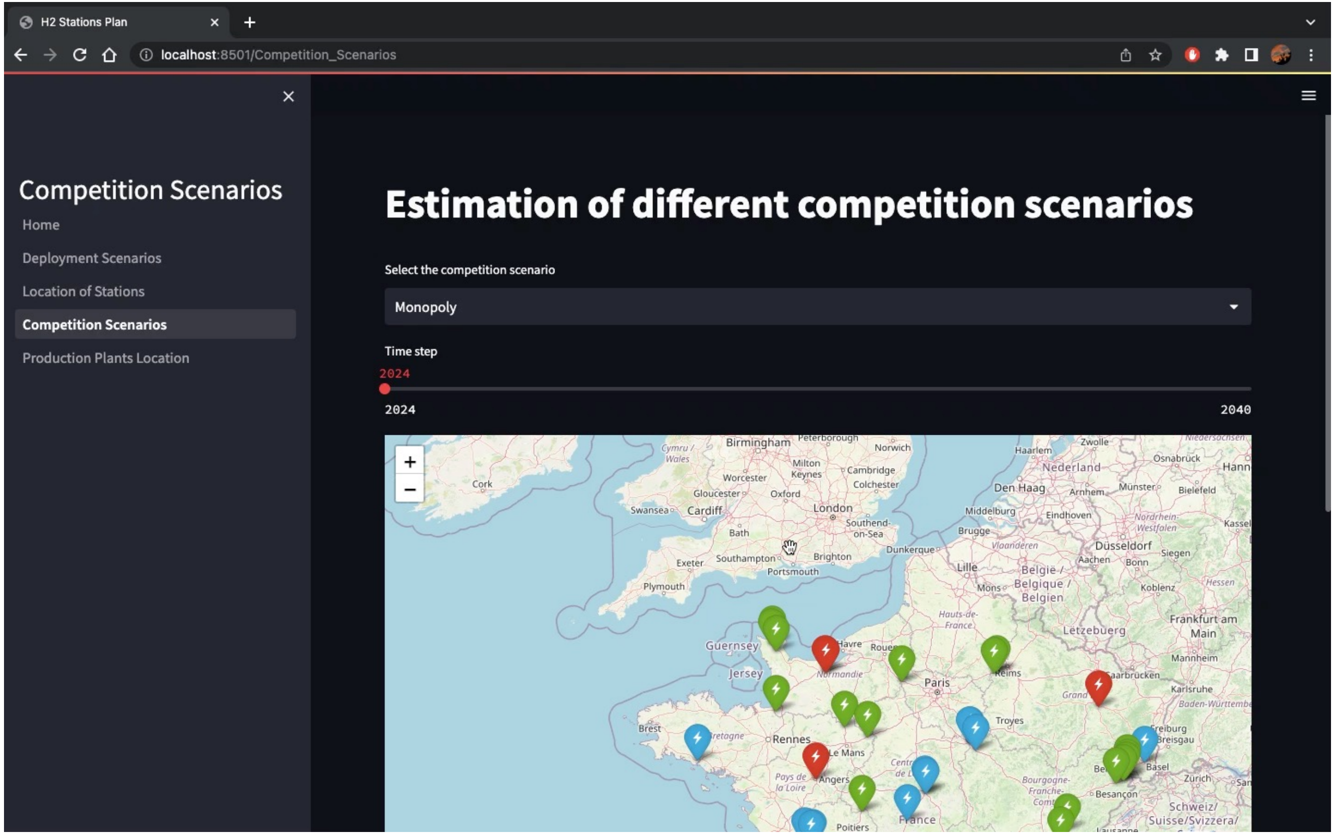
	2025	2028	2031	2033	2036	2038
Small	13	13	20	19	25	34
Medium	12	13	19	18	25	35
Large	12	13	20	19	25	35
	37	*76*	*135*	*191*	*266*	*370*

Late Entrant

Last year to enter

	2025	2028	2031	2033	2036	2038
Small	5	7	10	10	25	34
Medium	6	7	19	18	13	18
Large	6	7	10	10	13	18
	17	38	77	115	166	236

Visualisation of scenarios in App



Legend :

Monopoly :

- Green : small stations
- Blue : medium
- Red : large

Duopoly & late entrant:

- Green : our stations
- Red : competitor

Possible to choose the time step

Part 4 - H2 production facilities

- Size the need for H2 production plants based on stations data
- Identify what makes a good location for building a H2 production plant
- Find best locations according to our strategy

Output of Part 2 on region-linked target number of different stations

The data

Building and transport costs

Number of necessary plants

Potential locations dataset

Production and capacity

Identified locations over the whole territory

Defining our model parameters

Potential locations

- Need an expansive dataset for permutations
- Across whole territory
- Coherent with production plants

Industrial areas dataset

Sizing the need (2030 example)

Number of different stations needed

	region	quantity_h2_to_reac	quantity_h2_propose	small	medium	large	total
0	Auvergne-Rhône-Alp	41995	42000	8	6	2	16
1	Bourgogne-Franche-	17826	18000	4	2	1	7
2	Bretagne	7479	8000	1	2	0	3
3	Centre-Val de Loire	7985	8000	1	2	0	3
4	Grand Est	17201	18000	4	2	1	7
5	Hauts-de-France	9722	10000	2	2	0	4
6	Normandie	9338	10000	2	2	0	4
7	Nouvelle-Aquitaine	20772	21000	4	3	1	8
8	Occitanie	15763	16000	3	2	1	6
9	Pays de la Loire	6901	7000	2	1	0	3
10	Provence-Alpes-Côte	8152	10000	2	2	0	4
11	Île-de-France	22183	23000	5	3	1	9
12	Total	185317	191000	38	29	7	74

H2 requirements per station (at profitability threshold)

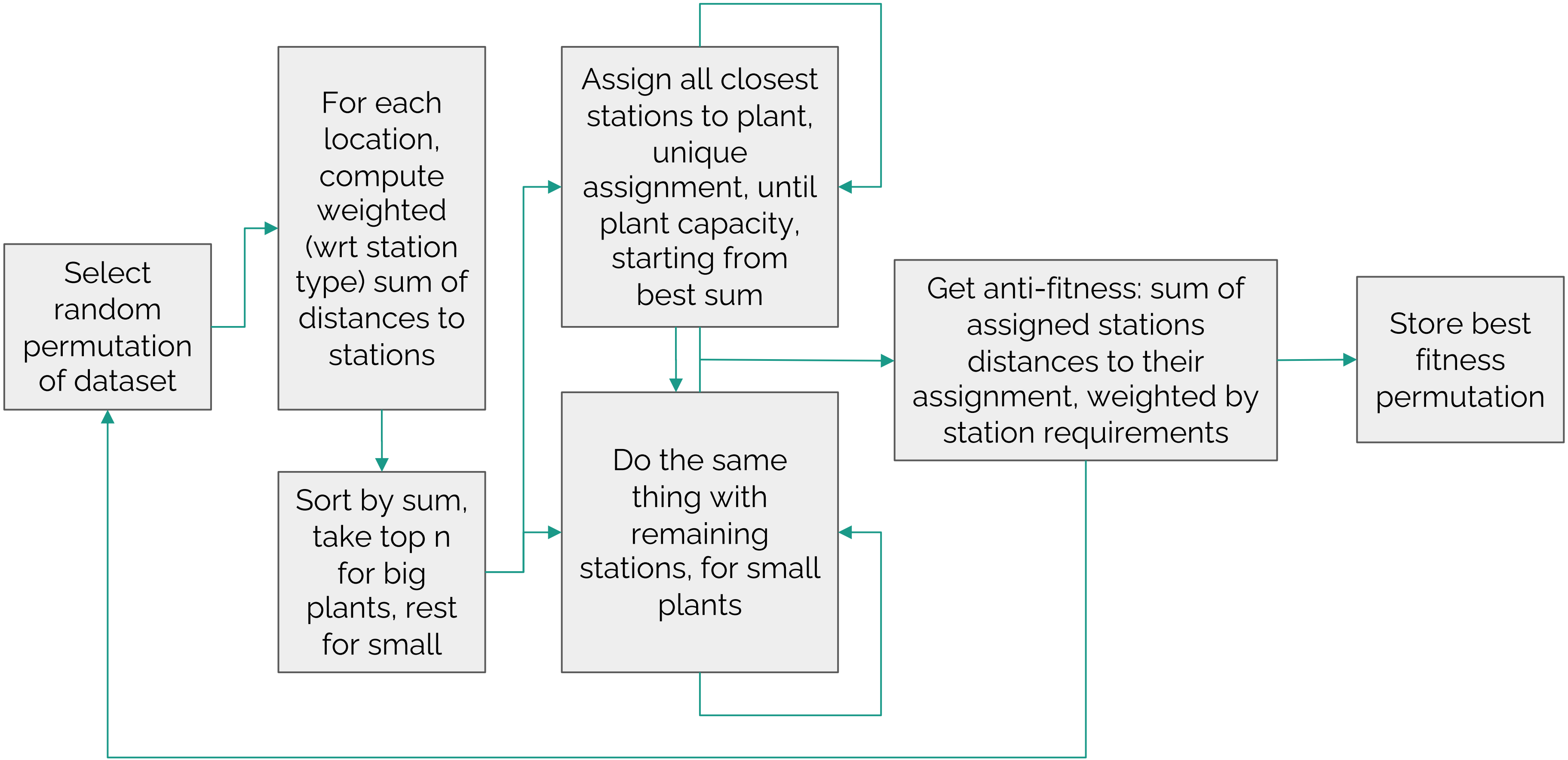
		Small - 1 tpd	Medium - 2 tpd	Large - 4 tpd
Capex (installed equipment)	m€	3	5	8
Depreciation	y	15	15	15
Yearly Opex	% of Capex	10	8	7
Storage Onsite	tH2	2	3	4
Construction time	y	1	1	1
Footprint	m2	650	900	1200
Profitability threshold	load (%)	90	80	60

Costs and production per H2 plant

		Small - 5MW	Large - 100MW
Capex (installed equipment)	m€	20	120
Depreciation	y	15	15
Opex (O&M, etc)	% of Capex	3	3
Power usage	kWh/kgH2	55	50
Water consumption	L/kgH2	10	10

Optimal Composition: **3 big and 5 small stations**

A more complex permutation-based model



Results and analysis

Red are large production plants, green are small

- ~ 600 potential locations
- Performed on 2030 stations dataset → 74 stations across the country
- Find best locations according to our strategy

	e1	center	big	lon	lat
0	595.0	(476894.29758616723, 6852370.098878635)	1.0	-0.034219	48.732871
1	2431.0	(348110.12465595786, 6785919.327932795)	1.0	-1.728165	48.078805
2	1553.0	(459195.3388018943, 6706610.073236429)	1.0	-0.194512	47.415993
3	1171.0	(759470.3392490665, 6259114.507366363)	0.0	3.734119	43.428653
4	693.0	(409641.850507698, 6260182.298579458)	0.0	-0.582506	43.381479
5	888.0	(693016.0716674337, 7061847.219311408)	0.0	2.901414	50.653500
6	139.0	(879871.0807835811, 6259419.916361741)	0.0	5.219965	43.411138
7	856.0	(207907.98133333336, 6772254.596)	0.0	-3.589191	47.865792

Cost-efficiency based analysis

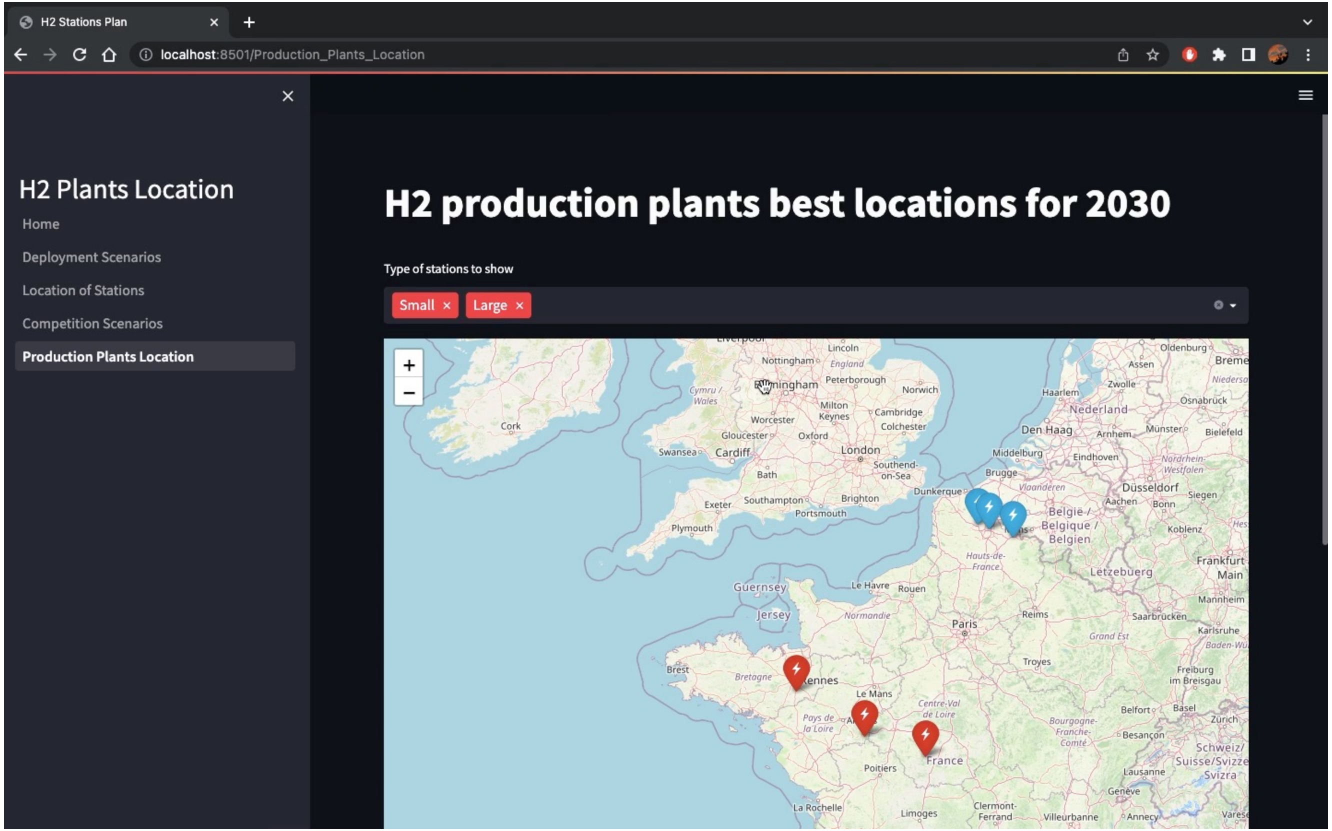
Station - plant mapping

Coherence with industrial locations

Very Computationally expensive : could only study ~4000 permutations in ~2h

Would require optimization or larger computational resources

Visualisation of H2 plants for 2030 in App



Current version :

Select options :

- small plants
- large plants
- both

Display each type of production plants according to choices.

Future version will include the 2040 stations.