Mise en place d'un jumeau numérique pour la mobilité et la qualité de l'air à Versailles Grand Parc

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Rencontres de la modélisation des déplacements, 19 mai 2025

PLAN

Mobilité durable

- **Context**
  - Tools for Monitoring Mobility Decarbonation Trajectories
  - UPPER EU project overview
  - PARIS LEZ context

- **Study of Adaptation Scenarios for the LEZ in Ile-de-France**
  - Simulation framework
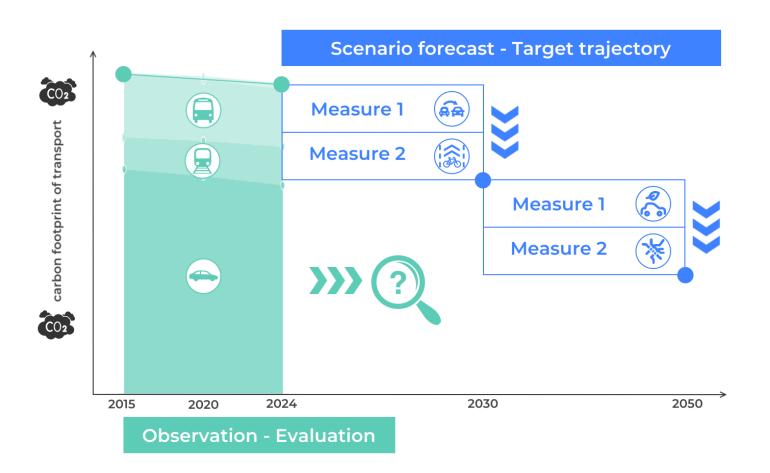 - Adaptations Scenarios
  - Results

TOOLS FOR MONITORING MOBILITY DECARBONATION TRAJECTORIES

Sustainable mobility

OBJECTIVES

Provide digital decision-support tools for territories to :

- **Define trajectories for decarbonizing mobility by quantifying the impact of implementing actions**

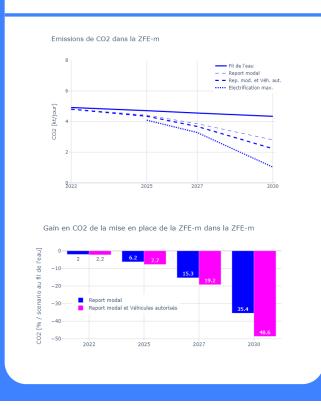- **Monitor the evolution of carbon footprints by exploiting a set of dynamic mobility data**

Scenario forecast - Target trajectory

carbon footprint of transport

Measure 1

Measure 2

Measure 1

Measure 2

CO_2

CO_2

2015   2020   2024   2030   2050

Observation - Evaluation

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TOOLS FOR MONITORING MOBILITY DECARBONATION TRAJECTORIES

Sustainable mobility

Tools for quantifying the impact of implementing decarbonization measures (vehicle restriction, addition of bike lanes, bus renewal, etc.) by creating prospective scenarios. → Use of mobility models and experience feedback.
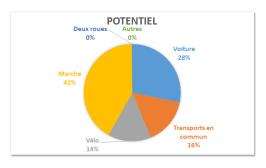
Scenario forecast - Target trajectory

Impact of LEZs on the vehicle fleet and emissions*

Emissions de CO2 dans la ZFE-m

Gain en CO2 de la mise en place de la ZFE-m dans la ZFE-m

Assessing the potential for modal shift to cycling

...

*Michel, P., Diallo, A. O., Chasse, A., and Feng, G. (2024) Enhancing Ile-de-France Agent-Based Model: Automotive Fleet Projection and Low Emissions Zone Model. *MATSim User meeting*

Scenario forecast - Target trajectory
Observation - Evaluation
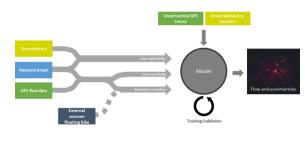
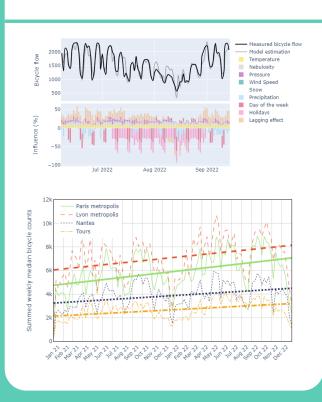## Estimation of traffic flow with multi-fidelity approach

Analysis of highlights in the temporal evolution of flows*

...

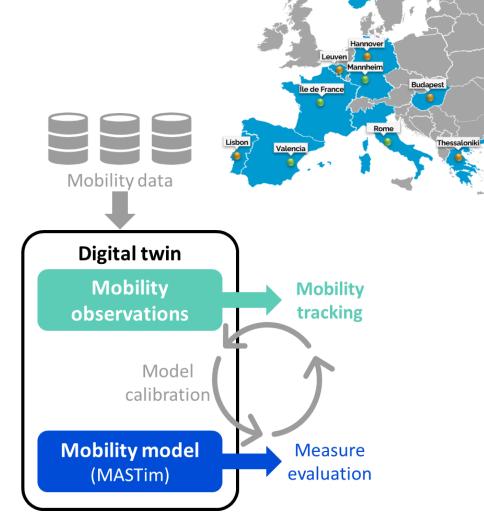Handling and merging a heterogeneous set of mobility data to provide the most accurate and up-to-date picture of mobility as possible
➔ Exploiting the potential of data using data processing sciences

*Lanvin, A., Michel, P., Charléty, J., & Chasse, A. (2024). Weathering heights: An updated analytical model of the nonlinear effects of weather on bicycle traffic. *Journal of Cycling and Micromobility Research*, *2*, 100031.

UNLEASHING THE POTENTIAL OF PUBLIC TRANSPORT IN EUROPE

- UPPER living labs
- UPPER twinning cities

- UPPER is a Horizon Europe project running from January 2023 to December 2026 (Innovation action call HORIZON-MISS-2021-CIT-02-02)

- **The project will implement a combination of measures looking to promote greater use of urban public transport in cities across Europe.**

- IFPEN main activities:
  - Involvement in horizontal carbon footprint analysis and digital twin projects
  - In charge of a task on the implementation of services based on mobility data
  - Implementation of a digital mobility twin in the Versailles Grand Parc pilot site

Mobility data

Digital twin

Mobility observations → **Mobility tracking**

Model calibration

Mobility model (MASTim) → Measure evaluation

CIVITAS
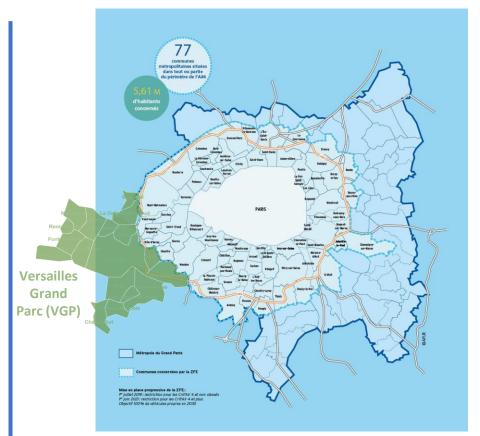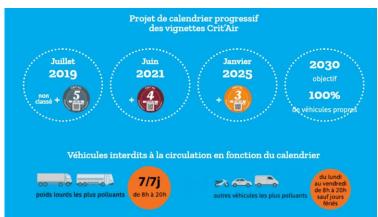Sustainable and smart mobility for all

EU MISSIONS
CLIMATE-NEUTRAL & SMART CITIES

UPPER contributes to achieving the aims of the CIVITAS Initiative and the goals of the EU Mission: Climate-Neutral and Smart Cities

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PARIS LOW EMISSION ZONE

- In France, cities where pollutant emissions thresholds defined by WHO are exceeded must implement a Low Emission Zone (LEZ)

- In Paris, the LEZ legislation includes
  - a perimeter and times slots where vehicles circulation is restricted,
  - a schedule for future restrictions,
  - and exemptions.

- The classification of vehicles in LEZ is determined by the Crit'Air system, which itself is based on the vehicle's Euro emission standard
  - Next vehicles restrictions is C3 in 2025
  - The next restriction will affect some or all vehicles classified as C2 with C2 including all diesel vehicles
  - 2030 objective of 100% of clean vehicles should be specified

Versailles Grand Parc (VGP)

*https://www.zonefaiblesemissionsmetropolitaine.fr/

STUDY OF ADAPTATION SCENARIOS FOR THE LEZ IN ILE-DE-FRANCE

DEFINITION OF A SCHEDULE UNTIL 2030

- Objective: evaluate the pollutant emissions reduction from various prospective scenarios of people's compliance with the Low Emission Zone (LEZ) until 2030

1. A restrictions schedule until 2030 is considered : very optimistic for improving air quality and very restrictive in terms of vehicles restrictions.

2. An evolution of the automotive fleet until 2030 methodology is introduced.

3. MATSim coupled with HBEFA is used to calculate vehicle pollutant and GHG emissions.

4. Several scenarios are defined and evaluated to quantify the impact of individuals adaptation to the LEZ such as switching to authorized vehicles and modal shift towards public transportation.

Modeled schedule of light vehicles restrictions

2022
Crit'Air 4 and 5 restrictions

2025
Crit'Air 3, 4 and 5 restrictions

2027 ➔ End of diesel
Crit'Air 2 to 5 restrictions
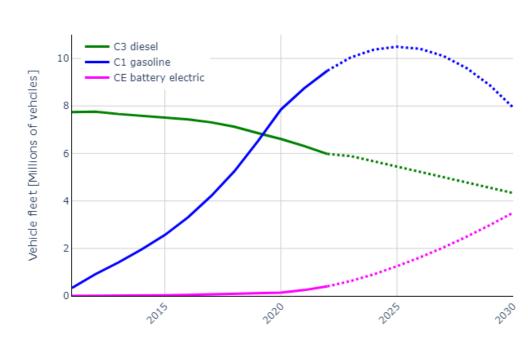
2030 ➔ End of combustion engine
Crit'Air 1 to 5 restrictions

FLEET GENERATION IN 2022 AND PROJECTION UNTIL 2030

Sustainable mobility

- The current fleet is defined using vehicle registration open-data* in France

- Definition of a local projection methodology until 2030:
  - for each fuel type including petrol, diesel, electric, diesel hybrid, petrol hybrid, and plug-in hybrid
  - and for each Crit'Air sticker
  - a projection of the vehicle fleet is conducted using a least squares method to model the trend that best predicts the fleet after 2022 based on French vehicle fleet open-data (SDES data)

- Several trends are defined
  - Linear decrease for all diesel vehicles
  - Linear decrease for all Crit'Air 2 petrol vehicles
  - Parabolic trend for Crit'Air 1 petrol vehicles
  - Exponential growth for Crit'Air 1 PHEVs
  - Exponential growth for Crit'Air E BEVs

*https://www.statistiques.developpement-durable.gouv.fr/donnees-sur-le-parc-automobile-francais-au-1er-janvier-2023

Sustainable mobility

- **Eqasim** generates Ile-de-France* population, travel demand and light vehicle fleet
  - The approach allows to assign a vehicle to each agent while retaining an age and energy distribution
- **MATSim** to model agent vehicle use and simulate change of behavior with the LEZ
- MATSim emissions contribution coupled with HBEFA to calculate pollutant (NO_X and particles) and GHG (CO_2e) emissions simulation with HBEFA factors

NO_X emissions for one agent vehicle from MATSim

Tools and outputs

eqasim
- IdF population
- IdF trave demand
- Vehicle fleet
- Road network

MATSim
- Agent displacements
- Agent LEZ behavior

Emissions contribution
- NO_X and particles pollutant emissions
- GHG (CO_2e) emissions

*Hörl, S. and M. Balac (2021) Synthetic population and travel demand for Paris and Île-de-France based on open and publicly available data, Transportation Research Part C, 130, 103291.

Sustainable mobility

- A reference simulation is performed without LEZ modeling to quantify the impact of natural fleet evolution on emission
  - ➔ **Agents impacted by the LEZ** are identified i.e., individuals using vehicles banned from circulation in the LEZ area in the reference simulation

- Scenarios to model and evaluate emissions impact of changes in individuals' mobility behavior in the face of the implementation of measures restricting the use of private cars, such as the LEZ
  - ➔ Different behaviors exist for an agent to adapt himself to the LEZ, with some proportions hypothesis
  - ℹ 1. Maintain the trip with another vehicle not affected by the restrictions (40% of impacted agents)
  - ℹ 2. Switch to public transport (30% of impacted agents)
  - 3. Switch to other modes, change their route to circumvent the LEZ, abandon the trip or commit fraud

3 scenarios

Reference
- Natural fleet evolution
- LEZ impacted agent identification

Switch to PT
- Switching agents to public transports identified

Vehicle change
- Vehicle reassignments to a compliant vehicle in LEZ
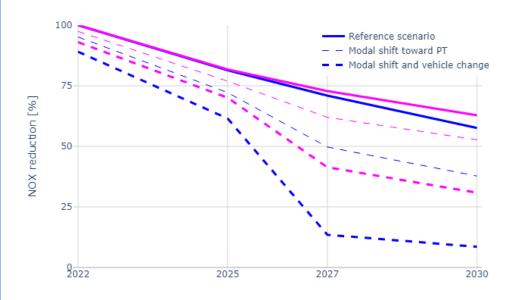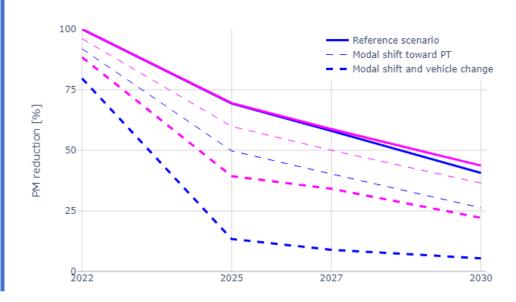
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RESULTS

- In the LEZ perimeter, natural evolution of the vehicle fleet reduces NO_X and particles emissions by about respectively 5% and 6% per year

- LEZ implementation achieve important pollutant emissions reduction especially
  - Particles emissions in 2025 when the circulation of Crit'Air 3 vehicles is banned
  - NO_X emissions in 2027 when the circulation of Crit'Air 2 vehicles is banned

- In the Ile-de-France perimeter, same conclusions can be drawn with less significant reductions confirming that the low-emission zone (ZFE) has an important impact on pollution reduction even outside its area of application

NOX emissions reduction
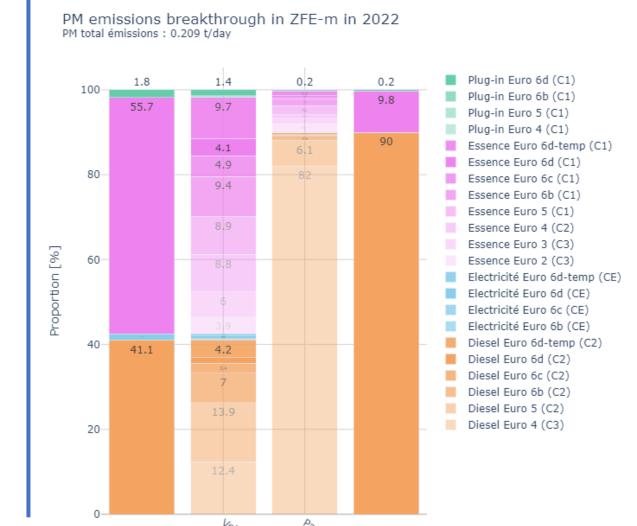
Particles emissions reduction

Diesel vehicles represent 41,1% of the vehicles circulating in the ZFE-m and account for 90% of particles emissions

- Euro 4 diesel vehicles represent 12.4% of the vehicles circulating in the ZFE-m and account for 82% of particulate emissions.
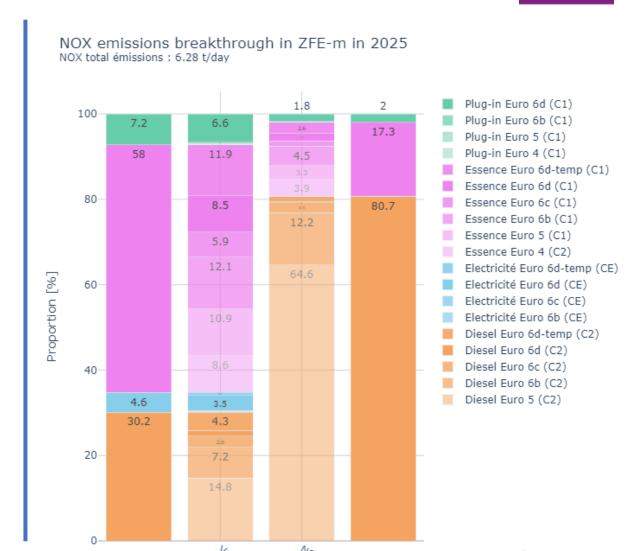

PM emissions breakthrough in ZFE-m in 2022
PM total émissions : 0.209 t/day

Sustainable mobility

- Diesel vehicles represent 30.2% of the vehicles circulating in the ZFE-m and account for 80.7% of NOX emissions
  - Euro 5 diesel vehicles represent 14.7% of the vehicles circulating in the ZFE-m and account for 64.6% of NOX emissions
  - Euro 6b diesel vehicles represent 7.2% of the vehicles circulating in the ZFE-m and account for 12.3% of NOX emissions
  - Euro 6c or newer diesel vehicles (i.e., post-Volkswagen Gate) represent 8.3% of the vehicles circulating in the ZFE-m and account for 3.8% of NOX emissions

NOX emissions breakthrough in ZFE-m in 2025
NOX total émissions : 6.28 t/day

- Analysis of the Crit'Air sticker ban on 3 axes towards the LEZ-m in the VGP area: A86, A12, and D10

- Different VGP inhabitants' contribution on traffic depending on the axes

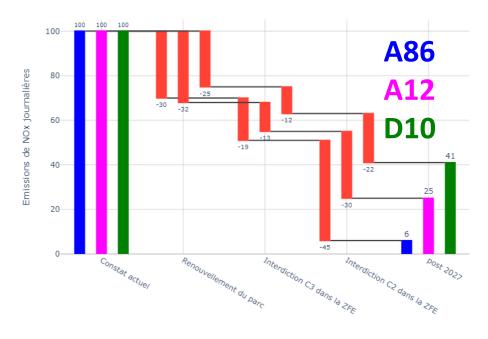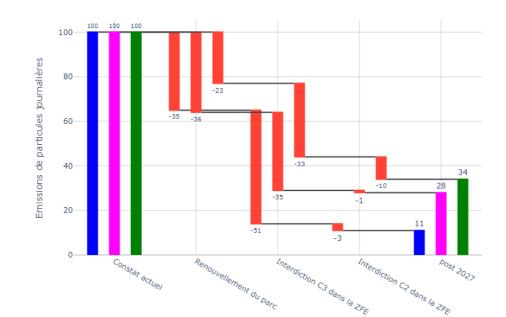|	Intra-VGP	To or from VGP	To or from ZFE
A86	3%	46%	62%
A12	2%	23%	43%
D10	45%	100%	42%
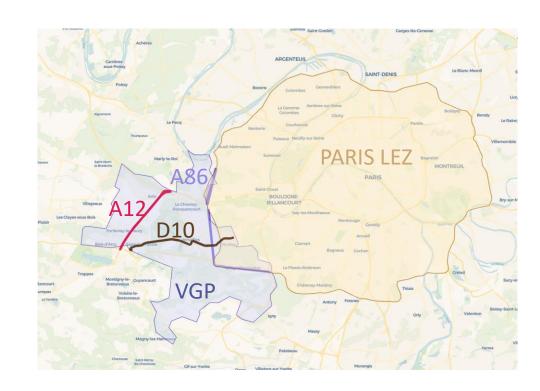
LEZ INDIRECT EFFECT IN VERSAILLES

- Analysis of the Crit'Air sticker ban on 3 axes towards the LEZ-m in the VGP area: A86, A12, and D10

- The LEZ has an indirect effect on each of the analyzed axes
  - The effect is more significant on the A86 and, to a lesser extent, on the A12 compared to the D10
  - The ban on Crit'Air 3 stickers allows for a significant reduction in particulate matter emissions
  - The ban on Crit'Air 2 stickers allows for a significant reduction in NO_X emissions

Effets du renouvellement du parc et des restrictions des vingettes Crit'Air

A86
A12
D10

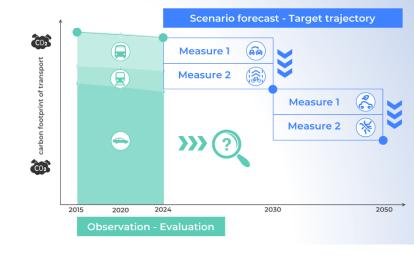Effets du renouvellement du parc et des restrictions des vingettes Crit'Air

CONCLUSIONS

- Le jumeau numérique au service de la planification territoriale
  - Synthèse des dernières sources de données avec des granularités variées
  - Modèle modulaire et évolutif adaptable aux contextes territoriaux
  - Aide à la décision pour les collectivités (villes, intercommunalités, départements)
    - **Mesurer les déplacements, la part modale, les émissions de GES et de polluants**
    - **Tester différents scénarios prospectifs pour orienter les choix stratégiques (optimisation des coûts, gains de temps, efficacité des politiques)**

<u>Le jumeau numérique</u> : un réceptacle des retours d'expérience territoriaux et un levier stratégique pour adapter, tester et affiner les politiques de mobilité.

- Perspectives
  - Intégration des flux de marchandises à l'analyse des émissions polluantes
  - Amélioration continue via la calibration dynamique avec des données en temps réel
    - Validation précise des flux de véhicules à partir des comptages disponibles

Innovating for energy

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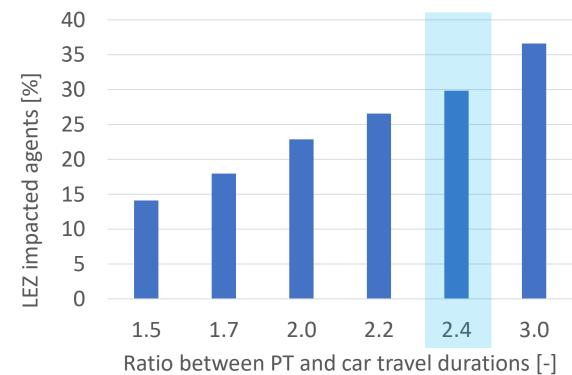🌐 www.ifpenergiesnouvelles.com

🐦 @IFPENinnovation

- Objective of shifting 30% of the individuals impacted by the Low Emission Zone (LEZ) towards public transportation

- identification of individuals based on trips likely to be made using public transportation.
  - Ratio between public transportation and car travel durations lower than 2.4 for home <-> work commuting trips
  - Rejection of individuals whose travel time by public transportation exceeds the 95th percentile, which is 1 hour and 38 minutes (on average 46 minutes in the Île-de-France region)

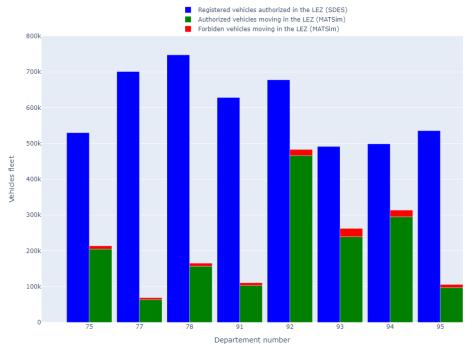|	Agents switching to PT [thousands]	PT modal share [%]	PT modal share relative increase [%]
2022	29	20,26	1,1
2025	82	20,67	3,1
2027	208	21,65	7,9
2030	473	23,63	17,9

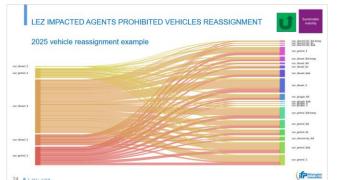# LEZ IMPACTED AGENTS PROHIBITED VEHICLES REASSIGNMENT

- Once LEZ impacted agents are identified, non-compliant vehicles are replaced based on ZFE-m compliant engine technologies distribution in each department

- LEZ compliant vehicle stocks (blue bars) are checked to ensure that reassigned vehicles (red bars) are physically available for agents.
  - Reassignments in 2022 and 2025 are straightforward with sufficient vehicles available.
  - Reassignments in 2027 are sensible because all vehicles available in the stock are allocated to the agents
  - 2030 reassignment is a theoretical case with a shortage of vehicles because only electric vehicles are considered

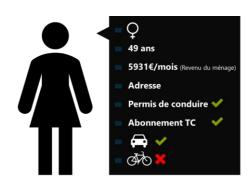## 2025 vehicle reassignment example

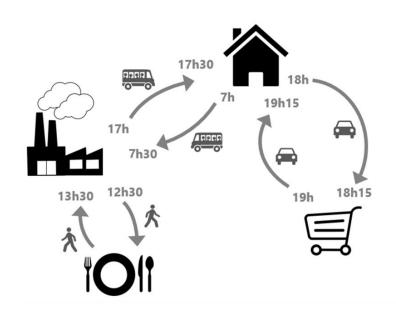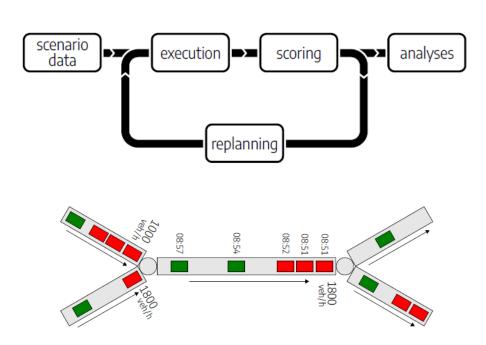# MULTI-AGENT MODEL - MATSIM

- Use of MATSim, an open-source and international project
  - Multi-agent model for mobility
  - Modeling individual behaviors
  - Interactions between agents and their environment
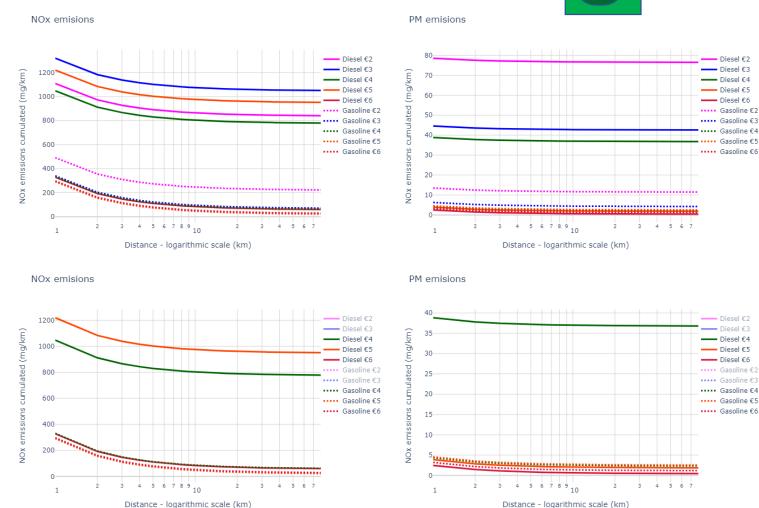 - Extended use at IFPEN using the Eqasim project"

MODELING EMISSIONS USING HBEFA EMISSION FACTORS

- Diesel vehicles particles emissions are higher than gasoline vehicles before €5

- In 2025 Crit'Air 3 vehicles restrictions corresponding to diesel €4 vehicles
  - ➜ important particles reduction

- Diesel vehicles NO_X emissions are higher than gasoline vehicles before €6

- When diesel vehicles €2 should be restricted in the LEZ?
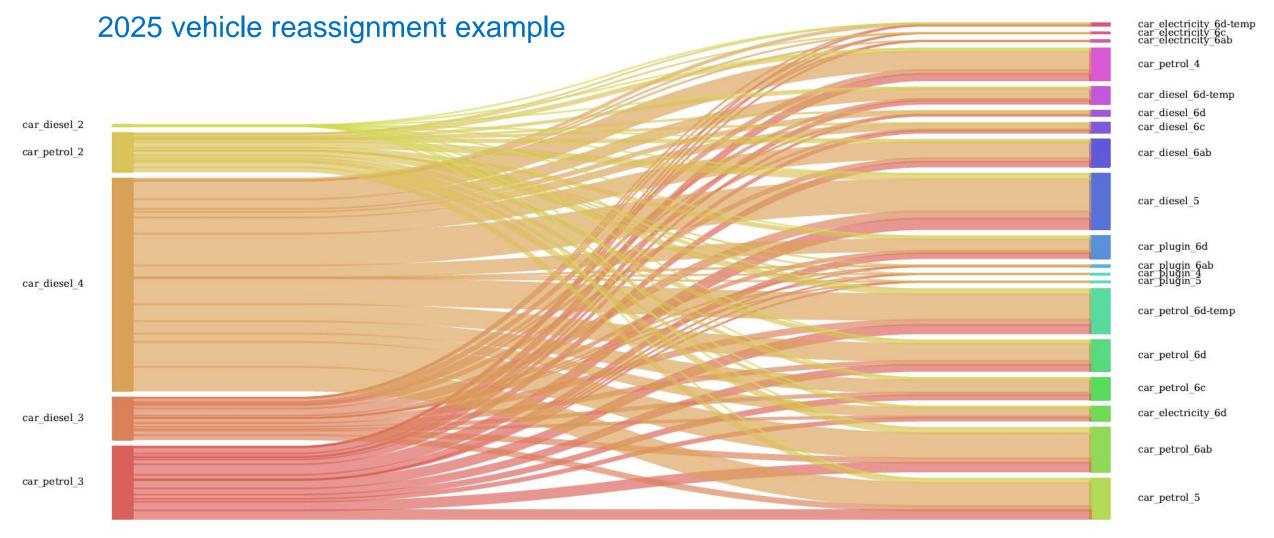 - ➜ important NO_X reduction

	Crit'Air 1	Crit'Air 2	Crit'Air 3	Crit'Air 4	Crit'Air 5	Non-classified
LEZ year	? (2030)	? (2027)	2025	2021		2019
Gasoline	Euro 5 & 6	Euro 4	Euro 2 & 3			Euro 1 and older
Diesel		Euro 5 & 6	Euro 4	Euro 3	Euro 2	Euro 1 and older

Sustainable mobility

2025 vehicle reassignment example

Trips on A86 through VGP