METROPOLIS2 & Synthetic Populations

+

Lucas Javaudin & André de Palma
THEMA, CY Cergy Paris Université

Synthetic population workshop

November 8th, 2024

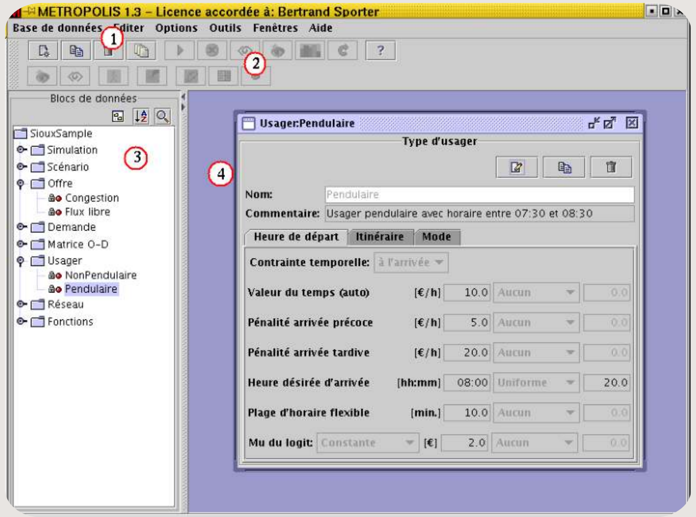
Outline

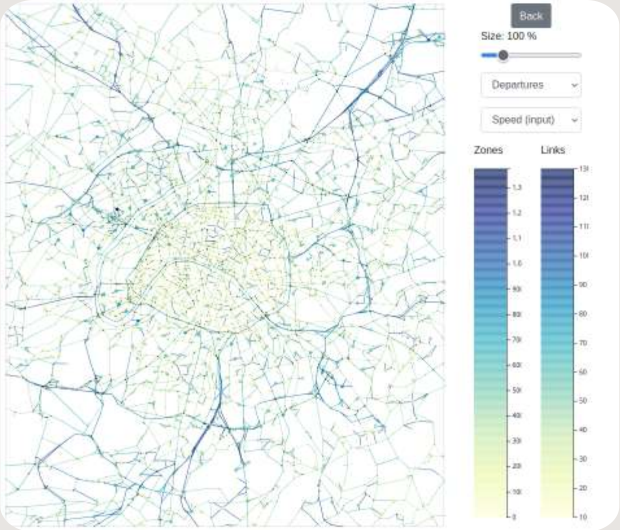
1. METROPOLIS2 Overview
2. Using and augmenting the synthetic population
3. Case studies

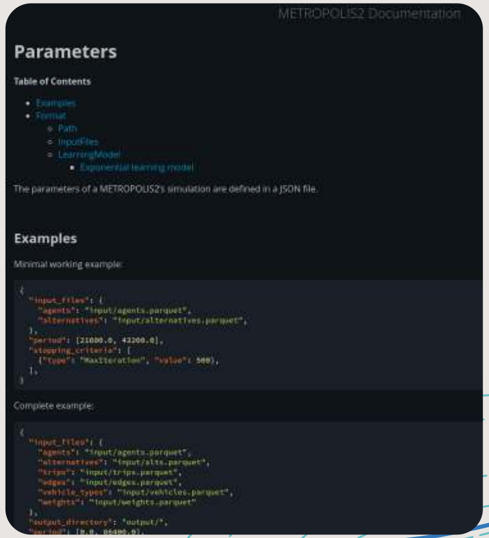
METROPOLIS2 Overview

History of METROPOLIS

+ 1994-1995: first simulator of METROPOLIS1 [C++] (A. de Palma, Y. Nesterov)
+ 1996-2003: simulator [C++] & Interface [Java] for METROPOLIS1 (A. de Palma, F. Marchal)
+ 2004-2018: applications, calibration, case studies, interface with VISUM
+ 2018-2021: Web interface for METROPOLIS1 [Python Django] (L. Javaudin)
+ 2021-: METROPOLIS2 [Rust] (A. de Palma, L. Javaudin), external modules [Python]

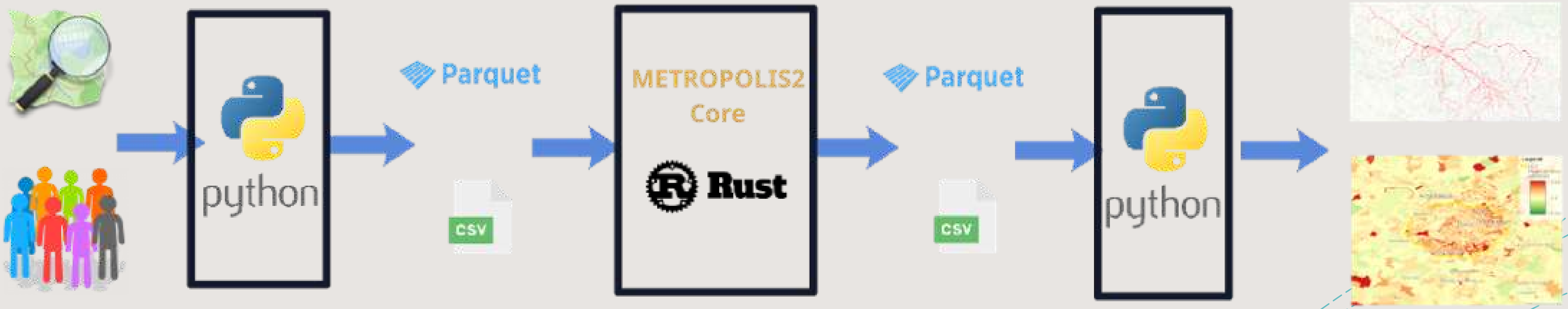






Workflow of METROPOLIS2

1. Python scripts are processing raw data to create the simulator's input data
2. The simulator reads input data and writes output data in Parquet or CSV format
3. Python scripts are processing the simulator's output data to create output tables / graphs / maps



Demand side: Discrete-choice models with agents

Agents are making travel decisions (mode of transportation, departure time, route)

Decision-making process based on **utility maximization** using **discrete-choice models** (e.g., Multinomial Logit, Continuous Logit)

Utility depends on value of travel time, schedule delays, fuel cost, etc.

Computation of **individual surplus** for policy evaluation

Demand side: Input data

List of agents with:

+ List of **trips** to perform (with origin and destination, desired departure / arrival time)
+ **Modes** available (road mode or constant-travel-time mode)
+ **Preference parameters** (e.g., value of travel time)
+ **Choice models** (how mode / departure time is chosen)

Supply side: mesoscopic & dynamic simulations

- Road trips take place on a **road network** (directed graph)
- **Vehicles** are simulated as autonomous entities
- **Mesoscopic:** Congestion is aggregated at the road-segment level
- **Dynamic:** All events are simulated in continuous time
- Congestion appears from **bottlenecks**, with queue propagation **(spillback)**

Supply side: Input data

List of road segments defining a directed graph with:

Source / target node

Length

Number of lanes

Free-flow speed

Bottleneck capacity

List of vehicle types with:

Headway length

Passenger car equivalent

Speed limit

Road restrictions

Output Data

Aggregate results (e.g., surplus, inequality measures, travel time, congestion, mode shares, vehicle kilometers)

Individual-level travel decisions (mode, departure time, route) and output (surplus, travel time, arrival time)

Road-level output (flows, travel-time function, local and global emissions)

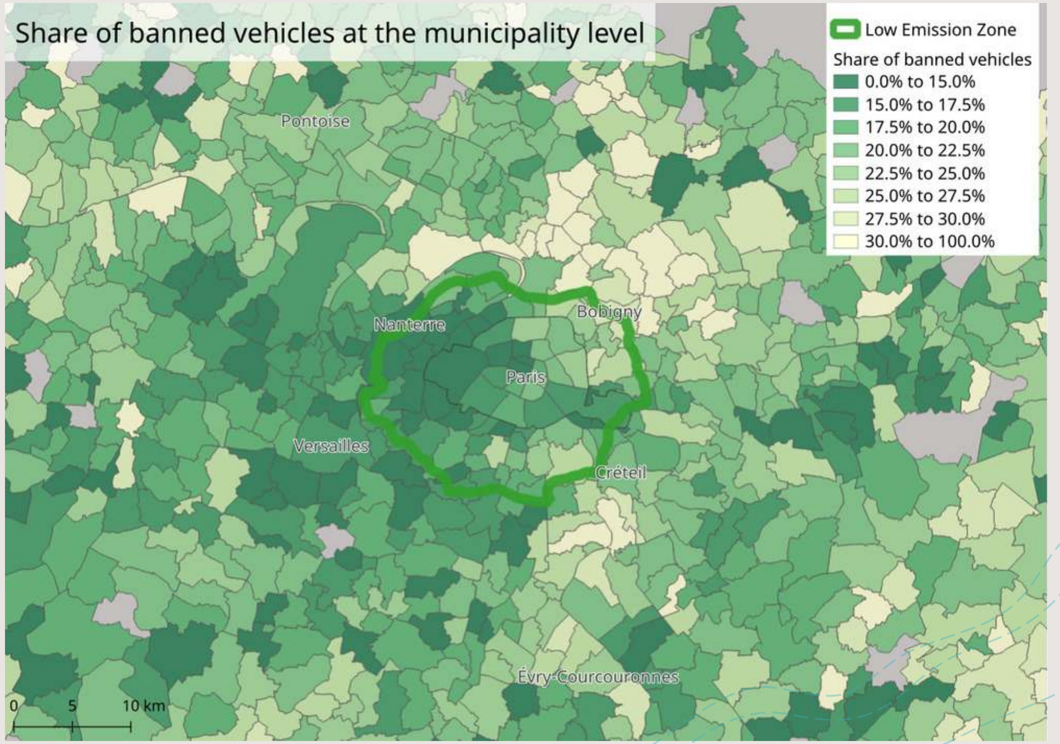
Using and augmenting the synthetic population

Household-level variables

Variable	Use
INSEE Commune	**Car ownership** (next slide)
Number of vehicles	**Car ownership** (next slide) / **access to car mode**
Number of bikes	Not used yet
Income	**Policy analysis**

Household car ownership

+ Data: **vehicle fleet at the municipality level** *(Ministère de la transition écologique)*
+ For each household with *n>0* vehicles, **draw *n* vehicles** from the vehicle fleet of the household's municipality
+ Vehicle characteristics: **fuel type** (diesel, petrol, electric, etc.), vignette **Crit'Air**, European emission standard
+ Use: computing **fuel cost** and **pollutant emissions**; Low Emission Zone restrictions



Person-level variables

Variable	Use
Sex	**Calibration**
Socio-professional class	**Calibration**
Age	Not used yet (calibration later?)
Employed	Not used yet (calibration later?)
Driving license	**Access to car mode as driver**
PT subscription	Not used yet

Trip- & activity-level variables

Variable	Use
Origin / destination	**Simulating trips**
Departure / arrival time	**Calibration**
Purpose	**Calibration**

Calibration in METROPOLIS2

Step	Calibrated parameters	Target values	Target source	Methodology
1	Intersection penalties and free-flow speed	Free-flow travel times	TomTom API	Lasso regression
2	Road capacities	Time-dependent congested travel times	TomTom API	OLS regression
3	Schedule-delay penalties by purpose	Distribution of departure times by cluster	Travel survey	Bayesian Optimization with Gaussian Process
4	Utility parameters by socio-demographic characteristics	Mode shares by cluster	Travel survey	Random Forest regression

Mode predictions & Congestion calibration

- We predict the **mode used** for each trip by estimating a **Multinomial Logit model** on travel survey data
- **Variables:** time of departure (hour), origin / destination département, Euclidean distance
- Mode predictions are used to select **all trips as car driver** to calibrate congestion

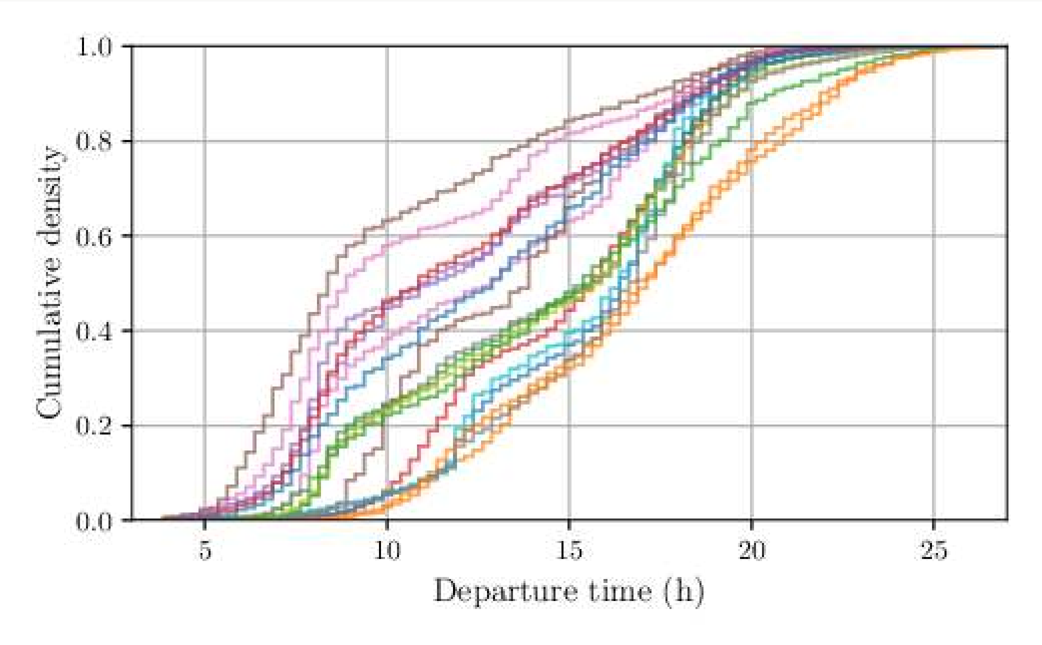
Departure-time choice

- Trade-off between **travel time** and **schedule delay**

$$V_{k|j}(t^{\mathrm{d}}, t^{\mathrm{a}}) = c_j - m_{k|j} \underbrace{-\alpha_j \cdot [t^{\mathrm{a}} - t^{\mathrm{d}}]}_{\text{travel utility}} \underbrace{-\beta_k [t_k^* - t^{\mathrm{a}}]_+ - \gamma_k [t^{\mathrm{a}} - t_k^*]_+}_{\text{schedule-delay utility}}$$

- t^* is the **desired arrival time at destination** / desired activity start time
- t^* values are **drawn for the synthetic population** based on travel survey data

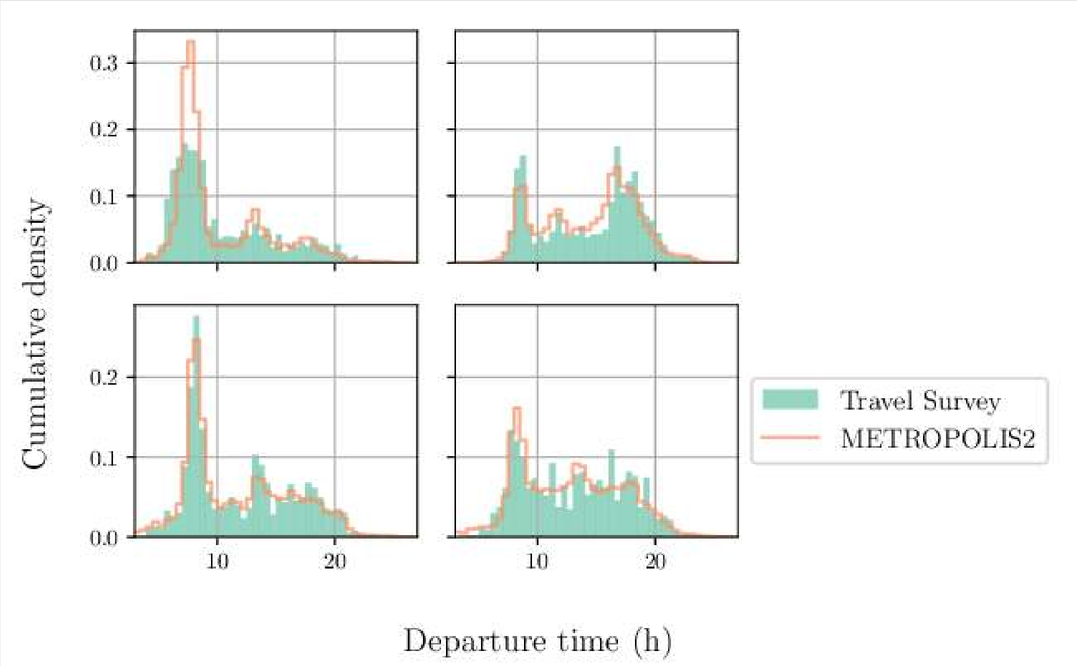
Departure-time calibration



1. Group trips in **clusters** *(K-means)* based on
   - preceding / following purpose
   - origin / destination département
   - Euclidean distance
2. Find the **departure-time distribution** in each cluster from EGT **travel survey**
3. Compute **purpose-specific schedule-delay parameters** that replicate best the departure-time distributions *(Bayesian Optimization)*

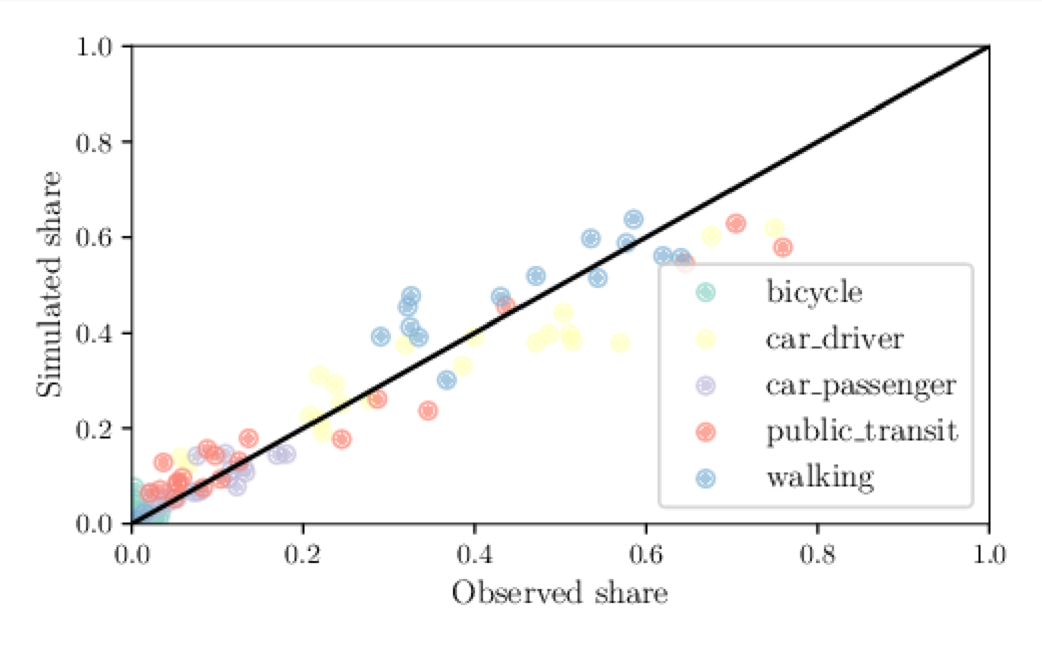
Departure-time calibration

- β: penalty for early arrivals
- γ: penalty for late arrivals



Purpose	β/α	γ/α
Work	0.61	1.16
Education	0.00	0.64
Shop	0.85	0.63
Leisure	0.25	0.03
Other	0.66	1.08

Mode calibration



- Population is split in **12 subpopulations** based on **sex** and **socio-professional class**
- **Goal:** replicate the mode shares from EGT travel survey in each cluster, for each subpopulation
- **Methodology:** Random Forest regression
- **Parameters calibrated:** utility constant and value of time for each mode, for each subpopulation

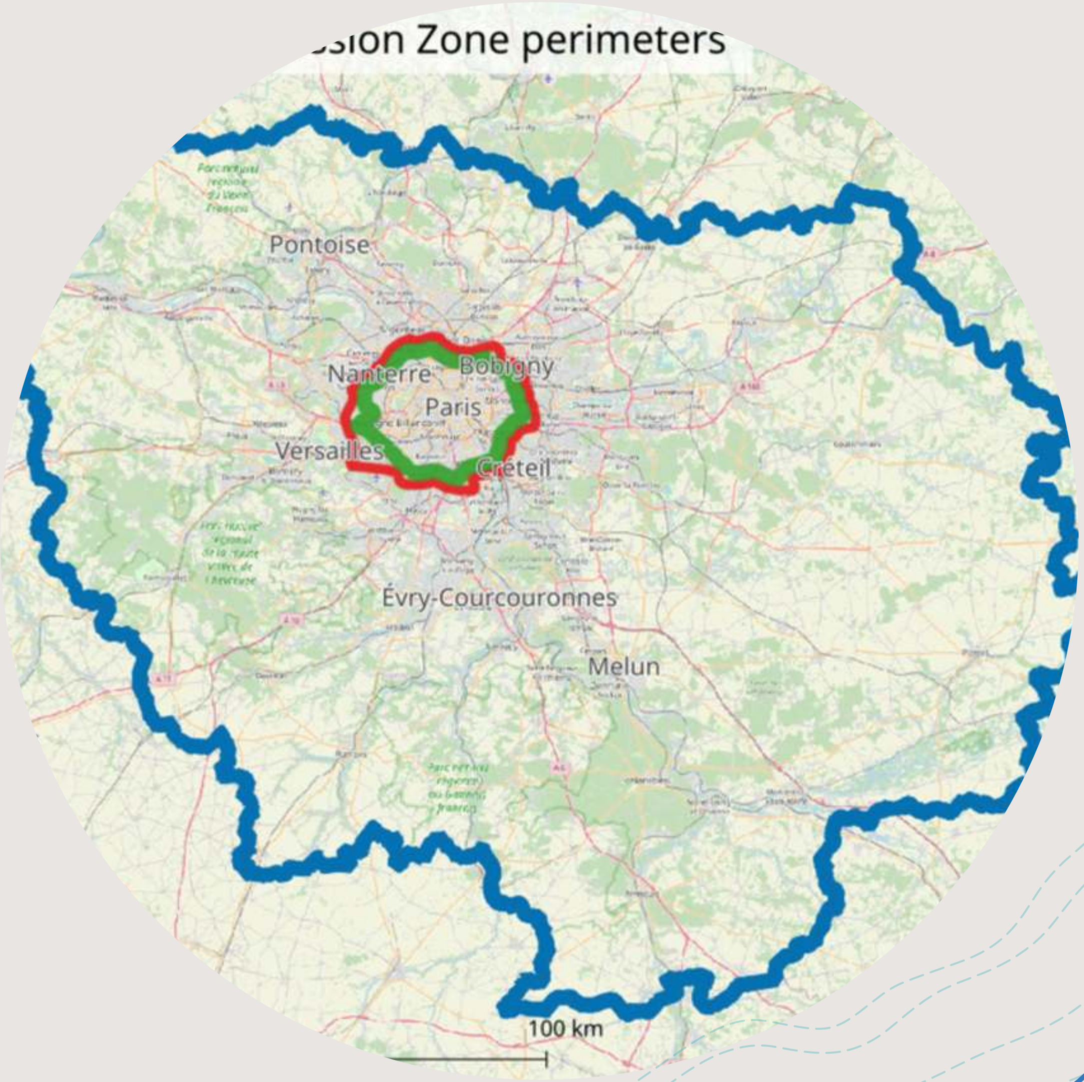
Case Studies

List of case studies

- Paris' **Low Emission Zone**
- **Carpooling** with socially optimal matching
- Changes in **speed limit**

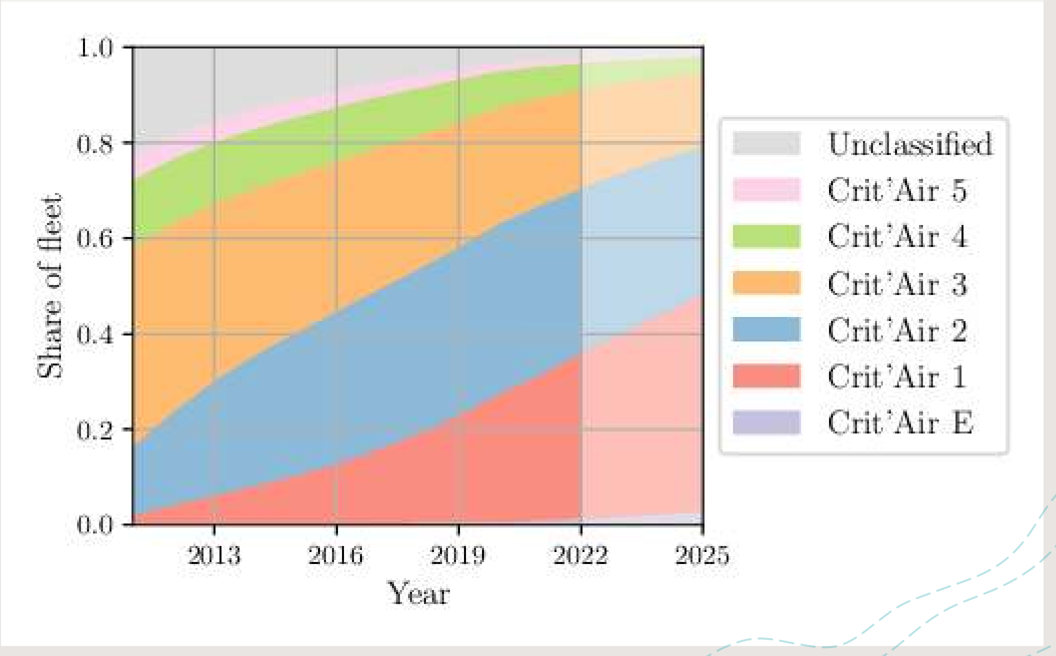
Low Emission Zone: Application scope

+ **Paris Low Emission Zone**
+ January 2025 version: vehicles **Crit'Air 3 or worse** are banned (around 20 % of the vehicle fleet)
+ Five **modes**: car driver, car passenger, public transit, bicycle, walking (+ exogenous truck trips)
+ **Average working day**
+ Population and capacities scaled down to **20 %**



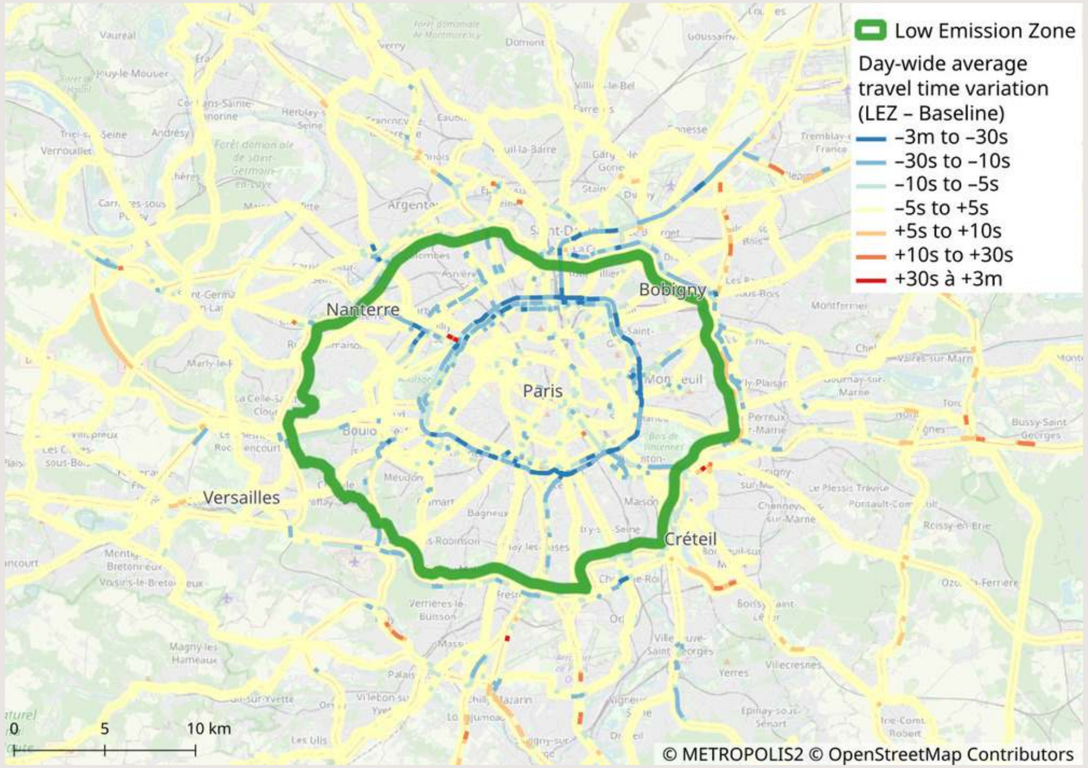
Methodology

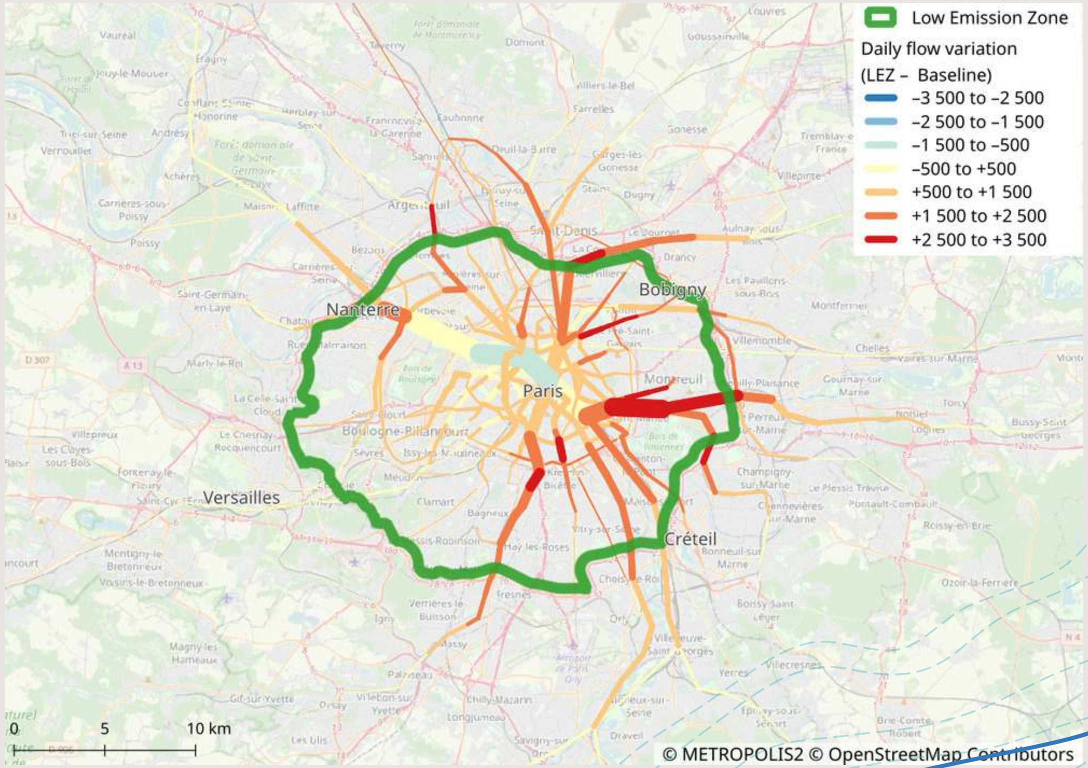
- Comparing **baseline and LEZ simulations**
- In the LEZ simulation, Crit'Air 3 or worse car owners **cannot drive inside the LEZ**
- Pollution emissions and exposure are computed with **METRO-TRACE** (Le Frioux et al., 2024)
- **Short-term analysis:** activity patterns and car ownership are held constant



Traffic results

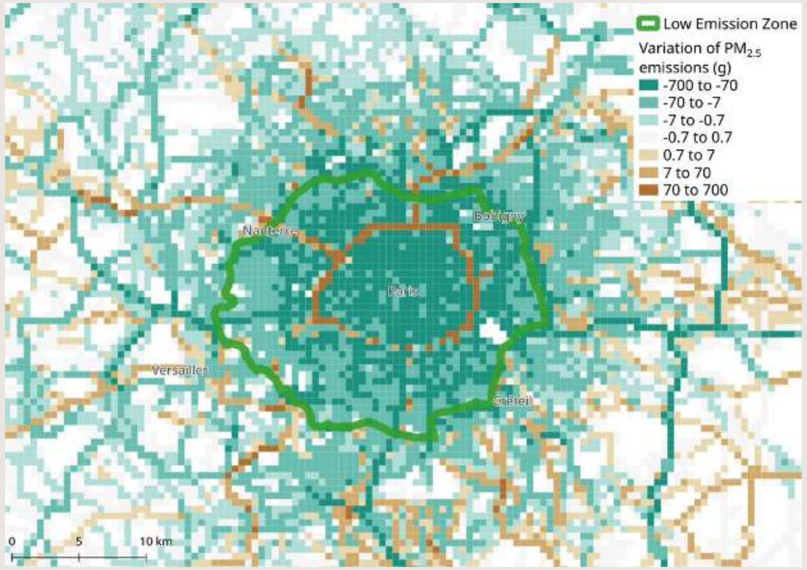
- **Decrease of car mode share** by 1.5 percentage point
- **Congestion reduction** on the *Boulevard Périphérique*
- **Increase in passenger flows** for lines connecting Paris to the suburbs

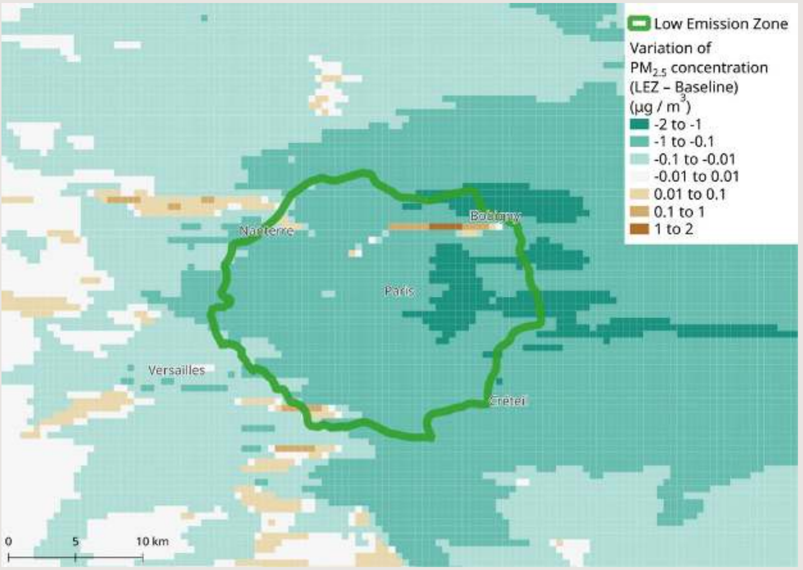


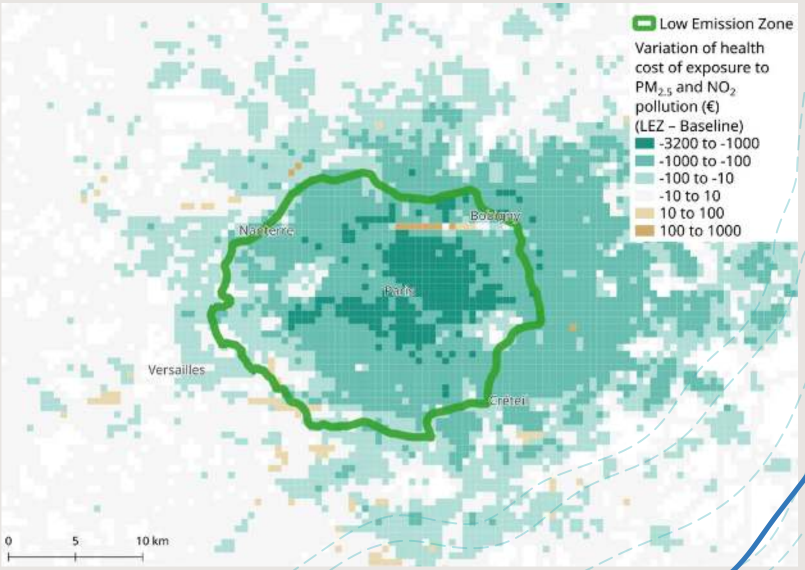


Local pollution

- **Vehicle-kilometers** decrease by 2.9 %
- $PM_{2.5}$ **emissions** decrease by 6%
- **Premature deaths** due to $PM_{2.5}$ exposure decrease by 10.1%

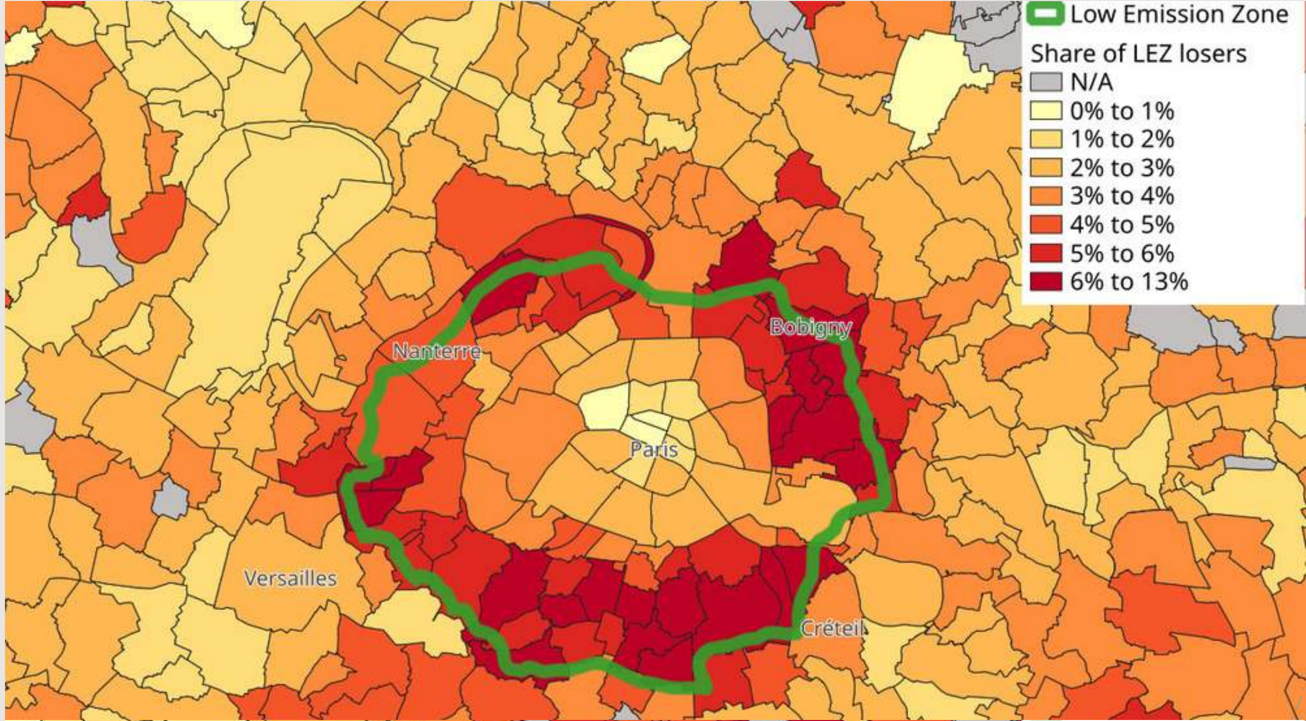


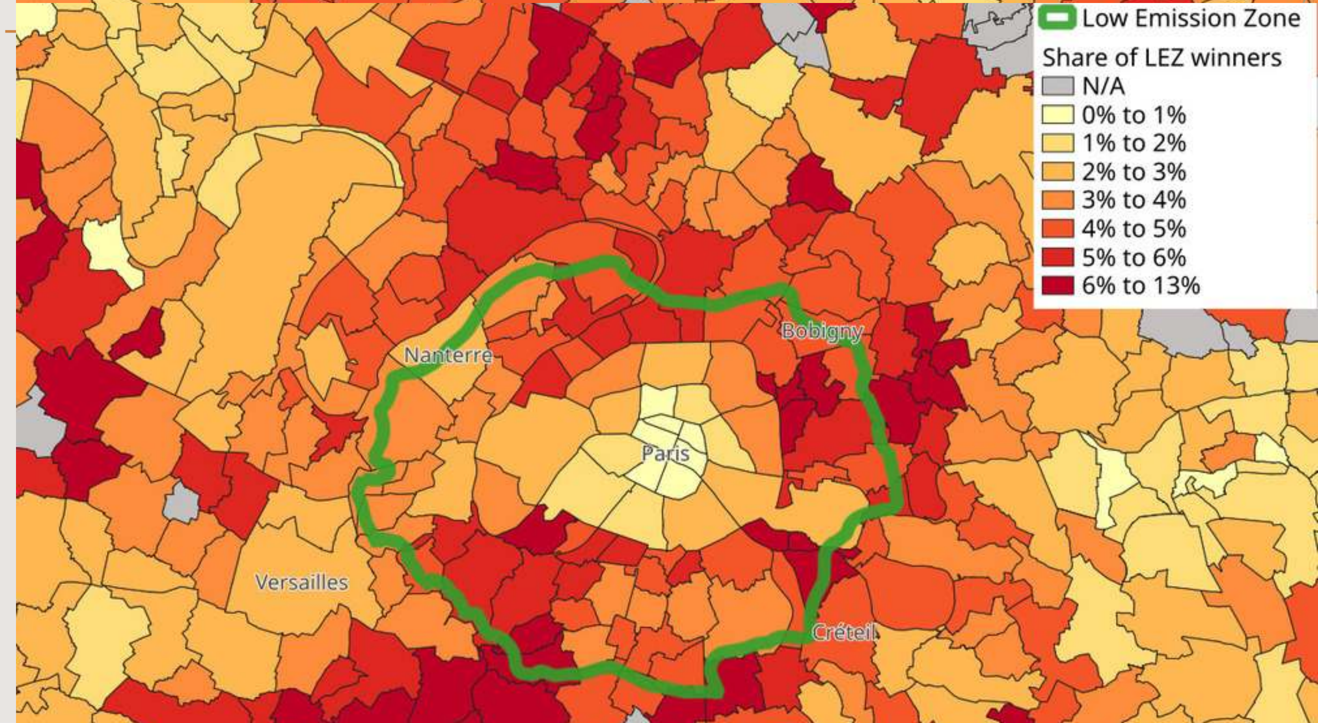




Individual surplus

- **LEZ winners:** surplus increase of more than 1€ (3.5% of pop.)
- **LEZ losers:** surplus decrease of more than 1€ (3.3% of pop.)
- LEZ winners are located inside / outside the LEZ with heavily congestion trips
- LEZ losers are located inside the LEZ with bad public transit alternatives





Potential improvements

Improvement Ideas

Synthetic population:

- **Car ownership** depending on persons characteristics / trips characteristics
- Add **desired activity start / end times**
- Define **tours** (sequence of trips starting / ending at home)

METROPOLIS2:

- **Household-level decisions** (who can use the car? who go shopping?)
- **Tour-level optimization** (intermodality, shopping before or after coming back home from work?)

Thank you

Lucas.javaudin@cyu.fr