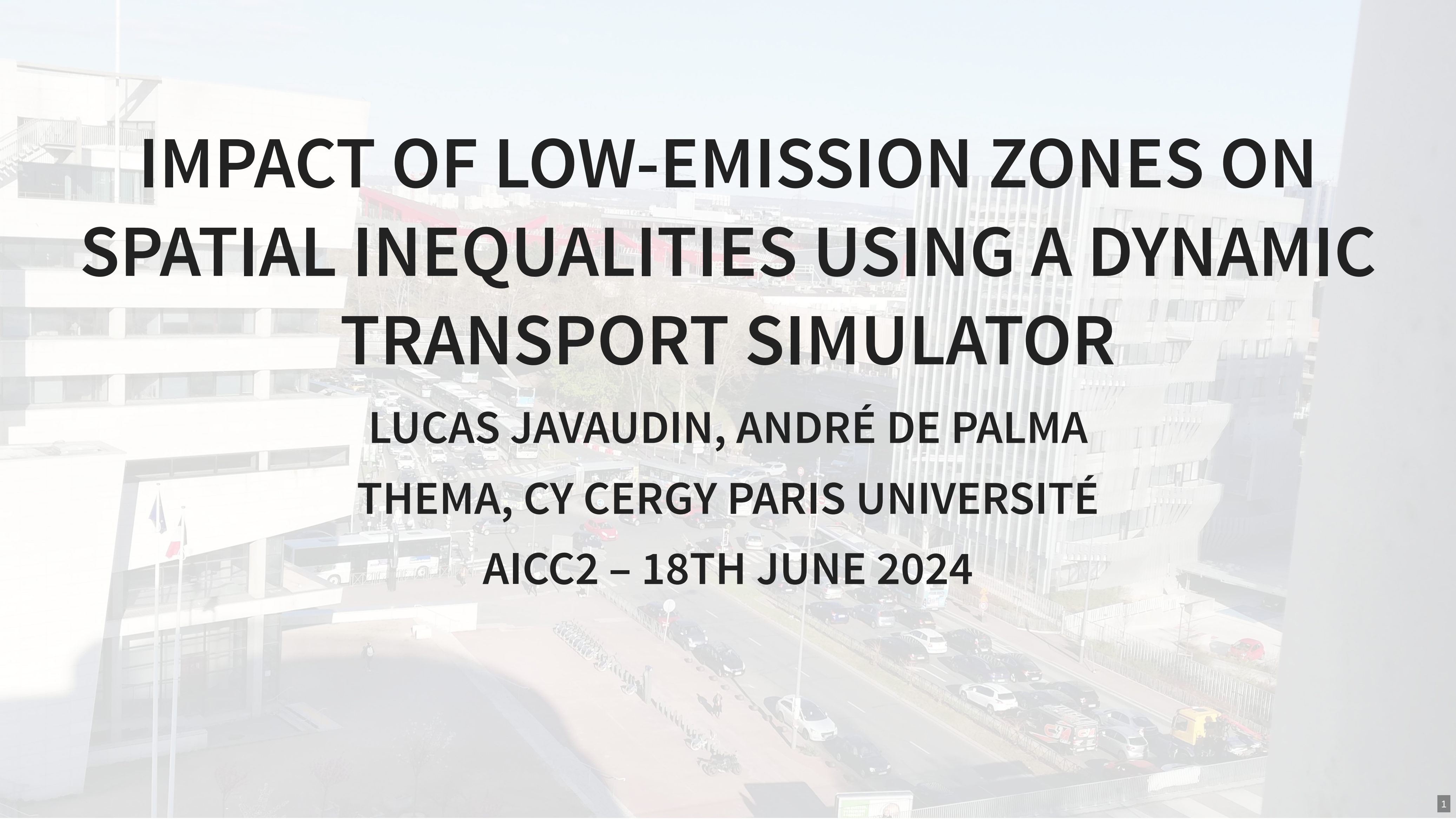




IMPACT OF LOW-EMISSION ZONES ON SPATIAL INEQUALITIES USING A DYNAMIC TRANSPORT SIMULATOR

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INTRODUCTION

CONTEXT

- **Air pollution** is estimated to have caused 311,000 premature deaths in Europe (EEA, 2022), representing a cost of 224 billion € or 1.4 % of GDP (using a statistical value of life of 700 k €)
- 7,920 premature deaths in Paris' urban area, Île-de-France (AirParif, 2022)
- Air pollution is mainly caused by nitrogen oxides (NO_x) and particulate matter (PM) **emitted by road vehicles**
- Popular instrument to improve air quality: **Low Emission Zones (LEZ)**

LOW EMISSION ZONES

- **Low Emission Zone:** area in the city center where the most polluting vehicles cannot travel
- In Europe, LEZs have been implemented in **hundreds of cities** as of today
- In France, 12 cities have implemented LEZs; cities are forced to implement a LEZ when pollution is above a threshold level

A CONTROVERSIAL POLICY

Arguments in favor of LEZ

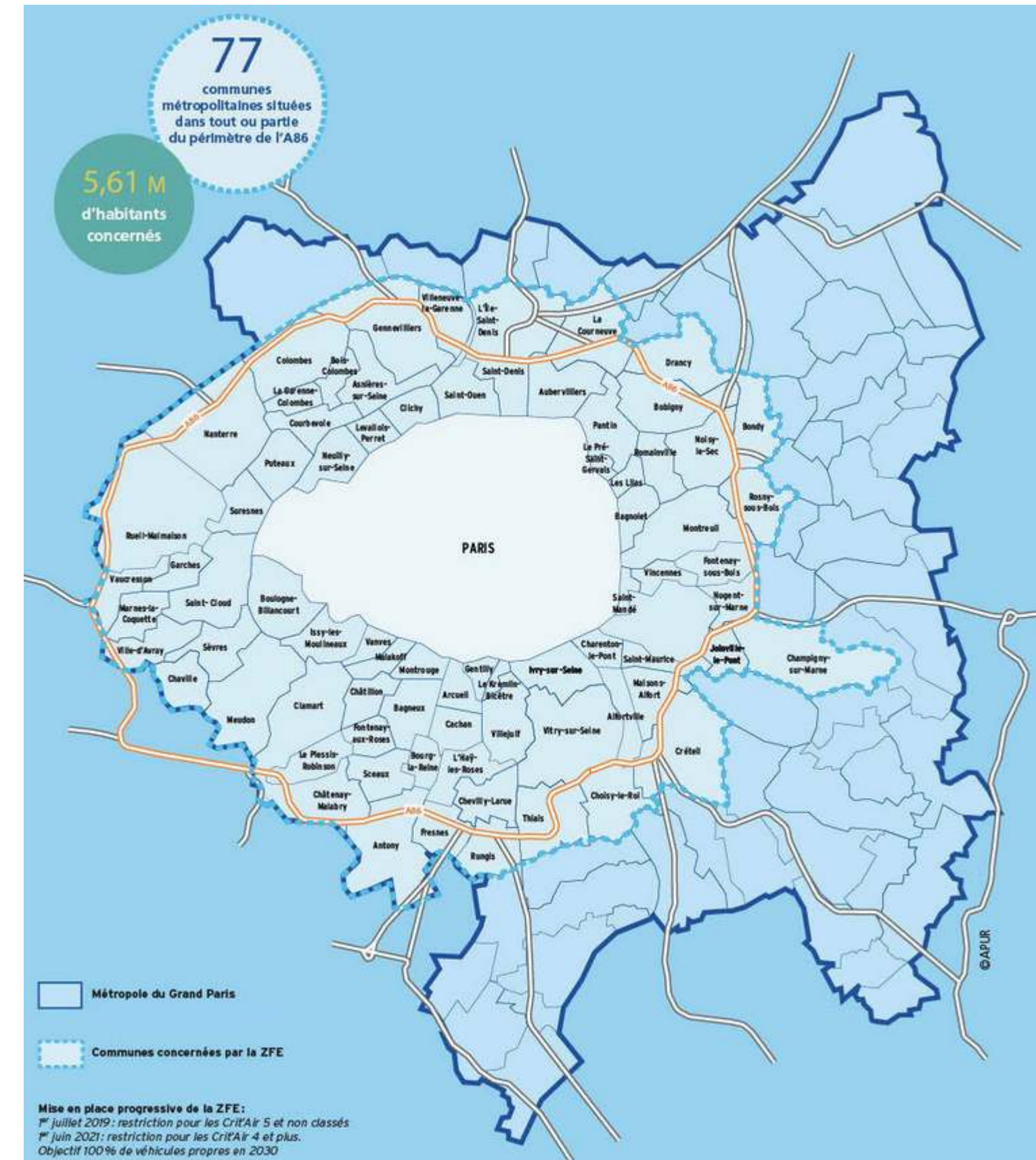
- Improved air quality
- Decreased CO₂ emissions
- Less noise pollution
- Less congestion

Arguments against LEZ

- Restriction of freedom
- Unfair: penalize people stuck with an old vehicle (poor and rural households)
- Some drivers might make a detour around the LEZ, polluting even more
- Drivers are induced to purchase new vehicles before their end-of-life

PARIS' LOW EMISSION ZONE

- More than 5 million inhabitants are living in the LEZ
- The LEZ represent around 10 % of the Île-de-France's road network
- June 2021: *Crit'air* 4 vehicles and worse are banned (11 % of the fleet)
- January 2025: *Crit'air* 3 vehicles and worse are banned (32 % of the fleet)
- **68 € fine** for non-respect (traffic-camera ticketing is planned)



RESEARCH QUESTIONS

- What is the impact of the **Low Emission Zone** of the *Métropole du Grand Paris* on global surplus?
- Which people are **winning** and **losing** from the Low Emission Zone (based on home location and income)?

LITERATURE REVIEW

- *Empirical evaluation*: focus on environmental impact, ambiguous effect (Holman et al., 2015; Wolff, 2014; Margaryan, 2021)
- *Ex-ante evaluation*:
 - Carslaw and Beevers (2002): approached based on traffic flow data, using an emission and dilution model
 - Dias et al. (2016): macroscopic transport model
 - de Bok et al. (2022): agent-based model, focus on freight transport
 - These studies do not find a large positive impact of Low Emission Zones.

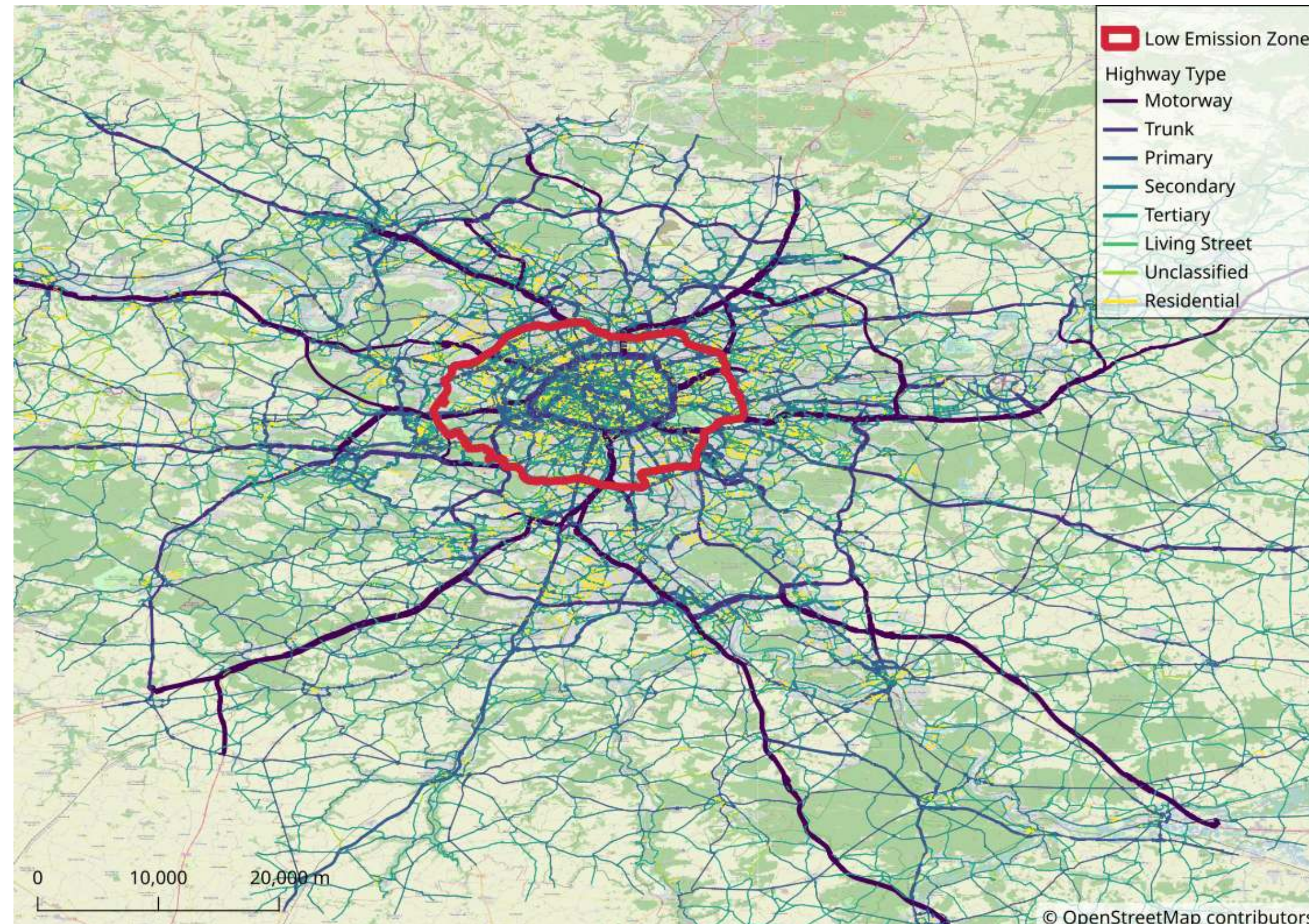
METHODOLOGY

INTRODUCTION

- **Scope:**
 - Île-de-France
 - 3AM to 10AM
 - Three modes: car, public transit, walk
 - All purposes
 - Representative working day
- **Limits:**
 - No car-ownership model (short-term analysis)
 - Trucks are not considered
 - Time restrictions are not taken into account
 - Cheating and exceptions are not considered

INPUT: ROAD NETWORK

- **Source:** OpenStreetMap
- **Highway types:** motorway, trunk, primary, secondary, tertiary, living street, unclassified and residential
- Living streets, unclassified and residential roads are discarded when not used
- Final network has **40 852 km** of roads (out of 91 859 km in the full network)

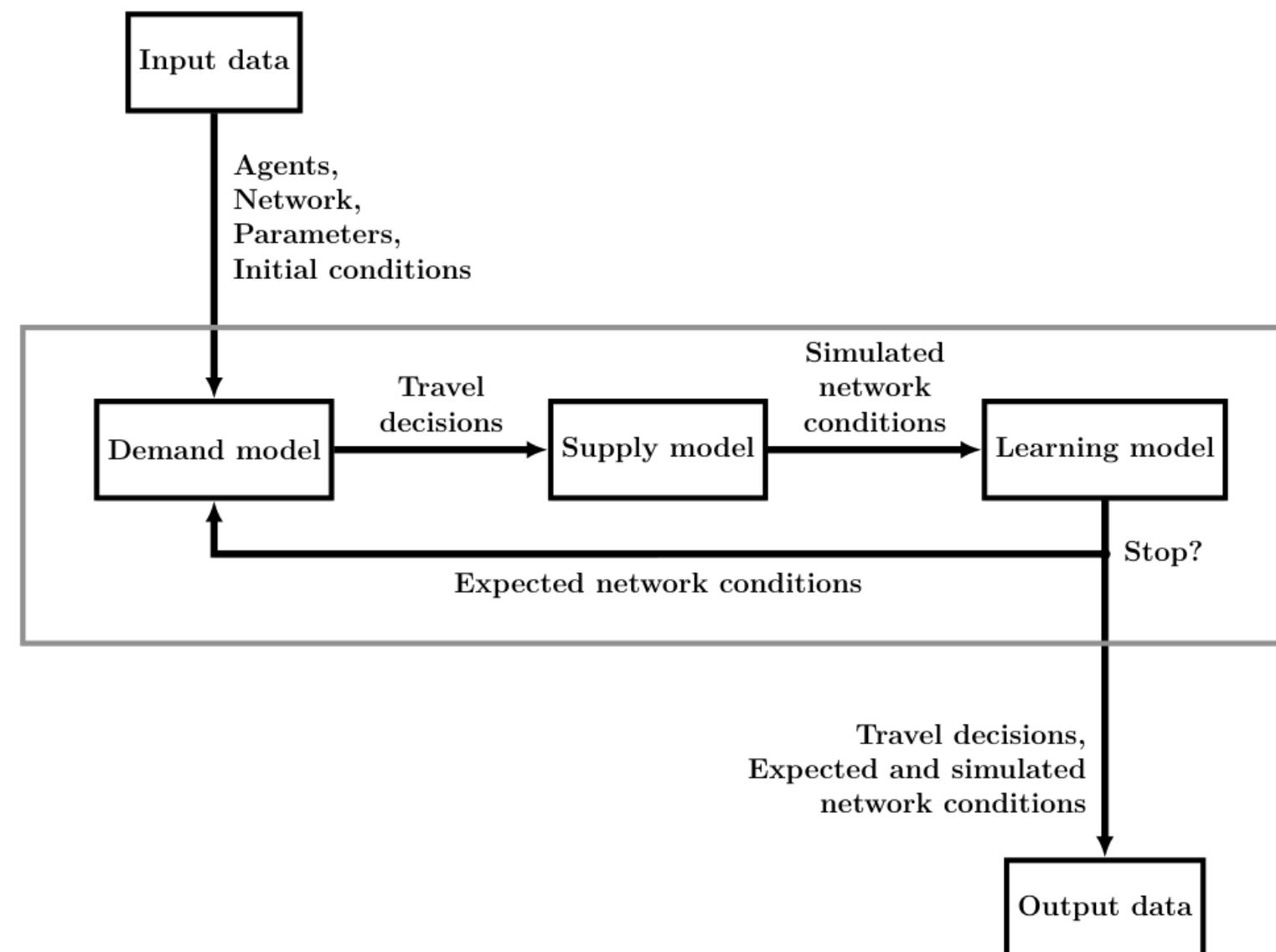


INPUT: POPULATION

- Generation of a **synthetic population** using Hörl and Balac (2021)
- **Data sources:** INSEE census, household travel survey, FiLoSoFi (household income), BD-TOPO (buildings data), SIRENE (entreprise census) and BPE (service and facility census)
- **Simulated household-level characteristics:** car availability, bike availability, income
- **Simulated individual-level characteristics:**
 - all activities performed during a day (home, work, education, leisure, shopping, other) with the activity duration and exact location
 - age, employment status, sex, socio-professional category, driving license, public-transit subscription
- **Final population:** 629k agents, with 819k trips (population and capacities are scaled down to 10 %)

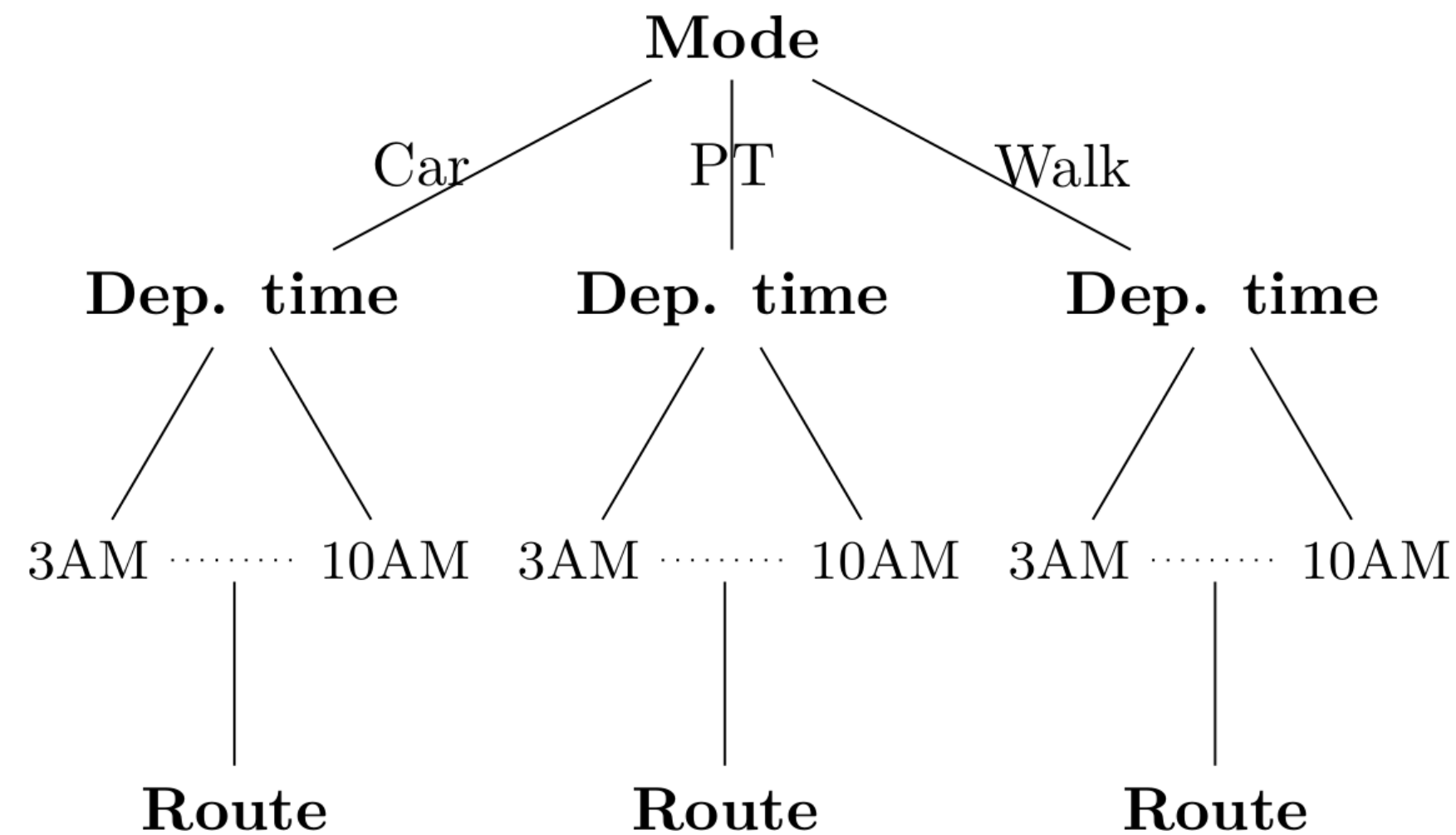
METROPOLIS2

- METROPOLIS2 is an **agent-based dynamic mesoscopic transport simulator**
- At each iteration, three models are run successively (**demand model**, **supply model** and **learning model**)
- The simulation stops when a **convergence criteria** is met or when the maximum number of iterations is reached



DEMAND MODEL

- **Input:** time-dependent travel-time function for each road of the road network
- **Output:** Mode, departure-time and route for each agent
- Mode choice: **Multinomial Logit model**
- Departure-time choice: **Continuous Logit Model**
- Route: **time-dependent Contraction Hierarchies** (state-of-the-art routing algorithm)

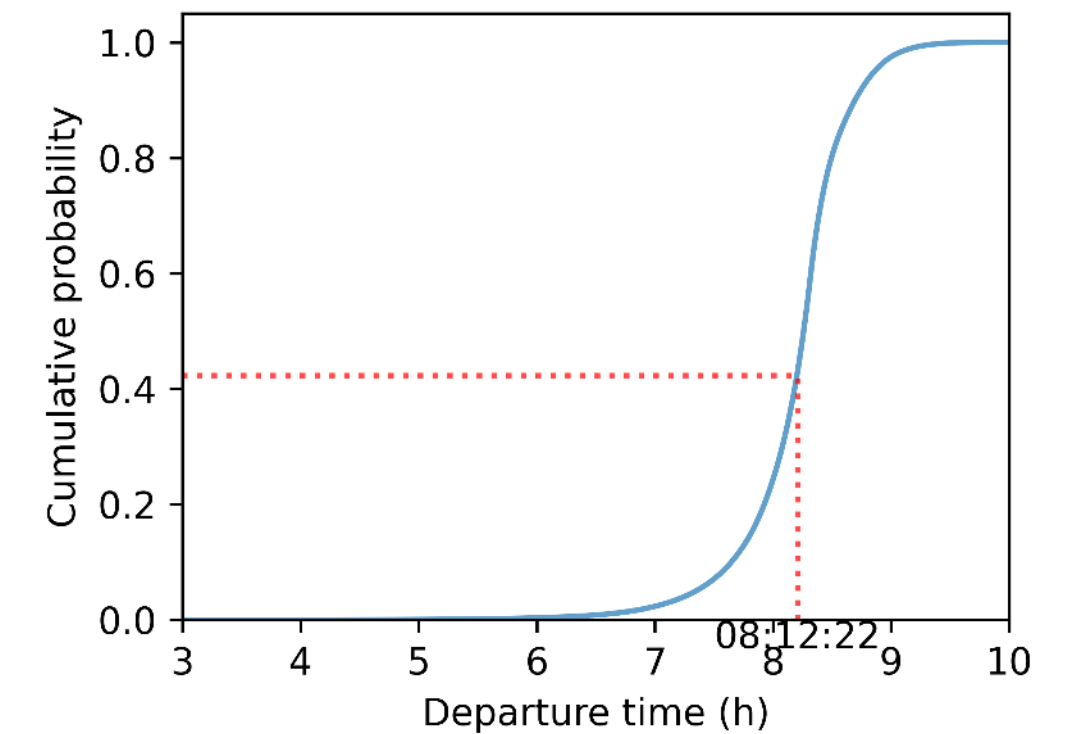
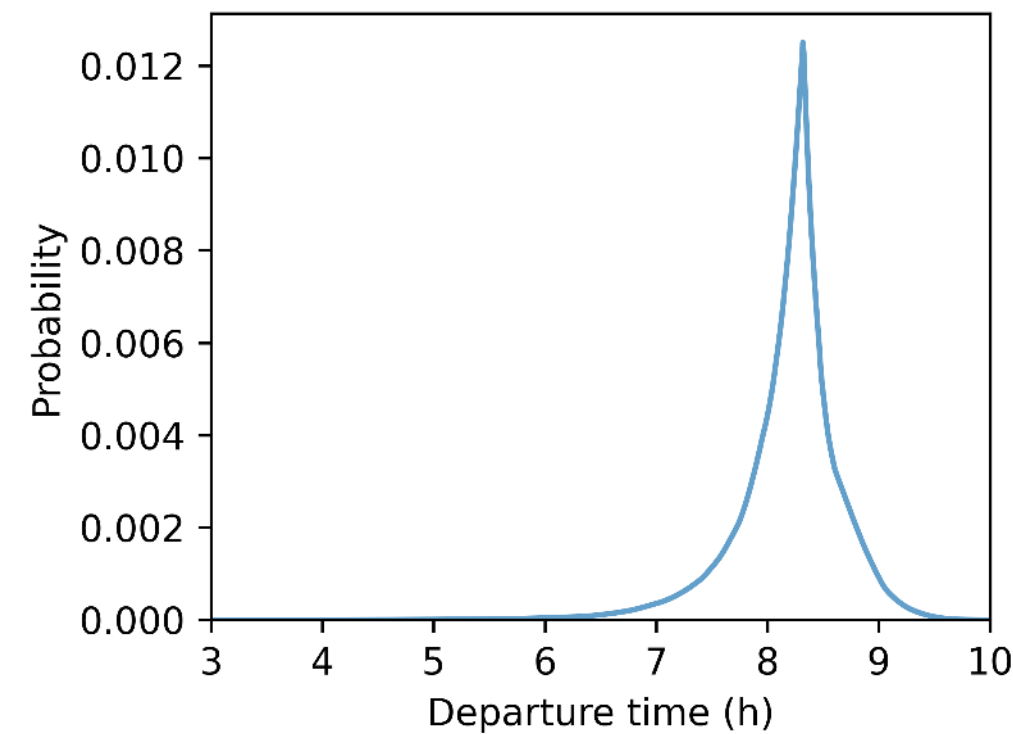
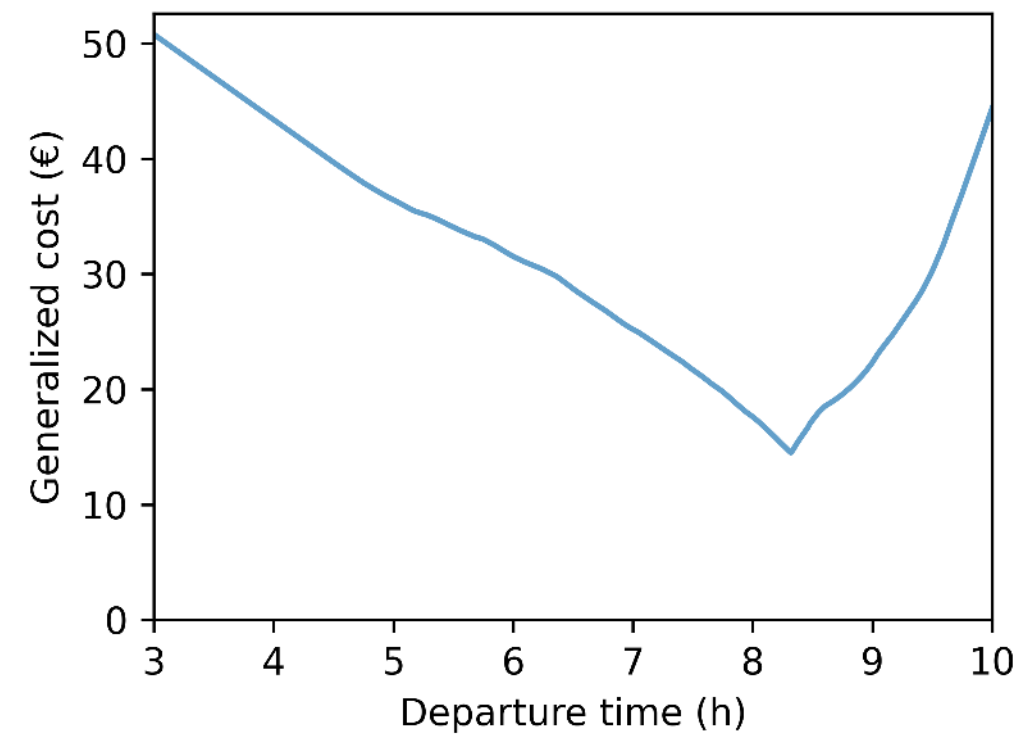


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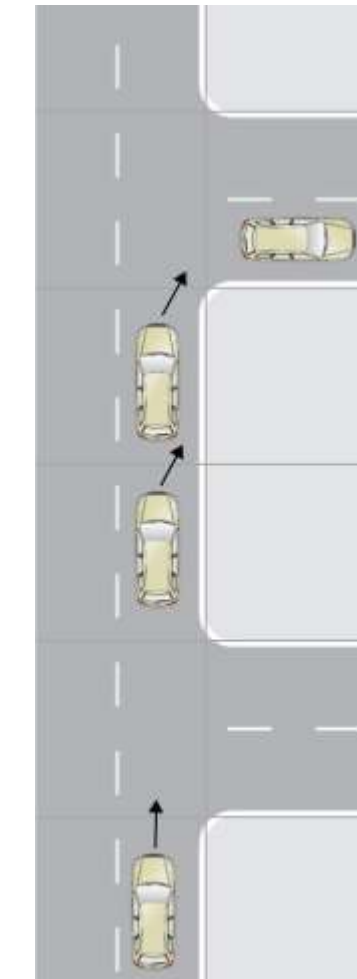
A trip **generalized cost** is ($\alpha - \beta - \gamma$ model: Vickrey, 1969, Arnott, de Palma, Lindsey, 1990)

$$c(t_d, t_a) = \underbrace{\alpha \cdot (t_a - t_d)}_{\text{travel cost}} + \underbrace{\beta \cdot [t^* - t_a]_+ + \gamma \cdot [t_a - t^*]_+}_{\text{schedule-delay cost}}$$



SUPPLY MODEL

- **Input:** Chosen mode, departure time and route of each agent
- **Event-based model:** Events represent an agent's or vehicle's action; they are simulated in a chronological order
- **Congestion model:** combination of speed-density functions, bottlenecks and queue propagation (spillback)
- **Output:** Edges' travel-time functions



LEARNING MODEL

- **Input:** Expected and simulated edges' travel-time functions
- **Learning process** based on **Markov decision processes**
- **Output:** Expected edges' travel-time functions for next iteration

$$tt_{\tau+1}^e = \lambda \cdot tt_{\tau}^e + (1 - \lambda) \cdot tt_{\tau}^s$$

LEZ POLICY

- **Scenarios:**
 - **No-LEZ simulation:** Simulation without the Low Emission Zone
 - **LEZ-2025 simulation:** Crit'air 3, 4 and 5 are forbidden (24 % of agents, 32 % of car owners)
- **Generating vehicle types:**
 - **Data:** Statistics on the vehicle fleet at the municipality level from the French Ministry of Transport (2021)
 - A vehicle is **randomly drawn** for each agent based on the vehicle fleet from his / her home municipality
- **Simulating:**
 - Road restrictions are implemented in METROPOLIS2 so that the owner of banned cars cannot take any road that is inside the LEZ

Share of banned vehicles



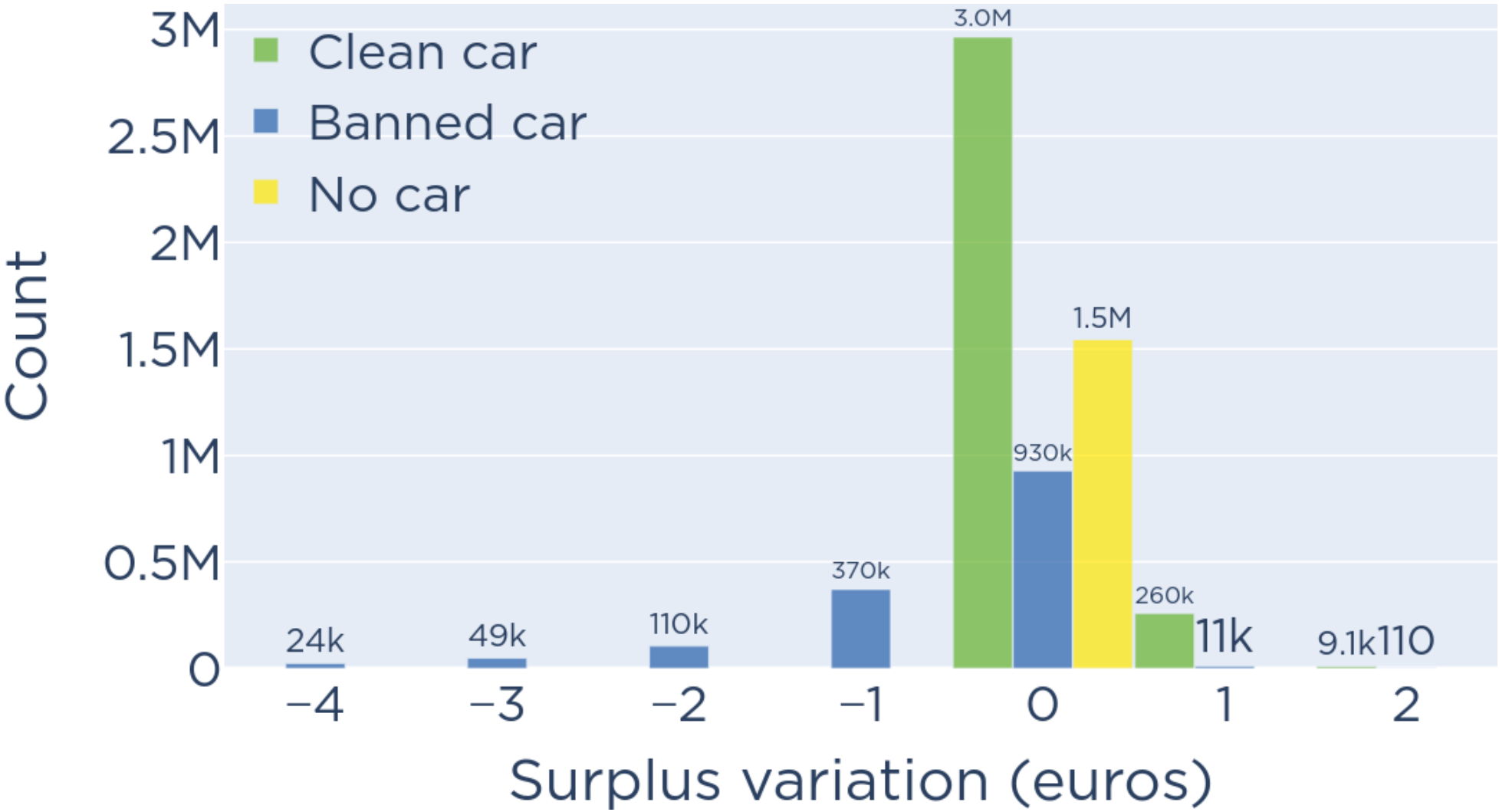
Median monthly income



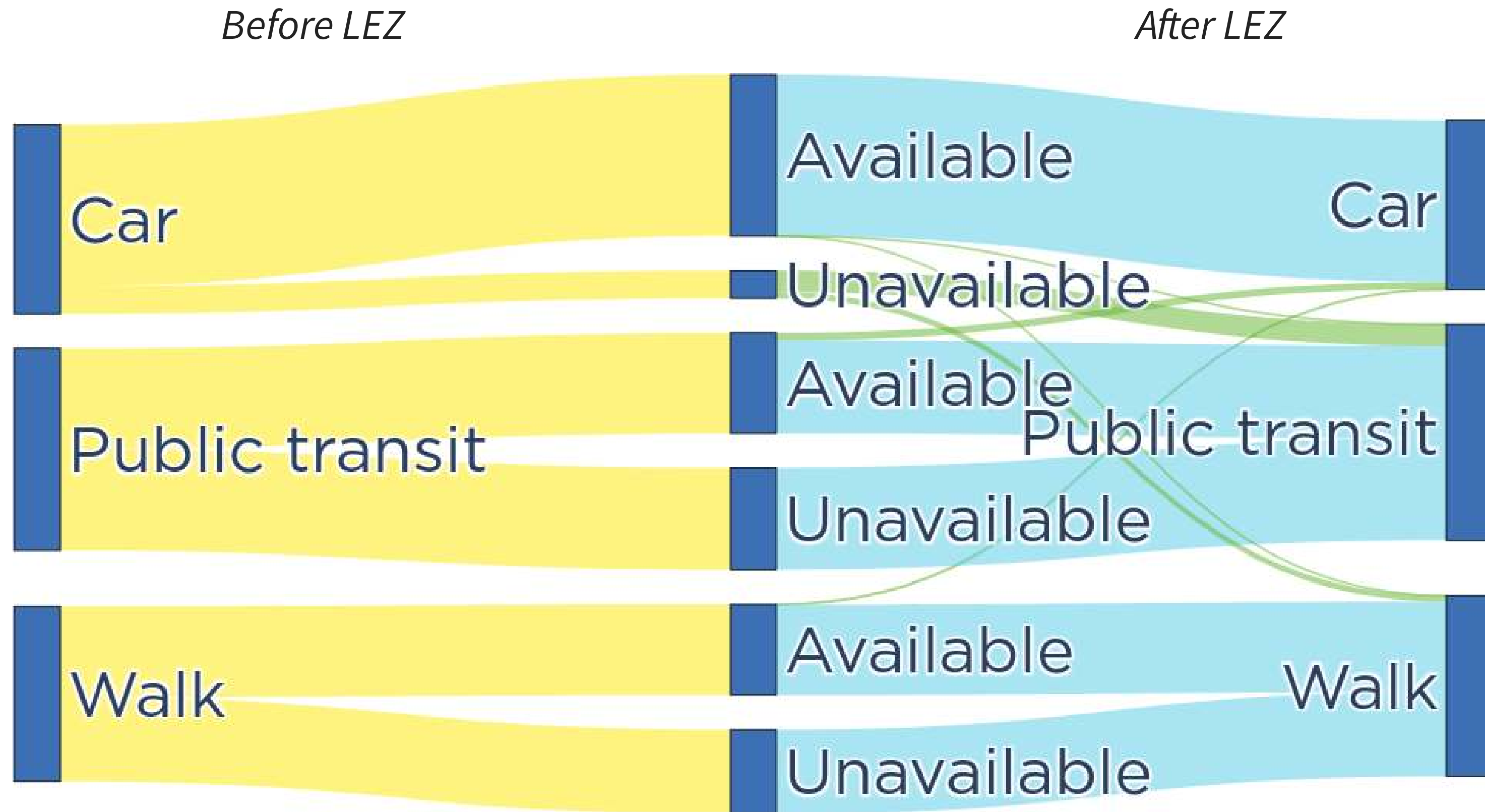
RESULTS

AGGREGATE RESULTS

	No LEZ	LEZ-2025	Variation
Car users	2.101 M	1.883 M	-10.4 %
Vehicle kilometers	31.04 M km	28.23 M km	-9.0 %
Travel time	29'24"	30'8"	+2.4 %
Congestion index	29.40 %	24.56 %	-16.5 %
Average travel surplus	7.37 €	7.25 €	-0.09 €



MODE SHIFTS



Available = clean car *OR* banned car with OD outside the LEZ

Unavailable = no car *OR* banned car with OD inside the LEZ

EMISSIONS

Emissions are a function of vehicles' fuel type and age, and instantaneous speeds (EMISENS model)

	No LEZ	LEZ-2025	Variation
NO_x	111 tons	87 tons	-21 %
PM_{2.5}	33 tons	28 tons	-14 %
CO	182 tons	122 tons	-33 %
CO₂	568 tons	510 tons	-10 %

Simulated emissions from 3AM to 10AM

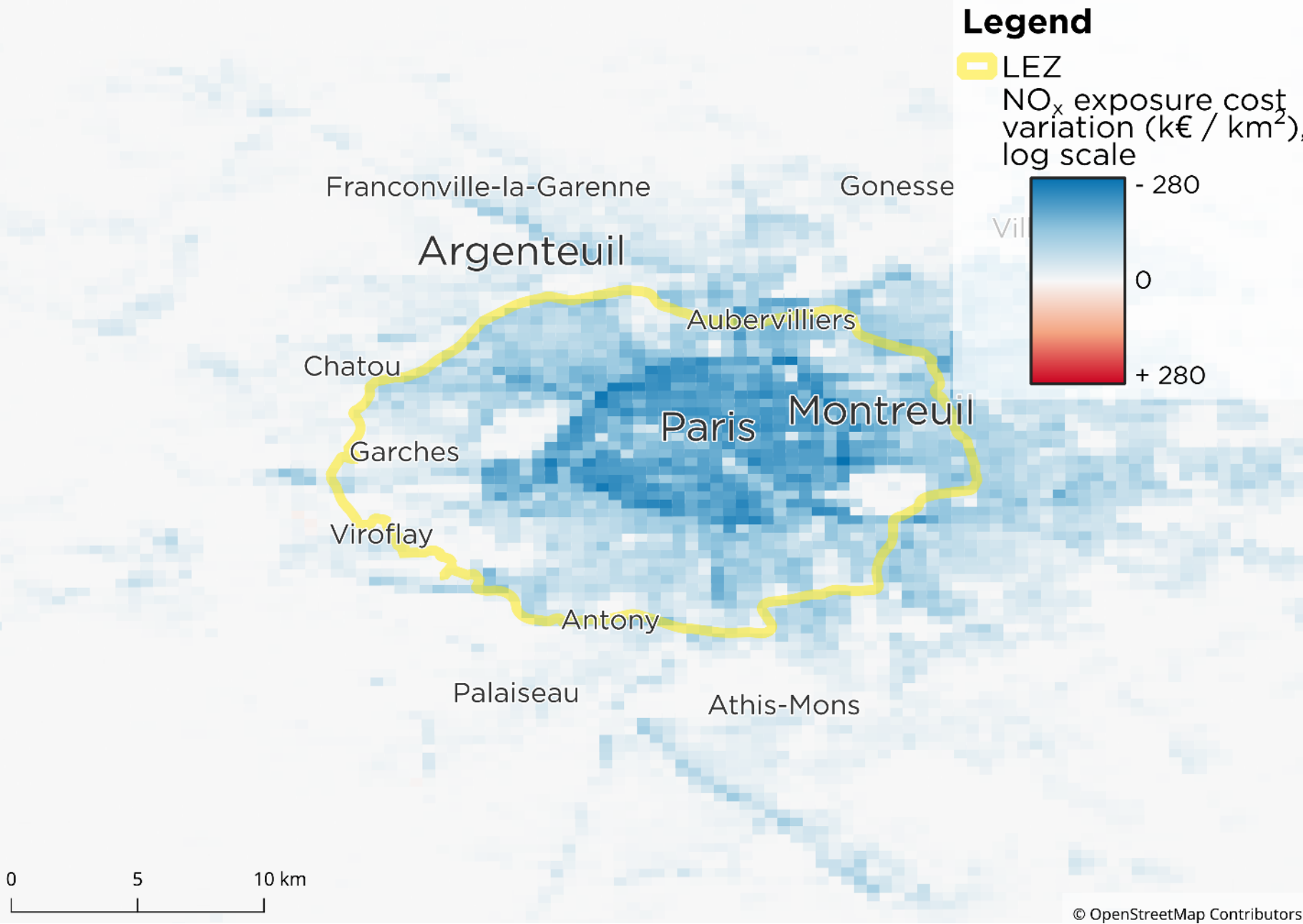


POPULATION EXPOSURE

Health impact of air pollutants on population are computed based on dynamic population distribution and pollution concentrations

	No LEZ	LEZ-2025	Variation
NO _x	47.3 M €	31.7 M €	-33 %
PM _{2.5}	11.4 M €	9.4 M €	-18 %
CO	0.6 M €	0.3 M €	-57 %

Total health costs from exposure to pollutants (3AM to 10AM)
Value of statistical life: 7.4 M €



SUMMARY: COST-BENEFIT ANALYSIS

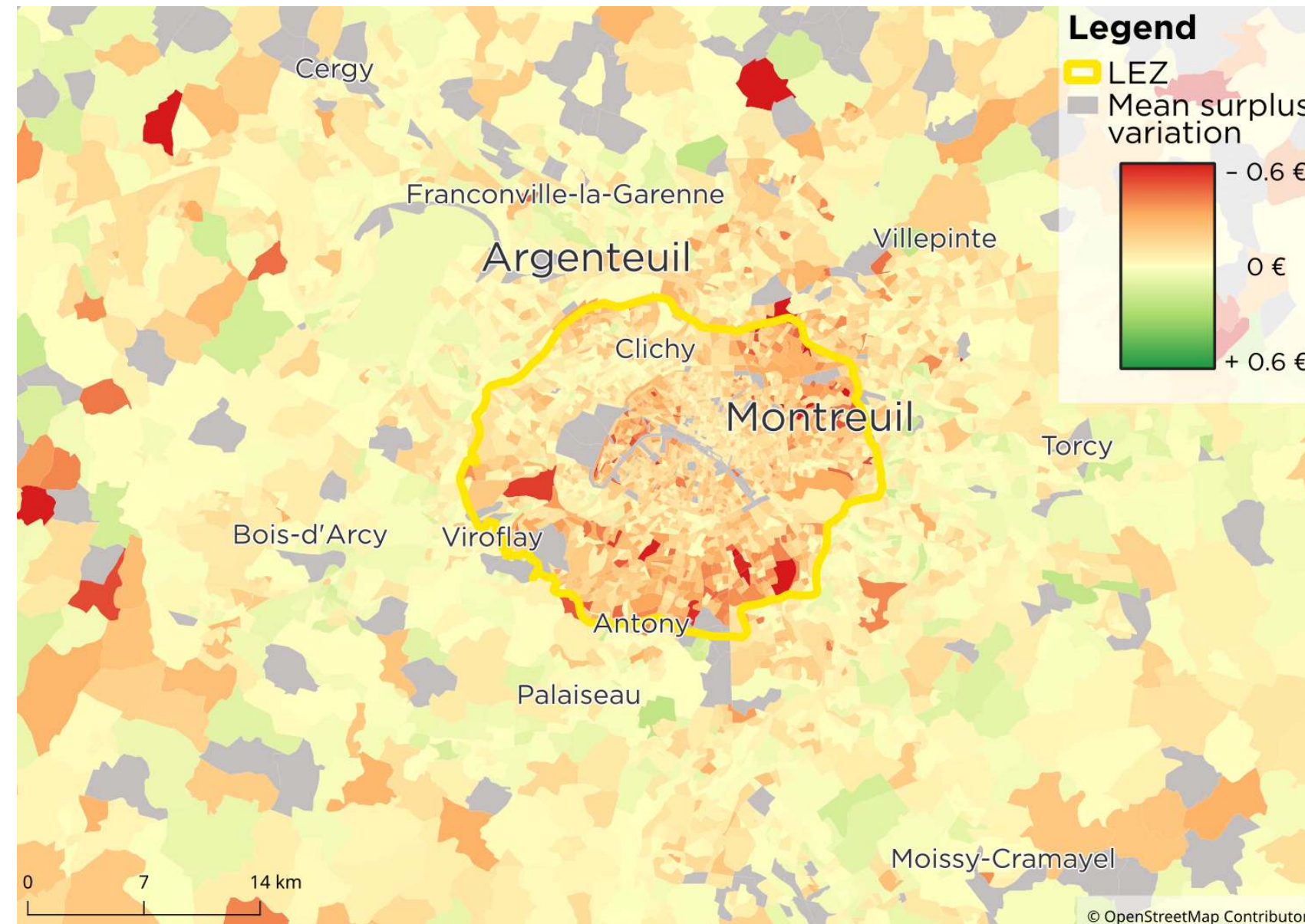
The benefits on air quality exceed the costs for owners of banned car

Travel surplus	- 565 k €
inc. owners of banned cars	- 1 010 k €
inc. owners of clean cars	+ 445 k €
Health surplus	+ 18 052 k €
inc. exposure to NOx	+ 15 616 k €
inc. exposure to PM2.5	+ 2 080 k €
inc. exposure to CO	+ 356 k €
Environmental surplus (200 € / ton CO ₂)	+ 95 k €
Net surplus	+ 17 582 k €

Values are for a single morning peak (3AM to 10 AM)
Estimated net surplus increase over 1 year: 8.8 billion euros

SPATIAL INEQUALITIES: TRAVEL SURPLUS

- *Inside the LEZ:* mostly losers because the banned car cannot be used anymore
- *Outside the LEZ:* some losers (car cannot be used to go to work in the LEZ), some winners (less congestion for those still taking their car)



SPATIAL INEQUALITIES: AIR QUALITY

Population exposure variation

- *Inside the LEZ:* everyone wins, especially nearby the main roads
- *Outside the LEZ:* some winners in the East (wind direction) and nearby the main roads



CONCLUSION

CONCLUSION

- A study of Paris' Low Emission Zone was carried over using the METROPOLIS2 transport simulator
- **Aggregate impact:** the benefits (improved air quality + decreased congestion) exceed the costs (mode shift for owners of banned car)
- **Inside LEZ:** great improvements to air quality and congestion but many owners of banned car are negatively impacted by the restrictions
- **Outside LEZ:** small improvements to air quality; ambiguous effects on travel surplus

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An aerial photograph of a busy city intersection. On the left is a modern, multi-story building with a light-colored, angular facade and large glass windows. A French flag and another flag are visible on poles in front of it. On the right is another modern building with a grey, vertically-slatted facade. The street is filled with cars, buses, and a truck. A large, bold, black text 'THANK YOU' is superimposed over the center of the image. In the background, there are trees, a bridge, and a large stadium with a red roof. The sky is clear and blue.

THANK YOU