Agent-based assessment of the Paris LEZ policy considering individual adaptations: vehicle replacement, modal shift, and route change

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1 Introduction

Many European cities are increasingly adopting restrictive measures on private car usage, such as congestion charges and Low-emission Zones (LEZ), to improve air quality in large urban areas[1]. The success of LEZ primarily stems from the behavioral changes they induce among current or future users of polluting vehicles within the restricted zones. Depending on the measure implemented, these behavioral changes can take several forms, the most notable or anticipated being the replacement of polluting vehicles Peters et al. (2021), modal shifts toward public transit (PT) or active transportation modes Tarriño-Ortiz et al. (2022), and the circumvention of restricted zones or the combined use of private vehicles and public transport through park-and-ride facilities Gonzalez et al. (2023). Therefore, such behavioral changes must be considered ex-ante to ensure the measure's acceptability (particularly for vulnerable populations) and achieve air quality improvement objectives.
Several studies have focused on ex-ante evaluations (Yin et al. (2024)) and ex-post assessments of LEZ implementations (Ferreira et al. (2015)) without explicitly accounting for the behavioral changes in mobility induced by such measures. To our knowledge, only the work by Ceccato et al. (2024) has explicitly considered these behavioral adaptations in their environmental assessment. This study, based on a mobility survey of LEZ implementation in the Municipality of Padova (Italy), employs an Integrated Choice and Latent Variable (ICLV) model to account for three behavioral alternatives (vehicle replacement, modal shift, and destination change) alongside a traffic simulation model.
The present work aims to investigate the impact of the LEZ measure implemented in the *Métropole du Grand Paris* (MGP), France, on traffic emissions while explicitly considering three central behavioral adaptations of individuals affected by the measure: prohibited car replacement, modal shift toward PT and active modes, and route change.

2 Methodology

This study employs agent-based modeling (*MATSim* Horni et al. (2016)) to simulate the main behavioral changes adopted in response to the implementation of the Low Emission Zone (LEZ) policy. The main adaptations considered include (i) the replacement of non-compliant vehicles with compliant models, (ii) a modal shift towards car alternatives (public transport and cycling), and (iii) route changes to bypass the restricted area. Figure 1 summarizes the steps of our workflow to consider the adaptations of agents impacted by the LEZ when evaluating this measure. The simulations are based on the open Île-de-France *MATSim* scenario Hörl & Balać (2021) called **Reference scenario**. Agents **impacted** by the LEZ are identified in the reference scenario (i.e., without the LEZ measure) as those traveling within the restricted perimeter using non-compliant vehicles. To design the main behavioral adaptations, three sub-populations with distinct strategies have been defined:

[1]`https://urbanaccessregulations.eu`, accessed October 8th, 2024

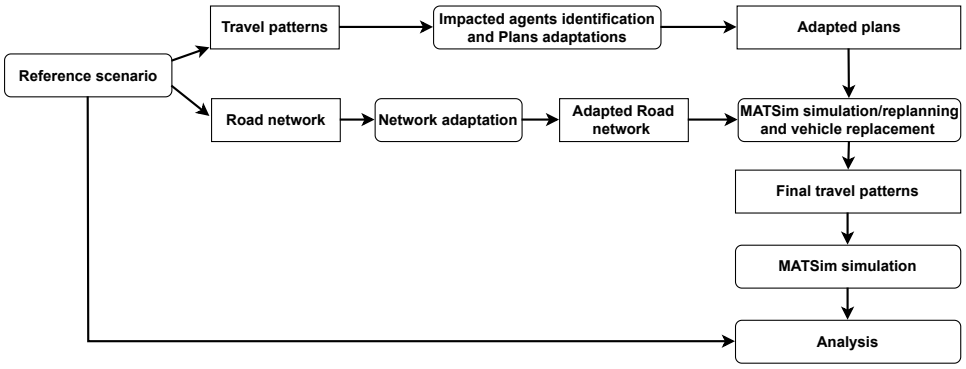

Figure 1: Steps of workflow to consider the adaptations of agents impacted by the LEZ.

- *lezConformAgent*: Includes agents who are either not affected by the LEZ policy or who have replaced their non-compliant vehicles. These agents can use their vehicles throughout the road network and adopt a modal shift strategy.
- *noConformInsideAgent*: Refers to agents affected by the LEZ whose travel patterns (fully or partially) occur within the restricted zone. This group represents individuals likely to shift to alternative private car transportation modes.
- *noConformFullCrossingAgent*: Refers to agents affected by the LEZ whose entire daily mobility chain takes place outside the restricted zone. These agents can therefore bypass the zone by modifying their travel routes. A **new car transportation mode and an adapted road network** have been created to account for this behavioral change.

The decision to replace a restricted vehicle is conditioned by the inability to fully or partially complete daily activities due to increased travel times associated with switching to alternative modes or rerouting. Thus, agents from the two sub-populations impacted by the LEZ (*noConformInsideAgent* and *noConformFullCrossingAgent*) who cannot achieve their daily activity schedules are identified as candidates to replace their restricted vehicles. Then, these agents transit to the *lezConformAgent* sub-population, thereby regaining access to the LEZ.

3 Results

According to the *Métropole du Grand Paris* LEZ policy in 2025, among the synthetic drivers affected by this measure (328,800 agents), only 10% belong to the *noConformFullCrossingAgent* sub-population. Specifically, 28.4%, 24.8%, and 46.8% of these trips were completed via walking, cycling, and public transit, respectively. The share of trips completed by walking is slightly higher than those completed by bike. This is mainly due to some agents not owning bicycles, making this alternative inaccessible. Walking and cycling are predominantly favored for short- to medium-distance trips, with a median trip duration of 14 min and 16 min, respectively. In contrast, public transit is mainly used for long-distance trips, with a median travel time of 45 min.
By applying the selection criteria (avoiding long trip duration) to identify truly eligible trip chains, 3%, 9%, and 15% of agents from the *noConformInsideAgent*, sub-population shifted to walking, cycling, and public transport, respectively. Subsequently, the prohibited vehicles of the remaining agents were replaced with compliant ones.
As expected, bypassing the restricted zone leads to an increase in travel duration. The median travel time when crossing the LEZ (reference scenario) is 27 min, compared to 40 min when bypassing it, representing a relative increase of 48%. Similarly, after filtering

trips with significantly long durations and high ratios, 94% of the agents circumventing the restricted zone retained their non-compliant vehicles. The remaining 6% vehicles were replaced with compliant ones.

	LEZ area			MGP			IdF		
	NO_x	PM2.5	CO_2	NO_x	PM2.5	CO_2	NO_x	PM2.5	CO_2
Ref. scena.	12	0.3	6,274	13.8	0.3	7,108	32.2	0.8	15,644
LEZ scena.	9.9	0.07	5,954	11.5	0.13	6,901	30	0.5	15,420
Variation (%)	**-17.8**	**-74.2**	**-5.1**	**-15.2**	**-62.2**	**-3**	**-6.8**	**-41.3**	**-1.4**

Table 1: Comparison of emissions in different zones for the reference and LEZ scenarios.

Table 1 presents the results of NO_X, particle, and CO_2 emissions (in tonnes/day) within the three perimeters: inside the LEZ, within the *Métropole du Grand Paris*, and across the IdF region, comparing the reference and LEZ policy scenarios. Emissions are calculated for each vehicle along each road segment using HBEFA, which enables precise modeling of road types and the impact of congestion. The impact of the restriction is evident in the reduction of emissions. As expected, the effect is most pronounced within the restricted zone, followed by the MGP and the region overall. Moreover, it can be observed that the measure does not affect all types of pollutants equally. The reductions in particle emissions are significantly more significant than those for NO_X and CO_2 across all three zones. This reduction is mostly explained by the ban on Diesel Euro 4 vehicles, which represent 10% of the vehicle fleet while are responsible for 80% of particle emissions.

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References

Ceccato, R., Rossi, R., & Gastaldi, M. (2024). Low emission zone and mobility behavior: Ex-ante evaluation of vehicle pollutant emissions. *Transportation Research Part A: Policy and Practice*, *185*, 104101.

Ferreira, F., Gomes, P., Tente, H., Carvalho, A., Pereira, P., & Monjardino, J. (2015). Air quality improvements following implementation of lisbon's low emission zone. *Atmospheric Environment*, *122*, 373–381.

Gonzalez, J. N., Gomez, J., & Vassallo, J. M. (2023). Are low emission zones and on-street parking management effective in reducing parking demand for most polluting vehicles and promoting greener ones? *Transportation Research Part A: Policy and Practice*, *176*, 103813.

Horni, A., Nagel, K., & Axhausen, K. (2016). *Multi-agent transport simulation matsim*. London: Ubiquity Press. doi: 10.5334/baw

Hörl, S., & Balać, M. (2021). Synthetic population and travel demand for paris and Île-de-france based on open and publicly available data. *Transportation Research Part C: Emerging Technologies*, *130*, 103291. doi: doi.org/10.1016/j.trc.2021.103291

Peters, J. F., Burguillo, M., & Arranz, J. M. (2021). Low emission zones: Effects on alternative-fuel vehicle uptake and fleet co2 emissions. *Transportation Research Part D: Transport and Environment*, *95*, 102882.

Tarriño-Ortiz, J., Gómez, J., Soria-Lara, J. A., & Vassallo, J. M. (2022). Analyzing the impact of low emission zones on modal shift. *Sustainable Cities and Society*, *77*, 103562.

Yin, B., Diallo, A. O., Seregina, T., Coulombel, N., & Liu, L. (2024). Evaluation of low-traffic neighborhoods and scale effects: the paris case study. *Transportation research record*, *2678*(1), 88–101.