

Supplementary Material

Public Bus Transportation System Environmental Impact Projections Regarding Different Policy Scenarios—An LCA Study

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1. Stakeholder Interview Report

On November 6, 2018, the transportation standardization coordinator of the public transport and traffic's company (form Portuguese, Empresa Pública de Transporte e Circulação, EPTC) received the first and second authors, research fellows from the LIFE / UFRGS research group- for an interview. In an informal conversation, the coordinator presented the functioning of the current public transport system and its history. The following changes occurred in the system were stand out:

- Expansion of the city: The development of the city in scarce areas, mainly caused by the construction of large social housings in the southern region, generated the need for public transportation by the population on the outskirts of the city. The main destination of journey is the central region of the city, and other commercial regions, for reasons of work and study. Consequently, in the last year there were an expansion of the public transportation system to these areas;
- Investment regulation in the transportation sector: companies with public transport consortia do not receive subsidies from the municipality. The investment arises from equity, depending on the financial return of the transportation fare;
- The emergence of individual demand transport through applications: the emergence of this new mode of transportation has led to a reduction in public transport demand, especially from paying users (those who do not receive tariff reduction or exemption benefits);
- From the single fare value: with the introduction of a new modal (transport by application) in the city's transportation market, the collective bus fare is no longer competitive for short-distance trips, as the same routes can be taken individually and with greater comfort from the demand for the application. Long-distance trips, which is more operationally expensive, is now proportionally more numerous among the total number of paying passengers. The potential increase in the single tariff generates a negative reaction in the demand for this mode.

The main result of these changes is noticed by the annual tariff adjustment. The calculation of the tariff adjustment takes into consideration the following cost variables, according to the order of influence: salary of service providers; variable operating costs (including fuel costs, vehicle maintenance and service providers' salary as a function of kilometers driven and fuel consumption efficiency per kilometer driven); depreciation cost of vehicles; return on investments; taxes; administrative costs. Profit is calculated from the estimate of paying passengers to be transported, given the variation in passengers and kilometers traveled in previous years.

The combination of these changes in system supply and demand behavior created a crisis in the sector. Historical data provided by EPTC show the increase in the number of kilometers traveled until 2013 and the reduction in the number of paying passengers carried, which confirms the reports. In order to mitigate part of the costs of the companies and contain the readjustment values, the regulation for the lifespan of the vehicles purchased by the companies has changed from 10 to a maximum of 14 years, with the condition of regular inspection and maintenance in these 3 increased years.

As for sustainability, the coordinator states that the mechanical requirements regulations for the purchase of new vehicles have historically been updated in line with the European heavy duty engine regulatory updates. Today, even if there are operating older vehicles with Euro II, III and IV engines, all new buses must have more efficient combustion-efficient Euro V engines with lower particle emission factors of particulate matter. In addition, according to the city's Public Transportation Association (ATP), all buses run on diesel fuel S10, whose sulfur content is reduced com-

pared to the old formula S50 (50 ppm to 10ppm), reducing carbon dioxide emissions, sulfur emissions and consequent impacts such as acid rain.

Efforts are also being made to encourage operating companies to purchase electric vehicles to gradually replace the current fleet. The purchase of these vehicles depends on the companies' financial capital, and financing is still under negotiation. However, tests with electric vehicles by the Chinese company BYD have already been done by the company Carris. The results are not yet public.

2. Simulated Evolution of Fleet Changes based on Car Similarities

Considering the restrictions imposed by law, it was assumed that the Micro Front Engine, Light Rear Engine, Heavy Front Engine style vehicles will be replaced by Heavy Air Conditioning Front Engine vehicles. Similarly, heavy-duty rear-engine vehicles without air conditioning and automatic or manual shifting will be replaced by their equivalents, but both with air conditioning. Bus 6x2 front engine, Special front engine, and Special auto-shift center engine vehicles will be replaced by Special-style air-conditioning and auto-shift Central engine vehicles, and those Special-style rear-engine airlift auto-replaced vehicles replaced by similar vehicles, however, with air conditioning. The change according to this fictitious scenario can be seen in Table 1, as well as the average efficiency value of the system as a function of the number of vehicles of each style and their corresponding efficiency in the year 2017. To facilitate the visualization on Table 1 air conditioning is abbreviated as AC and automatic gearbox as AG.

Table S1. Fleet replacement change (in vehicle units).

Year	Micro Bus Front Engine	Light Vehicle Rear Engine	Heavy Vehicle Front Engine	Heavy Vehicle Front Engine with AC	Heavy Vehicle Rear Engine	Heavy Vehicle Rear Engine with AC and AG	Heavy Vehicle Rear Engine AC	Heavy Vehicle Rear Engine with AG	Bus 6x2 Front Engine	Special Front Engine	Special Vehicle Central Engine with AC and AG	Special Vehicle Central Engine with AG	Special Rear Engine AC and AG	Special Rear Engine with AG
2017	1	26	655	144	182	219	127	130	8	12	30	14	43	60
2018	1	26	655	144	182	219	127	130	8	12	30	14	43	60
2019	1	22	557	246	182	224	127	125	1	12	37	14	45	58
2020	1	0	430	395	180	224	129	125	0	12	38	14	45	58
2021	0	0	348	478	156	266	153	83	0	0	50	14	45	58
2022	0	0	282	544	89	278	220	71	0	0	50	14	45	58
2023	0	0	220	606	50	285	259	64	0	0	50	14	74	29
2024	0	0	114	712	26	303	283	46	0	0	50	14	88	15
2025	0	0	66	760	14	333	295	16	0	0	50	14	99	4
2026	0	0	54	772	14	334	295	15	0	0	50	14	102	1
2027	0	0	54	772	14	334	295	15	0	0	50	14	102	1
2028	0	0	54	772	14	334	295	15	0	0	50	14	102	1
2029	0	0	0	826	0	349	309	0	0	0	50	14	103	0
2030	0	0	0	826	0	349	309	0	0	0	50	14	103	0
Efficiency on 2017 (l/km)	0.225	0.359	0.398	0.443	0.458	0.553	0.489	0.532	0.432	0.512	0.780	0.741	0.729	0.708