Decarbonizing the public bus fleet in the city of São Paulo until 2038

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In 2018, the city of São Paulo, Brazil enacted a law setting ambitious goals for the city's public bus transport CO2, particulate matter, and NOx with a deadline for reaching the target in January 2038. This encompasses a rapid technological transition of diesel-based buses towards cleaner options such as zero-emission or low-emission vehicles. However, for this transition to take place, decision-makers need to be aware of the technologies combination that can bring them closer to the legislation imposed. Therefore, this paper seeks to assess the goal imposed by the law, analyzing the interaction between biodiesel, electric, hybrid, biomethane, and natural gas technologies to achieve reductions in CO2, PM, and NOx.

1. Introduction

Reducing greenhouse gas emissions and mitigating climate change, as well as improving the well-being of the population, are essential items for a sustainable future. These actions directly influence the search for the achievement of sustainable development objectives, which are characterized as a universal call for action against poverty, protection of the planet, and guaranteeing peace and prosperity to society (UN 2023). According to the National Energy Balance (EPE 2018), the transport sector is the second sector that most demands energy in Brazil and the main source of carbon dioxide emissions (CO_2) (EPE 2018). Also, it is responsible for the emission of various pollutants harmful to health and degrading the urban environment (Carvalho 2011). Therefore, cities are increasingly evaluating and implementing sound policies to encourage the adoption of zero-emission vehicles (Slowik et al. 2018).

The city of São Paulo (Brazil) recently passed a law to promote the progressive reduction of CO_2 and other greenhouse gases emitted by its bus fleet, through the gradual introduction of more sustainable and cleaner public transportation. It is a means to reach SDS Goal 9[1], 11[2] and 13[3] (UN 2023). It is known that only with combustion engine technologies will it not be

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[1] ODS 9 - Build resilient infrastructures, promote inclusive and sustainable industrialization, and foster innovation

[2] ODS 11: Making cities and human settlements inclusive, safe, resilient, and sustainable

[3] ODS 13 - Take urgent measures to combat climate change and its impacts

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possible to achieve the goals imposed by the law, transitions to cleaner engine technologies and the use of non-fossil fuels will be necessary. Public transport operators will need to develop long-term acquisition strategies to plan for these transitions and ensure compliance with emission reduction targets.

Given the importance of the public transport fleet for mobility in São Paulo, as well as its impact on motor vehicle pollution, investments in buses are a key long-term strategy to meet the city's environmental and sustainability goals. Changes in fuel and bus fleet technologies aim at the dual objective of improving the quality of service provided to system users and reducing emissions of pollutants harmful to air quality in the city (Dallmann 2019). This must lead participants of the traditional mobility market to evaluate their strategy for future growth.

Alternative fuels can be used to reduce carbon emissions in the public transport domain, aiding in complying with the newer policies for greenhouse gas emissions and urban air pollution in the public transport sector, especially in the bus sector.

The literature highlights the need to study the impacts of different actions on public policies applied to the transport sector. In the models, different elements are interrelated, such as economy, infrastructure, number of vehicles, fuel consumption, and safety, among others. In the development of the models, different combinations of these elements are used, to represent the complexity of the transport system.

The expansion of cities meant that public transport assumed an essential role in displacing people within the urban environment. The bus is the most widespread mode of public transport worldwide. his fact is related to its flexibility, its ability to adapt to different demands, simple technology, ease of switching routes, and low cost of manufacture, implementation, and operation when compared to other modes (Segantin 2019).

São Paulo's public transport system operates with approximately 14,000 buses on 1,340 lines, is the largest system in Brazil, and is among the largest bus fleets in the world (SpTrans 2019). The fleet is mainly comprised (98%) of diesel fuel, which does not have the best technologies available to control diesel engine emissions (Façanha 2016). And they cover an average of 91,250 km annually (Raymundo and Reis 2015).

In January 2018, the municipality of São Paulo established Law No. 16,802, which determines that transport service operators (Urban Passenger Transport) should promote the progressive reduction of emissions of carbon dioxide from fossil origin, and toxic pollutants emitted in the operation of their fleets, through the gradual use of cleaner and more sustainable fuels and technologies. They also state that the process of replacing vehicles and cleaner technologies will occur gradually and will naturally occur when replacing the batches of older vehicles that are removed from the fleet, according to the maximum permitted age contractual rules of vehicles.

As Law 16.802 is formulated, reductions in exhaust emissions from fossil CO_2 are required. Thus, it does not regulate CO_2 emissions from producer to consumer (upstream emissions), associated with the production and distribution of raw materials and fuels, nor does it consider climate pollutants other than CO_2, such as methane, nitrous oxide, and black carbon (Dallmann 2019).

The targets for reducing fossil CO_2 exhaust emissions, PM, and NO_x adopted in Law 16,802, are 50%, 90%, and 80%, respectively, within 10 years after the law comes into force. Within 20 years, 100%, 95%, and 95% must be achieved respectively. The values are summarized in Table 1.

Table 1: Pollutant reduction targets

Pollutant	**At the end of 10 years (January 2028)**	**At the end of 20 years (January 2038)**
Fossil CO_2	50%	100%
PM	90%	95%
NO_x	80%	95%

As shown in Figure 1 and serving as a reference mode for the analyzes to be carried out, the emissions of the São Paulo fleet in 2016 were estimated at 1.24 million tons of $CO_2/year$. Based on this estimate, annual CO_2 emissions in the fleet must be reduced by 0.62 million tons/year to meet the 50% reduction target to the reference fleet within 10 years, and in the next 20 years fully eliminated. For PM, in 2016, 144.7 tons were issued, the target for 10 years is the value to reach 14.5 tons and in 20 years, 7.2 tons. For NO_x, 9,130 tons were issued in 2016, the target for 10 years is to reach 1,830 tons, and in 20 years 460 tons (Dallmann 2019).

In this context, the main aim of this paper is to assess the compliance to Law No. 16.802, with different transition strategies to zero emission and low emission vehicles and, to calculate the reductions achieved for carbon dioxide emissions (CO_2), particulate material (PM) and nitrogen oxides (NO_x), by means of a system dynamics (SD) model. SD uses a system of differential equations that are solved by numerical methods, and are composed of state variables (stocks), and rates (flows), generating - in the solution of the systems of equations - dynamic and non-linear behavior of the system (Sterman 2000).

2. Methods

The model was built from an aging chain of current buses, as shown in Figure 2. There is no entry of new buses in this chain, as we believe that the new buses will necessarily be exchanged for one with better technology regarding pollutant emissions. Thus, the entrance is in the aging chain of the different alternatives to the use of diesel buses.

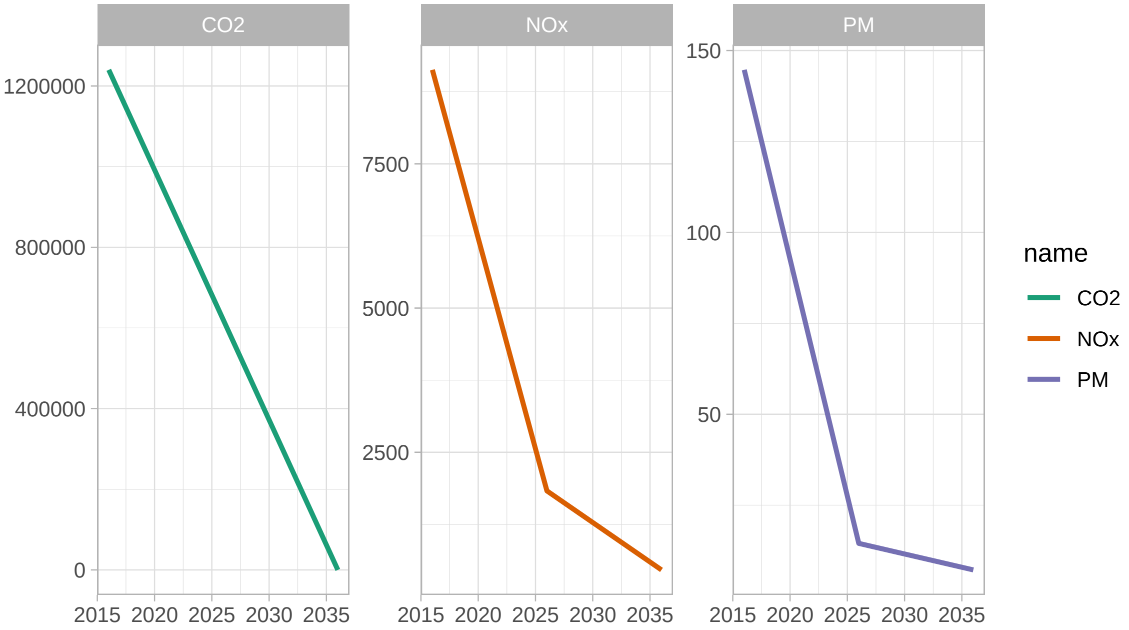

Figure 1: Reference values for 2019, 2026 and 2036

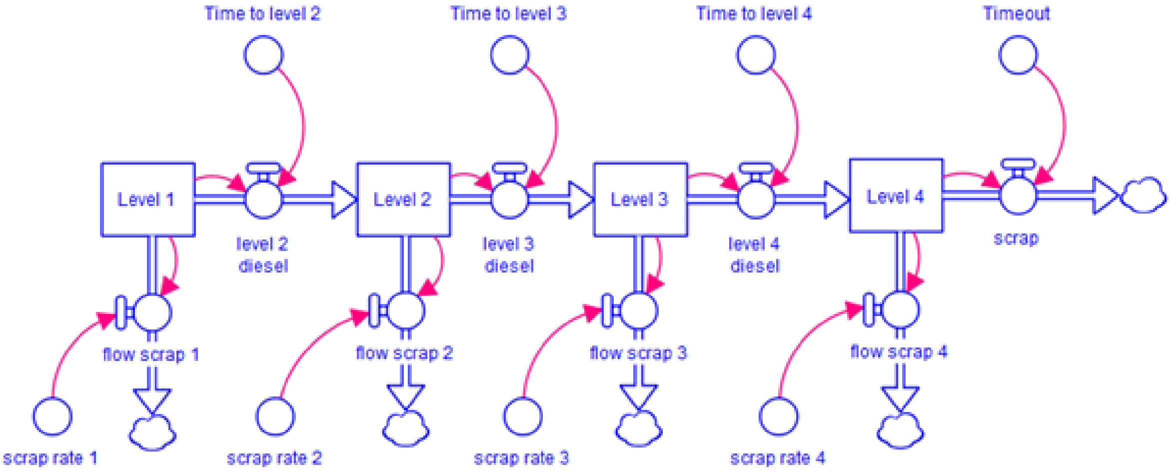

Figure 2: Aging chain for fossil fuel buses

The stocks are named level 1 for buses from 0 to 5 years, level 2 for buses from 6 to 15 years, level 3 for buses from 16 to 25 years, and level 4 for buses over 25 years. Scrapping rates for levels 1 and 2 are 1% (Automotive Business 2015), and 75% and 85% for levels 3 and 4 respectively. Later, we determine the equations for the exit of diesel buses for other chains, they follow the premise of Equation 1.

$$FlowScrap_1 = level_1 \times scraprate_1 \tag{1}$$

To follow from one stock to another, representing the aging of buses, we use Little's Law, in which a stable system the average amount of time something takes to go through a process is equal to the number of units in the process divided by its average rate, thus following Equation 2.

$$Level_2 = level_{Diesel2}/timetolevel_2 \tag{2}$$

There are several options of alternative engine and fuel technologies available commercially, which offer various degrees of emissions improvement compared to the diesel buses currently used in the São Paulo fleet. In this study, the technologies used are biodiesel, electric, compressed natural gas vehicles (CNG), biomethane, and hybrid (electric and diesel). As vehicles are being scrapped and leave the aging chain, they enter a new aging chain of bus options that emit less polluting gases, Figure 3, demonstrates the biodiesel and electric bus chain, the same is repeated for the other alternatives, i.e., biomethane, CNG and hybrid.

The variable "scrap flows" represents the sum of all outgoing stocks, both diesel and alternative fuel buses, later, this variable will be the system input. Together with it, there is the natural rate of increase of the transport system, which corresponds to a value close to 1% per year. Each of the proposed alternatives emits a specific value of CO_2, PM, and NO_x. In Figure 4 there is a part of the model that refers to the way emissions are calculated, the same structure is repeated for the other fuel and pollutant gas alternatives.

The variable "total biomethane buses" is repeated for the other technologies and represents the total of buses of that type in the model. The emission factor is then multiplied by the number of kilometers run in the year and the number of buses in the aging chain, thus generating the gas stock, according to Equation 3. This equation is replicated for different fuels and different gases.

$$CO_2 = emission.factor \times average.km.driven \times total.biomethane.buses \tag{3}$$

After this equation, and having repeated for the different fuel options, all emissions are summed up, having as the final value the total emissions for each gas (CO_2, PM, and NO_x). The parameters are summarized in Table 2.

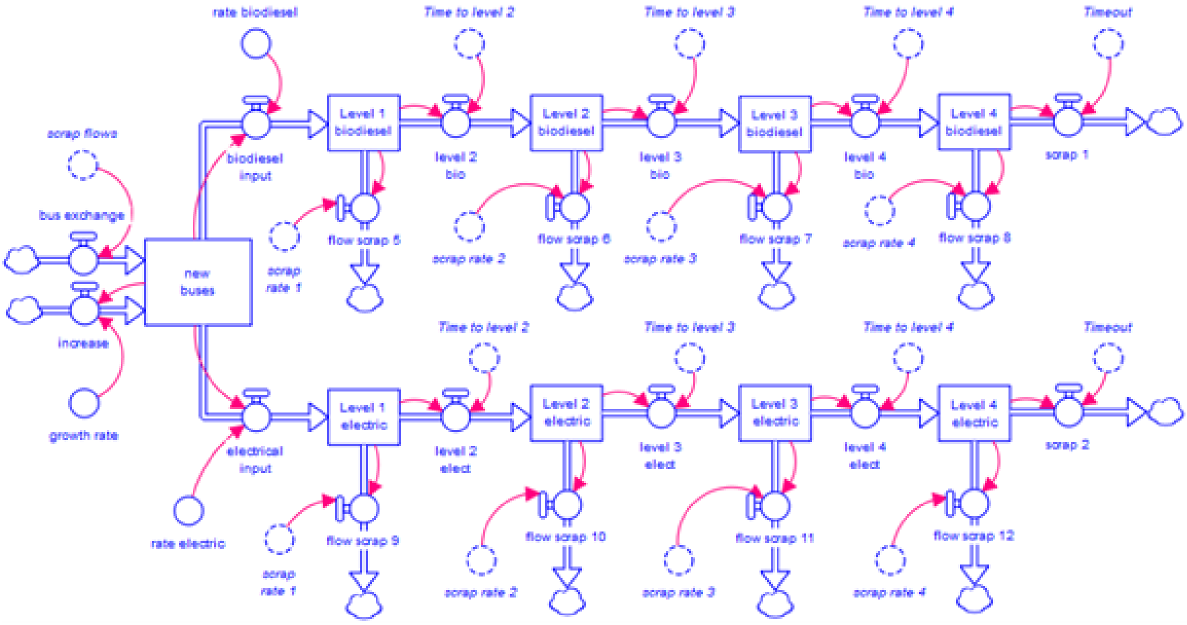

Figure 3: Zero and low-emission aging chain

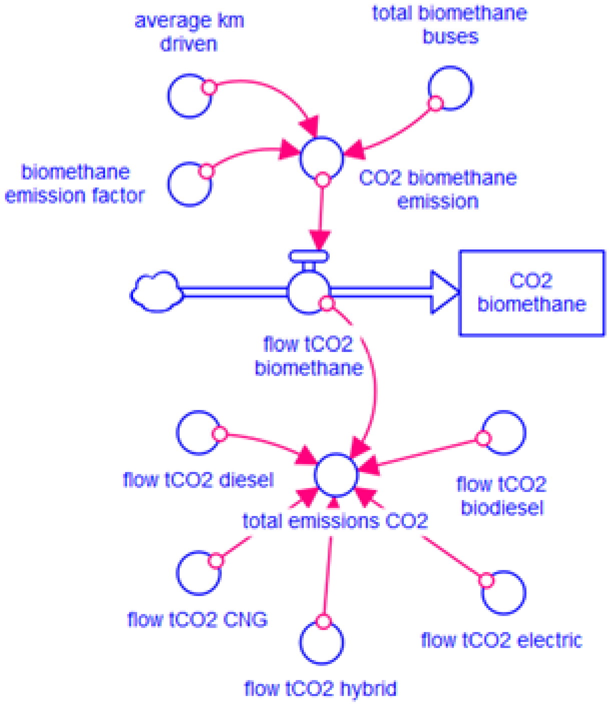

Figure 4: Emissions estimation structure

Table 2: Parameters

Parameters	**Values**
Average kilometers driven	91.250 km/year
Scrap rate – level 1 and level 2	1%
Scrap rate - level 3	75%
Scrap rate – level 4	85%
Growth rate	1%

The characteristics of the different types of buses are added to the model according to data from the literature. Thus, the CO_2 emission value for diesel buses is equivalent to an average of the different bus models, this value is approximately 1000 g/km (ANTP 2016). The PM emission is on average 0.115 g/km (ANTP 2016). For NO_x we also performed an average of the emission factor per g/km, of Euro III diesel, being a final value of 8 g/km (MMA 2013).

Biodiesel can be used in internal combustion engines and replace, partially or totally, diesel coming from petroleum. It can reach 15.79% less CO_2 emission than conventional diesel (only emissions in final use – fuel burning) (ANTP 2016), which also brings a 26.8% reduction in PM emission. However, it increases the emission of NO_x by an average of about 8% (Biodieselbr 2011). Biomethane can be produced from biogas generated by household, industrial, and agricultural waste.

The use of biogas from waste for transportation has two major advantages: it replaces a fossil fuel and prevents the release of biomethane directly into the atmosphere, simply by treating and purifying the biogas to meet official specifications of 90 to 99% methane. This type of fuel demands a supply infrastructure and technology for its combustion (Falco 2017). Biomethane emits on average 75% less PM than diesel (ABEGAS, 2019). It also emits 85% less and 86% less NO_x (Siamig 2018). Hybrid buses combine a conventional internal combustion diesel engine with an electric propulsion system, so they are called hybrids. Electric propulsion aims to achieve greater fuel economy since electric motors are more efficient than internal combustion engines.

They can be classified in parallel or series. In parallels, both the electric motor and the internal combustion engine are connected to the vehicle's mechanical transmission; in this technology, the electric motor usually transmits energy to move the wheels at low speeds, and the combustion engine enters when the vehicle acquires a higher operating speed (between 20 and 30 km/h). In series hybrids, only the electric motor drives the vehicle, so the combustion engine serves as a mini generator to recharge the batteries and drive the electric motor, which in turn drives the vehicle's wheels (Filho 2011).

Hybrid buses have greater mechanical complexity than conventional diesel buses and vehicle acquisition and maintenance costs are higher; however, this can be compensated over the lifetime by great fuel economy (ANTP 2016). They show a reduction of 80% of NO_x, 90% of PM, and 35% less when compared to diesel (ANTP 2016). The CNG is one of the partially sustainable alternatives, due to its reduced local environmental impact, reduction of internal and external bus noise, availability, and competitive cost with diesel technology. Surrounded by advanced distribution and motorization technologies, CNG has stood out as an alternative in several countries, such as Madrid - Spain, Frankfurt - Germany, and Athens - Greece, among others (ANTP 2016). They emit approximately 0.29 g/km of NO_x (MMA 2013), and also reduce CO_2 emissions by approximately 37% (EPA, 2019) and 98% of PM emissions to diesel (Scania 2018).

Electric buses reduce dependence on fossil fuels, eliminate greenhouse gas emissions because they do not emit exhaust gases such as fossil , PM, and NO_x, and also reduce noise in cities. Energy can be transferred to the bus in several ways: by charging the batteries at night in the garages, charging at the terminal (end or start of each line), and bus stops Olsson, Grauers, and Pettersson (2016), Dallmann (2019). The autonomy can reach about 300 km for a medium load and 280 km for a full load, according to tests conducted in São Paulo. Electric buses already operate in the thousands in major cities in Asia, Europe, the United States, Japan, Colombia, and Mexico (ANTP 2016).

Given the above, the quantities of gases emitted for each type of bus used in the simulation are summarized in Table 3.

Table 3: Emissions for different vehicle techonologies

Fuel	**CO_2 (g/km)**	**PM (g/km)**	**NO_x (g/km)**
Diesel	1000	0.115	8
Electric	0	0	0
Biodiesel	842.10	0.08418	8.64
Natural gas	630	0.0023	0.29
Hybrid	650	0.0115	1,6
Biomethane	150	0.02875	1.12

After obtaining all the variables and parameters, we performed some tests to improve the model. The modeling process was documented, which allowed the replication and review of the results. In addition, the units of measurement for all variables and parameters were checked and the dimensional consistency of all equations was verified. Extreme condition tests were also performed to check whether the model behaves realistically. After performing these tests, we observed that the model shows realistic behavior. Given this, we proceeded with the analysis of the scenarios in the next section.

3. Results and Discussion

Depending on the scrapping rates considered in the simulation, it is possible to observe the behavior of the substitution of diesel buses. The transition to sustainable buses takes place slowly, and in 2040 it is still concentrated in the fleet of around 1,500 buses, according to Figure 5.

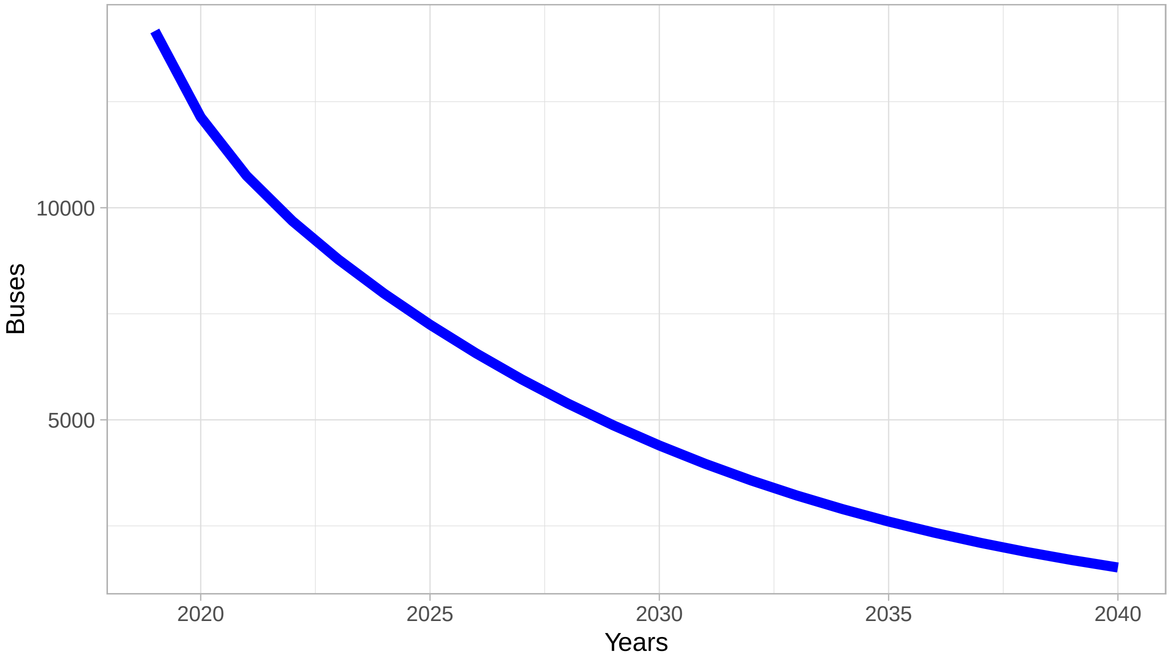

Figure 5: Decrease of fossil fuel bus fleet

Thus, at the end of the period stipulated by law, there are still fossil fuel vehicles in the public fleet, which consequently causes emissions of and other gases and cannot achieve zero emissions. This occurs because transitions are slow, the system must be reorganized to achieve the effectiveness of the service, and economic planning is necessary so that the costs do not reach the end customer. A way out of this bottleneck would be to speed up the process of fleet replacement so that in 20 years there is complete replacement. For the next simulations, we use the above scenario as a basis.

The scenarios were planned in such a way that there was a combination of most technologies available in the market, with two to three technologies dominating the market, being discarded the possibility of investing in a single alternative. This is due to the different characteristics of the technologies, which depend on the infrastructure itself. For buses that travel a longer mileage during the day, it is preferable to use fuels that give greater reach, this becomes a barrier for electric buses, which have limited reach and the need for their infrastructure for cargo that is not common in Brazil, thus favoring the use for smaller routes, for example, and do small recharges at the terminals in the intervals between routes. Table 4 shows the parameters for replacing the bus fleet for the different types of fuel.

Table 4: Scenarios

Abbreviation	**Combination**	**CNG**	**Electric**	**Hybrid**	**Biodiesel**	**Biomethane**
C1	Hybrid + Biodiesel	6%	6%	40%	40%	8%
C2	CNG + Biomethane	40%	6%	6%	8%	40%
C3	Electric + Hybrid	8%	40%	40%	6%	6%
C4	Electric + Biomethane	6%	40%	8%	6%	40%
C5	CNG + Hybrid + Biodiesel	30%	5%	30%	30%	5%
C6	CNG + Electric	40%	40%	5%	5%	10%
C7	Biomethane + Biodiesel	4%	3%	3%	45%	45%
C8	equal	20%	20%	20%	20%	20%

The first scenario (C1) expresses the investment in hybrid buses and biodiesel. Hybrids are intermediates between electricity and combustion, a technology that does not depend on infrastructure, and biodiesel-powered buses are already a reality in many countries. In Brazil, the advantage comes from the large biodiversity of oilseeds for fuel production. Given this, 40% of investment in buses is simulated for each of them, for the other 6% in CNG and electricity, and 8% for biomethane.

The second scenario (C2) values CNG and biomethane as options. CNG has been available in Brazil since 1980, but consumption in the transportation sector is low, only 2% in 2016. As for biomethane, it can be leveraged by Renova-Bio, which establishes targets for reducing carbon intensity in the fuel matrix by 10% by 2028 and creates carbon credit trading mechanisms (Roitman and Silva 2018). In addition, the infrastructure of these two fuels is similar and can be shared. Therefore, the simulation is based on 80% divided equally between CNG and biomethane, the rest being divided into other technologies.

For the third scenario, C3, the focus is on the shift to electric mobility, having a focus on electric and hybrid buses. According to the IEA (2018), more than 1 million electric cars were sold worldwide in 2017 and the world fleet already exceeds 3 million vehicles. In Brazil, sales do not exceed 10,000 units, being an incipient technology. It is expected that sales will become higher when the cost of batteries is reduced. Consequently, given the technological evolution, and because these vehicles have better technology, performance, and energy efficiency, the demand for electrics will increase, leading to higher growth of the fleet (Roitman and Silva

2018). Hybrids resemble electrics on a technological basis, so they may grow together in the market.

With 40% for electric bus and 40% for biomethane the fourth scenario (C4) was formed, the technologies were chosen because both presented the lowest values of emission, the electric considered null (for exhaust) and the biomethane about 150 g/km, 85% lower than diesel, from the point of view of emission, would be the best environmentally. Later, there is the fifth scenario, C5, which covers three technologies: CNG, hybrid, and biodiesel. These technologies, which have already been described above, together may become a dominant scenario, due to the existing knowledge about them and dominated by companies and researchers in Brazil.

In the case of the sixth scenario, C6, investments are in CNG and electricity. In this case, it is believed that as the CNG is already known by the actors of the sector, investments and greater acquisition of vehicles with this technology may occur, and combined with the electric one, which has significant benefits in the short and long term in the environmental issue, can together be driven.

The seventh scenario (C7) is biomethane and biodiesel. This combination meets the country's potential in producing these fuels. The last scenario, C8, has equal investment among the technologies, being elaborated to demonstrate a greater diversification of the fleet and identify the potential benefits for the user and the environment. Returning to the targets imposed by Law 16,802, the reduction in emissions should be 50% by 2028 (0.62 million tons) and in 2038 years should be zero. The results of the simulations for each scenario are presented in Figure 6.

The goal of reducing by 50% is achieved in 2029, by C4 (electric + biomethane), with approximately 602 thousand tons. However, in 2038 the value is not zero, because there are still diesel buses in the fleet and the biomethane emits polluting gases, however, the reduction is significant if compared to 2016 data, reaching a value close to 70% reduction. Another scenario with significant results is C6, with a predominance of CNG and electric fuels, reaching 2028 approximately 743,673 tons of CO_2.

Scenarios C1 and C5, with a predominance of hybrid and biodiesel for the first and CNG, hybrid, and biodiesel for the second scenario, are the ones that present the worst results of emission reduction. They are less aggressive technologies than diesel, however, still emit considerable and do not meet the targets required by law. However, the C3 scenario, electric + hybrid, i.e., electric mobility, presents a median result, although electric buses predominate, hybrids occupy half of the fleet, which are more efficient than diesel, but still emit around 650 g/km of CO_2, higher emissions than CNG and biomethane. For the PM, the reduction targets are 14.5 tons for 2028 and 7.2 tons for 2038. The results of the simulations for the different scenarios established are presented in Figure 7.

The value of the PM target imposed by the law is not reached by any scenario, what comes closest is the C6, with a combination of CNG and electricity, presenting a reduction of approximately 53% for the first 10 years and in 20 years a reduction of 83%. These two technologies present the best emission rates among those analyzed, thus, together they have the best result.

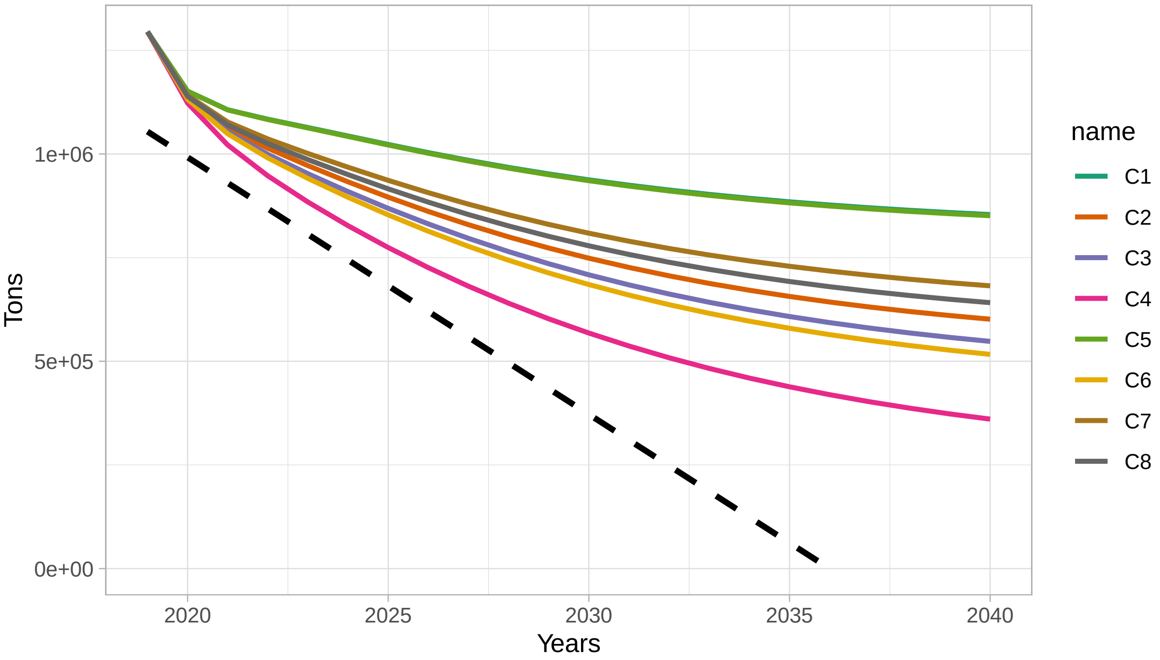

Figure 6: CO2 emissions

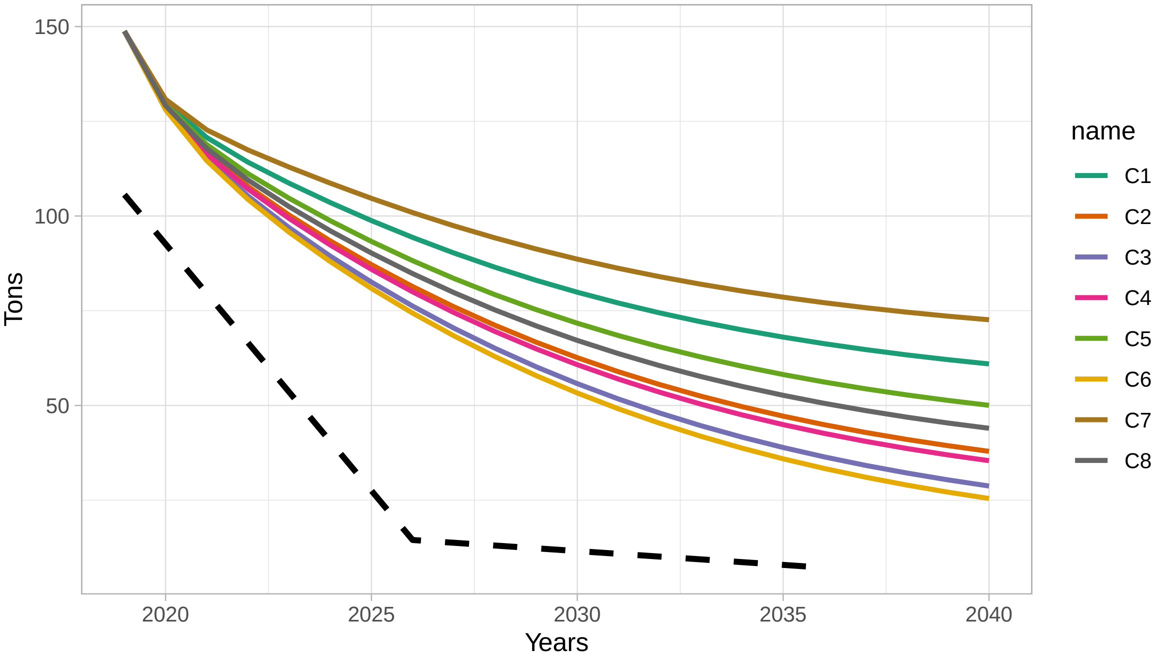

Figure 7: Particulate Matter emissions

Next, there is the C3 scenario (electric and hybrid), with 55% and 75% PM reduction, for 2028 and 2038, respectively.

The scenario that presented the worst result is C7 (biodiesel + biomethane), which reduces on the year 2038 only 48% of the base value of 2016, this result comes from the PM emission factor, for the technologies analyzed are the two largest emitters after diesel. The C1 scenario (hybrid and biodiesel) also presents a low performance, reducing in 20 years only 56% of emissions.

To anaylze the NO_x emissions, we also consider the target imposed by law, which is 1,830 tons for 2028 and 460 tons in 2038. The results based on the scenarios are presented in Figure 8.

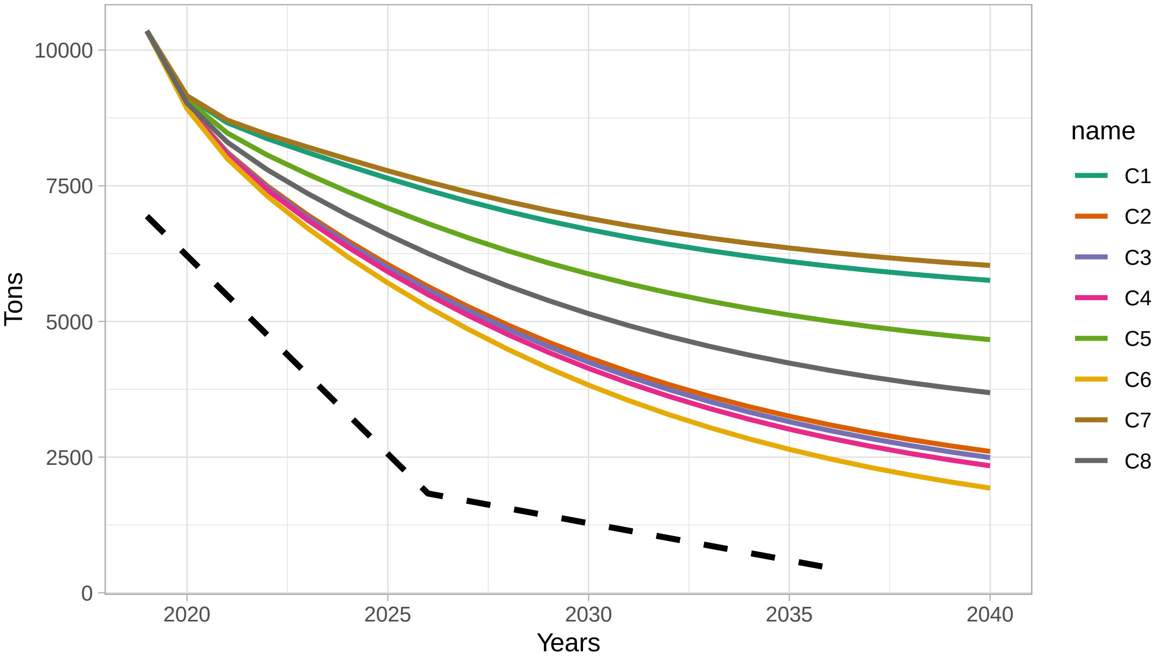

Figure 8: NOx emissions

Based on our simulation, none of the scenarios presents the achievement of the goals imposed by law. The closest scenario is C6, a combination of CNG + electric, with reductions close to 50% in 2028 and 76% in 2038. Similar to the previous simulation, the worst results are the combination of biodiesel and biomethane (C7) and the C1 scenario, which consists of hybrid models and biodiesel, which in 2028 will reduce an average of 23% and for the year 2038 the value of 34%. The rates used in the study, which are the highest concerning diesel, are also due.

Given the simulations carried out, the best combinations of alternatives for diesel-powered buses included the use of electric buses. The emissions for the different pollutants analyzed were considered null, considering only the exhaust emission. In Brazil, the energy matrix is predominantly hydroelectric, which helps in the low pollution of electric buses, but it is necessary to take into consideration the thermo-electric plants or other sources that can be used, which can emit pollutants.

However, although in two cases the target will not be achieved, in any selected fleet combination, the substitution of diesel by other types of technologies, results in reductions in emissions in the range of 51% , 70% PM, and 64% NO_x by 2040, which corresponds to a local environmental benefit of extreme importance for public health, given the large total mileage traveled by public buses and their proximity to the population exposed to these emissions.

4. Conclusion

According to the sustainability transitions theory, transitions refer to large-scale transformations in society or important subsystems, during which the structure of the social system changes fundamentally. These changes are usually slow and require enormous efforts from different stakeholders in order to succeed. The study showed one of the most radical sustainability laws in Brazil and the potential outcomes of switching fossil fuel buses of the public transportation system in the city of São Paulo for zero or low emission ones over a period of two decades. The proposed scenarios were based on existing technologies and were organized to reflect possible choices that would be made by those responsible for operating the bus system, once favorable conditions were created for the introduction of zero or low emission technologies. Given the results found in our simulations, the mix with best results are electric and biomethane, for CO_2 reduction, and CNG and electric buses for PM and NO_x reductions. Although, as shown in our results, none of the policy scenarios is able to fully comply with the Act, therefore suggesting that a stronger enforcement should be in place (such as enforcing faster substitution) if the City desires to achieve the goals imposed by the Act.

The emission factors of the polluting gases used for the simulation are preferably illustrative and not conclusive, as there may be data considering life cycle emissions and not just exhaust emissions. In addition, we stress that the analysis made in this work is simplified, considering only the benefits caused by the reduction of pollutant gas emissions. Thus, for future work, the insertion of cost variables is suggested, since it is necessary that the decision makers responsible for bus changes also have the economic vision of each technology and thus make it efficient both economically and environmentally.

References

ANTP. 2016. "Impactos Ambientais Da Substituição Dos Ônibus Urbanos Por Veículos Menos Poluentes." Report. http://files.antp.org.br/2016/6/21/vv-antp-substituicao-de-bus-final-2016-06-13-1.pdf.

Automotive Business. 2015. "Frota Circulante Atinge 41,5 Milhões de Veículos." Web Page. http://www.automotivebusiness.com.br/noticia/21922/frota-circulante-atinge-415-milhoes-de-veiculos.

Biodieselbr. 2011. "Emissao de Gases Poluentes e Biodiesel." Web Page. https://www.biodieselbr.com/efeito-estufa/gases/emissoes.

Carvalho, Carlos Henrique Ribeiro de. 2011. "Emissões Relativas de Poluentes Do Transporte Motorizado de Passageiros Nos Grandes Centros Urbanos Brasileiros." Report. Texto para Discussão, Instituto de Pesquisa Econômica Aplicada (IPEA). https://www.econstor.eu/bitstream/10419/91332/1/664398472.pdf.

Dallmann, Tim. 2019. "Benefícios de Tecnologias de ônibus Em Termos de Emissões de Poluentes Do Ar e Do Clima Em são Paulo." Technical report. *The International Council on Clean Transportation (ICCT): Relatório técnico. São Paulo. Washington, DCICCT, 2019.* Vol. 6. The International Council on Clean Transportation (ICCT).https://www.theicct. org/publications/beneficios-de-tecnologias-de-onibus-em-termosde-emissoes-de-poluentes-do-ar-e-do-clima.

EPE. 2018. "Balanço Energético Nacional 2018: Ano Base 2017." Report. Empresa de Pesquisa Energética. http://epe.gov.br/sites-pt/publicacoes-dados-abertos/publicacoes/PublicacoesArquivos/publicacao-303/topico-419/BEN2018___Int.pdf.

Façanha, Joshua Miller Cristiano. 2016. "Cost-Benefit Analysis of Brazil's Heavy-Duty Emission Standards (p-8)." Generic. https://theicct.org/publications/cost-benefit-analysis-brazils-heavy-duty-emission-standards-p-8.

Falco, Daniela Godoy. 2017. "Avaliação Do Desempenho Ambiental Do Transporte Coletivo Urbano No Estado de São Paulo: Uma Abordagem de Ciclo de Vida Do Ônibus a Diesel e Elétrico à Bateria." Dissertação de mestrado. http://repositorio.unicamp.br/bitstream/REPOSIP/322592/1/Falco_DanielaGodoy_M.pdf.

Filho, Adalberto Felício Maluf. 2011. "Avaliação Do Ciclo de Vida de Diferentes Tecnologias de Ônibus: Eficiência Energética e Emissões de Poluentes Em Operação Real." Journal Article. *Rede C40 Cities (Grupo Das Grandes Cidades Líderes Pelo Clima).*

IEA. 2018. "Global EV Outlook 2018: Towards Cross-Modal Electrification." Conference Proceedings. In. IEA.

MMA. 2013. "Inventário Nacional de Emissões Atmosféricas Por Veículos Automotores Rodoviários." Journal Article. http://www.antt.gov.br/backend/galeria/arquivos/inventario_de_emissoes_por_veiculos_rodoviarios_2013.pdf.

Olsson, Oscar, Anders Grauers, and Stefan Pettersson. 2016. "Method to Analyze Cost Effectiveness of Different Electric Bus Systems." Conference Proceedings. In *29th World Electric Vehicle Symposium and Exhibition, EVS 2016, 19 June 2016 Through 22 June 2016.*

Raymundo, H., and J. G. M. Reis. 2015. "Renovação Da Frota de Ônibus Urbano: Redução de Consumo de Energia e de Impactos Ambientais." Journal Article. *5^{a} Academic International Workshop Advances in Cleaner Production.* http://www.advancesincleanerproduction.net/fifth/files/sessoes/5B/7/raymundo_and_reis_academic.pdf.

Roitman, Tamar, and Tatiana Bruce da Silva. 2018. "Concorrência Interenergética e Intermodal No Setor de Transportes: Possibilidades Para o Brasil." Journal Article. *Boletim de Conjuntura*, no. 7: 15–23.

Scania. 2018. Web Page. https://www.scania.com/br/pt/home/experience-scania/news-andevents/News/archive/2018/11/default-press-release2.html.

Segantin, Cristiano Catto. 2019. "Barreiras e Facilitadores Para a Implantação de Ônibus Elétrico No Sistema de Transporte Público de São Paulo." Dissertação de Mestrado. http://bibliotecatede.uninove.br/bitstream/tede/1993/2/Cristiano%20Catto%20Segantin.pdf.

Siamig. 2018. "Biometano e a Reducao Das Emissoes Do Transporte Urbano." Web Page. http://www.siamig.com.br/artigos/biometano-e-a-reducao-das-emissoes-do-transporte-urbano.

Slowik, Peter, Carmen Araujo, Tim Dallmann, and Cristiano Façanha. 2018. "Avaliação Internacional de Politicas Públicas Para Eletromobilidade Em Frotas Urbanas." Report. https://theicct.org/sites/default/files/publications/ICCT_Brazil-Electromobility-PT-20122018.pdf.

SpTrans. 2019. "Information on Mobility." Web Page. https://www.prefeitura.sp.gov.br/cidade/secretarias/transportes/institucional/sptrans/acesso_a_informacao/index.php?p=227887.

Sterman, John D. 2000. "Learning in and about Complex Systems." *Reflections: The SoL Journal* 1 (3): 24–51. https://doi.org/10.1162/152417300570050.

UN. 2023. "UN Sustainable Development Goals." Web Page. https://nacoesunidas.org/pos2015/agenda2030/.