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GREENHOUSE GAS EMISSIONS ANALYSIS IN CURITIBA'S PUBLIC TRANSPORT: BRAZILIAN HYBRID BUSES AND SUSTAINABILITY

ANÁLISE DE EMISSÕES DE GASES DE EFEITO ESTUFA NO TRANSPORTE PÚBLICO DE CURITIBA: ÔNIBUS HÍBRIDOS BRASILEIROS E SUSTENTABILIDADE

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ABSTRACT
The public transport mode is one of the major contributors to increasing discharge of Greenhouse Gas Emissions (GGEs). This research highlights the strategic importance of renewable technologies in bus public transport in Curitiba's city, south of Brazil. The country signed the first United Nations Framework Convention Climate Change in 1992, and Curitiba supported this vision of sustainability since years 1970, when the City Hall created exclusive bus corridors and an integrated transport network. In Curitiba's city, in 2012, there was the inclusion of 30 called "hybrid buses" (hibribus) in the city's public transport fleet with an electric motor and biodiesel cycle engine, operating on diesel fuel and biodiesel fuel. The paper presents an inventory of GGEs comparing emissions of 30 buses with hybrid technology (biofuel and hydroelectric power) and diesel buses. To compare parameters among the three fuel bus types showed that such improvement actions of Curitiba's city could tackle the problem of environmental aspects related to low emissions level, climate change, contributing to reduce fuel emissions, recovering principles of urban sustainability, equity and mitigating health risks. The voluntary and political mitigation actions increase the confidence in the multilateral response of international sustainable development

KEYWORDS: Renewable technologies. Public transport. Biofuel. Gas emissions.

RESUMO
A modalidade de transporte público é um dos principais contribuintes para o aumento da descarga de Emissões de Gases de Efeito Estufa (GEE). Objetivou com esta pesquisa mostrar a importância estratégica das tecnologias renováveis no transporte público de ônibus na cidade de Curitiba, sul do Brasil. O país assinou a primeira Convenção-Quadro das Nações Unidas sobre Mudança do Clima em 1992, e Curitiba apoiou esta visão de sustentabilidade desde os anos 1970, quando a Prefeitura criou corredores de ônibus exclusivos e uma rede de transporte integrada. Na cidade de Curitiba, em 2012, houve a inclusão de 30 chamados "ônibus híbridos" (hibribus) na frota de transporte coletivo da cidade com motor elétrico e motor de ciclo a biodiesel, operando com óleo diesel e biodiesel. O artigo apresenta um inventário de GGE's comparando as emissões de 30 ônibus com tecnologia híbrida (biocombustível e energia hidrelétrica) e ônibus a diesel. A comparação dos parâmetros entre os três tipos de ônibus a combustível mostrou que tais ações de melhoria da cidade de Curitiba podem enfrentar o problema dos aspectos ambientais relacionados ao baixo nível de emissões, mudanças climáticas, contribuindo para a redução das emissões de combustíveis, recuperando princípios de sustentabilidade urbana, equidade e mitigação de riscos à saúde. As ações voluntárias e políticas de mitigação aumentam a confiança na resposta multilateral dos objetivos internacionais de desenvolvimento sustentável.

PALAVRAS-CHAVE: Tecnologias renováveis. Transporte público. Biocombustível. Emissão de gases.

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INTRODUCTION

The Ministry of Science and Technology (MCT), in 2004, coordinated Brazil's national communication about the commitment to the United Nations Framework Convention on Climate Change (UNFCCC), signed in 1992 and ratified by the Brazilian National Congress in 1994. "The UNFCCC is a "Rio Convention", one of two opened for signature at the "Rio Earth Summit" in 1992. Its sister Rio Conventions are the UN Convention on Biological Diversity and the Convention to Combat Desertification. The three are intrinsically linked" (UNITED NATIONS, 2021).

UNFCCC, created in 1994, has 197 memberships, called "parties of de Convention" that recognize the fact that humanity need a safer future and the existence of dangerous anthropogenic interference (Convention means the United Nations Framework Convention on Climate Change, adopted in New York on 9 May 1992. Paris Agreement, 2015). The main Convention objective is to stabilize GGE in a way that food production, climate change, ecosystems and economic development policies and measures on putting things right in the coming years (UNITED NATIONS, 2021).

The document referred "National Communication by the Convention" contains national inventories of anthropogenic emissions from various sectors as energy, industry, forestry, agriculture and others. Brazil's main commitment with the Convention is to develop and update inventories, recurring to scientific knowledge, which can clarify the ways to implement measures and improvements in the anthropogenic activities (BRAZIL, 2004).

The country is always organizing programs and actions, as the clean energy matrix, the National Alcohol Program, Rational Use of Natural Gas and Oil Products, to reduce emissions, change the tendencies of fossil fuel uses and increase awareness of society regarding global warming and the sustainable development goals. Most of the emissions come from deforestation for agriculture and breeding stock land uses. Even though the absence of adequate methodology and data to calculate GGEs in agriculture and land use change and forestry, Brazil concentrates its emissions in those sectors in 1994.

The 1990-1994 report showed that Brazil was on the top of list as world's greenhouse gas emitters. The authors updated the data and concluded that from 1990 to 2005 the CO2-eq total emissions increased 17% [4].

"Because of the large size of the Brazilian territory, the estimation of values for this sector was one of the most complex parts of the Inventory preparation, which required an extensive work of assessment and treatment of remote sensing and statistical data from the forest inventory" (BRAZIL, 2004, p. 11).

In 2016, in the third communication, Brazil further added that is conducting a Low Carbon Agriculture Plan as a policy to mitigate emissions - Sectorial Plan for the Mitigation and Adaptation to Climate Change for a Low Carbon Emission Agriculture. The difficulties for Brazilian methodologies, despite the Intergovernmental Panel on Climate Change's (IPCC) suggestions, to obtain accurate

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information still a problem to resolve. The Third National Communication of Brazil to the Climate Convention presents a revise estimate for 2006-2010 periods. The table 1 presents the estimates of carbon dioxide (CO2) emissions by economic sectors [6]. (BRAZIL, 2016).

Table 1. Sectors and sub-sectors share of net CO2 emissions in 2010

Sector	Percent
Fuels combustion – energy	8%
Fuels combustion – industry	9,2%
Fuels combustion – transport	22,8
Fuels combustion – other sectors	5%
Fugitive emissions	2,1%
Industrial process	10,9%
Land use, land use change and forestry	42%
Waste	10,9

Source: BRAZIL (2016).

The evolution of fuel consumption is associated to GGEs in the air as carbon dioxide, methane, water vapor, ozone, nitrous oxides and fluorinated gases. Greenhouse gas is "any gas that has the property of absorbing infrared radiation (net heat energy) emitted from Earth's surface and reradiating it back to Earth's surface, thus contributing to the greenhouse effect" (MANN, 2021).

United Nations Paris Agreement (2015) remarks the importance of low GGE's development strategies to reach responsible sustainability that co-benefits all Parties. Brazil, reflecting his special circumstances and institutional capacity to mitigate emissions of gases that empower global warming, has, as shown in Table 1, to create alternative policies and legislation to reduce CO2 emissions from deforestation and forest degradation, and sustainable management of forests (42%)

"Ideally, the carbon cycle would keep Earth's carbon concentrations in balance, moving the carbon from place to place and keeping atmospheric carbon dioxide levels steady. However, the carbon cycle is changing because of human activity. People are releasing more carbon into the atmosphere by using fossil fuels and maintaining large livestock operations. Deforestation is depleting Earth's supply of carbon sinks. As a result, the amount of carbon in the atmosphere is rising" (NATIONAL GEOGRAPHIC, 2021).

According to Kyoto Protocol international treaty that entered into force in 2005, there are rules for international emissions trading and assigned amounts for the Parties so that they can meet commitments. The countries must work 'at home' to remove emissions from the atmosphere in a safe level. The document indicates the market-based mechanisms to encourage GGE's avoidance of excess: international emissions trading (IET); clean development mechanism (CDM) and joint implementation (JI). The national government must create a system to observe private entities' emissions obligation and the compliance or not-compliance to the assigned amount. "National governments should keep track of the impact of entity and government transactions on the national

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assigned amount and periodically report this information to the international community" (OECD. Environment Directorate and International Energy Agency, 2001, p. 9).

The IPCC, constituted in 1988 by the World Meteorological Organization and the United Nations Environment Program, organizes and directs worldwide surveys, expert meetings, working group plenary sections, and publishes reports, technical papers, on the field knowledge of climate changes. Taking the environmental lead, IPCC recommends methodologies actions and efforts to advance understanding, especially about many interactions among climate change responses and human activities. "The IPCC was created to provide policymakers with regular scientific assessments on climate change, its implications and potential future risks, as well as to put forward adaptation and mitigation options" (IPCC, 2021).

Climate change actions and sustainable development in real world time depend on technological and economic capacity and strategies to accomplish recommendations, to remove or create policies for communities' needs, investments, value judgments, time aspects, opportunities, and risk. Together, the 2030 Agenda for Sustainable Development from 2015 comes with a collective journey that organizes and directs activities to advance the human rights to live in a healing and secure Planet. The Agenda's goals and targets conceived five critical areas: poverty and hunger, Planet's degradation, balance among human activities and nature, peace, and Global partnership.

"We are committed to achieving sustainable development in its three dimensions – economic, social and environmental – in a balanced and integrated manner. We will also build upon the achievements of the Millennium Development Goals and seek to address their unfinished business" (UNITED NATIONS, 2020).

The Agenda considers that climate change is one of the greatest countries' challenges. However, the available studies would contribute to improve and to strengthen administrative capacities to align these goals with IPCC methodologies. It is essential to mention Global interconnectedness that deals with information and communications technologies to help the Competent Authorities to deal with economic deterioration, to enrich ecosystems of great biological diversities and to stimulate the adequate use of resources, and to evaluate the communities' abilities to maintain projects to solve emerging problems.

Notwithstanding those remarks, the environmental influence of transport in an economic and ecological way to climatic changes is a reality to face. The effects of global warming from fossil fuels grow and transport needs alternatives to gasoline and diesel. Carbon dioxide (CO2) is a greenhouse gas that affects transport operations. To reduce CO2 emissions in this sector, focusing on roads, adaptation measures are necessary regarding the mode and the geographic location of regions. "There are fewer studies examining the vulnerability of air and water transport modes than of road or rail. However, climate change can affect more severely air and sea transport modes than land transport (CHRISTODOULOU; DEMIREL, 2018, p. 7).

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The higher emissions of transport activities considered the total activity and the negative impact on the environment depends, as well, on the design of the infrastructure. Public transport is a large contributor to gas emissions. A sustainable public transport can play a vital role to decrease emissions. Biogas buses can contribute with reduction of emissions of air pollutants and harmful gases because the methane, the main ingredient in the natural gas, can be part of the solution if captured to be treated, converted into fuel, or burned to produce electricity.

"Some processes release more carbon dioxide into the atmosphere than they absorb. Any process that uses fossil fuels— such as burning coal to make electricity—releases carbon into the atmosphere. Raising cattle for food also releases carbon into the atmosphere. These processes that release carbon into the atmosphere are known as carbon sources" (NATIONAL GEOGRAPHIC, 2021).

This paper presents an experience in Curitiba's city, in the south of Brazil, which adopts, until nowadays, hybrid buses as an action to collaborate to diminish the extra greenhouse gases emissions to the atmosphere. The fleet still has buses burning fossil fuels and releasing carbon dioxide, but the major is including subsequent cases to use biodiesel fuel in articulated buses. These bendy buses are running in public transportation since 1974, crossing the city from north to south, and from east to west. They have a higher passenger capacity (270 persons per vehicle) and belong to the category of bus rapid transport (BRT) because they circulate in exclusive lanes.

Considered a sustainable political action, the hibribus uses an alternative fuel classified as clean energies technologies. It is an electro mobility vehicle moved by means of an electric motor with two sources options of energy: a diesel or a biofuel engine-generator set and plug-in technologies with rechargeable batteries. With flexibility of operation, the plug-in buses can operate in 100% electric mode, period when it does not emit pollutants and is very silent, and in hybrid mode.

The research quantifies, through an analysis, Curitiba's total emissions in the public transport sector from September 2012 to August 2013 to verify the changes arising from this differentiated use of alternative energies. The scenario has changed after the years, but the city took conviction and kept the system. In 2016, URBS - Urbanização de Curitiba S. / A., the company responsible for developing infrastructure works, urban equipment programs related to urban development, for the public transportation in Curitiba, published news about the economic technology and the less pollution consequences of diesel buses, hybrid buses, hybrid and electric buses.

"In comparison with the diesel model, the HibriPlug emits 55% less CO2 (carbon dioxide); 540% less NOx (nitrogen oxides) and 1,500% less particulate material (black smoke). It is practically twice the result obtained by hibribus, in circulation for four years in Curitiba. Compared to the same conventional diesel, hibribus emits 26% less CO2; 430% less NOx and 700% less particulate matter" (CURITIBA, 2016).

URBS, institution created with the objective of managing the Curitiba Urbanization Fund, develops urban infrastructure works, and urban equipment programs and activities. It is a mixed

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economy company for 58 years and to its original functions has been added: the management and operational planning of public transport, the management of the official taxi system and more recently, in 2006, the assignment to operationalize the motorcycle shipping activity in the city.

During vehicle operation and fuel production, the author's studies show us about air pollution, the ambient air quality standards, and the risks for human health and for environment. Thus, to care about clean vehicles and fuel technologies, at community level is relevant and can reduce air pollutant emissions from buses, cars and trucks. Talking about climate change in pandemic time and the opportunities for students, activists, stakeholders to become more fully involved, Thomsen and Creelman (2021) believe that a 10.000 people population size can promote better solutions for this wicked problem. We are aware of global trends and challenges, and so it is imperative to nourish localized scale to glimpse socio-political-geographical characteristics, barriers, opportunities, social networks and institutions, similarities, abilities and so forth.

"The decadal old approach to fly people around the world to negotiate and discuss climate issues has failed. The CO2 emissions are a problem, but even more is the message, which is sent to everyone. So, are there other ways? This approach has not led to any reduction of the CO2 emissions and even less to a reduction of CO2 concentrations in the atmosphere, which is needed to stabilize climate. The combination of the climate and biodiversity crisis and the covid-19 pandemic had brought the unsustainability of the traditional international scientific conference into sharp focus" (THOMSEN; CREELMAN, 2021).

1 LITERATURE REVIEW – FUELS AND AIR POLLUTION

Inserted in the Brazilian energy matrix through Federal Law number 11.097, May 13, 2005, Biodiesel still a common fuel for buses. However, its incorporation in the other fuels, as diesel oil, had been carrying out gradually, 2%, 5%, 7%. 8% and 10%. In March 2021, the Brazilian government, represented by the National Energy Policy Council, authorized the National Oil Agency to add 13% of the renewable biodiesel to the fossil diesel (GOV.BR, 2021). However, due to the biodiesel and fossil diesel prices, the increases and legal taxation, in April 2021, a new resolution changed the percentage to 10%. "As an interest of the National Energy Policy, the reduction of the percentage of mandatory mixing of biodiesel in fossil diesel oil from 13% (thirteen percent) to 10% (ten percent), during the 79th Biodiesel Auction (L79) (GOV.BR, 2021).

Biodiesel is a fuel that has similar characteristics to diesel, and practically has the same properties. It presents advantages compared to fossil fuel, because it is derived from renewable raw materials, biodegradable, generates a reduction in the main emissions present in exhaust gases (except nitrogen oxides), and has a high flash point with an excellent lubricity (FERRARI; OLIVEIRA; SCABIO, 2005).

Since public transport infrastructure improvement is not a government priority, and the frequently ticket price increases, people migrates to cheaper alternatives to go from one place to

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another. Toledo (2019) believes that the Bus Rapid Transport (BRT) systems, implemented in some Brazilian cities, as Curitiba-PR, in 2018, brings economic benefits, create jobs and support industrial activities. Nevertheless, Brazil needs not only to use sustainable biofuels. It is urgent to create policies to reduce the motorized individual transport. The country has to offer eco-driving options, tax incentives, and to motivate consumers to adhere to Intelligent Transport Systems (ITS), economically viable and customized public transit systems.

Figure 1. Bus Rapid Transport in Curitiba, Brazil. Biodiesel fuel. 2021

Toledo (2019, p. 107) studied the public transport case of a Brazilian city, situated in the northeast of the country. He says, "The implementation of electric buses, in replacement of current diesel buses, in urban transport, could increase its contribution to emission reduction if associated with a change in the bus network from a point-to-point network to a trunk-feeder network".

Businesses and Governments may work together to remove public small buses and coaches emitting exhaust fumes, using more fuel, creating costs and no. Fixed-route large buses must run properly to prevent waste of resources and enhancing operational costs.

The option of lowered emissions hybrid-electric buses powered by an electric motor allows the combustion engine to operate at periods of maximum efficiency and decreasing maintenance costs. The combustion engine connected to electric motor work independently. "The electric motor is designed to provide power during stop-and-go traffic while at highway speeds the vehicle is powered solely by the internal combustion engine" (EESI, 2021, p. 2). When accelerating, the transmission is

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produced by both powers. "In addition, through a process called regenerative breaking, energy lost due to braking is recovered and utilized to charge the battery" (EESI, 2021, p. 2).

Figure 2. The hibribus in Curiitiba-Brazil.

These buses run without exhaust emissions. Fuel consumption is 39% less than fossil diesel buses. The industry Volvo (Volvo Car Corporation) is producing those buses, and they do not need special investments in infrastructure. "Their batteries are charged on board the vehicle using the energy generated by engine braking. This means that hybrid buses can be used on any bus route both in inner-city operations and in the suburbs" (VOLVO, 2019). Britain is the main customer "Customers on the Spanish market have invested in a total of more than 300 hybrid buses from Volvo, of which 120 in the past year alone. In Sweden Volvo Buses sold more than 200 hybrid buses to cities such as Gothenburg, Sundsvall, Nässjö, Värnamo and Kungsbacka" (VOLVO, 2019).

In July 2016, Curitiba's public transport fleet started to operate with Electric Hybrid Volvo buses. The major main objective of this sustainable deed was to reduce the city levels of emissions of pollutants and the use of fossil fuels. Volvo working in partnership with Siemens, unifying research, technology, and expertise, maximizing return on investment, they projected quick charge stations for the batteries of the electric motor. "The system reduces up to 75% the consumption of diesel" and "the model's total energy consumption is 60% lower than those powered by diesel, representing a huge environmental gain for the city" (AUTOMOTIVE WORLD, 2016).

As business, objectives require, depending on the demand, the hybrid buses can run in 100% electric mode and in hybrid mode. Curitiba bought the standard type of vehicle, with capacity for 91 passengers. The conventional hybrid in Brazil is part of the electro-mobility project in Latin America. Glensor and Muñoz (2019), working on the Life Cycle Analysis, examined the effect of gradual adoption of either electric vehicles or biofuels. In 2050, the Brazilian passengers transport would be composed by a 100% of vehicles running with biofuel (sugarcane ethanol or soy-based biodiesel).

The air pollutant emissions would be reduced but there were the negative effects, "such as human toxicity, water eco-toxicity, freshwater eutrophication, acidification, and metal depletion, amongst others […], estimating that human health damage accounts for 43% of the complete environmental burden caused by the production of a Li-ion battery" Glensor and Muñoz (2019). The biofuels, in the other hand, compared to electric vehicles, do not reduce global warming as much as it is expected. "In addition, it is important to bear in mind that sugarcane production is associated with

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the following environmental and social impacts": deforestation, soil, and air and water pollution, loss of biodiversity, poor work conditions, and landscape alterations.

The Brazilian Life Cycle Analysis of Glensor and Muñoz show that if the policy focus remains on biofuels, "it should be ensured that any additional land used to grow biofuel feedstocks should not have high stored carbon. That is, "should be Cerrado or plantation forest, or similar biomes, or even better that it must come from already cleared land, such as farmland used for other crops, degraded pastureland or brownfield sites" Glensor and Muñoz (2019, p. 22).

2 MATERIALS AND METHODS

This is a quantitative and qualitative study. There is platform developed by the Brazilian GHG Protocol Program called 'Public Emissions Registry' that assists her members' organizations in the publication of inventories about GGE. Considered one of the largest databases of corporate inventories in Latin America, this research used their data to compare hybrid and fuel technologies emissions and the contributions to reduce GEE and to reach new steps of responsible sustainability.

Only the gas combustion emissions from vehicles in the city's public urban bus fleet, regarding the territory city area (435,036 Km2) and terrestrial mobile sources have been evaluated. The air pollutant emissions' analysis had its consistency in the data quantifying emissions comprised in the period of 12 months, from September 2012 to August 2013, considering the following greenhouse gases: CO2, CH4 e N2O.

The city's fleet had 1,930 buses, of which 34 used pure B100 biodiesel, 30 were hybrid buses and 1,866 ran on metropolitan diesel, with a 5% biodiesel blend. For the fleet that consumed diesel fuel, it was possible to obtain CO2, CH4 e N2O quantification. Nonetheless, for hybrid technologies, the calculator does not consider N2O and CH4 emissions. Therefore, only equivalent CO2 emissions were accounted, using emission factors available in the database that follow the rules and guidelines established by IPCC, presented in table 2 (multiplying each liter of fuel consumed by the emission factor).

Table 2. Emission Factors

Fuel	Unit	Emission Factors CO2 (kgGEE's/unit)	Emission Factors CH4 (kgGEE's/unit)	Emission Factors N2O (kgGEE's/unit)
Diesel	Liter	2,6710	0,0001	0,00014
Biodiesel	Liter	2,4991	x	x

Source: Programa Brasileiro GHG Protocol (2013).

The URBS' inventory data source was the primary location from where came air pollutant emissions calculations. The dataset of smoke opacity measured on the bus analysis used the methodology adopted for conducting the opacity tests, complying with the national standard ABNT NBR 13037 legal parameters, and ABNT NBR 12897 for the equipment used (Opacimeter), brand Napro, Model NA9000P (ABNT, 2001).

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For discussions, a proper comparison of hybrid and diesel fuel technologies use and air pollution emissions analysis, the following bus factory information accepted as done are: Particulate material - Reduction of 89%; Nitrogen oxides (NOX) - reduction of 80%; CO2 - Reduction of 35%.

To consider air pollutant emissions avoided by biodiesel use, we resorted to Gazzoni's study. It presents an emission factor for biodiesel produced in Brazil that evaluated the entire life cycle of a production chain, considering a raw material mix average of 82% soy oil and 18% bovine tallow, with the emission factor used for this purpose being 862 g/l of CO2 equivalent [30].

The next two examples were useful for the database economic analysis of air pollution effects proposed in this paper. An economic analysis of fuel consumption is presented in table 3. One hybrid bus made an average of 3, 14 km per liter, and the diesel-powered model has an average of 2, 03 km per liter. In 100 kilometers, this represents a difference of 54, 68% fuel economy, regarding traveled in kilometers, and also a difference of 35, 35% reduction in fuel consumption. This means that to travel this distance, it would be necessary 49, 26 liters of diesel for Volvo's B7R buses (16 tones model) while the hybrid bus model fuel consumption would be 31, 85 liters.

Table 3. Comparison of diesel and hybrid buses fuel consumption (estimation)

Fuel economy	One Diesel Model B7R Volvo	One Hybrid Model Volvo	Difference (Traveled 100km)
Average/ 1 km/liter.	2,03%	3,14%	54,68%
Average/ fuel consumption 100km/liter.	49,26%	31,85%	35,35%

Source: Adapted from URBS (2010).

Regarding table 3 and table 4, the differences indicate an energy efficiency favored by the reduction of GGEs by the hibribus fleet. The modeling estimation of air pollutant emissions from one hybrid bus, for 70.000-traveled kilometer/year are lower in carbon dioxide (35%), nitrogen oxides (80%), and particulate matter (89%).

Table 4. CO2, NOx, and Particulate Matter (PM) emissions per bus (estimation).

Estimation of air pollutant emissions for one bus (Kg)	Diesel Model	Hybrid Model Volvo	Difference
Emissions	B7R Volvo	58.560	(Traveled 70.000km)
CO2 (Kg)	90.870	164	59,22
Emissions	637	1,64	25,75

Source: Adapted from URBS (2010).

3 RESULTS

The results, divided in four sections, bring forward discussions about GGEs total emissions profile, smoke opacity test, avoided GGEs emissions, economic analysis.

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a) The GGEs total emissions profile - During the research-delimited period, the city's public transport sector consumed a total of 74,803,477.00 liters of fuel, being 72,528,003,898 liters of diesel and 2,275,471.59 liters of B100 biodiesel. For this consumption, the city's public transport was responsible for the emissions of 184,036.19 metric tons of CO2, 14.93 metric tons of CH4, 1.47 metric tons of N2O, and a total of 184,804.93 metric tons of CO2 from the use of diesel in engines.

Biodiesel emissions corresponded to 14,749.18 metric tons of CO2, videlicet 9,062.62 metric tons coming from the 5% present in diesel, and 5,686.56 metric tons from the use of pure biodiesel in buses with adapted engines and duly regulated by the National Agency for Petroleum, Natural Gas and Biofuels (ANP). Thus, the total CO2 equivalent emitted in the period corresponded to an emission of 199,554.10 metric tons of CO2 equivalent.

b) Smoke opacity tests - By evaluating the opacity levels (black smoke), it is conceivable to identify diesel cycle vehicles conservation status. In addition, opacity tests are appropriate to classify emission levels of diesel vehicles and measure the environmental performance of burning fuels and/or biofuels. As previously stated, in Brazil the effectiveness of the action is through inspection and maintenance programs, supported by NBR 13.037 and the National Environment Council (CONAMA) resolutions. For in-use vehicles, the Resolutions numbers 16/95 and 251/99 establish procedures and maximum limits of opacity for evaluating motor vehicles of the Diesel cycle status (CONAMA, 1995; 1999). The measurement must be made using an opacimeter certified by the National Institute of Metrology, Standardization, and Industrial Quality (INMETRO).

Table 5 introduces the tests of hybrid buses fleet - BR7 model from Volvo Car Corporation - conducted by URBS in Curitiba. According to the Resolution 003/90 (CONAMA, 1990), that regularizes the permitted concentration levels of air pollutants, the maximum concentration limits of black smoke in the urban area obeys the indices described in Table 4. It is important to take into account that these vehicles, manufactured after the year 2000, operated at an altitude of more than 900 meters above sea level, whose maximum limit index is 2.3 m^{-1}.

At the beginning, the entire fleet complied with the maximum limits required by current laws. Subsequently, provided afterwards in table 5, for nine months, with the incorporation of the new buses, the numbers were below CONAMA's permissible limits, gaining prominence in the opacity values emitted by the hybrid fleet operated mainly with model B100.

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Table 5. Opacity Tests Results for Curitiba's bus fleet.

Aver.*	Jan/13	Feb/13	Mar/13	Apr/13	May/13	June/13	Jul/13	Aug/13	Sep/13	Aver.
Hybrid bus B100	0,05	0,05	0,04	0,05	0,03	0,06	0,02	0,01	0,10	0,04
Hybrid bus B5	0,31	0,30	0,28	0,25	0,24	0,24	0,26	0,12	0,23	0,25
B7R B5	0,29	0,29	0,37	0,34	0,30	0,29	0,27	0,53	0,22	0,32

Source: Adapted from URBS (2012).

As shown in Table 5, opacity tests are within the limits allowed by current legislation. For the diesel-powered buses, represented by BR7 model, there is greater opacity in the emission of gases compared to the hybrids B100 and B5. The BR7 model has higher emitted opacity level (88, 90%) if compared to the B100 (56, 13%). The best scenario is the use of hybrid technology with biofuel. In this case, the use of 100% biodiesel combined in parallel with the electric motor presents a 93.45% reduction in the emission of opacity levels. In other words, the hybrid model operating at B100, emits about 93% less black smoke.

The reduction in opacity is representative and favorable to the use of Biodiesel, partly explained by the absence of sulfur (SOx) in the biofuel. The sulfur (SOx) shares the oxygen available in the late stage of combustion with the carbon resulting from partial burning. Under engine operating conditions, it increases particulate matter production (MAZIERO et al., 2006).

Guariero et al., (2011) report that pollutants released in the atmosphere by vehicles come from the incomplete combustion process. When the fuel injected into the cylinder does not find the necessary amount of air to burn, the gases are emitted directly by vehicles' exhaust pipes, such as carbon and nitrogen oxides, sulfur, alcohols, aldehydes, hydrocarbons, organic acids, and particulate matter. They also emphasize that the primary pollutants can interact among themselves or react – photolysis - and form secondary pollutants, such as ozone, peroxyacetyl nitrates (PAN) that can be harmful to them and to the environment.

c) GGE's avoided emissions - Considering the annual consumption of B100, plus the 5% biodiesel included in diesel, during the months of September 2012 to August 2013, there is a consumption of renewable fuel used in Curitiba's urban bus fleet of 5,901. 871.78 l biodiesel liters.

Based on the total value of B100 emissions, arising from the burning of fuel and discounting the results obtained with the emission factor of Brazilian biodiesel, a real difference in emission has been achieved, called in this paper as GGEs avoided emissions, totaling a value of 9,661.96 metric tons of CO2 equivalent, as shown in Graph 1. The United States Environmental Protection Agency (US-EPA) provides premises and guidelines for making and improving inventories as part of its Air Pollutant Inventory Improvement Program. In Graph 1 it was used the emission factors, despite their limitations, for air quality management depicted by the Agency.

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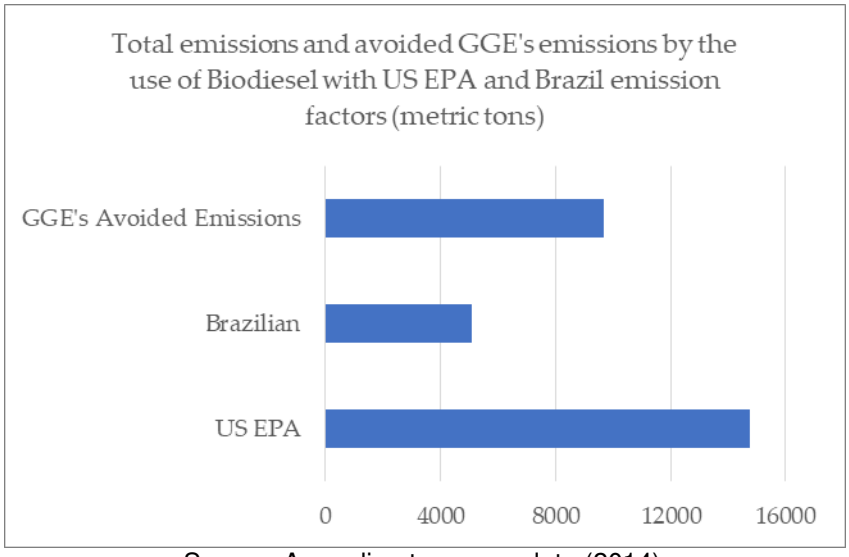
Graph 1. Total emissions and avoided GGE's emissions using Biodiesel with US EPA and Brazil emission factors (metric tons).



Source: According to survey data (2014).

The results from this individual source have a typical design of emissions but support the broad adoption of good practices taking into account regulatory purposes. In the study period, considering the total GGEs emissions from urban Curitiba bus transport, approximately 10,000 metric tons of CO2 were avoided. Encouraging the use of hybrid vehicles provides quick and direct changes in the transport sector, with the use of clean nd renewable energy sources, representing energy efficiency and a reduction in GGEs rates (WORLDLII, 1989).

It is essential therefore to consider that motorization has multiplied in XXI century and move in opposite directions of investments in public transportation. The increased urban traffic on roads creates problems regarding congestion, accidents, environmental damage and contamination, harmful effects on human health, excessive noise, and pollutant emissions (ESSEN et al., 2008).

Based upon a projection that in 2050 the urban population growth would be like approximately 54% over the 2008's numbers, and the fuel consumption remains without alterations, the emissions of CO2, in the Planet, would increase by 590% above the baseline. Rosa et al., scenarios are more optimistic. If the fuel consumption would have replaced by biofuels, substituting automotive gasoline by ethanol, for all types of vehicles, whereas the standard European mobility, in percentage terms, the GGE had decreased to 165% (Rosa et al., 2008).

4 Economic analysis - As outlined above, BR7 model total annual diesel oil consumption was 72,528,003.90 liters, for a covered distance of 147,231,847.92 km, running at an average of 2.03 km/l, and the hybrid buses consumption, in the same framework, accounted for about 46.889.123,54 liters with an average of 3.14 km/l. The analysis revealed that hybrid buses consume 35.35% less fuel than BR7 model.

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At that, multiplying consumed diesel liters for the 2014 Brazilian prices (72,528,003.90 l for R$ 2.44 for one liter), and doing the same for hybrid bus consumption, it obtained a significant difference in value and in emissions (R$ 176,968,329.52 - R$ 114,409,461.44 = R$ 62,558,868.08). The difference can be recognized directly as an income statement. The bus with the highest emission is a costly and harmful model and does more damage in terms of environmental consequences than the hybrid one (see table 6).

Table 6. Comparison of fuel consumption costs between BR7 and hybrid bus in Curitiba (2014)

Vehicle	Km /l	Km traveled	Liter consumption	% Consumption	Brazilian Diesel prices (ANP)	Total costs (Real)
BR7 Volvo	2,03	147.231.847	72.528.003,90	100%	R$ 2,44	R$ 176.968.329,52
Hybrid bus	3,14	147.231.847	46.889.123,54	-35,35%	R$ 2,44	R$ 114.409.461,44
Difference	-	-	25.638.880,36	-	-	R$ 62.558.868,08

Source: According to survey data (2014).

Moreover, it is relevant to look beyond financial gains, and not miss out the clean technologies for renewables. Zero sulfur emission when combined with biodiesel, produces 25.75% less nitrogen oxides and 11.2% less particulate matter. Air pollutants are by far one of the greatest causes of the burden of disease and we must state to put the public resources where they will be most effective.

The biggest cause of death from pollution was due to the inhalation of a fine dust and particulate matter, and 80% of these pollutants is produced by incomplete combustion of fuels. Particles, when inhaled, harm the respiratory system, and children and the elderly are the most vulnerable risk groups to unleash respiratory problems (VORMITTAG; SALDIVA; MIRANDA, 2013).

CONCLUSIONS

The global world reduced distances with the internet movement, but broader efforts are substantial to live in the planet. Faced with new realities, to travel every day is necessary, even though we are living a pandemic time. The improper distances between home and workplace require daily local displacements and the use of public transport for lower-income citizens. In Curitiba, during years 1970 and 1980, the transport system changed. Urban sustainability was the magic word to transform realities, especially with exclusive lane and integrate transport network proposed.

The culture of clean technology efficiency that denies air pollutants is extending always, and arrived to hybrid buses. The city is a place to created stable bonds and update knowledge. Based on values, which lead to rights and duties, the city is looking for new markets and feasible projects.

The use of hybrid electric and biofuels in buses in the public transport fleet significantly contributed to improving the quality of air and life of Curitiba population. The buses are still running in

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2021. A substantial cumulative GGEs and pollutant emissions reductions has been implemented.

The environmental gains of using renewable fuel reduced emissions approximately accounted for 10,000 metric tons of CO2 in one year.

In 1992, the country signed the first United Nations Framework Convention Climate Change. The Brazilian National Environmental Council provided the air quality standards in 2018 to preserve the population health and to combat the pollutant adverse effects. The main objective is to inform the population the relations between the concentrations of monitored pollutants to possible unfavorable health effects. Curitiba's voluntary and political mitigation actions strengthen also the multilateral response of international sustainable development goals.

Changes in the choice of fuel in public transport fleets can be one way to reduce GGEs emissions and introduce benefits to population health. It is a multilevel and transversal process and depends on many agreements, funding, research, and testing. We must stay focused on transport system development improving the critical discussions, in a scenario of global production, to participate in the good action plans.

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