ASSESSMENT OF AIRCRAFT EMISSIONS DURING LANDING AND TAKE-OFF (LTO) CYCLES AT GALEÃO INTERNATIONAL AIRPORT, RIO DE JANEIRO

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ABSTRACT

Recent studies of environmental sustainability in civil aviation show specific interest in the impacts of atmospheric pollutant emissions from the landing and take-off cycles of aircraft (LTO) near airports. These impacts are more worrisome at airports surrounded by a dense urban occupation. Although international entities already have methodologies for evaluating emissions, there is a need to expand the case studies to different regions of the world to discuss the various factors that influence pollutant emissions and to define the best actions to mitigate unwanted effects in each case. Traffic intensity, aircraft mix, operational efficiency and weather are among the important elements to consider. The Brazilian case is quite critical, since most of its large airports are in dense urban networks, which implies a significant population being affected by civil aviation activity. This paper estimates the emissions of LTO cycles in an airport of great relevance in the Brazilian scenario and discusses the results in face of its causative elements, comparing them with the results of studies from other airports around the world. Results show relevant aspects to be considered in actions to mitigate the effects of emissions from LTO cycles and research gaps in the literature.

Keywords: Airports; Aviation emissions; Sustainability; LTO cycle; Nitrogen oxides; Particulate material.

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1. INTRODUCTION

With the expansion of the economy, air transportation has become increasingly important for Brazil's commercial operations, and air traffic has expanded steadily over the previous two decades. Aviation has shown rising demand and above-average market growth, with an annual rate of nearly 5%, indicating that the sector's contribution to air pollution is always increasing, which can have negative consequences on the health of system users and those present in neighboring areas. Recent research has focused on the study of emissions during the landing and takeoff cycle (LTO), which occurs in urbanized areas and emits multiple pollutants such as nitrogen oxides, hydrocarbons, sulfur oxides, and particulate matter (Sabatier et al., 2021; Yim et al., 2015; Mazaheri et al., 2011). Many studies have demonstrated that air pollutants emitted by a big airport may have an impact on air quality around the airport and even throughout the region (Centracchio et al., 2018; Henkes & Pádua, 2017; Masiol & Harrison, 2014; Schürmann et al., 2007). As a result, the environmental effect of airport emissions remains a key problem to address for air quality control.

There is evidence that airports' presence in urban residential areas increases the incidence of health problems or exacerbates pre-existing diseases owing to exposure to several air contaminants (Fajersztajn et al., 2019; Heal et al., 2012; Raper et al., 1970). Because most large airports are located near densely populated metropolitan agglomerations, their LTO cycles have the potential to have a substantial influence on the environment and health of those who live nearby (Masiol & Harrison, 2014). It is generally known that most Brazilian airports are in this condition, placed in the urban environment, near major city marketplaces, as is the case with the international airport of Galeão in Rio de Janeiro (SBGL). Described as a high-traffic airport and one of the most important in all of Brazil.

One of the fundamental and successful steps for assessing pollution, simulating the environment, and developing pollution management plans for cities is the creation of pollutant emission inventories (Fan et al., 2012). Although several studies have been conducted to quantify and analyze airport emissions, most of them evaluate only one or a small group of engines as an emission source and do not address the quantities of particulate matter (PM) emitted because they are not available and are not listed in the ICAO database. Furthermore, there is a severe labor shortage in the Brazilian context. This research provides the consideration of the elements that lead to pollution emissions from LTO cycles, as well as the identification of potential airport activity hotspots. To that end, the goal of this study is to quantify the HC, CO, NO_x, SO_x, and PM emissions caused by aircraft movement at Galeão International Airport. Through analyzing the LTO cycles for a year (2019), it will be possible to verify the pollutant concentrations and the marginal contribution of aviation to air quality, supporting the determination of mitigating actions for the sources generating the emissions.

The article is organized into topics, following this introduction, which sets the background of the study and its aims, if it presents topic 2 with a review of selected studies. Topic 3 demonstrates the analytical methods and data used to achieve the study's objectives. Topic 4 presents the findings, including a discussion of the variables that cause emissions and strategies to limit their effects. Topic 5 highlights the study's findings and recommendations.

2. LITERATURE REVIEW

Several studies have been done to analyze the emissions of LTO cycles and their possible consequences on local air quality in response to the increased concern about exposure to pollutants from aircraft movements at airports. Airport activities, according to authors Hudda et al. (2020), Shirmohammadi et al. (2018), Masiol and Harrison (2014), Hsu et al. (2013), Dodson et al. (2009) and Schürmann et al. (2007), contribute considerably to pollution and decrease of local air quality and in nearby communities. During a market assessment in Brazil, it was discovered that cities have suffered from increasing soil and air pollution, as well as noise pollution, as a result of increased airport operations and intensified car traffic near the airport (Henkes & Pádua, 2017).

The activities at Warwick Airport led to a rise in pollutant concentrations in five separate areas ranging from 160 meters to 3.7 km from the airport. For this investigation, models, and regression, as well as operational monitoring, were employed to correlate high levels of pollutant concentration, particularly particulate matter, to LTO cycle modes. According to the investigations, proximity to residential areas necessitates tougher concentration controls and investigations to describe and establish the potential effects on the health of individuals living nearby. (Dodson et al., 2009; Hsu et al., 2012; Hsu et al., 2013)

Sabatier et al. (2021) discovered, on a bigger scale, airport-related emissions lead to NO_2 levels rising throughout several square kilometers. The size of the areas impacted by the plume is very sensitive to traffic activity and rises at a pace that exceeds the rate of activity increase. Tokuslu (2020) used emission parameters from the ICAO engine emission database to estimate aircraft air pollution (HC, CO, NO_x) during LTO cycles at Georgia's Tbilisi International Airport. According to the calculation, a 2-minute reduction in taxiing time can result in a 5% reduction in LTO cycle emissions. Furthermore, it was shown that a 50% increase in LTO cycles at the airport might result in between 55% and 60% greater emissions and the continuation of deteriorating local air quality. Vujović and Todorović (2017) examined several pollutants emitted by aviation traffic at Nikola Tesla Airport in Belgrade using LTO cycle statistics from 2008 to 2015. According to the study, as the number of LTO cycles increased, so did local air pollution.

Considering the significance of LTO cycle research, when exhaust gases generated near airports affect directly or indirectly human health and ecosystems, these investigations raise awareness of the level of environmental pollution among those affected. According to the literature analysis, the consequences of LTO cycles may be evaluated using local atmospheric conditions and the efficiency of techniques used during LTO cycles. Otherwise, the aircraft mix at the airport will have an impact on emissions. According to this assessment, there will be numerous stakeholders at the airport who may help to mitigate the detrimental impacts of pollution emissions on LTO cycles at airports. As a result, the effort of this study will be limited to analyzing operational alternatives that might increase productivity and providing short-term solutions to minimize the environmental problems produced by airport activities.

3. DATA AND ANALYTIC METHODS

Figure 1 depicts a typical LTO cycle according to the ICAO (2016) definition. The taxi/idle, approach, climb-out, and take-off modes comprise the LTO cycle. Climb, descent, and cruise modes are not available in this instance.

Time in mode ($\boldsymbol{TIM}$), fuel flows, and engine emission indices ($\boldsymbol{EI}$) will be utilized in the calculations. $\boldsymbol{TIM}$ is the amount of time an aircraft engine spends in one of the LTO cycle modes of operation, stated in minutes. The $\boldsymbol{EI}$ is the amount of a certain pollutant released per unit mass of fuel consumed in a specific engine. Thus, by multiplying the flight mode-specific $\boldsymbol{EI}$ by the $\boldsymbol{TIM}$ fuel flow, a mode emission rate in grams of pollutant per LTO cycle is generated (ICAO, 2016). The data is accessible at four standard operating points, which are as follows: idle (7% of maximum thrust), approach and landing (30 %), climb-out (85%), and takeoff (100%). Figure 1 illustrates a typical LTO cycle. It should be noted that the relative distances between where the final approach begins and where the climb-out stage concludes are defined by the airport's instrument approach and take-off procedures.

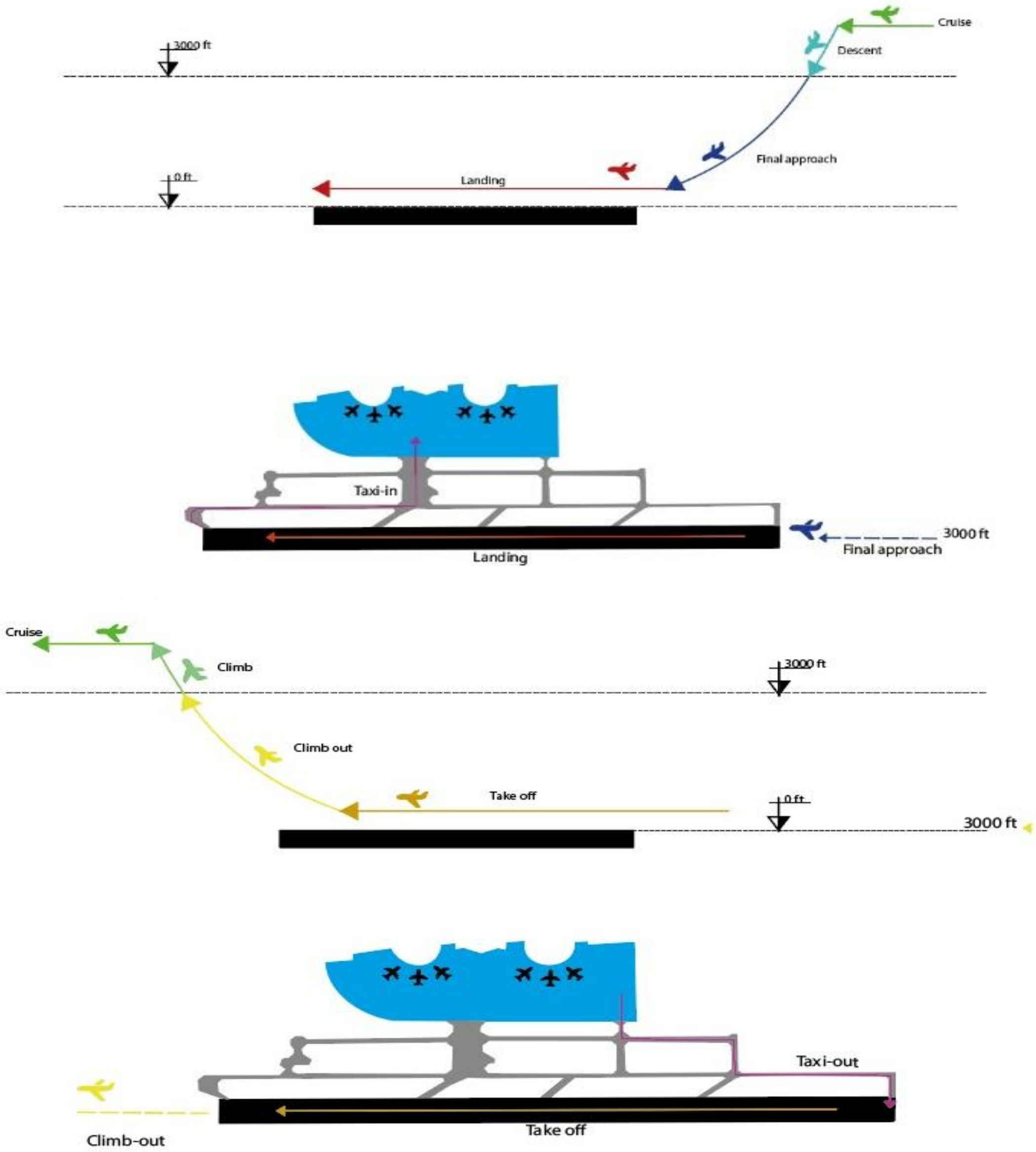

Figure 1 Demonstration of representative Landing and Take-Off (LTO) phases

3.1. Calculation Method

The LTO cycle methodology (ICAO, 2016) is used to calculate hydrocarbon (HC), carbon monoxide (CO), and nitrogen oxide (NO_x) emissions from aircraft operations near airports below 3000 feet in altitude (915 m). Emissions are determined by the time in mode ($\boldsymbol{TIM}$), the emission index ($\boldsymbol{EI}$), and the engine fuel flow ($\boldsymbol{FF}$) (ICAO, 2020). Furthermore, information about the kind of aircraft and engine is considered. Equation 1 calculates the total emissions of a pollutant *i* released by an aircraft *j* during an LTO (g) cycle, $\boldsymbol{E_{ij}}$.

$$\mathrm{E_{ijk}} = \sum\left(\mathrm{TIM_{jk}} \times 60\right)\left(\mathrm{FF_{jk}}/1000\right) \times \mathrm{EI_{jk}} \times \mathrm{NE_j} \qquad (1)$$

Where:

$\boldsymbol{E_{ijk}}$ is the pollutant *i* emission index (in grams per kilogram of fuel) in mode *k* (takeoff, climb, taxi/idle, and approach) for each engine used in an aircraft *j*. The time in mode *k* (in minutes) for aircraft *j* is represented by $\boldsymbol{TIM_{jk}}$. $\boldsymbol{FF_{jk}}$ is the mode k fuel flow (in kilograms of fuel per second - kg s^{-1}) for each engine in an aircraft *j*. The emission index for each engine of aircraft *j* in operating mode *k* is given by $\boldsymbol{EI_{jk}}$. The number of engines utilized in aircraft *j* is denoted by $\boldsymbol{NE_j}$. The NO_x, CO, and HC calculation approach is divided into two parts. First, the type of aircraft is determined. The emissions (pollutant mass) may then be computed using equation 1 using the ICAO database for aircraft engines.

Since there is no standard definition for the evaluation of emissions required by ICAO, the model of the System for Assessment of Global Aviation Emissions (SAGE) stipulated by the Federal Aviation Administration Agency (FAA, 2005) was used to calculate SO_x. In SAGE, the amount of sulfur oxides released is proportional to the amount of sulfur in the fuel, which is specified as 0.8 g/kg. It is expected that all of the sulfur (S) present is transformed into SO_2 throughout the combustion process. The total SO_x emission for aircraft *j* for an LTO cycle in grams ($\boldsymbol{E_j}$) is then computed using equation 2.

$$E_j = \sum(TIM_{jk} \times 60) \times ER_{jk} \times NE_j \qquad (2)$$

Where:

$\boldsymbol{TIM_{jk}}$ is the time in mode *k* (in minutes) for aircraft *j*. $\boldsymbol{ER_{jk}}$ is the total SO_x emission rate per second by mode *k* (gs^{-1}) for aircraft *j* ($\boldsymbol{ER_j = 1 \times FF_{jk}}$). $\boldsymbol{FF_{jk}}$ is the fuel consumption per mode *k* (in kilograms of fuel per second - kg s^{-1}) for each engine of aircraft *j*.

3.2. Particulate Matter Assessment (PM)

The smoke number (***SN***) is used in part to calculate the particulate matter released in LTO cycles. The ***SN*** is calculated from the loss of reflectance of a smoke particle filter, and its values are stored in the ICAO database for aircraft engines (ICAO, 2021). Wayson et al. (2009)'s First Order Approximation (FOA-3.0) approach was also used. Volatile PM ($\boldsymbol{PM_{vol}}$) and non-volatile PM ($\boldsymbol{PM_{nvol}}$) may be calculated, where $\boldsymbol{PM_{nvol}}$ is regarded as soot owing to its high black carbon content, while $\boldsymbol{PM_{vol}}$ is the consequence of the interaction of secondary pollutants such as sulfates (Wayson et al., 2009).

$\boldsymbol{PM_{vol}}$ is estimated using two indices: one based on sulfur content and the other on organic chemical interactions with vapor pressure. Equations 3 and 4 are used to calculate these indices.

$$EI_{vol-FSC}(mg/kg) = 3 \times 10^6 \times FSC \times \varepsilon \qquad (3)$$

$$EI_{vol-fuel-organic}(mg/kg) = \delta \times EI_{HCj} \qquad (4)$$

Where:

$\boldsymbol{EI_{vol-FSC}}$ is the emission index for $\boldsymbol{PM_{vol}}$ of the sulfur content of the fuel ($\boldsymbol{FSC}$). $\boldsymbol{FSC}$ is the ratio between the mass and the standard value of 0.00068. $\boldsymbol{\varepsilon}$ is the fractional conversion of sulfur into its elemental form (S^{IV}) into sulfuric acid (H_2SO_4: S^{IV}) (used to approximate the process of multiple immediate chemical reactions), with a standard value of 0.033. $\boldsymbol{EI_{vol-fuel-organic}}$ is the emission of $\boldsymbol{PM_{vol}}$ from organic fuel (in milligrams per kilogram of fuel). $\boldsymbol{\delta}$ is the mode-dependent factor, with values determined in Table 1. $\boldsymbol{EI_{HCj}}$ is the HC emission index for aircraft engine *j*, established according to the ICAO database.

$\boldsymbol{PM_{vol}}$ is the product of the outputs of equations 3 and 4, multiplied by TIM and fuel flow. The $\boldsymbol{\delta}$ values by LTO cycle mode given by Wayson et al. (2009) for the FOA-3.0 approach are shown in Table 1.

Table 1 $\boldsymbol{\delta}$ values

Mode	δ
Take-off	115
Climb Out	76
Approach	56,25
Taxi/Idle	6,17

Considering $\boldsymbol{PM_{nvol}}$ correlates with ***SN***, a concentration index ($\boldsymbol{CI}$), which is the mass of $\boldsymbol{PM_{nvol}}$ per standard exhaust volume, and a volumetric flow rate of core exhaust per kilogram of combustible ($\boldsymbol{Q_{core}}$), based on the air-fuel mass ratio ($\boldsymbol{AFR}$) and the molar amounts of the chemical reaction oxidation of fuel combustion, are used to evaluate PMnvol emissions. Equations 5 and 6 demonstrate how to calculate $\boldsymbol{CI}$ and $\boldsymbol{Q_{core}}$.

$$CI(mg\ m^{-3}) = 0,0694 \times SN^{1,24} \qquad (5)$$

$$Q_{core}(\ m^3 kg_{fuel}^{-1}) = 0,776 \times AFR + 0,877 \quad (6)$$

The $\boldsymbol{AFR}$ varies by the engine and for the different power settings used in LTO cycle modes. The FOA-3.0 assumes mean $\boldsymbol{AFR}$ values for all engines as shown in Table 2. The total $\boldsymbol{PM_{nvol}}$ is obtained by multiplying the $\boldsymbol{CI}$ and $\boldsymbol{Q_{core}}$ by $\boldsymbol{TIM}$ and fuel flow. Table 2 shows the AFR values suggested by Wayson et al. (2009)

for different power configurations in FOA-3.0. The $\boldsymbol{AFR}$ fluctuates depending on the engine and the power settings employed in LTO cycle modes. As indicated in Table 2, the FOA-3.0 assumes mean $\boldsymbol{AFR}$ values for all engines. Total $\boldsymbol{PM_{nvol}}$ is calculated by multiplying $\boldsymbol{CI}$ and $\boldsymbol{Q_{core}}$ by $\boldsymbol{TIM}$ and fuel flow. Table 2 displays the $\boldsymbol{AFR}$ values recommended by Wayson et al. (2009) for different power settings in FOA-3.0.

Table 2 AFR values by power setting

Power Setting	*AFR*
100% (Take-off)	45
85% (Climb Out)	51
30% (Approach)	83
7% (Taxi/Idle)	106

The overall amount of PM released throughout the LTO cycle is the total of $\boldsymbol{PM_{vo}}$ and $\boldsymbol{PM_{nvol}}$.

3.3. Research Area

The Tom Jobim International Airport, also known as Galeão International Airport (SBGL) is the second-largest Brazilian airport in terms of international traffic and the sixth-largest in terms of total traffic, with commercial aviation accounting for 88 percent of total traffic in 2019 (CGNA, 2019). According to Riogaleão (2021), the airport's operator, more than 13.5 million passengers moved in 2019, in addition to local and international flights.

Figure 2 shows the location of the SBGL and a 10 km marker around it, a possible area of perception of the pollutants generated in the airport LTO cycles The Santos Dumont airport, one of the busiest in the country, is located within the boundaries of this neighborhood. There is a large region between the two airports that will be hit by both, as well as an intersection of a direct action of the two aerodromes. Within the area of 10 km around the airport, there is one of the largest oil refineries in Brazil, the University city with its technological park, the entire Port region of Rio de Janeiro, the yellow and red lines and the avenue Brazil, highways, and highways Presidente Dutra (the country's most important highway) and Washington Luís. So, because the airport's contribution is driven by the vast activity of the city surrounding it, its activity becomes a latent danger to air quality as traffic grows and the form of airport operation changes.

The study analyzes all LTO cycles of 2019, including those referring to alternative flights for domestic and international traffic, without distinction. For the assessment, movements of military aircraft and traffic crossing over the field accounted for in the airport balance sheet were excluded, in addition to the others in visual flight rules. In this way, HC, CO, NO_x, SO_x, and PM emissions were calculated from 62 airlines that operated at the airport in question during 2019. ANAC (2021) open database was used to consult the number of flights performed, scheduled airlines, type of aircraft, among others.

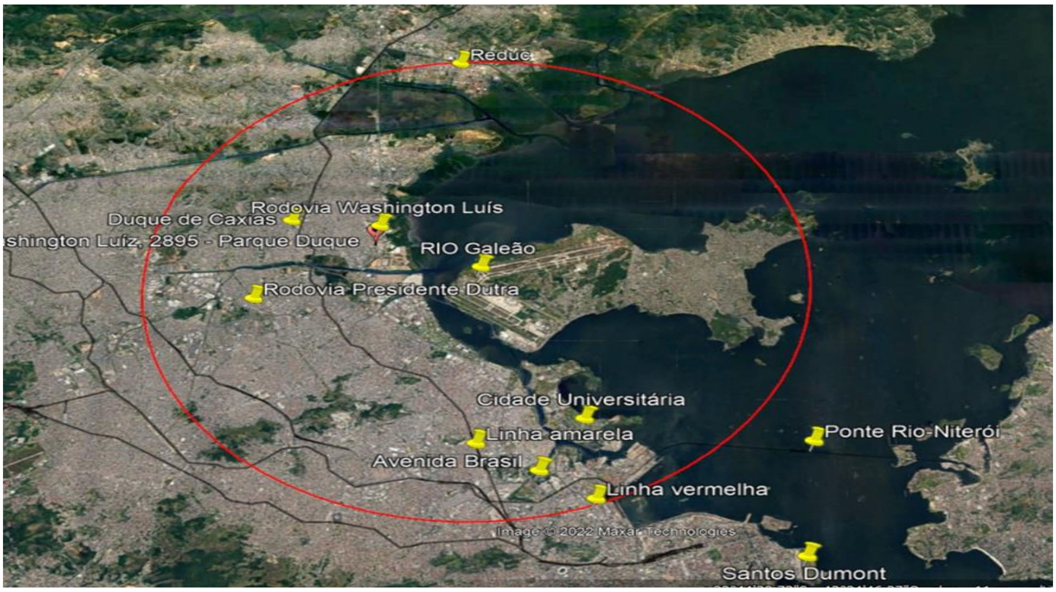

Figure 2 Geographic Location of SBGL. Source: Google Earth, 2022

3.4. Aircraft/engine Combinations

For the analysis, the most typical combinations were chosen according to information from aircraft manufacturers and the ICAO Emissions Database (ICAO, 2021). Since aircraft of a specific type can be equipped with different engine types for the same carrier, such simplification is essential as detailed aircraft/engine information is difficult to obtain. The combinations used for the calculation are listed in Table 3.

Table 3 Typical aircraft/engine combinations

ACFT type	*Engine type*	*ACFT type*	*Engine type*
A300-2	CF6-80C2A5	*B738*	CFM56-7B27
A319	CFM56-5A5	*B747*	CF6-80C2B1F
A320	CFM56-5-A1	*B763*	PW4062
A330	PW4168	*B777*	GE90-115B
A350	Trent XWB-84	*B787*	Trent 1000-E
AN-124	CF6-80C2A1	*CRJ-200*	CF34-3B
ATR-42	PW1215G	*C208*	PW6124A
ATR-72	PW1217G	*E190*	CF34-10E6
B722	JT8D-15	*E195*	CF34-10E7
B733	CFM56-3-B1	*RJ100*	LF507-1F-1H
B734	CFM56-3C-1		

3.5. Assumptions

The following assumptions have been made:

a) Aircrafts perform as the designed performance.

b) The LTO cycle stages, their time allocation, and requirements of engine thrust are as follows: The take-off process demands 100% engine thrust and takes 0,7 minutes (42 seconds); The climb-out process demands 85% engine thrust and takes 2,2 minutes (132 seconds); The approach process (the final approach and landing) demands 30% engine thrust and takes 4 minutes (240 seconds); Taxiing and idle process (taxi in and out) demands 7% engine thrust and takes 26 minutes (1560 seconds).

c) All flights fly in a standard atmosphere.

d) All flights fly as planned.

e) Wind and temperature and humidity conditions are disregarded.

f) The emissions are added up simply, disregarding the chemical reaction, drift, and diffusion of pollutants in the atmosphere.

3.6. GHG Calculation

The ANAC (2019)calculation approach was applied with standard values of emission factor and fuel properties for aviation kerosene published by the IPCC (2006) to calculate direct greenhouse gases: carbon dioxide (CO_2), methane gas (CH_4), and nitrous oxide (N_2O). The table 4 shows the emission factors by mass used in calculation, in kilogram of gas per kg of fuel burned, in addiction to fuel consumption per aircraft estimations in the LTO cycle.

Table 4 GHG Emissions Factor

GHG	*EF*	*Unity*
CO_2	31,5(10^{-1})	$kgCO_2/kgQAv$
N_2O	88,2(10^{-6})	$kgN_2O/kgQAv$
CH_4	22,1(10^{-5})	$kgCH_4/kgQAv$

4. RESULTS AND DISCUSSION

In this study, to comprehend the operations at SBGL airport in 2019, and provide an overview potential for operations and pollutants emission, the HC, CO, NO_x, SO_x and PM emissions were estimated for each LTO phase. Also, CO_2, N_2O and CH_4, was calculated according to LTO phases and distributed by aircraft and carriers. With the trend of the increase in traffic volume and passenger transport for the near future, it will tend to increase the values found here.

The results point to NO_x as the largest emitted pollutant, and its growth potential will mainly affect communities near the airport. The effects of taxi time also become relevant given the potential congestion caused by a greater number of aircraft, as well the passenger occupancy rates.

4.1. Aircraft Movements

The SBGL experienced a total of 90.878 landing and takeoff movements in 2019, of which 83% were domestic and 17% were international. It operated with 62 regular carriers, distributed in passenger and cargo, with a wide variety of aircraft types, including different manufacturers and specifications. Table 5 depicts the distribution of aircraft types and participation in the SBGL movement in 2019. As can be seen, the B738 (Boeing 737-800) represented 54% of all aircraft movement at the airport, followed by the A320 (Airbus 320) with 23% and E195 (Embraer 195) with 9%, all aircraft of typical use by major domestic passenger transport carriers.

Table 5 Distribution of aircraft types by LTO cycles in 2019 at SBGL

Aircraft type	*LTO*	*Aircraft type*	*LTO*
A300-200	2	*B738*	49.400
A319	1.886	*B747*	760
A320	20.756	*B763*	1.974
A330	2.788	*B777*	2.586
A350	4	*B787*	1.028
AN-124	4	*C208*	4
ATR-42	14	*CRJ-200*	14
ATR-72	8	*E 195*	7.984
B722	358	*E190*	124
B733	250	*RJ100*	2
B734	932		

4.2. Pollutant and GHG Emission Results

During the LTO cycle in 2019, aircraft emissions were expected to be 1,308,928 kg NOx, 844,747 kg CO, 93,757 kg HC, 72,112 kg SOx, and 11,482 kg PM, totaling roughly 2.33 million pollutants discharged. During the assessed time, the GHG received 283.940,4 tons of CO_2, 8 tons of N_2O, and 7,9 tons of CH_4 from the LTO cycle. According to the fuel flow rates in the ICAO (2021) database, the total fuel consumption for the LTO cycles in the SBGL was predicted to be around 90.140 tons/year in 2019. Table 6 depicts the distribution of pollutant emissions (HC, CO, NO_x, SO_x, and PM) for the modes of LTO cycles

Table 6 Distribution of LTO cycle emissions by mode

Pollutant (kg)	*Take-off*	*Climb-out*	*Approach*	*Taxi /Idle*
NO_x	103,2	199	53	48,8
CO	1,6	4,2	12	342,4
HC	0,2	0,6	0,7	51
SO_x	2,6	6,7	4,1	9,1
PM	0,5	0,9	0,6	1,1

When the distributions per mode for each pollutant are examined more closely, a slight variance for the flying modes is discovered. CO is the most prominent contaminant during downtime and taxis, accounting for 95% of all CO emissions. This trend is especially relevant to air quality around airports since aircraft spend the greatest time at terminals (Masiol and Harrison, 2014; Schürmann et al., 2007) The climb-out mode accounts for most NO_x emissions, accounting for 50% of total emissions, followed by the take-off mode, which accounts for 25%. Thus, time reduction in each mode is critical. Alternatives include the building of upgraded taxiways with quick intersections (straight taxiways with fewer stops, bends, and junctions) or pre-clearance and push-back traffic coordination, which would assist minimize taxiing times and downtime in aircraft operation, as well as monitoring and advertising daily taxi durations, which would aid in the quality control of operations.

The time in taxi mode, given as normal, is 26 minutes. Modifying this time, lowering it by 5 or 10 minutes, a reduction of 23% and 42% was discovered for the values mentioned in this study. The largest opportunities in approach mode are centered on traffic management measures, where you may prevent any form of radar vectors, delays, or actions that occur in the adoption of procedures for missed approaches by aircraft. The proper selection of leaving and arrival slots to the airport, in conjunction with the AMAN (Arrival Manager - Arrivals Manager) tool, also provides options for decreasing congestion, both during taxi and on approach. Furthermore, management methods that allow takeoffs without halting at the threshold, as well as the implementation of fines for carriers that do not adhere to the exact schedules of blocks outside, should be considered as a future potential, where there is increased congestion and demand for airport usage.

When analyzed the specific results shown in table 7, the B738 aircraft and the A320, had the highest percentages of participation and wind up being the largest pollutant emitters for the final amount. The A319, B722, B733, and B734, older aircraft with high consumption and emissions standards, also participated in the LTO cycles in substantial numbers. This level of operation should be observed since the airport's activities are expanding, and the involvement of older aircraft is a hindrance. As a strategy to restrict rising emissions, life expectancy and engine type should be monitored. It is well known that airplanes with older engines (30 years on average) have higher emission indices than the same but new kind. As a result, prohibiting the operation at the airport of aircraft/companies with engine types other than those tested on a test bench and with more than 30 years of operation is a management technique to minimize local emissions.

below 65% or even lower. This suggests that some companies are inefficient and contribute to more emissions than others.

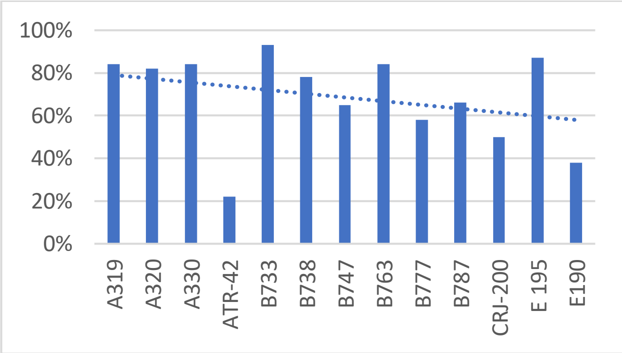

Figure 3 Average passenger occupancy per aircraft

Table 7 The SBGL's total emissions per LTO cycle in 2019

Aircraft	*HC*	*CO*	*NO_x*	*SO_x*	*PM (kg)*	*CO_2*	*N_2O*	*CH_4*
A300-200	11,86	55,87	49,41	2,79	0,41	10974,93	0,3	0,3
A319	1.121,65	11.974,87	16.473,53	1.102,67	188,66	4341752,30	121,6	127,4
A320	11.833,47	128.377,31	87.038,28	12.801,70	2.297,14	50406705,67	1411,4	1446,9
A330	434,93	37.590,49	77.709,27	4.537,54	626,23	17866577,94	500,3	480,6
A350	3,41	78,20	161,97	6,84	0,81	26938,55	0,8	0,8
AN-124	46,64	218,29	198,12	10,52	1,56	41412,47	1,2	1,1
ATR-42	0,13	49,71	62,77	5,05	0,46	19865,64	0,6	0,6
ATR-72	0,34	53,55	51,92	4,05	0,36	15958,14	0,4	0,5
B722	459,79	3.173,79	4.450,76	417,81	13,84	1645120,34	46,1	54,7
B733	208,93	3.258,63	1.797,47	156,69	17,12	616952,70	17,3	19,7
B734	534,63	10.421,87	8.966,63	668,77	76,82	2633271,68	73,7	79,7
B738	33.114,64	339.483,87	663.863,32	6.067,85	5.672,65	142017155,28	3976,5	3951,2
B747	9.596,16	44.059,74	32.583,85	2.001,10	295,65	7879343,47	220,6	214,9
B763	14.918,98	58.519,81	57.464,54	2.826,36	882,22	11128782,29	311,6	285,8
B777	10.158,05	98.469,68	176.436,48	6.013,55	650,46	23678371,79	663,0	608,0
B787	31,56	6.645,20	27.673,21	1.293,47	130,75	5093053,91	142,6	157,4
C208	0,00	19,61	16,68	1,37	0,14	5403,96	0,2	0,2
CRJ-200	10,21	103,12	30,17	3,68	0,60	14490,18	0,4	0,5
E190	211,57	1.686,13	704,37	60,12	8,30	16257707,42	455,2	478,9
E195	11.057,59	100.485,35	53.186,82	4.128,94	617,47	236717,66	6,6	7,2
RJ100	2,70	22,43	8,69	0,96	0,16	3799,47	0,1	0,1

However, in the case of cargo companies who use these older aircraft, further aspects must be considered. When compared to passenger carriers, cargo operational management is typically more efficient, resulting in superior aircraft performance even in the absence of technology that optimize fuel use.

4.3. Passenger Carrier Evaluation

Examining passenger carrier outcomes describes and explains about the company's operational management and efficiency rates. When it comes to occupancy rates, as indicated in figure 3, the average used by carriers in 2019 was around 80% or close to it, with some falling

As a matter of fact, any use of older aircraft is not really the first problem to be considered, because raising passenger load factor offers a short-term pollution mitigation method as well as a potential for higher profits for airlines. The table 8 illustrates how much a passenger contributed to emissions by aircraft under the conditions investigated.

When examining emissions per passenger, it is highlighted that the B733, an older aircraft, manages to retain a high degree of efficiency, especially when compared to the CRJ-200 or the E190, which are more contemporary and have lower emission rates, but are more polluting due to their low occupancy rates. The same is true for the B763, which has greater overall emissions than the B747 but is more efficient when emissions are apportioned per passenger.

emissions mitigation is critical, as there is an immediate need for reduction measures and

Table 8 The SBGL's total Passenger Emissions in 2019

ACFT	Pollutants (kg/passenger)					GHC (kg/passenger)		
	NOx	***CO***	***HC***	***SOx***	***PM***	***CO2***	***N20***	***CH4***
A319	42,4	30,8	2,9	2,8	0,5	11176,1	0,3	0,3
A320	262,7	180,5	16,6	18,1	3,2	70795,7	2	2
A330	80,3	38,8	0,5	4,7	0,6	18455,9	0,5	0,5
ATR-42	5,4	4,2	0,01	0,4	0,04	1697,93	0,1	0,1
B733	0,1	0,2	0,01	0,01	0	35,51	0	0
B738	651,4	333,0	32,5	35,4	5,3	139331,7	4	3,9
B744	81,1	109,6	25,8	5	0,7	19601,7	0,6	0,5
B763	48,8	64,4	17,9	3,1	1	12245,5	0,3	0,3
B777	150,3	83,9	8,7	5,1	0,6	20167,7	0,7	0,5
B787	62,9	15,1	0,07	2	0,3	11572,6	0,3	0,4
CRJ-200	1,2	4,0	0,4	0,2	0,02	560,4	0,02	0,02
E190	6,2	14,9	1,9	0,5	0,1	2096,6	0,1	0,1
E195	501,3	947,6	103,9	39,2	6	153270,4	4,3	4,5

Figure 4 illustrates the difference in total pollutants emitted and the quantities that would be emitted if the maximum passenger capacity was used. Through using maximum occupations, almost 20% of the pollutants released over the year may be prevented. In the case of GHG, the reductions would be between 15% and 20%, resulting to an estimated 307.799 kg of CO_2 less per year just in LTO cycles.

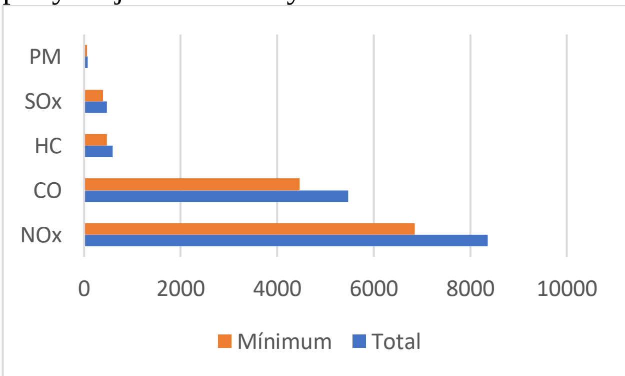

Figure 4 Amount Emissions Comparison

As an aggregate of all organizations that utilize comparable patterns and aircraft, this sort of analysis still provides a lot of uncertainty. In 2019, a regular passenger in SBGL released around 146 kgNO_x, 141 kgCO, 16.25 kgHC, 8.96 kg SO_x, 1.41 kgPM, 35,462 kgCO_2, 1.02 kgN_2O, and 1.01 kgCH_4. An evaluation of individual airline performance can reveal considerably more in the quest for strategic possibilities to reduce emissions. However, understanding how this component has a beneficial influence on international pressure for national operations to fit in the same way as the world's major economies.

5. CONCLUSION

It should be noted that the amount of pollutants created in this study is estimated using a set of assumptions. LTO cycle emissions are determined by the amount of time spent on-ground operations, idle time, and the actual and distinct procedures for each carrier. The ICAO criteria were employed in situations where engine timings and regiments are uniform, as well as in regular weather conditions, as were the techniques F.O.A 3.0 to assess the PM and ANAC to compute CHG. SBGL appears to be a polluting source with an impact on nearby areas. The increase in aviation operations, and therefore in LTO cycles, may have a significant influence in worsening local air quality. Based on the foregoing, it was determined that:

1. According to projections, SBGL's total fuel usage in LTO cycles in 2019 was 90.140 tons. There were about 2.33 million pollutants discharged, which were distributed as follows: 1.308.928 kgNOx, 844.747 kgCO, 93.757 kgHC, 72.482 kgSOx, and 11.482 kgPM. Only from airplane activity during the LTO cycle, 283.940,4 tons of CO_2, 8 tons of N_2O, and 7.9 tons of CH_4 were calculated. A typical SBGL passenger released around 146 kgNO_x,

141 kgCO, 16.25 kgHC, 8.96 kg SO_x, 1.41 kgPM, 35,462 $kgCO_2$, 1.02 kgN_2O, and 1.01 $kgCH_4$.

2. The domestic market has a significant impact on emissions, as evidenced by the B738 and A320 aircraft being the major polluters in 2019, with the greatest consumption and emissions rates. The aircraft mix at the airport must be regularly assessed to avoid obsolete engines contributing to emissions over the intended average for the operation. As the values of occupancy and carried cargo provide a short-term chance to minimize emissions, as certain firms run with occupancy below the average of 65 percent, an assessment of the individual performance of the companies becomes significant. If the maximum passenger occupancy was employed, all emissions would be reduced by roughly 20% for the numbers indicated. Although this method extends the usable life of particular engines, the operation of these aircraft must be balanced against the airport's environmental costs.

3. Taxi mode contributes the most to overall LTO cycle emissions, accounting for the most of CO, HC, SO_x, and PM emissions, as well as accounting for the full quantity of CH_4.The timing of this mode's occurrence can have a significant impact on emission rates, with a reduction of up to 42 percent in emissions for every 10 minutes less spent by taxi. The modes of climb-out and take-off contributed the most to NOx emissions, the pollutant with the greatest mass emitted throughout the year. Construction of improved taxiways, traffic coordination, and prior orders for taxi-in, take-off, and taxi time monitoring are all opportunities to minimize emissions in these modes. The management of radar vectors and holds during the final approach, as well as measures to prevent aircraft from performing missed approach procedures, are examples of how quicker operations in approach mode might be favored to lower emissions. Other managerial measures, such as an adequate program for distributing departure and arrival slots, the use of electronic air traffic management tools, and penalties for companies that do not comply with time-peak schedules, are necessary to avoid airport congestion and the consequent increase in time in each LTO cycle mode of operation.

SBGL appears to be a polluting source with influence in adjacent communities. The increase in air operations, and therefore LTO cycles, can play a substantial role in degrading local air quality. This analysis provides a preliminary step for future research on the consequences of pollution dispersion and its influence on communities surrounding airports and the opportunities to mitigate emissions from aviation activity. However, an individual assessment of the companies operating at the airport, their occupancy rates and values of cargo transported is necessary, as well as the real time spent in each mode of the LTO cycle. It is also proposed an examination of local collection in several locations close to the airport to determine the true impact of air activities on pollution in neighboring residences, in addition to analyzing the joint involvement of the two main airports in the city, since the area of operation of both airports can cover a considerable percentage of the metropolitan territory of the state and contribute negatively to critical neighborhoods in Rio de Janeiro.

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