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INVENTORY OF ATMOSPHERIC EMISSIONS (NO_x and SO_x) FROM GOL LINHAS AÉREAS S.A

ENGEAR consultoria

GOL

INVENTORY OF ATMOSPHERIC EMISSIONS (NOx and SOx)
FROM GOL LINHAS AÉREAS S.A

HELD IN OCTOBER 2024

Report code: ENGTC_24088_CONS_GOL_LINHAS_AEREAS

Revision 02

Belo Horizonte/MG

LIST OF ABBREVIATIONS AND ACRONYMS

ANAC	National Civil Aviation Agency
APU	Auxiliary power unit
CETESB	São Paulo State Environmental Company
EMEP/EEA	European Environment Agency
FEAM	Minas Gerais State Environmental Foundation
GSE	Ground support equipment
ICAO	International Civil Aviation Organization
LTO	Landing and Take Off: This includes all the flight phases close to the aerodrome carried out by aircraft at altitudes below 914.4 meters.
NO_x	Nitrogen oxides
SO_x	Sulfur Oxides
USEPA	US Environmental Protection Agency

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SUMMARY

1 PRESENTATION

GOL Linhas Aéreas S.A. requested that ENGEAR Consultoria prepare an inventory of the company's nitrogen oxide and sulfur oxide emissions in 2023. Accordingly, this study quantifies NOx and SOx gas emissions.

1.1 Company data

Company name	GOL Linhas Aéreas S.A
CNPJ	07.575.651/0004-00
Address	PC COMANDANTE LINNEU GOMES - 04.626-900
Responsible person / Contact	Fernando Henrique Matos Neres
E-mail	fhneres@voegol.com.br

1.2 Details of the company responsible for the Atmospheric Emissions Inventory and Atmospheric Pollutant Dispersion Study

Company name	ENGEAR Consultoria LTDA
CNPJ	32.998.954/0001-21
Address	Rua Suzana Maria, 191, Bairro Paquetá, Belo Horizonte/MG.
CREA registration	81513
Responsible person/ Contact	Raisa H. Sant’Ana Cesar
E-mail	contato@engearconsultoria.com.br

1.3 Technical team responsible for the Atmospheric Emissions Inventory

Name	Undergraduate degree	Grade Council	CTF	Assignment
Raisa H. S. Cesar	Chemical Engineering	CREA MG 242749/D	7353958	Assignment Technical Responsibility and Elaboration
Vinicius G. M. Silva	Environmental Engineering	-	8039519	Inventory preparation

2 CHARACTERIZATION OF THE PROJECT

GOL Airlines is Brazil's largest airline, standing out as a leader in corporate and leisure transportation. Founded 22 years ago, the company played a crucial role in democratizing air travel in the country, establishing itself as the leading low-cost carrier in Latin America. With a flight network covering 141 domestic and 12 international destinations, GOL operates directly at 75 airport bases (GOL LINHAS AEREAS, 2022).

The company's headquarters are located at Congonhas Airport in São Paulo, while its main maintenance center, GOL Aerotech, is in Confins, Minas Gerais, with new facilities in Congonhas and Brasília. This study aims to quantify NOx and SOx gas emissions across its entire national and international operations.

3 INVENTORY OF SOURCES OF ATMOSPHERIC EMISSIONS

For the preparation of the emissions inventory for GOL Airlines, information related to its operations, provided by the company's technical team, was used as a basis. Based on this data, methodologies and emission factors available in global technical literature were adopted, including guidelines from ICAO (International Civil Aviation Organization), EMEP/EEA (European Environment Agency), AP42 USEPA (United States Environmental Protection Agency), CETESB (São Paulo State Environmental Company), and FEAM (State Environmental Foundation).

The pollutants addressed are those with a local impact on air quality, such as sulfur oxides (SOx) and nitrogen oxides (NOx).

3.1 Stationary Sources

3.1.1 Diesel Generators

According to data provided by GOL Airlines, two generators were used in 2023, which consumed around 7,438 liters of diesel for use in various activities at the enterprise. When this fuel is compressed and combusts, exhaust pollutants are emitted into the atmosphere. Knowing that the generators used have a power of less than 600 hp, the reference AP 42, volume 1, sub-item 3.3 (EPA, 1996) was used to determine the emission factors for this equipment, as shown in Table 1.

Table 1: Emission factors of the constants for calculating the combustion of generators

Pollutants	Emission Factors (lb/MMBtu)	Emission Factors (g/kcal)
NOx	4.41	7.93E-03
CO	0.95	1.71E-03
SO_x	0.29	5.22E-04
MP_{10}	0.31	5.58E-04
HC	0.35	6.30E-04

Source: EPA (1996)

However, using these factors requires prior knowledge of the physical and chemical characteristics of the fuel used, as shown in Table 2.

Table 2: Characteristics of the diesel oil used in GOL's generators

Diesel density (kg/L)	0.8414
%S diesel S-500 (mg/kg)	500
PCI diesel with 7% biodiesel (kcal/kg)	9,663

Source: ANP (2018) e PETROBRÁS (2019)

Once the emission factors have been defined, the pollutant emission rate is calculated according to Equation 1, proposed by (EPA, 1996).

$$E = A * EF \quad \text{Equation 1}$$

Where: E = emission rate (t.year-1); A = activity: fuel consumption by generators per time (L.month-1) and EF = emission factor (kg.L).

A Table 3 shows the emissions, in tons, obtained from the estimated use of the generators used at the GOL Airlines facilities.

Table 3: Generator characteristics and emission flow conditions at 2023

Volume of diesel consumed (L) per year	7,438.00
Mass of diesel consumed (kg) per year	6,258.33
Energy generated (kcal) per year	60,474,273.71
Emissions per pollutant in t/year	
NOx	0.48
SOx	0.03

Source: GOL atmospheric emissions inventory (2023)

3.2 Non-stationary sources

3.2.1 Aircraft

The emission factors are established according to the movement of aircraft below 3,000 feet (914 meters) above the ground, where the Landing and Take-Off (LTO) cycle is made up of the departure and arrival stages, as described below (EEA, 1999):

- Departure: Taxi out; Take off and Climb out.
- Arrival: Final approach; Landing and Taxi in.

In order to calculate the exhaustive emissions, the total LTOs for each model of cargo or passenger-carrying aircraft belonging to GOL Airlines were collected during the stipulated period. The emission factors used were defined in the laboratory and published by EEA/EMEP.

After determining the emission factor, the emission is defined according to Equation 2. The results obtained are shown in Table 4.

$$E = A * EF \quad \text{Equation 2}$$

Where: E = emission rate ($t.year^{-1}$); A = activity: rate of landings and take-offs carried out by each type of aircraft ($LTO.month^{-1}$) and EF = emission factor ($kg.LTO^{-1}$).

Thus, the emission factors used in this study, the consumption of aviation kerosene (QAv), as well as the number of LTOs carried out per type of aircraft and their respective emission rates, are listed in Table 4.

Table 4: Emissions from GOL Airlines aircraft flights

Issuing Aircraft Activities							
Aircraft	LTO	Cons. QAv (kg/LTO)	Emission Factors (kg/LTO)		Emission rate (t/year)		SOURCE
			NOx	SOx	NOx	SOx	
B73C	888	187.81	10.30	0.69	9.14E+00	6.15E-01	EMEP/EEA 2023
B38M	61,354	730.68	12.66	0.61	7.77E+02	3.77E+01	
B737	27,667	824.65	10.30	0.69	2.85E+02	1.92E+01	
B738	113,659	824.65	10.30	0.69	1.17E+03	7.87E+01	
Total					**2,241.06**	**136.17**	

Source: GOL atmospheric emissions inventory (2023)

In Table 5 shows the aircraft emission rates per LTO cycle. It can be seen that the B38M aircraft has higher emissions for each LTO cycle compared to the other aircraft in the project.

Table 5: Emissions by aircraft type per LTO

Aircraft	Emission rate (t/year)	
	NOx	SOx
B73C	0.01030	0.00069
B38M	0.01266	0.00061
B737	0.01030	0.00069
B738	0.01030	0.00069

Source: GOL atmospheric emissions inventory (2023)

3.2.2 Auxiliary Power Unit

The auxiliary power unit (APU) is an auxiliary generator whose function is to supply electrical and pneumatic power to the plane's systems during the period when the engines are not running, normally used on the ground or as a back up during flight. During its period of operation, the APU uses fuel to carry out its activities, so burning this material results in the emission of gases and particulates into the atmosphere.

It should be noted that, as with aircraft, the estimated rates of particulates and gases expelled during the operation of APUs depend on the number of LTOs carried out by each type of aircraft and its landing period.

According to ICAO (2016), little data is available on APU emission rates for each aircraft model. Therefore, it is recommended to use the "Simple Approach" methodology, which is based on engine-specific average values provided by APU manufacturers. This method recommends dividing aircraft into two groups, according to flight range greater or less than 8,000 km: short-range aircraft and long-range aircraft (ICAO, 2020).

However, according to the methodology recommended by ICAO (2016), the duration of the APU operation process varies on average between 45 (short-haul aircraft) and 75 minutes (long-haul aircraft). The National Civil Aviation Agency (ANAC) estimates that for domestic flights, the average time can reach 75 minutes, due to airport conditions and the type of aircraft. Therefore, adjustments were made to the emission factors recommended by ICAO (2016) in order to adapt them to the conditions of the main flights carried out by GOL Airlines aircraft, as can be seen in Table 6.

Table 6: Emission factors issued by APUs according to ICAO timeframe and projected for Brazil by ANAC

Parameters	Short Range Aircraft		Long-distance aircraft	
	ICAO	ANAC	ICAO	ICAO
APU duration (minutes)	45	75	75	75
QAv consumption (Kg/LTO)	80	133	300	300
NOx Emission Factor (Kg/LTO)	0.70	1.17	2,.0	2.40

Fonte: ICAO (2016), adapted

Once the emission factor (EF) has been defined, the equation for determining pollutant emissions will be as shown in Equation 3.

$$E = EF * A \qquad \text{Equation 3}$$

Where: E = emission rate ($t.year^{-1}$); A = activity: rate of landings and take-offs carried out by each type of aircraft ($LTO.month^{-1}$); EF=emission factor ($kg.LTO^{-1}$).

Thus, the Table 7 shows the estimated emissions generated from the use of GOL Airlines' Auxiliary Energy Units.

Table 7: Emission rate (g/s) according to the use of APUs on GOL's short-haul aircraft, at 2023

Directions	Emission rate by aircraft type (t/year)		
	Aircraft	LTO	NOx
Short distance	B38M	61,354	7.16E+01
	B737	27,667	3.23E+01
	B738	113,659	1.33E+02
	B73C	888	1.04E+00
Total		203,568	237.496

Source: GOL atmospheric emissions inventory (2023)

3.2.3 Emissions from Vehicle Traffic

Several activities related to the project require vehicles for their operation, some examples of which are: transportation between airports, internal transportation at the headquarters, trips, among others. In order to estimate the emissions generated by the circulation of these vehicles, the emission factors defined by FEAM (2017) and CETESB (2023) were considered.

The methodology adopted for estimating atmospheric emissions from motor vehicles is that published by CETESB (2023) and defined by Equation 4.

$$EF = FE * A * C \qquad \text{Equation 4}$$

Where: EF = emission rate, mass of pollutant emitted per time ($t.year^{-1}$); A = activity: vehicle range ($km.L^{-1}$); C = fuel consumption per type of vehicle (L/year) and FE = Emission Factor ($g.km^{-1}$).

The total fuel consumption was provided by the enterprise, as shown in Table 8, which considered all fuel consumption used in 2023 by the operations of GOL Airlines. Since the vehicle traffic is highly varied, the following calculation assumptions were established:

- The year considered for the vehicles was 2012, as this is the average year among the years considered for CETESB emission factors.

Table 8: Fuel Consumption (liters) at 2023

Fuel	Total
Ethanol	0
Petrol	31,440
Diesel	1,548,814

Source: GOL Airlines (2023)

Table 9 presents the emission factors, fuel efficiency, and emission rates for air-side support vehicles. It is noteworthy that the emission factors for light vehicles were considered. For SOx, although the emission factor for ethanol and diesel is not defined (nd), the same gasoline factor (0.070 g/km) was used for calculation purposes.

Table 9: Emission rates for vehicles in 2023

Types	Emission Factor (EF) - g/km			Emission rate - t/year	
	NOx	SOx	Autonomia (km/l)	NOx	SOx
Ethanol	0.045	nd	6.20	0.00E+00	0.00E+00
Petrol	0.010	0.070	10.10	3.18E-03	2.22E-02
Diesel	0.311	nd	10.60	5.11E+00	1.15E+00
Total				**5.11**	**1.17**

Source: GOL atmospheric emissions inventory (2023)

3.2.4 Emissions from Ground Support Equipment - GSE

Ground support equipment (GSE) is a tool used to maintain aircraft during take-off and landing periods. ICAO (2016) recommends using the "Simple Approach" method to determine the emissions caused during LTOs, because for APUs, there is not enough information to estimate the impacts caused by GSEs during the support period for each type of aircraft. The emission factors for this method divide aircraft into narrow-body/single-aisle and wide-body/double-aisle classes, as follows Table 10.

Table 10: Emission factors for ground operations of support vehicles and equipment (GSE)

Pollutants	Unit	Narrow fuselage and single aisle aircraft	Wide-body and twin-aisle aircraft	Narrow fuselage and single aisle aircraft	Wide-body and twin-aisle aircraft
NOx	Kg/cycle	0.4	0.9	0.26	0.51

Fonte: ICAO (2016)

Emission rates are estimated according to Equation 5:

$$E = EF * A \quad \text{Equation 5}$$

Where: E = emission rate ($t.year^{-1}$); A = activity: rate of landings and take-offs carried out by each type of aircraft ($LTO.month^{-1}$); EF = emission factor ($kg.LTO^{-1}$).

Thus, the results of the estimates for each type of aircraft are shown in Table 11 for narrow-body and wide-body aircraft respectively.

Table 11: Ground Support Equipment emission rate by aircraft type (t/a), in 2023 - Narrow fuselage

Emission rate by aircraft type (t/year)			
	Aircraft	LTO	NOx
Narrow fuselage	B73C	888	2.31E-01
	B38M	61,354	1.60E+01
	B737	27,667	7.19E+00
	B738	113,659	2.96E+01
	Total	**203,568**	**52.93**

Source: GOL atmospheric emissions inventory (2023)

6 STATISTICAL ANALYSIS OF THE INVENTORY

Table 12 shows the emission rates of the pollutants NOx and SOx in tons per year and the percentage of emission contribution per emission source per pollutant.

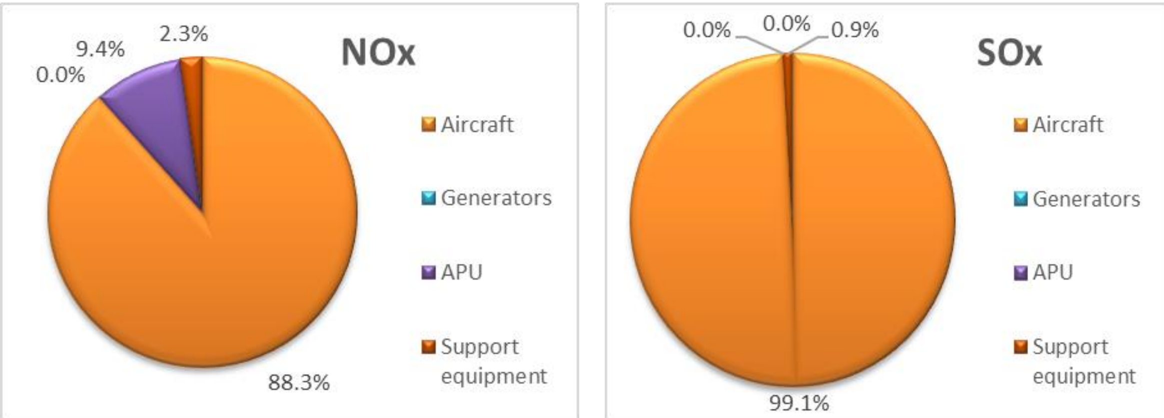
Table 12: Summary of GOL Airlines emissions

Emission sources	Pollutants (t/year)		Percentage of contribution	
	NO_x	SO_x	NO_x	SO_x
Aircraft	2,241.06	136.17	88%	98%
Generators	0.48	0.03	0%	0%
APU	237.50	-	9%	-
Support equipment	58.04	1.17	2%	2%
Total	**2,537.07**	**137.37**	**100%**	**100%**

Source: GOL atmospheric emissions inventory (2023)

Thus, the influence of emissions from aircraft on the total emissions of GOL Airlines is notable. This source accounts for more than 88% of NOx emissions and approximately 98% of SOx emissions, while the other sources together account for less than 12% and 2% of the pollutant emissions, respectively. Figure 1 presents pie charts that illustrate this relationship in a more visual and intuitive manner, with the chart on the left referring to NOx and the one on the right to SOx.

Figure 1: Sector graph for pollutant emission contribution



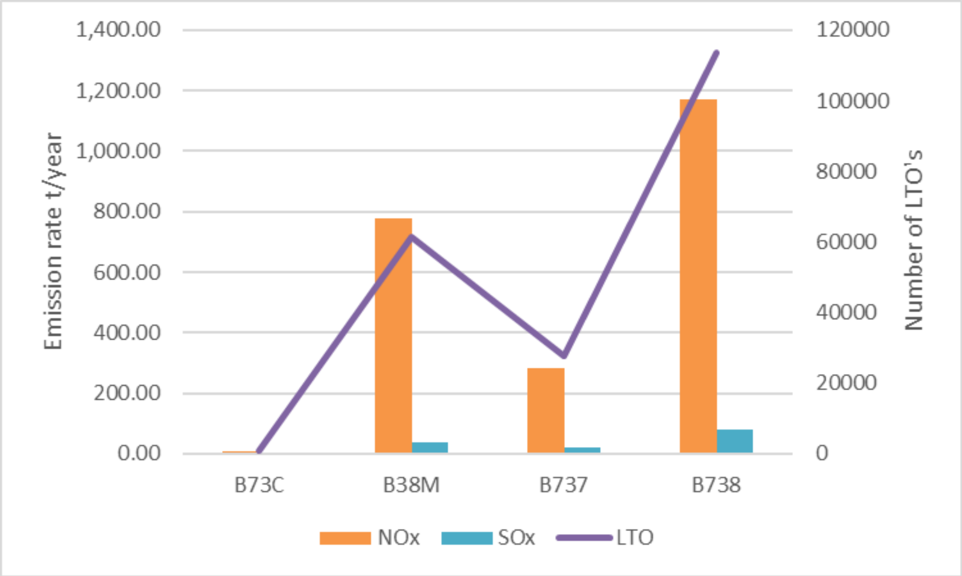
Source: Authors (2023)

6.1 Aircrafts

As we have seen, aircraft are the emission sources that have the greatest influence on emissions of the pollutant's NOx and SOx. It is worth noting that, despite the direct relationship between atmospheric emissions and the number of landings and take-offs, emissions can vary according to various conditions, including the type of engine and fuel consumption by each type of aircraft. Figure 2 shows the relationship between aircraft types, atmospheric emissions and the number of LTOs. As the aircraft models belonging to GOL Airlines are very similar, the relationship between the number of LTO's and emissions stands out, i.e. aircraft with more flights have higher emissions.

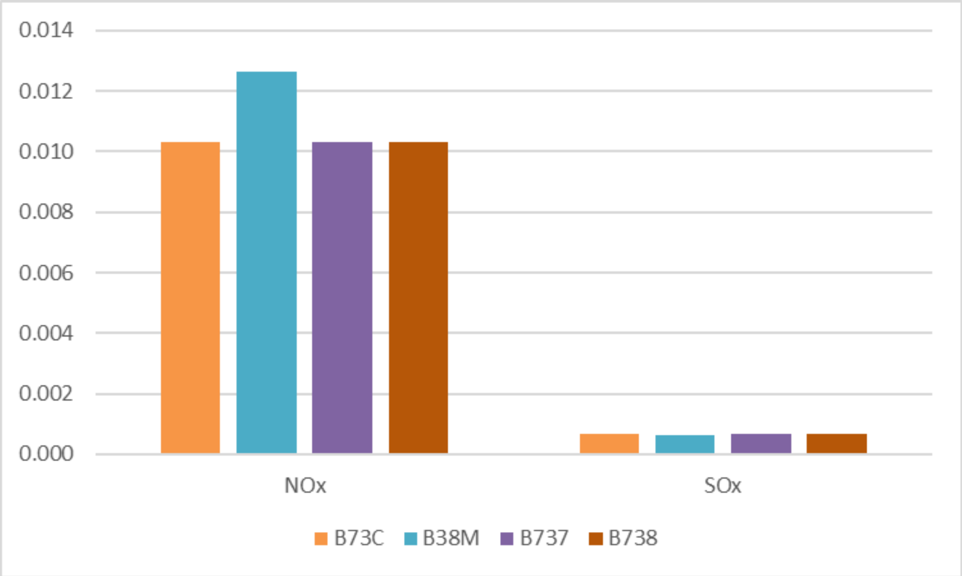
Figure 3 presents the emissions by aircraft type per LTO cycle, showing that for NOx, the B38M model has a higher emission rate, while other aircraft have the same emission rate per LTO. For SOx emissions, all aircraft have the same emission rate per LTO.

Figure 2: Emission per LTO quantity



Source: Authors (2023)

Figure 3: Emission per aircraft

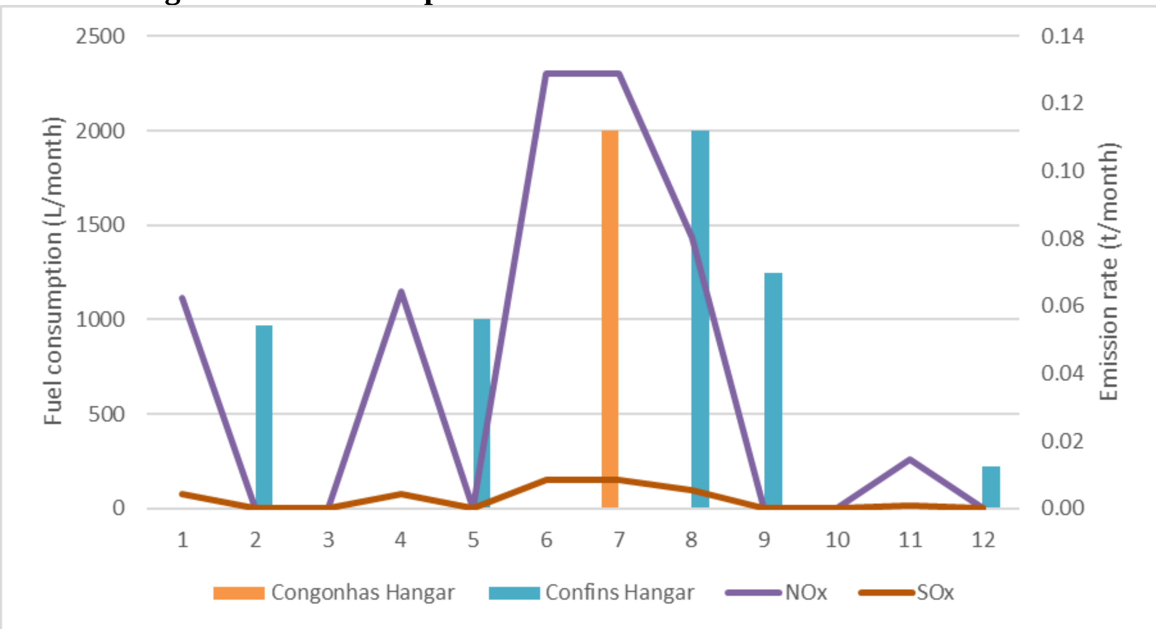


Source: Authors (2023)

6.2 Stationary sources

According to information provided by GOL Airlines, generators are used in both the Confins and Congonhas hangars. Figure 4 shows the emission rate of each hangar per month, as well as the use of fuel in each unit. It can thus be seen that the use of generators is more recurrent in the Congonhas hangar. At Confins airport they were only used in July.

Figure 4: Relationship between diesel use and total emission rate

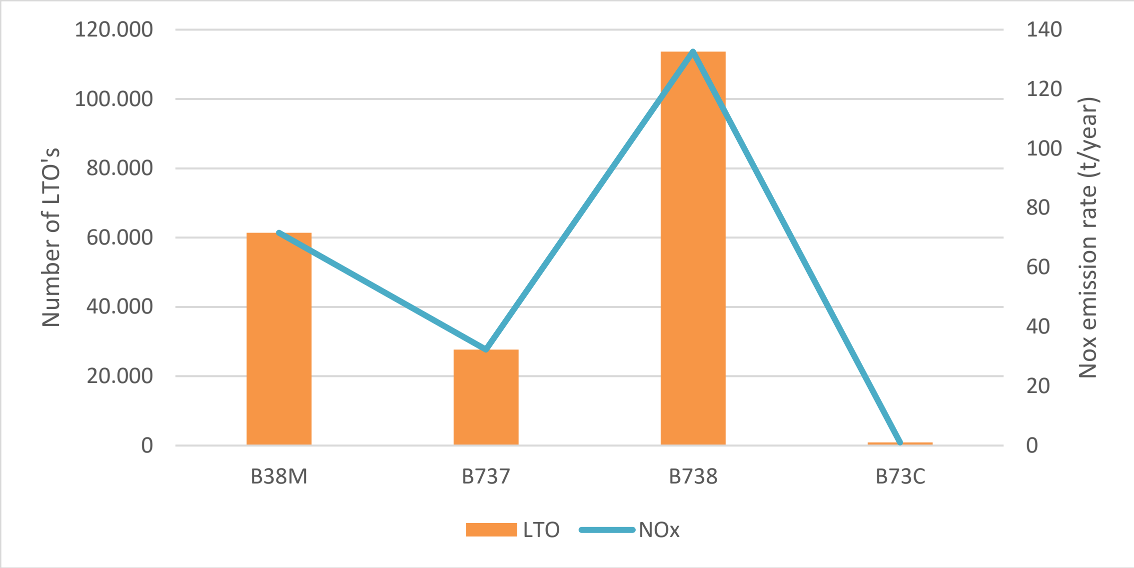


Source: Authors (2023)

6.3 Auxiliary Power Unit (APU)

Figure 5 shows the contribution of atmospheric pollutants, by aircraft, generated during the operation of short-haul APUs in 2023. It is worth noting that all GOL Airlines aircraft are considered short-haul, as they do not reach altitudes of more than 8 km. It is therefore possible to see that emissions are directly proportional to the number of journeys. Furthermore, this type of source only emits NOx.

Figure 5: Issuance by number of LTO's per APU

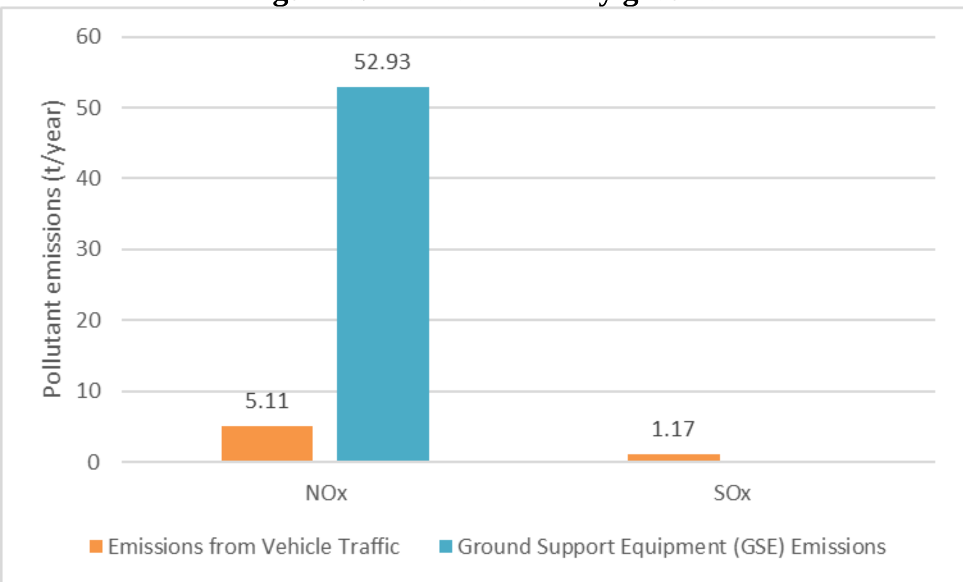


Source: Authors (2023)

6.4 Support equipment

Support equipment was divided into two main sources of NOx and SOx emissions: vehicle traffic emissions and Ground Support Equipment (GSE) emissions. Figure 6 shows the emission rate and contribution of each source. It can be seen that GSE emissions are only NOx, while vehicle traffic emissions are both pollutants. In addition, the GSE emission rate is higher than the vehicle emission rate for NOx.

Figure 6: Emission rate by ground



Source: Authors (2023)

7 CONCLUSIONS

The present study presented the Air Pollutant Inventory of GOL Airlines for the year 2023, focusing on two main emitted pollutants: sulfur oxides (SOx) and nitrogen oxides (NOx), as well as their emission sources. The emissions inventory was conducted for the entire operation of the enterprise, both national and international.

The emission rates of pollutants produced by the generators were estimated based on the American standard AP42 from the USEPA. The emission rates for aircraft were estimated according to the EMEP/EEA documents, based on the specific aircraft model evaluated. Atmospheric pollutants produced by the APUs were determined according to ICAO documentation. Similarly to the aircraft, the support equipment had their emission rates estimated following the methodology recommended by ICAO. Lastly, the methodologies from FEAM and CETESB were used to determine the emissions resulting from motor vehicle traffic.

The results of the study indicate an emission of 2,537.07 tons per year of NOx and 137.37 tons per year of SOx. In terms of contribution by emission source, aircraft are the largest sources of emissions for GOL Airlines, a result that was expected considering that this is the main activity of the enterprise. Additionally, it is evident that the amount of NOx emitted is greater than that of SOx, due to the nature of the emissions from the sources present in the operation.

8 BIBLIOGRAPHICAL REFERENCES

ANAC. **Metodologia de Cálculo - Inventário de Emissões Atmodféricas**. [S.l.]. 2019.

CETESB. **Emissões Veiculares no Estado de São Paulo: 2021**. Governo do Estado de São Paulo. São Paulo, p. 226. 2022.

EEA. **Emission Inventory Guidebook: Solvent and other product use**. [S.l.]. 1999.

EMEP/EEA. **EMEP/EEA air pollutant emission inventory guidebook 2023**. [S.l.]. 2023.

EPA. **Gasoline And Diesel Industrial Engines**. [S.l.]. 1996.

FEAM. **FATORES DE EMISSÃO DA FROTA MUNICIPAL - Belo Horizonte**. [S.l.]. 2017.

GOL LINHAS AEREAS. **Relatório ESG 2022**. GOL LINHAS AEREAS. São Paulo, p. 120. 2022.

ICAO. **Airport Air Quality Manual**. [S.l.]. 2016.

ICAO. **Aircraft Engine Emissions Databank - Emissions Databank (New Format)**. [S.l.]. 2020.

NOTATION OF TECHNICAL RESPONSIBILITY

Anotação de Responsabilidade Técnica - ART
Lei nº 6.496, de 7 de dezembro de 1977
Conselho Regional de Engenharia e Agronomia do Estado de São Paulo

CREA-SP

ART de Obra ou Serviço
2620241626384

1. Responsável Técnico

RAISA HELENA SANT ANA CESAR

Título Profissional: **Engenheira Química**

RNP: **1418573124**

Registro: **5071335802-SP**

Empresa Contratada:

Registro:

2. Dados do Contrato

Contratante: **GOL LINHAS AEREAS S.A.**
CPF/CNPJ: **07.575.651/0004-00**
Endereço: **Praça Praça Comandante Linneu Gomes, s/n**
N°: **S/N**
Complemento: **PORTARIA 3**
Bairro: **Santo Amaro**
Cidade: **São Paulo**
UF: **SP**
CEP: **04626-900**
Contrato:
Celebrado em: **20/06/2024**
Vinculada à Art n°:
Valor: R$ **14.450,00**
Tipo de Contratante: **Pessoa Jurídica de Direito Privado**
Ação Institucional:

3. Dados da Obra Serviço

Endereço: **Praça Praça Comandante Linneu Gomes, s/n**
N°: **S/N**
Complemento: **PORTARIA 3**
Bairro: **Santo Amaro**
Cidade: **São Paulo**
UF: **SP**
CEP: **04626-900**
Data de Início: **20/06/2024**
Previsão de Término: **30/11/2024**
Coordenadas Geográficas:
Finalidade: **Ambiental**
Código:
Proprietário: **GOL LINHAS AEREAS S.A.**
CPF/CNPJ: **07.575.651/0004-00**

4. Atividade Técnica

				Quantidade	Unidade
Elaboração					
1	**Estudo de viabilidade ambiental**	**de modelagem ambiental**		**1,00000**	**unidade**
	Estudo de viabilidade ambiental	**de diagnóstico e caracterização ambiental**	**identificação e potencialização de impactos ambientais**	**1,00000**	**unidade**

Após a conclusão das atividades técnicas o profissional deverá proceder a baixa desta ART

5. Observações

Elaboração do Inventário de emissões atmosféricas dos poluentes NOx e SOx, ano de 2023 das atividades da GOL LINHAS AEREAS S.A, localizada em São Paulo, estado de São Paulo.

6. Declarações

Acessibilidade: Declaro que as regras de acessibilidade previstas nas normas técnicas da ABNT, na legislação específica e no Decreto nº 5.296, de 2 de dezembro de 2004, não se aplicam às atividades profissionais acima relacionadas.

7. Entidade de Classe

Nenhuma

8. Assinaturas

Declaro serem verdadeiras as informações acima

Belo Horizonte, 23 de setembro de 2024

Local — data

RAISA HELENA SANT ANA CESAR - CPF: 109.554.746-12

GOL LINHAS AEREAS S.A. - CPF/CNPJ: 07.575.651/0004-00

9. Informações

- A presente ART encontra-se devidamente quitada conforme dados constantes no rodapé-versão do sistema, certificada pelo *Nosso Número*.

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