Pollution Emissions Forecasting: Case Study of Domestic Flights of the Petrolina Airport

Daniel Alberto Pamplona, Bruno Bezerra Bluhm, Claudio Jorge Pinto Alves

***Abstract*— In the last decades, the concern with the emissions of the pollutants by the air transportation and the impacts caused to the human health has increased. The aim of this paper is to present an econometric model for forecasting emissions of pollutants generated by domestic flights, with a case study at Petrolina Airport. A demand forecast study was carried out until the year 2020. The number of flights and the emissions generated in the landing and take-off cycles were taken into account. With the results, it was possible to present a predictive model of the number of pollutants emitted in the atmosphere.**

***Keywords*— Emissions, Air Pollution, Linear Regression and Predictive Model**

I. INTRODUCTION

The environmental issue has become critical to the evolution of humanity, especially considering the impacts of human activity on the environment, which have been exponentially intensified post-industrial revolution. According to Reference [1], human activity has become a critical factor for changes in the environment due to its speed of growth.

An increase on Carbon Dioxide (CO_2) has been noted in the last decades. For about 800,000 years, CO_2 concentrations in the atmosphere ranged from about 150 to 280 parts per million (ppm), while in the last 150 years (Post-Industrial Revolution period) it has reached 400 ppm. Several effects of this concentration increase have been noticed, for example, the greenhouse, the acidification of oceans and human health impacts.

In the last decades, the concern with the emissions of pollutants by the air transportation and the impacts caused to the human health has increased. Due to the recent characterization of the study of the impact of human activities on the environment, this scope of knowledge still holds a large field of open discoveries and analyzes. The impact of civil aviation on the environment is not completely clear. The present work seeks to help in the understanding of such an impact.

D. A. Pamplona is with the Air Transportation Department, Aeronautics Institute of Technology, Praça Marechal Eduardo Gomes, 50. 12280250 - São José dos Campos-SP, Brazil, (Email: pamplonadefesa@ gmail.com)

B. B. Bluhm was with the Aeronautics Institute of Technology, Praça Marechal Eduardo Gomes, 50. 12280250 - São José dos Campos-SP, Brazil

C. J. P. Alves is with the Air Transportation Department, Aeronautics Institute of Technology Aeronautics Institute of Technology, Praça Marechal Eduardo Gomes, 50. 12280250 - São José dos Campos-SP, Brazil, (Email: claudioj@ita.br)

The aim of this paper is to present an econometric model for predicting emissions of pollutants generated by domestic flights, with a case study at Petrolina Airport in Brazil. The academic gain is achieved by an econometric study and a forecast of passenger demand, estimating the future environmental impacts, particularly, the emission of CO_2. The results may support airport administrators and authorities in environmental planning.

This work is divided into four sections besides this introductory one. The second section deals with the research methodology. The third section deals with econometric modeling and demand forecasting. The fourth section discusses the results and analysis and the fifth section is the conclusion of the paper.

II. RESEARCH METHODOLOGY

The present research focuses on the calculation of emissions of pollutants due to domestic flights at Petrolina Airport, with a forecast for future scenarios using econometric modeling, aiming to analyze the airport demand. From it, a derivative study on the emission of pollutants is made.

A. Literature Review

The emissions of pollutants caused by civil aviation is a subject of global interest, gaining relevance in the last decades. Its impact is still the subject of studies because it presents itself as a scientific field of wide openness, in which scientist try to understand the magnitude of the impact of aviation on the environment.

Academic studies on the subject have focused on the emission of Carbon Dioxide (CO_2). Reference [2] analyze the environmental impact of civil aviation given the high consumption of fuel used. With increasing use of the air modal, its impact as a source of CO_2 emissions naturally increases. The authors estimate that globally, airlines consume over five million barrels of oil per day. The growing use of airplane will make the modal an important contributor in the emission of pollutants. As a result, measures should be taken to mitigate such impact, some of which may be taken naturally by the market and others not. It is noticeable that the environmental impact generated by civil aviation can be felt both at higher altitudes when flying at cruise level, and at lower altitudes, focusing on the airport surrounding.

Reference [3] warn of the importance of studying the impact of the airport on neighborhoods in a wide range of areas, including the case of air pollution. For the authors, environmental impact studies should focus not only on engine emissions but on emissions from aircraft auxiliary power units, auxiliary power sources in the ground, motorized ground support equipment, the airport installed heaters, intermodal transport systems and land transit that connect cities to airports.

Besides more general approaches on the subject, it is perceived that the reality of each airport can be studied hastily, thus generating case studies, just like this study. Here, there is access to local data, and it is possible to study their variation over time, a better understanding of the local impact of the airport, as is the case of Reference [4], where the Zurich Airport in Switzerland is analyzed.

B. Case study: the Petrolina Airport

Petrolina is one of the most important cities in the northeastern Brazilian, mainly due to its privileged location, on the banks of the São Francisco River. Because it is in a region typically characterized by droughts, the possibility of irrigation provided by the waters of the river allows Petrolina a unique agrarian development. The airport is directly linked to such economic development generated by the advances in irrigation technologies.

Petrolina airport (ICAO designator - SBPE) has an asphalt runway with an extension of 3,250 meters long by 45 meters wide, being considered the second largest runway in the Northeast Region, which allows the operation of large size aircraft. The passenger terminal can receive up to 1 million passengers per year. The apron has 16,406 m^2, with five parking positions for large aircraft and 10 positions in total [5]. It presented a growing demand in recent years and it can be translated into numbers from 6,634 landings and takeoffs in 2010 to 7,396 in 2013, or 254,185 passengers in 2010 to 473,471 in 2013.

To study the airport movement, the econometric study and forecast of demand will be carried out in the next section.

III. ECONOMETRIC MODELING AND DEMAND FORECAST

The econometric modeling, in this study, is made through a study of demand and a derived study. The demand model is defined as, in this case, a linear regression modeling, using historical data from Petrolina Airport as a basis for such a model.

The linear regression is given as a predictive model in which are considered basic metrics (defined as x_i) that serve, through linear coefficients, to determine a desired function (defined as y). As examples of metrics used as the basis for such a model, there are ticket prices and Brazilian Gross Domestic Product (GDP), while for the function to be estimated, the metric number of domestic passengers is used. As for the derived study, demand forecasting scenarios are used as a basis for determining the number of flights and, considering the usual type of aircraft at the airport and calculate the emission of pollutants.

In the current study, to obtain the pollutant emission result from domestic flights, the pollutant gases to be considered first were defined, then the aircraft typically operating at that airport and the emission rate of such gases relative to those by aircraft were analyzed. This requires the number of flights, based on considerations and assumptions about average flight occupancy and a model for forecasting number of passengers, following over one possible scenario. A linear regression model estimates the forecast model, based on historical data related to the airport and considerations about its growth over the coming years.

[6]-[8] are the main sources of data.

A. Specification of the Econometric Model

Equation (1) below presents the econometric model used in the present work.

$$\boldsymbol{local\_pax_t} = \beta_0 + \beta_1 gdp + \beta_2 tp + \beta_2 csvt + \beta_2 gc + \textstyle\sum_k \gamma_k month\_seasonalityk + u_t \qquad (1)$$

Where:

local_pax$_t$: movement of local passengers at Petrolina Airport;

gdp: Gross Domestic Product of the Pernambuco microregion;

tp: ticket price**;**

csvt: the period in which the Varig-TAM codeshare occurred;

gc: global crisis of 2008;

month_seasonalityk: seasonality control; and

u$_t$: error variable.

The Ordinary Least Squares (OLS) estimator was used. This estimator seeks to minimize the differences, in the quadratic case, between the value found in the regression line and the actual value of the function y considered. In a multivariate regression, as in the regression's case of this study, it is common that the parameters used to explain the variable in question are related to each other. To analyze the relationship between the parameters there is the concept of autocorrelation. It explains how related the parameters are and how one interferes with the value of the other. Besides the correlation analysis, a change is made through the Newey-West procedure, to overcome possible problems generated by autocorrelation, heteroscedasticity and error terms of the model, considering that the data are presented in the form of time series.

Regarding the sensitivity analysis, the Regression Equation Specification Error Test (RESET) is performed to omit disturbances possibly caused by non-linear combinations between the estimating parameters. The statistical significance of the variables is shown in the regression table in the form of asterisks, with a parameter with asterisks considered more significant.

B. *Descriptive Statistics and Graphical Analysis*

Fig. 1 shows the time series of the number of passengers at Petrolina Airport.

Fig. 1. Movement of passengers at Petrolina Airport

It is noticed the growth of passengers in recent years. The increase in the purchasing power of the passengers, who could use the airplane as a means of transportation and the increase of Petrolina and region as an exporter of fruit and wine can explain this phenomenon.

The correlation analysis showed the relationship between the number of passengers and the price of air tickets, being inversely proportional. As the price decreases, the number of passengers increases. As the level of consumption increases, measured by the GDP of the micro-region, the number of passengers also increases, being directly linked. The results of the regression will be analyzed below.

IV. RESULTS AND ANALYSIS

To interpret the results of a regression, the main aim is to analyze if it can reach satisfactory results in what concerns the analysis of a variable in relation to the parameters considered in the regression. Among the parameters used, it is necessary to analyze if they have statistical significance. It directly relates to the theory of hypothesis tests if those parameters really interfere in the analyzed variable or if the interference was only accidental. To do so, we analyze values of significance, usually associated with the probability that the values are outside the range of probabilities considered, and according to the significance of the parameters, they will be relevant to the analysis and may even be discarded with low significance.

Table I indicates the regression model generated as well as alternative regression models to verify if the model used would be the best model that would fit the demand study. For the choice of the best model, the criterion of statistical significance was used.

TABLE I
REGRESSION RESULTS

	(1)	(2)	(3)	(4)	(5)	(6)	(7)
Brazilian GDP	-0.9792	12.192	1.9751 ***	-	-0.6317	-0.3452	-0.0054
	[1.323]	[1.529]	[0.615]	-	[0.699]	[0.727]	[0.815]
Microregion GDP	0.2882	0.6003	-	1.4423 ***	-	-	-
	[0.815]	[1.098]	-	[0.410]	-	-	-
Electrical Energy	1.9081 ***	-	-	-	1.9195 ***	1.9477 ***	1.7852 ***
	[0.410]	-	-	-	[0.425]	[0.464]	[0.519]
Ticket Price	-0.2847 **	-0.4032 ***	-0.3675 ***	-0.4794 ***	-0.2670 **	-0.2399 *	-0.2885**
	[0.111]	[0.115]	[0.129]	[0.124]	[0.132]	[0.127]	[0.117]
Varig-Tam	-0.381	-0.0237	-0.0159	-0.0366 **	-0.0345 **	-0.0316 *	-
	[0.023]	[0.029]	[0.019]	[0.015]	[0.017]	[0.017]	-
Global Crisis 08	-0.0036 *	-0.0062 **	-0.0059 **	-0.0061 **	-0.0034 *	-0.0048 ***	
	[0.002]	[0.003]	[0.003]	[0.003]	[0.002]	[0.001]	-
New Consumers	0.0357	0.0446	0.0530	-	0.0397	-	-
	[0.054]	[0.072]	[0.070]	-	[0.053]	-	-
R^2	0.9179	0.8783	0.8774	0.8762	0.9177	0.9159	0.9049
RMSE	0.1787	0.2166	0.2166	0.2177	0.1782	0.1793	0.1892
F	463.376	197.802	209.014	210.743	429.862	448.448	385.105
F_pvalue	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000
RESET	13.277	0.3697	0.5488	0.3024	13.438	28.999	24.162
RESET pvalue	0.2492	0.5432	0.4588	0.5824	0.2464	0.0886	0.1201

[a]Standard errors of heteroskedasticity and robust autocorrelation estimated in brackets. *, ** and *** represent, respectively, a significance level of 10%, 5% and 1%. Elasticities estimated in the sample mean. Fictitious variables of monthly seasonality omitted.

The number (4) regression model was chosen as the model used in this study because it presented the best levels of statistical significance. The chosen model presented as significant the variables GDP micro-region, price of tickets, VARIG-TAM codeshare, global crisis of 2008 and the seasonality of some critical months. Signals of the coefficients of such variables are consistent, considering, for example, a positive relationship between passenger numbers and GDP of the micro-region and a negative relation between the number of passengers and ticket prices.

A. *Demand Forecast and Numerical Analysis of Results*

The forecast of passenger demand for Petrolina Airport is presented in Fig. 2. In such a forecast, three possible scenarios are considered: pessimistic, neutral and optimistic. The assumptions of each scenario relate to the performance of the Brazilian economy in future years, considering greater or lesser impacts on air transportation, depending on the situation adopted.

From the number of estimated passengers for the future scenario, it was possible to calculate the number of annual domestic flights and, thus, to forecast the emissions of pollutants. To do so, we performed an analysis of the current flights of the airport and the type of aircraft most commonly operated.

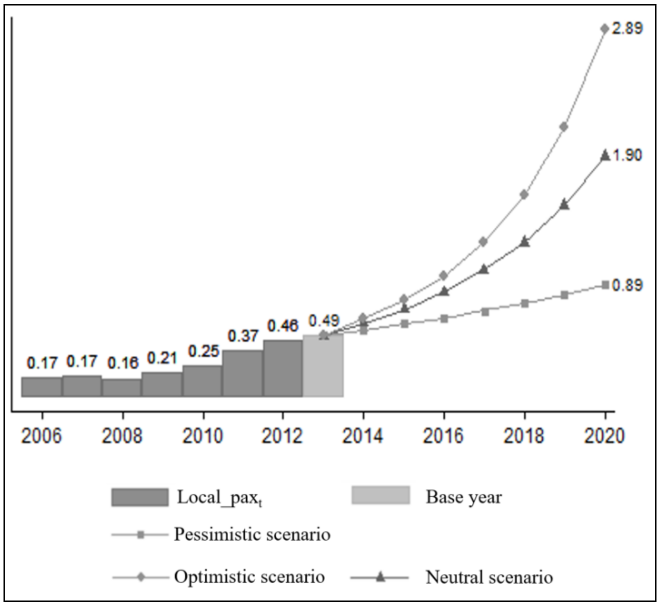

Fig. 2. Time series of the number of domestic passengers.

Considering ANAC data, the typical aircraft at such airport is the Airbus A320. For the regional operations, the maximum occupancy of this airplane is given as 162 passengers. Thus, the average occupancy for the year 2013 (59.19%) is estimated, considering average occupancy scenarios for the future, with pessimistic (55%), neutral (65%) and optimistic (75%) possibilities. In this way, the forecast for the number of flights in the year 2020 is determined.

According to Reference [8], the emissions of civil aviation aircraft come from the burning of fuel, which may be kerosene or aviation gasoline. Emissions from the engines are approximately 70% CO2, slightly less than 30% H_2O and slightly less than 1% each for NOx, CO, SOx, NMVOC. Modern engines emit low levels of N_2O. CH_4 emissions can occur with the aircraft idle, but modern engines do not emit this type of gas.

For pollutants calculation, Reference [8] divides the airport operations into Landing and Take-off (LTO) Cycle and cruise flight. Approximately 10% of aircraft emissions, except hydrocarbons and CO, are produced when the aircraft is in the ground and during the LTO cycle. The LTO cycle comprises emissions during takeoff and approach for landing below 3000 feet (approximately 1000 meters) in height. Figure 5 shows the LTO cycle. Data provided by Reference [8] were used to determine the emissions per flight considering the pollutant gases analyzed as CO_2, CH_4, N_2O, NOx, CO, NMVOCs and SO_2, as presented in Table II.

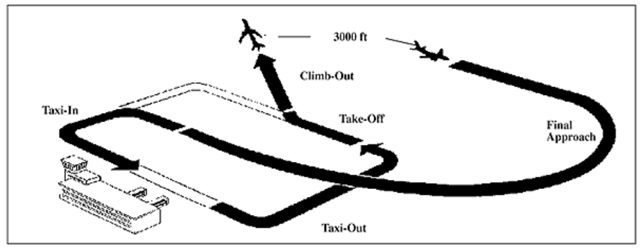

Fig. 3. Landing and Take-Off Cycle [8].

TABLE II
EMISSIONS OF POLLUTANTS IN KILOGRAMS PER LANDING AND TAKE-OFF CYCLE OF THE A320 AIRCRAFT [8]

CO_2	CO	CH_4	N_2O	NO_X	NMVOC	SO_2
2560	5.3	0.04	0.1	11.0	0.4	0.8

Emissions are connected to the number of aircraft operating at an airport; the type and efficiency of aircraft engines; the fuel used; the duration of the flight; the power level; the time spent at each stage of the flight; and to a lesser extent, the altitude at which gases are emitted [8].

The pollution scenario considered is the surrounding of the airport, contemplating, therefore, the landing and takeoff procedures, regarding fuel consumption and, emission of pollutants. The result of the pollutant forecast is shown in Table III.

TABLE III
FORECAST OF ANNUAL EMISSIONS IN TONS, FOR PESSIMISTIC (P), NEUTRAL (N) AND OPTIMISTIC SCENARIOS (O)

Year	CO_2	CH_4	N_20	NO_X
2013	6540.98	0.1	0.26	28.11
2020.p	17580.25	0.27	0.69	75.54
2020.n	25020.58	0.39	0.98	107.51
2020.o	28543.21	0.45	1.11	122.65
Year	**CO**	**NMVOC**	**SO_2**	**Fuel**
2013	13.54	1.02	2.04	2069.61
2020.p	36.4	2.75	5.49	5562.5
2020.n	51.8	3.91	7.82	7916.67
2020.o	59.09	4.46	8.92	9031.25

The air demand growth will increase the emission of pollutants. When compared to 2013, it is projected that in 2020, an increase between 169% and 336% of CO_2, NOx, CO, NMVOC, SO_2 and Fuel; between 170% and 350% for CH_4; and between 165% and 327% for N_2O. This increase in pollution could have consequences for people living in the airport's vicinity.

V. CONCLUSION

The present work had the aim of forecasting the emissions of pollutants from domestic flights to Petrolina airport. A linear regression model was used to forecast the growth of the number of passengers at the airport by 2020, following three scenarios of possibilities. From this predictive model and the emission characteristics for the typical aircraft of the airport, it was possible to predict emissions of gaseous pollutants for the year 2020.

This work is added to the existing and growing literature, which concerns the environmental impacts of civil aviation, besides being a case study for a Brazilian regional airport of increasing importance.

The limitations of the work are given in the adoption of a typical aircraft, with no emission segmentation for other operating aircraft. In addition, the analysis is restricted to domestic flights, thus understanding the impact of passenger aviation regarding local emissions, but not from the airport given the local importance of cargo flights.

As a complement of this work, studies other forms of pollution, such as noise, caused by flights at such an airport, and studies of the environmental impact caused by the emissions analyzed in this study, may be presented mitigation measures to make civil aviation more sustainable, enabling its continuity in a non-harmful way.

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Daniel Alberto Pamplona is a PHD student in Aeronautical Infrastructure Engineering, Air Transport concentration line, at the Technological Institute of Aeronautics (ITA). Graduated in Aeronautical Sciences from the Brazilian Air Force Academy (AFA), BSc in Mathematics at UCS with minor in Computer Science, with a Master's Degree in Aeronautical Infrastructure Engineering from the Aeronautical Technological Institute (ITA),

Bruno Bezerra Bluhm is a Civil Engineer from the Technological Institute of Aeronautics (ITA)

Claudio Jorge Pinto Alves holds a degree in Aeronautical Infrastructure Engineering from the Technological Institute of Aeronautics (ITA) (1977), a master's degree in Civil Engineering from the University of São Paulo (1981) and a PhD in Aeronautical and Mechanical Engineering from the Technological Institute of Aeronautics (ITA) (1987). He has experience in Transportation Engineering, with emphasis on Planning and Organization of the Transportation System, working mainly in the following subjects: airports, air traffic, capacity, simulation and terminals.