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Environmental impact assessment and the environmental (in)feasibility of alternative sites of airports

Avaliação de impacto ambiental e a (in)viabilidade das alternativas locacionais de aeroportos

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ABSTRACT: Studies on alternative sites related to Environmental Impact Assessment (EIA) require the typology-location approach regarding the development project under analysis. However, shortcomings regarding the alternative sites of Dr. Leite Lopes airport (Ribeirão Preto, Brazil) were reported, such as a lack of multi-criteria analyses. This study aims to reanalyze the eight alternative sites proposed by the Environmental Impact Statement (EIS) for expanding the Dr. Leite Lopes airport. We applied a methodology based on technical, economic, environmental, and social factors, using multiple criteria proposed by aviation agencies for avoiding and reducing impacts caused by airports. We classified each alternative site, calculating the product of these factors. If one of the factors received a zero score, the product was zero. Consequently, the alternative site was considered infeasible. We compared the alternative site selected by our study and the EIS. The results indicated that Ribeirão Preto has feasible alternatives for expanding the airport. Based on our multi-criteria reclassification, the Usina Galo Bravo II site had the highest score, while the current site - Dr. Leite Lopes - was considered infeasible. In contrast, the EIS indicated the Dr. Leite Lopes site as the best alternative.

Keywords: environmental impact statement; multi-criteria analysis; mitigation hierarchy; sitting alternative.

RESUMO: O estudo de localização da Avaliação de Impacto Ambiental (AIA) requer a abordagem do binômio tipologia-localização do empreendimento em análise. Para atividades aeroportuárias, estão previstas regulações legais ambientais e determinações de agências de aviação, que visam a evitar e reduzir impactos causados por esta tipologia de empreendimento. O aeroporto Dr. Leite Lopes de Ribeirão Preto tem histórico de problemas envolvendo suas alternativas locacionais, incluindo a falta de multicritérios na análise de suas alternativas. O objetivo deste estudo foi reanalisar as oito alternativas locacionais apresentadas no Estudo

de Impacto Ambiental (EIA) da ampliação do Aeroporto Dr. Leite Lopes, em Ribeirão Preto. Aplicou-se análise multicritério para fatores técnicos, econômicos, ambientais e sociais, atribuindo valor zero para fatores que indicassem inaptidão. Para classificar cada alternativa locacional, calculou-se o produtório dos fatores, resultando na exclusão de locais considerados inaptos para, pelo menos, um dos fatores. A partir disso, ocorreu uma comparação entre a escolha do sítio pelo EIA e a alternativa em potencial apontada pelo presente trabalho. A classificação obtida indica que Ribeirão Preto dispõe de sítios com viabilidade ambiental para a atividade aeroportuária, mas que o sítio do aeroporto Leite Lopes é considerado inapto para operação e ampliação com base na análise multicritério aplicada, devido aos impactos significativos ali presentes. Com base no EIA, o sítio com a maior pontuação dos critérios é do aeroporto Dr. Leite Lopes, enquanto a reclassificação indica o sítio da Usina Galo Bravo II.

Palavras-chave: análise multicriterial; estudo de impacto ambiental; estudo de localização; hierarquia de mitigação.

1. Introduction

In Brazil, the Environmental Impact Assessment (EIA) is one of the prognostic instruments of the Brazilian Environmental Policy. The EIA supports decision-making in environmental licensing by analyzing the environmental feasibility of different projects, such as airports (Brazil, 1981; CONAMA, 1986; 1997; Oliveira *et al*., 2009). In EIA, the typology-location binomial is essential when analyzing the alternative sites, which aim to avoid areas with high levels of environmental vulnerability, considering the principle of prevention (Souza, 2000; Steinemann, 2001; Montaño *et al*., 2012; Yang *et al*., 2016; Comendador *et al*., 2019; Contreras-Alonso *et al*., 2020; Gaspar *et al*., 2020).

Decisions on environmental licensing depend on the quality of the alternatives proposed (Steinemann, 2001), with a recommendation that the analysis of alternative sites consider the typology-location binomial (Montaño *et al*., 2012). The analysis of alternative sites must consider the effects of the project in that location, the characteristics of the activity to be implemented and its technological processes (Steinemann, 2001; Montaño et al., 2012). The carrying capacity of the sites should also be considered in the analysis (Benson, 2003; Upham et al., 2003; Tang et al., 2009; Marsh, 2010; Sánchez, 2020).

Characterizing the environment and the activities should include multi-criteria, such as physical, biological, technological, economic, sociocultural, and infrastructure components (Bryan *et al*., 2011; Montaño *et al*., 2012; Comendador *et al.*, 2019). After applying multi-criteria, the alternative sites can be ranked to identify the viable ones, i.e., sites where the project is viable to be implemented, expanded, or operated. Applying multi-criteria and ranking the alternative sites can contribute to identifying feasible and infeasible sites.

Due to the complexity of analyzing the impacts caused by airport activities and the vulnerabilities of the environment for the installation of airports, the agencies associated with the aviation sector have developed policies, guidelines, technical norms, and environmental protection standards to be met in the sector (INFRAERO, 2018; FAA, 2020; IATA, 2020; ICAO, 2020). These regulations aim to limit

or reduce the environmental impacts resulting from the implementation or expansion of airports, the number of people affected by the impacts of aircraft noise, the risks associated with the operation of the airport, the impacts resulting from traffic, and the emission of pollutants and greenhouse gases. The actions to avoid or reduce the impacts of airports agree with the mitigation hierarchy of the EIA, which prioritizes, in this order, avoiding impacts, mitigating impacts, and repairing impacts (Bechara, 2009; Tallis *et al*., 2015).

Globally, the airport sector and domestic aviation have increased. For instance, there was a preference for air transport (76.2%) compared to road transport for interstate trips in Brazil (ANAC, 2021). Furthermore, the Brazilian airport sector grew almost 200% from 2003 to 2013 and 3.3% from 2017 to 2018, despite the global economic crisis (ANAC, 2019). Nevertheless, an increase in airport and domestic aviation sectors has resulted in problems such as aircraft congestion, flight delays, and exhaustion of the capacity in worldwide airports (Vogiatzis, 2012; Ozkurt *et al*., 2014; ANAC, 2015).

Shortcomings regarding alternative sites for airports' expansion are reported, such as analyses limited to physical or financial issues without considering environmental factors (Upham *et al*., 2003; May & Hill, 2006; Freestone & Baker, 2010). These shortcomings can result in increased political, social, and environmental opposition to these developments (Nero & Black, 2000; Stevens *et al*., 2010; Suau-Sanchez *et al*., 2011). Moreover, Environmental Impact Statements (EISs) tend to favor alternatives already chosen in the past (i.e., rarely consider new alternatives), need more reliable and updated information, and show a lack of previously defined decision criteria. All these shortcomings can result in the inclusion of infeasible alternatives (Steinemann, 2001; MPU, 2004; Pinho *et al*., 2007; Mattos, 2019). Furthermore, EISs exclude some alternative sites before detailed analysis and do not consider the counterfactual scenario (Mattos, 2019; Carvalho, 2020; Mandai *et al*., 2021).

In this context, the Dr. Leite Lopes airport, in the municipality of Ribeirão Preto (São Paulo, Brazil), had a proposal to expand in 3,500 meters its landing and take-off runway in 2005 (Figueiredo Ferraz, 2007). The expansion was proposed to transport long-distance cargo between Ribeirão Preto and Miami (USA). However, the environmental licensing of this airport had socio-environmental shortcomings, especially related to a lack of multi-criteria when selecting alternative sites. For example, civil society and the Public Ministry of the State of São Paulo criticized the expropriations, resettlement, and noise levels expected for an area with housing, trading, services, industry, and a consolidated road system (Figueiredo Ferraz, 2007). Table 1 describes events related to the Dr. Leite Lopes airport since its implementation and operation in 1992. The Dr. Leite Lopes airport in Ribeirão Preto was chosen as a case study because it involves criticisms among alternative sites, such as a lack of a multi-criteria method when analyzing the alternative sites.

Therefore, this study reanalyzes the alternative sites proposed by the Environmental Impact Statement of the airport Dr. Leite Lopes of Ribeirão Preto. To do so, we use international and national multi-criteria methods.

TABLE 1 – Chronology of events related to the implementation and operation of the Dr. Leite Lopes Airport, Ribeirão Preto, São Paulo, Brazil.

DATE	EVENT
1939	Creation of an aerodrome in the city of Ribeirão Preto – Dr. Leite Lopes airport.
1990s	TAM* starts regular flights to some cities, including São Paulo.
1995 - 1997	News in the press about the expansion of the Dr. Leite Lopes airport. Request by State Public Prosecutor's Office and civil society for the elaboration of an Environmental Impact Statement (EIS).
	Opening of a public civil inquiry against the São Paulo Aviation Department (in Portuguese, *Departamento Aeroviário do Estado de São Paulo* - DAESP).
1997	Public civil action to ensure the elaboration of an EIS.
	The Judiciary determines the elaboration of an EIS.
	DAESP hires a company to elaborate an EIS.
April, 2004	Public hearing of the EIS reunited more than 1,500 people. The EIS was harshly criticized by civil society and public prosecutors. The likely impacts on urban infrastructure were changes in the route of the Thomas Alberto Whately Avenue, occupation of 140,000 m² of urban green area, land use change from a housing to an industrial role, incompatible noise with the surroundings, and urban disarticulation, changing the infrastructure of water, sewage, urban drainage, and road networks.
2004	The São Paulo Department of the Environment rejects the EIS. The EIS does not meet the requirements, such as for alternative sites.
	DAESP hires another company to elaborate a new EIS.
2004 - 2007	The Public Prosecutor or Public Ministry (MP) and civil society, represented by the *Associação Cultural Ecológica Pau Brasil*, organize meetings at the headquarters of DAESP in São Paulo and in the MP of Ribeirão Preto.
	DAESP presents the EIS without discussing it with society and MP staff.
2007	The EIS suggests the current airport site (Dr. Leite Lopes) as the most suitable alternative site.
	Civil society starts a social movement in disagreement with the EIS in Ribeirão Preto.
July, 2007	Following a DAESP request, the State Environmental Council canceled the public hearing scheduled for July, 2007.
2008	The MP and the Transport Secretariat of the State of São Paulo, to which DAESP is linked, sign a Term of Adjustment for the non-expansion of the runway of the Dr. Leite Lopes airport.
2008 – 2015	DAESP improved infrastructure at the airport without changing the basic structure.

2015	New attempt to license the "airport expansion on the current site" project through an Environmental Regularization Report, not an EIS. Civil society and the MP prepare reports showing shortcomings and non-conformities. The initiative does not prosper. Public civil actions are underway against the irregular operation of the airport, calling for its closure. There is a request for regularization through EIS for its expansion. The airport is in the process of being awarded a concession to the private sector.
Current situation	The airport continues to operate, and Ribeirão Preto remains on the Thomás Alberto Whately Avenue without public lighting for a 700-meter stretch. As a result, the population does not feel safe walking or cycling, and there are accidents and deaths in the area. This avenue is the main connection between the central region of the city and the neighborhoods in the northeast, with an estimated population of 40,000 people. Amid a movement to privatize airport terminals in the state of São Paulo, in July 2021, Rede VOA won the concession auction for Dr. Leite Lopes airport. In February 2022, the contract was signed, replacing the São Paulo State Aviation Department (Daesp), with a planned investment of R$130 million for the next 30 years of operation of the terminal.

* TAM - *Táxi Aéreo Marília,* since 2012, TAM is part of the LATAM Airlines.

SOURCE: preparation of the authors.

2. Material and Methods

To include the typology-location binomial in our analyses, we considered the characteristics and likely impacts of airports and the local characteristics of the environment, following criteria from national and international aviation agencies. Technical, economic, environmental, and social criteria were integrated into the analysis in successive approximations for the eight alternative sites proposed by the EIS Dr. Leite Lopes airport (CETESB SMA process #13.509/2005). The alternative sites were Jardinópolis, Presídio I, Presídio II, Sertãozinho I, Sertãozinho II, Usina Galo Bravo I, Usina Galo Bravo II, and the one where Dr. Leite Lopes airport currently operates (Figure 1). The alternative sites analyzed are in Cravinhos, Ribeirão Preto, and Serrana.

By integrating typology and location requirements, the study of alternative sites overcomes the traditional cost-benefit analyses applied to engineering projects, which have shortcomings in including environmental criteria (Montaño *et al*., 2012). We weighted unacceptable (unsuitable) impacts as zero to avoid any significant and irreversible environmental impact.

2.1. Establishing the criteria

To verify the criteria from the typology-location binomial, we chose criteria that meet the legal requirements of the International Civil Aviation Organization (ICAO) and the Federal Aviation Administration (FAA) of the USA - the leading international civil aviation agencies. We also included criteria from the Brazilian Airport Infrastructure

Company (in Portuguese, *Empresa Brasileira de Infraestrutura Aeroportuária* - INFRAERO) (Table 2). These criteria are related to risks associated with airports, such as:

1. damage to flora and fauna,
2. noise caused by aircraft,
3. emission of polluting and greenhouse gases,
4. high levels of energy consumption,
5. generation of solid and liquid waste,
6. risk of accidents,
7. devaluation of land around airports,
8. disruption of the neighborhood due to increased traffic of vehicles, and

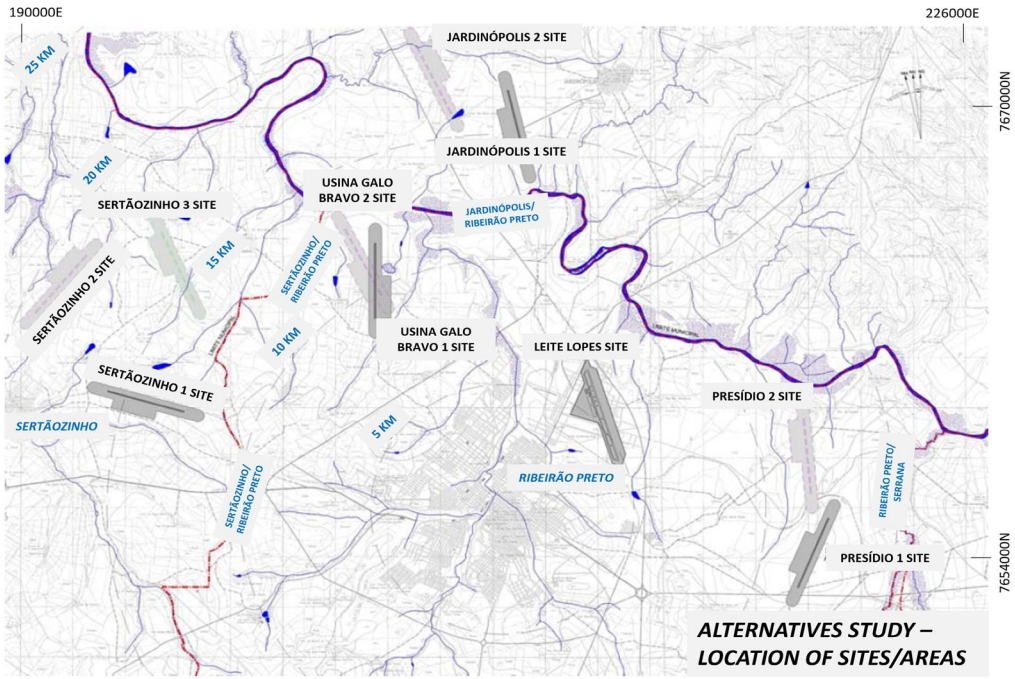

FIGURE 1 – Pre-selected alternative sites evaluated in the Environmental Impact Statements of 2005 and 2007.
SOURCE: Figueiredo Ferraz, 2009.

TABLE 2 – Criteria for sitting airports according to three agencies in the airport sector: the International Civil Aviation Organization (ICAO); the Federal Aviation Administration (FAA) of the U.S. Department of Transportation; and the Brazilian Airport Infrastructure Company (INFRAERO). The recommendation of a criterion by a given agency is indicated by an "x."

Categories	ICAO	FAA	INFRAERO	Considerations
Topography	x	x	x	1% – 2% slope is recommended
Pedology	x	x	x	Restrictions for gleisol soils
Geology	x	x	x	Greater suitability for less permeable rocks
Accesses	x	x	x	Proximity to accesses

Visual barriers	x	x	x	Proximity, approximately 5 km, to the cone zone
Costs	x	x	x	Monetary value
Distance from another airport		x	x	10 – 70 km
Property size	x	x		Around 10 million m²
Cultural or archaeological heritage sites	x	x	x	Present or absent
Meteorological conditions	x	x	x	Runways oriented according to the prevailing wind direction. Beware of fog
Local infrastructure	x	x	x	Enough to offer services
Danger zones	x			Present or absent
Sensitive areas	x	x		Schools, hospitals, housing
Light emission	x	x		Legislation and Distance from emission sources
Noises	x	x	x	Legislation
Wildlife and native vegetation protection areas	x	x	x	Legislation and municipal location
Air quality	x	x	x	Legislation and social demand
Bird attraction	x	x	x	3 – 8 km radius
Compatibility with land use/ occupation	x	x	x	Legislation and social demand

SOURCE: preparation of the authors. Adapted from Furlanetto (2012).

9. likely traffic jams, impacts on the local landscape, and land use and planning conflicts.

2.2 Scoring classes

We used multi-criteria to analyze the characteristics of the project (typology) and the carrying capacity of the environment (location), aiming to examine the environmental impacts that could be mitigable (acceptable) and non-mitigable (unacceptable). Table 2 describes the criteria for alternative sites, while Table 3 shows the environmental categories and factors used.

The factors were classified based on economic, technical, social, and environmental criteria and weighted according to their suitability for installing the project. The greater the suitability of a category, the higher the value of its attribute in the information plan. Table 3 shows the relationship between the suitability scale (classes) and the values assigned to classify each category (or groups of categories associated with a factor).

TABLE 3 – Assigned values to each class for the suitability of each alternative site for the installation or expansion of an airport.

Suitability scale (classes)	Assigned values
Unsuitable	0 (zero)
Poor	1
Good	3
Excellent	5

SOURCE: preparation of the authors. Adapted from Furlanetto (2012).

To analyze each airport location alternative, the classes for suitability were expressed by multiplication, where a zero-value (unsuitability) in at least one factor makes the area infeasible as an airport alternative site (Table 3). Thus, the multiplication excludes any site that could generate an unmitigable impact concerning one or more factors considered.

Classes of the region = π classes (factors: geology, pedology, relief, vegetation, urbanization)

The weighting of factors indicates the viability of mitigating environmental impacts and repairing and restoring impacted environmental factors. This approach allows development projects to agree with established environmental standards. Furthermore, this approach excludes alternative sites likely to cause unmitigable impacts and irreversible damage, i.e., compensating is impossible in an unsuitable site.

All the information plans generated were reclassified into four classes: (0) unsuitable, (1) poor, (3) good, and (5) excellent. This reclassification used the RECLASS module to standardize the elements under analysis. The information plans relating to hydrography and native vegetation were treated as restrictive to occupation and classified into two categories (suitable or unsuitable). Within the 200-meter buffer from the watercourses, the restriction of the territory was determined, while distances greater than 200 meters indicated suitability. Regarding the presence of remnants of native vegetation, the RECLASS module was used to classify the area based on the absence or presence of vegetation.

2.3 Data collection

The criteria listed in Table 2 were applied to the alternative sites, considering the distance between the urban area and its expansion area, relief, hydrography, pedology, geology, remnants of native vegetation, permanent preservation areas, land use (housing, urbanization), and urban and road infrastructure in the region of Cravinhos, Ribeirão Preto, and Serrana.

The Geographic Information System (GIS) data was obtained from maps ranging from 1:10,000 to 1:100,000. We used official sources from Brazil: the Brazilian Institute of Geography and Statistics (IBGE), the Agricultural Institute of Campinas (IAC), the São Paulo State Department of the Environment (SMA), the São Paulo State Forestry Institute (IF), and the National Institute for Space Research (INPE).

The CARTALINX software was used to structure the vector data, the topological structure, and the storage of attributes. The generated vectors were converted into a matrix format (raster) with 10x10-meter pixels on IDRISI 32 software. This

software was used to process images and define the classes and categories for each factor and criterion.

The digital elevation model was obtained from the topography in matrix format using IDRISI's INTERCON module. This module interpolates the contour lines by calculating the values (elevations) for each pixel between them. The INTERCON module, however, has interpolation algorithms that produce gross flaws in the digital elevation models. Filtering the resulting images using a 5x5 average filter, followed by another 3x3 intermediate filter pass, using the FILTER module, MEAN option, attenuated errors in the original image generated by INTERCON.

The slope information plan was generated from the digital elevation model using the SURFACE module, SLOPE option. The result was an image with slope (%) for each pixel, which was used to obtain slope class information plans. The DISTANCE module was used to calculate the distance of each site from waterbodies and urban areas from the images in matrix format of the respective parameters, calculating the length of each pixel from the nearest object. The pedology information was based on the percentage of clay in each soil type in the study area to indicate soil erosion and liquid percolation.

2.4 Approximations for analyzing alternative sites

The methodology adopted two successive approaches (Montaño *et al*., 2012) to indicate viable alternative sites for installing airports. The approaches vary in level and scale: the first has regional and municipal scales, and the second has municipal and local scales (Montaño *et al*., 2012).

The premise of the first approach is to consider each site's physical, biological, and anthropic characteristics that provide greater or lesser potential for sitting the project. In the first approximation, we consider geology, pedology, slope, and proximity to urban centers, based on Montaño *et al*. (2012) (Table 4).

TABLE 4 – Categories considered in the first approximation of criteria (regional and municipal scales) for the alternative sites of the Dr. Leite Lopes airport, Ribeirão Preto, São Paulo, Brazil.

CATEGORY	CLASS	SCORE
Geology: soils in the alternative sites (IG, 2004)		
Serra Geral Formation and Soleira	excellent	5
Botucatu, Bauru e Piramboia Surface Formations	poor	1
Alluvium (QAL)	unsuitable	0
Pedology: types of soil in the alternative sites (IAC e IBGE, 2007)		
Red latosol	excellent	5
Red-yellow latosol and red nitosol	good	3
Quartzarenic neosol, rendzico chernosol, litholic neosol	poor	1
Gleisol abd cambisol	unsuitable	0

Relief - Natural Slope (ICAO, 2009; FAA, 2010)		
0 – 3 %	excellent	5
3 – 7 %	good	3
7 – 10 %	poor	1
> 10 %	unsuitable	0
Proximity to urban centers* (IAC, 1998)		
> 6.000 m – ACCIDENT RISK	excellent	5
2.500 – 6.000 m – AIRCRAFT APPROXIMATION CONICAL	good	3
600 – 2.500 m – NOISE CURVE II	poor	1
0 - 600 m – NOISE CURVE I	unsuitable	0
Proximity to waterbodies* (MINTER 124/80)		
> 200 m	suitable	1
0 – 200 m	unsuitable	0
Native vegetation* (IF, 2010)		
Absent	suitable	1
Present	unsuitable	0

* Restrictive occupation categories, treated only in two classes: suitable or unsuitable.

SOURCE: preparation of the authors. Adapted from Furlanetto (2012).

The thematic information was overlapped sequentially, generating integrated information on the following categories: geology and pedology, resulting in GEOPED; GEOPED and slope, resulting in GEOPEDDE; GEOPEDDE and proximity to the urban center, resulting in GEOPEDDEUR (Table 5). Finally, the GEOPEDDEUR information was overlapped with images of the remnants of native vegetation and the proximity of surface water, both with a Boolean image.

TABLE 5 – Integrated analysis of the categories considered in the first approximation (regional and municipal scales) for choosing the alternative site for expanding the Dr. Leite Lopes airport, Ribeirão Preto, São Paulo, Brazil.

GEOPED		GEOLOGY		
PEDOLOGY	0- Unsuitable	1- Poor	3- Good	5- Excellent
0- Unsuitable	0	0		0
1- Poor	0	1		3
3- Good	0	3		5
5- Excellent	0	5		5
GEOPEDDE		SLOPE		
GEOPED	0- Unsuitable	1- Poor	3- Good	5- Excellent

0- Unsuitable	0	0	0	0
1- Poor	0	1	1	1
3- Good	0	1	3	5
5- Excellent	0	3	3	5
GEOPEDDEUR		URBAN		
GEOPEDDE	0- Unsuitable	1- Poor	3- Good	5- Excellent
0- Unsuitable	0	0	0	0
1- Poor	0	1	1	3
3- Good	0	3	3	5
5- Excellent	0	3	5	5

SOURCE: preparation of the authors. Adapted from Furlanetto (2012).

The areas with a zero (unsuitable) in the first approach were not considered in the second approach. The second approach considered socio-economic factors on a more detailed scale and scope. The infrastructure of each potential site was analyzed by assessing the distance of each area from the main paved roads in the region, considering the convenience for airport users, the cargo flow, and the costs of building, duplicating, or paving the roads. A buffer of 3,000 meters was therefore established around the roads.

The distances from the noise curves and the aircraft approach cone were also taken into account, as well as the distance of each area from the region's urban centers to analyze the ease of obtaining basic services. To clarify the suitability of the alternative sites about the slope, we conducted a detailed analysis using IGC maps on a scale of 1:10,000.

2.5. Data analysis

Based on the two approaches, maps and tables were elaborated to reclassify the alternative sites proposed by the EIS Dr. Leite Lopes airport. We indicated the potential and weakness of the environment regarding the possible impacts caused by the installation or expansion of the airport. Based on the reclassification, the alternative sites were ranked from the highest to the lowest scores. This ranking was compared with the one suggested by the EIS. The criteria used by the EIS to classify these alternatives were also analyzed.

3. Results

Applying the criteria of Tables 2 and 3 in the alternative sites resulted in a reclassification of the sites, making it possible to identify the pros and cons of expanding the Dr. Leite Lopes airport in Ribeirão Preto. In the first approach (Figure 2), several sites were suitable for installing an airport or expanding the Dr. Leite Lopes airport. Regarding size, the excellent and good categories accounted for 39% of the total area under analysis (105,997 hectares). In contrast, the unsuitable and poor categories corresponded to 50% (137,016 hectares) and

11% (30,955 hectares) of the region under study, respectively (Figure 3A).

In the second approach (Figure 2A), considering the 3,000-meter buffer, the excellent and good categories accounted for 32% of the total buffer area (47,696 ha) (Figure 3B). Conversely, the unsuitable and poor categories corresponded to 53% (80,050 hectares) and 15% (22,695 hectares) of the area, respectively (Figure 3B). This second approach considered that the region represented in Figure 2A (red circle) is the most suitable area. However, this area is around 40 km from the center of Ribeirão Preto, a distance greater than that established as economically viable by the EIS but acceptable to aviation agencies (ICAO, 2020; FAA, 2020; IATA, 2020). This large area is also far from the urban area, making it difficult to access the infrastructure for expanding the airport.

When comparing the scenario generated in this study with the EIS (Figueiredo Ferraz, 2007), our analysis shows that most alternatives are in unsuitable areas for the installation of airports (Figure 2C). According to the EIS, the current Dr. Leite Lopes airport site (156) had the highest score, i.e., the most suitable alternative site for the airport. However, our reanalysis indicated that Dr. Leite Lopes airport was unsuitable (Figure 2C). Our study showed that the alternative sites Galo Bravo I and II and Sertãozinho I (Figure 2D) are in suitable areas (excellent and good categories) for an airport without restrictions. Therefore, our reclassification indicates the Galo Bravo II site (149) as the most suitable for the airport (Table 6), while the EIS indicates the current Dr. Leite Lopes airport site (156).

3.1 Choosing the alternative site

We critically analyzed the criteria used by the EIS to choose the alternative site for the airport. We highlight the following topics:

• Sites with similar scenarios scored differently in the EIS (e.g., Presídio I and II, and Sertãozinho I and II). Despite the high score given to the Dr. Leite Lopes site, the access to the airport would embrace the urban area.

• The EIS did not identify the presence of the Palmeiras waterbody near the Dr. Leite Lopes site, excluding a likely fog scenario. In the revised analysis, the Sertãozinho I site scored 8, and all the other sites received a score of 4.

• When describing the natural obstacles criterion, the EIS did not consider the remnants of native vegetation in the area to be acquired for the airport expansion. The failure to consider the Palmeiras water body and the remnants of native vegetation near Dr. Leite Lopes site hindered the analysis of avian risk.

• The presence of neighborhoods near the current Dr. Leite Lopes site was not considered a restriction by the EIS. In our reclassification, the score of this item decreased to 1.

• In the airport and access construction criterion, the permanent impacts and costs of the works were considered. In our reclassification, the Dr. Leite Lopes site scored 1, considering works with high costs (e.g., rock underpass).

• According to municipal land use legislation and the Ribeirão Preto Master Plan, the current site of Dr. Leite Lopes airport is considered illegal.

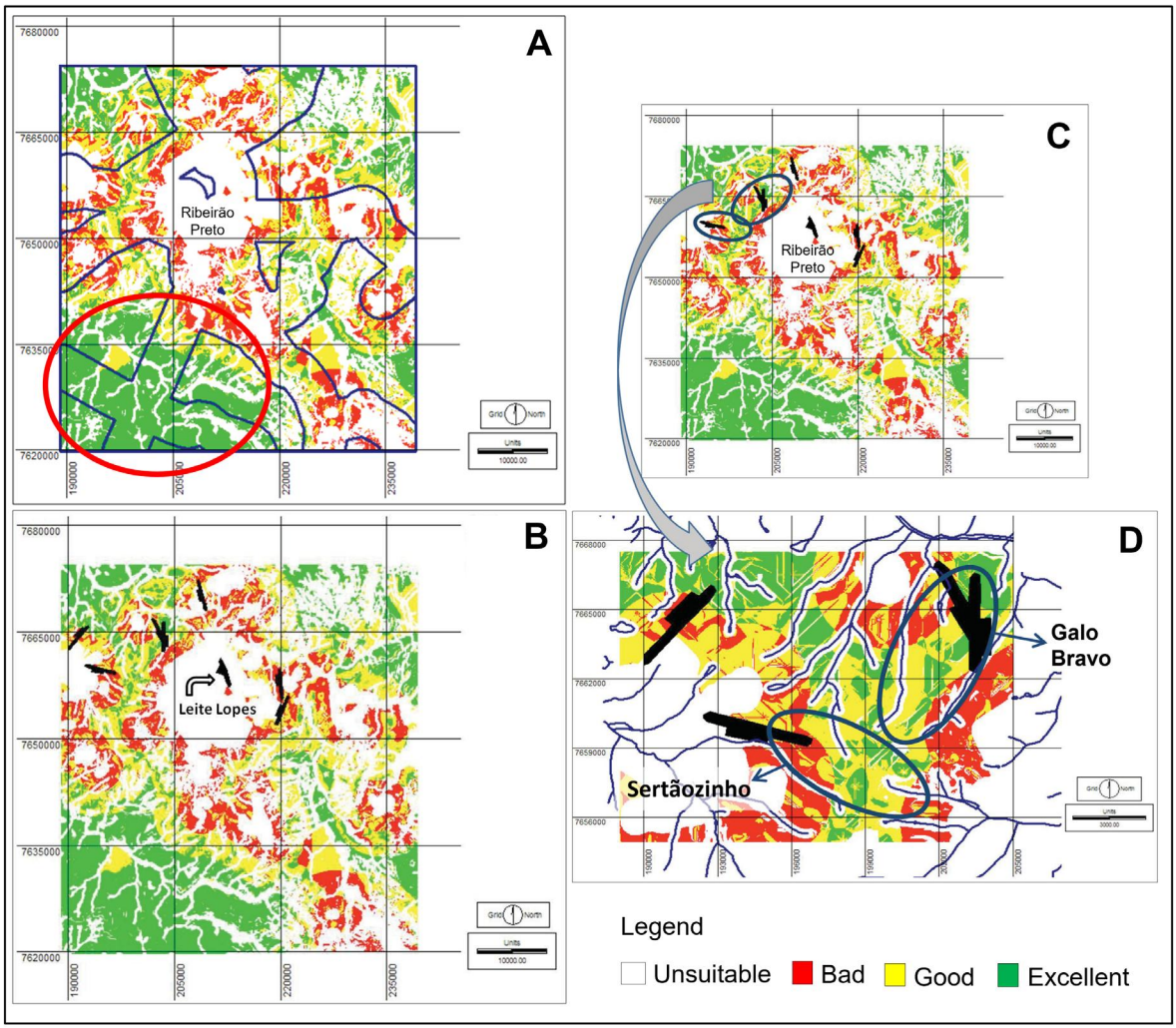

FIGURE 2 – Overlap of multi-criteria information plans for analyzing the alternative sites to expand the Dr. Leite Lopes airport (Ribeirão Preto, São Paulo, Brazil). Classification indicating a buffer of 3,000 meters around highways (A). The red circle shows a region with high suitable levels (A). The final scenario indicates the Dr. Leite Lopes airport site as an unsuitable area (B) and the Galo Bravo and Sertãozinho I sites as the most suitable alternative sites (C e D). Information plans considering the Northwest - Galo Bravo (D) - and West regions - Sertãozinho (D) slope classes.

SOURCE: preparation of the authors. Adapted from Furlanetto (2012), based on IBGE maps at a scale of 1:10,000.

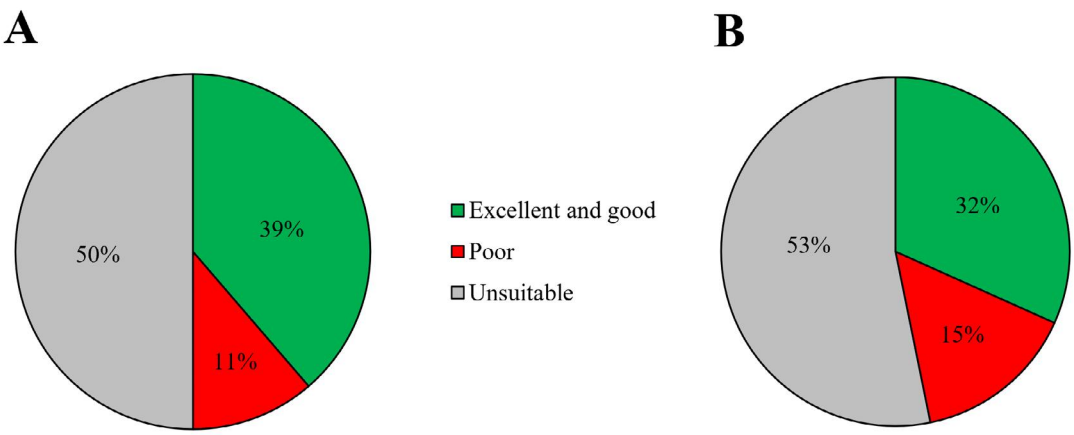

FIGURE 3 – Percentage of factors classified as excellent, good, poor, and unsuitable when analyzing the environmental viability of the alternative sites for the Dr. Leite Lopes airport (Ribeirão Preto, Brazil). Application of multi-criteria in two approaches: first (A) and second (B).
SOURCE: preparation of the authors. Adapted from Furlanetto (2012).

TABLE 6 – Ordinal classification of the alternative sites according to the Environmental Impact Statement (EIS) and the multicriterial reclassification of this study.

Classification	EIS		Reclassification	
	Alternative site	Score	Alternative site	Score
1º	Dr. Leite Lopes	156.0	Usina Galo Bravo II	149.0
2º	Usina Galo Bravo I	150.0	Usina Galo Bravo I	148.0
3º	Usina Galo Bravo II	141.5	Sertãozinho I	142.5
4º	Sertãozinho I	126.5	Sertãozinho II	135.0
5º	Presídio I	125.0	Jardinópolis	129.0
6º	Jardinópolis	120.5	Presídio I	128.0
7º	Sertãozinho II	119.0	Presídio II	122.5
8º	Presídio II	105.5	Dr. Leite Lopes	090.0

SOURCE: preparation of the authors. Adapted from Furlanetto (2012).

• The EIS did not consider the presence of the Guarani Aquifer on the Dr. Leite Lopes site and its expansion, which would increase soil sealing.

• At the Dr. Leite Lopes site, expanding the road would obstruct the main access route to some Thomas A. Whatelly Avenue neighborhoods, isolating people and interfering with urban mobility. In our reclassification, Dr. Leite Lopes site scored 1 in this criterion.

• The site with the most significant potential to cause disturbance in terms of airport noise is the current Dr. Leite Lopes airport site because it

is entirely urban. In our reclassification, Dr. Leite Lopes site scored 1 in this criterion.

• The EIS did not consider that the airport expansion could reduce the value of residential properties in the surrounding area.

4. Discussion

The novelty of our study is weighing criteria based on the suitability of each alternative site for installing or expanding airports: unsuitable (0), poor (1), good (2), or excellent (5). With these factors, the product excludes sites that show one or more unsuitable criteria. This methodology meets the typology-location binomial, considering specific location characteristics and not merely the type of project. Thus, we avoid considering a site likely to generate significant impacts, i.e., this methodology complies with the mitigation hierarchy.

Our reanalysis included norms, policies, guidelines, legislation, and EIA criteria with GIS techniques, similar to a methodology that examined the impacts of the Barcelona airport (Contreras-Alonso *et al*., 2020). In the present study, the characterization of the area in three successive approaches resulted in detailed and specific analyses of the proposed alternative sites. The combination of different parameters (urban area, slope, hydrography, pedology, geology, remnants of native vegetation, permanent preservation areas, and land use) resulted in a decision different from that proposed by the EIS.

Our methodology focused on identifying mitigable and non-mitigable critical impacts on the alternative sites for airports based on methodological rigor and environmental factors that reflect the environment's carrying capacity. The methodology also considered a holistic approach – overcoming the technical and economic approaches - that inserts sustainability in planning and proposal of environmentally less harmful alternative sites. A study of the Lisbon airport in Portugal also integrated a sustainability approach to EIA and planning (Partidário & Coutinho, 2011).

The Sydney airport (Australia) case shows the relevance of policies that regulate and restrict land use and occupation around airports. The main reason is the negative impacts of airports on the environment and the surrounding population, such as noise, risk of accidents (Nero & Black, 2000; Stevens *et al*., 2010), and the attraction of commercial and industrial activities, which can result in other cascading impacts (Freestone, 2009; Freestone & Baker, 2010). Our methodology brings some of these necessary regulations to be applied in the EIA, environmental licensing in Brazil, and, consequently, for decision-making regarding the environmental viability of an airport (Brasil, 1981; CONAMA, 1986; 1997).

4.1. Comparing the EIS final decision and our reanalysis

Based on the classification presented in the EIS of Dr. Leite Lopes airport (Figueiredo Ferraz, 2007), the site where the airport already operates was indicated for the airport's expansion. However, based on the multi-criteria classification proposed in the

present study, this site was considered unsuitable. Our analysis showed that the EIS disregarded social conflicts involving expropriations, interference in urban mobility, and the impossibility of public lighting on neighboring roads. Furthermore, an increase in vegetation suppression and the inconvenience for the population due to the movement of airplanes were also disregarded.

In contrast, properly choosing a site would avoid or minimize the impacts caused by the installation and operation of airports (Forsyth, 2007; Stevens *et al*., 2010). However, this choice is weakened by the bias of alternative sites, the low quality of EISs, or the prioritization of other criteria in decision-making.

In 2005, when the first EIS was presented, the population's pressure during the public hearing was fundamental for the non-approval of the environmental license for the airport expansion. This public participation corroborates what Sánchez (2020) states regarding the importance of social participation in the EIA, including all stakeholders. A similar situation occurred in the Netherlands with the Schiphol airport, where social mobilization and public participation prevented an expansion of the airport (Morrell & Lu, 2000; Deelstra *et al*., 2003; Ale *et al*., 2006; Kroesen *et al*., 2010; Lijesen *et al*., 2010). Nevertheless, in 2007, the Dr. Leite Lopes site was chosen despite social protests during public hearings, disregarding public opinion and the desired environmental quality standards. A similar scenario occurred in Sweden with the Örebro airport (Soneryd, 2004). Residents were protesting against the expansion of the airport and an increase in the number of landings and take-offs. Despite this social movement, the project was approved before the EIS and without the participation of the people to be affected (Soneryd, 2004).

Likewise, the analysis of EISs in the state of São Paulo referring to airports showed that public participation has little influence on the decision of which site should be chosen. The analysis of the EISs also showed that multiple criteria have been overlooked when selecting the most viable alternative sites for airports. However, the quality of the location study in the EIS would be crucial to minimize controversial interpretations and improve the comparison among alternative sites.

Choosing an alternative site depends also on political and other factors influencing the decision-making process (Cashmore *et al*., 2004). For instance, Bauru and Ribeirão Preto's airports are located in residential areas and are managed by the same agency, the Department of Airports of the State of São Paulo (DAESP). On the one hand, the EIS of Bauru's airport considered incompatibilities between urban and airport activities – including the costs of expropriating the area – as criteria for selecting the alternative site. The chosen site was an area without housing, about 15 km from downtown (TERRA, 1991). On the other hand, the EIS of Ribeirão Preto did not consider expropriations, and the chosen site was in the urban area. The Bauru EIS recommended moving the airport to another location, the Bauru/Arealva site (TERRA, 1991). Despite the likely socioenvironmental conflicts, the Ribeirão Preto EIS indicated the environmental viability of expanding the current Dr. Leite Lopes airport. Thus, we inferred that other factors and interests must have guided decision-making in

Ribeirão Preto. In this case, the environmental factors considered do not meet the requirements specified in the Conama Resolutions nº 01/1986 and nº 237/1997. Both Resolutions regulate the EIA and environmental licensing in Brazil. However, they do not mention the criteria for sitting airports, such as the safe distance from housing in urban centers.

4.2. Instrument to analyze alternative sites

The analysis of the EIS showed that the study of the alternative sites was mainly based on technical and economic aspects, not emphasizing socio-environmental parameters. A factor contributing to the shortcomings to EIS is a lack of land planning regarding the conditions, weaknesses, and aptitudes of the environment in which a project or human action is to be installed. A lack of prior information transfers to the EIS the role of analyzing the whole baseline, which can bring shortcomings to the EIS.

A possible solution to this problem would be implementing a diagnostic instrument to provide prior information regarding environmental factors to be considered in the EIS. This diagnostic instrument would be essential to avoid and reduce likely social and environmental impacts and conflicts. Thus, a prior study of all alternative sites would allow the EIS to present the choice of the most viable alternative.

Using available information that indicates restrictions in the studied environment would provide a broader view of the possibilities for installing a project or activity, such as airports. This approach would anticipate identifying critical and highly restricted regions (Oliveira *et al*., 2009; Montaño *et al*., 2012). Providing prior information would also enable better analyses of the environmental viability of the projects, considering the typology-location binomial. Therefore, a diagnostic instrument would be a way to put the Principle of Prevention into practice and, consequently, the mitigation hierarchy.

One of the roles of the EIS - a significant instrument in impact assessment in Brazil – is to indicate the most viable site among the alternative sites under analysis based on the diagnosis and location studies (Oliveira *et al*., 2009). Before selecting the site for an airport, it is vital to establish the criteria for choosing viable sites based on socio-environmental, technical, and economic factors in different project phases. Complying with legal requirements is another point that should be considered when selecting an alternative site. Therefore, studying alternative sites requires a systematic process with clear criteria (Bojórquez-Tapia *et al*., 2005).

In general, approving an alternative site relies on adopting mitigating measures to guarantee the environmental viability of the project or activity. However, the desired direction would be disregarding alternative sites that involve critical impacts that cannot be mitigated (zero output). In other words, a reasonable approach would be to consider measures that mitigate and reduce the impacts on viable alternative sites (non-zero output). Therefore, it is not about choosing the best site for the airport but a viable site that allows the control and mitigation of environmental impacts.

5. Conclusions

Considering the typology-location binomial, our study showed the importance of applying multi-criteria (economic, technical, social, and environmental aspects) when analyzing airport alternative sites. However, the EIS of the Dr. Leite Lopes airport in Ribeirão Preto did not consider multi-criteria in the environmental viability analysis. This shortcoming weakens the quality of the alternative sites, the performance of the EIS, and decision-making. These issues make the process more costly for the entrepreneur, who must manage permanent unmitigated environmental impacts in the installation and operation of the airport. Although it was not the object of this study, we suggest future analyses of the role of the participation of various social actors in public hearings.

The methodology employed proved adequate in including the typology-location binomial to consider the specific restrictions of the location and not only the typology of the project, as it usually happens. Such consideration is essential to support more informed and long-term sustainable decisions. The weighting of the criteria in a product form prevents the choice of alternative sites with some unsuitable criteria. The goal is to avoid impacts the project cannot mitigate, a priority item in the mitigation hierarchy. This approach implies only considering environmentally viable alternative sites with impacts that can be mitigable.

Our study indicated many unsuitable sites where mitigation is impossible, suggesting these alternatives be excluded. The multi-criteria application identified the Galo Bravo I, Galo Bravo II, and Sertãozinho I as the most suitable alternative sites to install an airport. The reanalysis of the Ribeirão Preto airport location site allowed us to confront the final decision of the EIS – which chose the current Dr. Leite Lopes site – with the reclassification made in the present study - which considered this site entirely unsuitable. This contradiction is related to the fact that the EIS allows the possibility of adopting compensatory measures for non-mitigable environmental impacts and, consequently, the conflicts arising from this decision.

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