Aircraft Ground Energy & Air Conditioning Systems Implementation in Brazilian Airports: A Feasibility Study

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Abstract

This capstone sheds light on the challenges Brazil faces to expand the usage of external energy sources in the airports. The primary objective of this study is to examine the issues and risks confronting airports in this endeavor. At the same time, it highlights the advantages of integrating external energy sources, particularly in terms of mitigating ground emissions. Notably, these emissions contribute significantly to 13% (ANAC, 2019) of the overall landing and take-off cycle (LTO) emissions. To comprehensively address this subject, interviews were conducted with key stakeholders, including airport concessionaires, service providers, and equipment manufacturers. The research incorporates a cost-benefit analysis, encompassing capital expenditure (CAPEX) and operational expenditure (OPEX) related to investment and ongoing operations. The results are systematically presented, displaying the technical, economic, and environmental viability of adopting external energy sources within airport operations. Ultimately, this document serves the purpose of identifying strategic opportunities for enhancement. Moreover, it proffers actionable recommendations to stimulate the wider adoption of sustainable energy sources across Brazilian airports. The overarching aim is to foster a shift towards eco-friendly practices. Simultaneously, facilitating the provision of services geared towards minimizing CO_2 emissions and reducing fuel consumption costs for airlines.

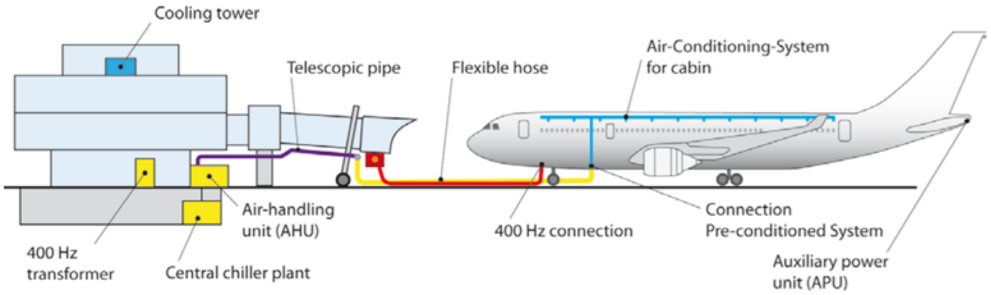
Keywords: Energy, APU, Brazil, service providers.

Introduction

The Auxiliary Power Unit (APU) is located on the aircraft's tail and functions akin to a jet engine. Whenever the aircraft's main jet engines are inactive, the APU supplies electrical power, air conditioning, pressurization, and hydraulic pressure. When the aircraft is stationary, a savvy approach is to replace the APU with a ground unit, a practice acknowledged by the Airport Cooperative Research Program (ACRP) on the report nº64 (ACRP et al, 2012). This transition has proven to cut jet fuel emissions by half (Padhra, 2018), with potential to reduce the on-ground fuel consumption by 13% (ANAC, 2019), consequently lowering CO_2 emissions at airport sites by 9.5% (ICAO, 2011).

Figure 1

AGES Illustration



Note. By Zurick Airport, 2018, AGES Illustration, Zurick, Switzerland

In Brazil, the prevailing practice is for aircraft operators to utilize their own diesel-powered equipment for ground power, and air conditioning in some cases. A common alternative across the globe involves contracting Aircraft Ground Energy Systems (AGES) with the airport or a third party. Currently in Brazil only Brasília and Confins airports provide such service. This model is advantageous for airlines where it increases fuel savings that do not require a considerable investment. Conversely, airports or third-party entities can offer these services to airlines, contingent on an appealing business model. Finally, replacing APU on the ground fosters sustainability and reduces fossil fuel emissions such as CO_2, NOx and PM10 (ICAO, 2011).

Nevertheless, the "pay per use" model for AGES remains underutilized in Brazil. In recent interviews with airport operators, high implementation and operational costs elongate the tradeoff period, contingent on the airports. Additionally, uncertainties arise concerning the return-on-investment period, given the dynamic nature of airline schedules.

Problem Statement

Changing any power source from fossil fuels to electric is beneficial to the environment. Fuel is one of the biggest costs for the airlines, and many airports around the world provide AGES. In the other hand, considerable implementation costs and complex variables such as airline schedule impact the provision of AGES in Brazilian airports.

But how do those qualitative aspects translate into a quantitative assessment? There is no answer until calculations are made, and as far the literature review of this capstone could achieve there is no work or initiative dedicated for the application of AGES on Brazilian airports. No comprehensive financial model was developed to address the country's macroeconomic environment and market projections.

Project Goals and Scope

This capstone aims to elucidate the financial and environmental outcomes AGES offers for airports and airlines. The financial outcomes would be assessed through a financial model aiming to determine which is the best financial tool for airports to provide this service (e.g., leasing, financing, etc.). The model encompasses an examination of implementation and operational costs tied to the utilization of AGES on a charge-per-use model. This evaluation involves an assessment of CAPEX, winch includes the costs associated with adapting airport infrastructure, as well as procuring and installing equipment. Simultaneously, OPEX is assessed considering expenses related to energy consumption, training, and maintenance costs, with operational responsibilities vested in the staff of the contracting company.

This approach ensures a comprehensive understanding of the financial implications and logistical considerations associated with integrating these alternative units into airport ground operations. The result will be the Net Present Value (NPV) and the Internal Rate of Return (IRR) for each one of the biggest 21 Brazilian airports, considering the different acquisition strategies. These airports encapsulate around 80% of Brazil's domestic Available Seat Kilometers (ASK) (ANAC, 2023a).

The environmental outcomes will be drawn from calculations on the anticipated reduction in CO_2 emissions resulting from the adoption of the proposed alternatives, also considering the expected value on carbon compensation. This method ensures a sound and practical basis for assessing the economic and environmental implications of transitioning away from APU usage during ground operations.

Definition of Terms

ACU	The Aircraft Cooling Unit is a mobile unit powered by diesel or electricity. It provides air-conditioning to parked aircraft during turnaround.
ACRP	The Airport Cooperative Research Program is a practical, industry-led research initiative focused on addressing challenges faced by airports.
AGES	"Aircraft Ground Energy Systems" represents a combination of GPU and ACU.

ANEEL	Agência Nacional de Energia Elétrica is the Brazilian Energy Regulatory Body
ANP	Agência Nacional do Petróleo, Gás Natural e Biocombustíveis is the Brazilian Petroleum Agency
APU	The Auxiliary Power Unit is a small jet engine usually placed in the aircraft's tail. It provides electrical power and air conditioning to the aircraft in-flight and on-ground operations.
ASK	Available Seat Kilometers is the aviation demand indicator indicating how many seats per kilometer certain airline or market has.
CAEP	Committee on Aviation Environmental Protection is a technical committee of the ICAO Council
CAPEX	Capital Expenditures are funds used by a company to acquire, upgrade, and maintain assets. Some examples are properties, buildings, technologies, and equipment.
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation is a ICAO regulatory framework to offset CO_2 emissions by airlines.
ETS	Emissions Trading System is a European carbon market that works in a 'cap and trade' system aiming to reduce CO_2 emissions.
GPU	The Ground Power Unit can be a fixed or mobile unit connected to an aircraft's electrical system. Its purpose is to provide electrical power to the airplane while on the ground.
IBGE	Instituto Brasileiro de Geografia e Estatística is the Brazilian Census Bureau.
ICAO	The International Civil Aviation Organization is a United Nations agency established to help countries share their skies to their mutual benefit. It adopts standards, practices, and policies for international civilian flight.
IRR	Internal Rate of Return is a financial analysis to estimate the profitability of an investment. IRR is a discount rate that equals the net present value to zero in a cash flow.
LTO	The Landing and Take-off cycle covers idle, approach, climb-out and take-off modes of engine operation. Each one is associated with a specific engine thrust setting and a time in mode.

NPV	Net Present Value is a financial metric that looks for the present value of cash inflows and outflows over a period and considering a discount rate. It is used to evaluate the viability of a project.
OPEX	Operating Expenses are expenses that any business incurs in regular operations. Some examples are rent, equipment, marketing, payroll, insurance, etc.

Literature Review

Below is presented the literature used as the basis of this study.

References Sources	Reference Summary
ANAC (2019). *Inventário Nacional de Emissões Atmosféricas da Aviação Civil 2019, volume único, 1ª edição, Agência Nacional de Aviação Civil.*	The report's introduction provides an overview of the evolution of demand in Brazilian air transport. Then, the document's concentrates on calculating the emissions of civil aircraft (commercial and private), both on regular flights (domestic and international) and on general aviation flights operated in Brazil.
IBGE (2021). Study shows status of the aviation sector in Brazil and impacts of Covid-19. https://agenciadenoticias.ibge.gov.br/en/agencia-news/2184-news-agency/news/32550-study-shows-status-of-the-aviation-sector-in-brazil-and-impacts-of-covid-19	IBGE is one important player for Brazil, creating studies and forecast. According to them, even before the COVID-19 pandemic, Brazil had suffered with a reduction in the aviation market. For example, between 2015-2019 the number of passengers decreased by around 1%. It creates a risk for the airport because the reduction of movements will affect the income with the GPU service and change the return time for the investment. According to some airport administrators, this uncertainty is one of the biggest barriers for the project today.

ICAO (2011). Doc 9889 First Edition Corrigendum No. 1 – Airport Air Quality Manual	This ICAO's manual brings some sources of airport pollution. For instance, APU, incinerators, motor vehicles, and infrastructure. In our business research, the focus was the APU. So, the manual brought the relationship between the APU usage and the fuel burn and gas emissions. The relationship was used as a justification to reduce the APU during ground operation. In the mitigation measure table, one of the solutions for this case is the use of 400Hz/PCA (AGES) at aircraft gates/stands.
ACRP et al. (2012). Airport Cooperative Research Program (ACRP) Report 64: Handbook for Evaluating Emissions and Costs of APUs and Alternative Systems. Transportation Reaserch Board. https://doi.org/10.17226/22797.	The report discusses the importance of reducing aircraft ground emissions by replacing the use of the APU with alternative sources of energy and A/C. The study provides an overview for the implementation of such alternative sources, addressing operation, regulations, environmental considerations, costs, and funding. In the second and third parts of the report, quantitative and qualitative analyzes and results are reported.
Padhra, Anil (2018). *Emissions from auxiliary power units and ground power units during intraday aircraft turnarounds at European airports*	This article analyzed the APU's contribution to air pollution during ground operation. It mentioned it is possible to reduce emissions using external electrical power and pre-conditioned air in the cabin. So, there was a comparison between the APU and external power usage during intraday aircraft turnaround. The sample contains 125 airports and 25,195 aircraft turnarounds during June 2015. Finally, this study found an emission reduction of 47.6%. This value can vary depending on the source of external power and the OAT.

ACI (2023a). Airport Carbon Accreditation—6 levels of accreditation. https://www.airportcarbonaccreditation.org/about/6-levels-of-accreditation/optimisation.html	The airport carbon accreditation program is developed by the Airports Council International (ACI) and aims to assess and recognize airport initiatives for CO_2 emission reduction. It is divided into 6 levels of certification that drive airports to a carbon neutral operation. Level 3 named as optimization has in its scope the reduction of landing and takeoff cycle emissions being one of them the reduction of APU usage during ground times.

Methodology

The airport's historical data was gathered to derive the utilization of APU. The calculation methodology considered the Percentile (P50) of the turnaround time for each aircraft type, delineated per airport, based on the historical dataset. Additionally, a crucial element in this estimation was the consideration of APU fuel flow. This, in turn, formed the basis for estimating the APU fuel burn cost, achieved by multiplying the APU fuel burn by the fuel price. This was done specifically for each airport-an important output for the subsequent feasibility study.

To consolidate the necessary AGES implementation data, equipment suppliers and airport operators were contacted to provide CAPEX and OPEX values. Also, publicly available documents of actual bidding process for these systems were used. CAPEX includes equipment, training and airport infrastructure adjustment. OPEX includes equipment maintenance, energy supply, water/gas supply, and labor. With all the data together was possible to reach the necessary investments and operating costs. In addition, by using the airport and airline costs, the price of the service was estimated. Then, a sensitivity analysis was performed in key variables to identify the most impactful in the project feasibility.

Finally, the project's environmental aspect underwent evaluation by quantifying the potential reduction in CO_2 emissions. This quantity was then transformed into value using an assessment of Carbon Credit prices based on World Bank data and ICAO projections to analyze possible future carbon offset costs.

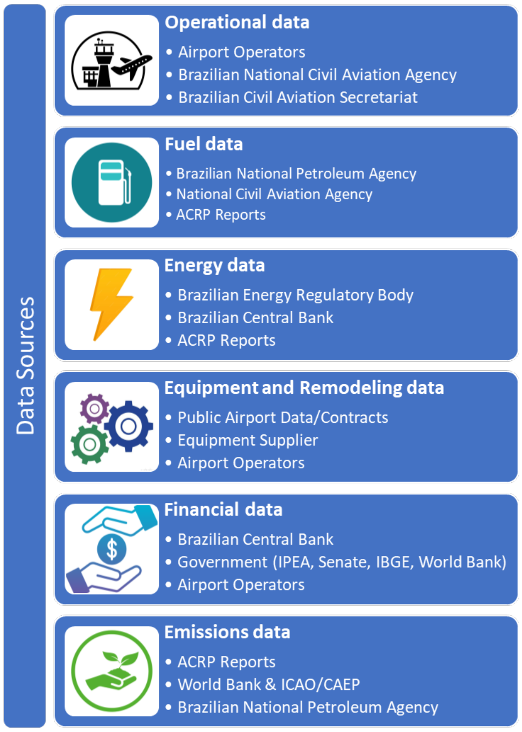
Data Source(s), Collection, and Analysis

Data Sources and Collection

This section presents the data used in this project and their sources. To design this case study, it was required to collect six types of quantitative data: operational, fuel, energy, equipment, and remodeling, financial, and emissions. The image below shows the summary of the data sources:

Figure 2

Groups of Data and Sources



Note. Own work.

Firstly, the operational data came from the airport operators, ANAC database, and Secretaria de Aviação Civil (SAC). The Google Earth application was used to account for the number of bridges for each airport. The turnaround times were calculated using ANAC (2023a) database. Then, the forecasts of the number of flights for each airport were retrieved from the Plano Aeroviário Nacional at SAC's (2022) website.

Secondly, the fuel data came from ANAC, ACRP report nº64, and the Brazilian Agência Nacional do Petróleo, Gás Natural e Biocombustíveis (ANP). By using ANAC (2023a) statistical data, it was possible to estimate the turnaround time per airport. The data also showed the APU fuel flow was extracted from the ACRP report, and the fuel price source was the ANP (2022).

The energy price was retrieved from the Brazilian Agência Nacional de Energia Elétrica (ANEEL), and the aircraft energy requirements came from the ACRP report. ANEEL's web portal provided the energy price for different consumer classes (e.g., industries, street lighting, etc) in Brazilian currency (ANEEL, 2023). The ACRP report presents the electricity requirements, both for ground power and cooling, for the aircraft type chosen for this model.

The equipment specifications and prices were determined based on the literature, interviews with airport operators, and two AGES providers. The equipment, training and airport remodeling costs data came from two secondary sources. The first one was a technical bidding for Manaus (Infraero, 2013) and Congonhas (Infraero, 2012) airports that aimed at passenger boarding bridge equipment and remodeling costs according to their specification. The maintenance expenses, depreciation, and training costs were collected from a Brazilian equipment supplier through a formal request. Then, interviews with four airport operators provided valuable understanding of other key aspects of the project.

Financial data such as minimum wage, inflation rate, and dollar exchange rate are applied as secondary parameters and can be found on the official government websites. These indexes were used to either bring equipment and remodeling costs to present value or make revenue and operational cost projections. The percentages of airport tax rates, airport cost of debt, and airport cost of capital were collected in the airport operator financial report (ANAC, 2023b), Brazilian Banco Nacional de Desenvolvimento Econômico e Social (BNDES, 2023), and Banco Central do Brasil (BCB, 2023), respectively.

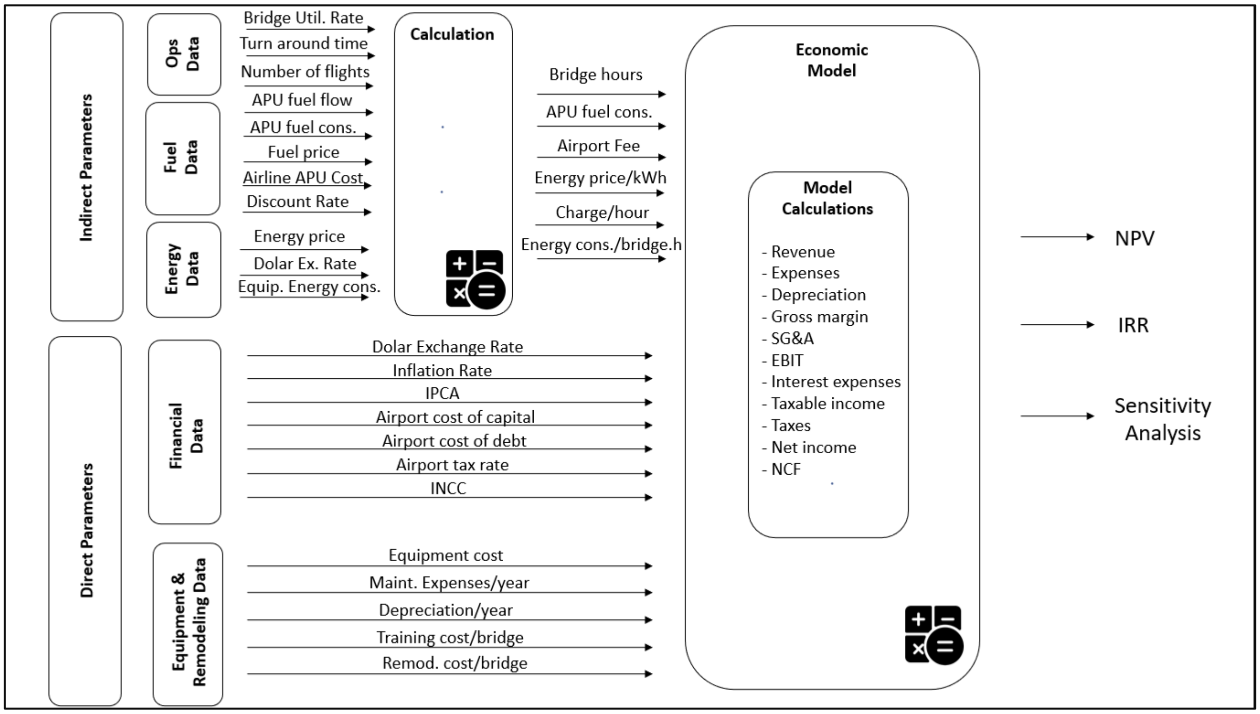
Finally, the data from CO_2 emission was retrieved from the ACRP report, World Bank, ICAO Committee on Aviation Environmental Protection (CAEP), and ANP. The report provides the coefficient of fuel converted to CO_2 emissions; the World Bank (2023) provides an estimate of Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) eligible carbon credit prices, while ICAO CAEP (2022) provides a forecasted price of Carbon Credits for the next years, and ANP presents information on fuel prices.

Data Analysis

The data analysis process includes several steps before getting the final products from the economic model, including the NPV, IRR, and sensitivity analysis. The image below illustrates the economic model:

Figure 3

Economic Model



Note. Own work.

1. Indirect parameters

a. Operational data

❖ Bridge hours

To calculate the amount of bridge hours, the equation below should be used for each airport:

$$Bridge\ Hours = Median\ turnaround\ time\ x\ Number\ of\ Flights\ x\ Bridge\ Utilization\ Rate$$

Where:

- The median turnaround time was estimated from January until August 2023.
- The number of flights was projected until 2035.
- Then, the bridge utilization rate was assumed 70% for the model.

b. Fuel data

❖ APU fuel consumption

The formula to estimate the APU fuel consumption is:

$$APU\ Fuel\ Consumption\ =\ APU\ Fuel\ Flow\ x\ Median\ Turnaround\ Time$$

Where:

- The APU Fuel Flow was collected from ACRP report.
- The median turnaround time was estimated from January until August 2023.

❖ Airport charge

The first step to calculate the suggested service price is to estimate how much the cost of APU to the airline per turnaround. To do this, the formula below should be used:

$$Airline\ APU\ Cost\ =\ APU\ Fuel\ Consumption\ x\ Fuel\ Cost$$

Where:

- The APU Fuel Consumption was previously calculated.
- The Fuel Cost was collected from ANP with the fuel price data from 2022.

After calculating the Airline APU Cost, the airport can use a margin of saving for the airline. To do this, the following formula was used:

$$Airport\ Charge\ =Airline\ APU\ Cost\ x\ Discount\ Rate$$

Where:

- The Airline APU Cost was previously calculated.
- Discount Rate was estimated for different scenarios in the sensitivity analysis.

c. Energy data

❖ Energy price

The energy prices available in the ANEEL dashboard are in Reais per Megawatts per hour, but for the analysis, these values were transformed into Reais per kilowatts per hour dividing by 1000. This transformation was applied to match the values to the same order of magnitude of aircraft energy requirements. The model considers the average price in reais provided for the whole Brazil regions from January to June 2023, then turned into US dollars considering 5.05 as exchange rate.

$$x\text{R\$/MWh} \div 1000 = x\text{R\$/kWh} \div exchange\ rate = x\text{\$/kWh}$$

❖ Aircraft energy consumption/bridge-hour

This parameter represents the amount of energy (kWh) needed by one aircraft to provide sufficient electricity and colling capacity during turnaround and comes directly from the ACRP report. Not considering heating requirements.

2. Direct Parameters

a. Financial data

Some financial inputs are needed to calculate the economic model, such as:

- Dolar exchange rate: used to convert the Brazilian currency values in the model on October 11st, 2023 (BCB, 2023).
- Inflation rate: the 2013-2023 average of Brazilian inflation rate was used to project the hourly charge, energy price and maintenance costs. (IPEA, 2023a).
- Airport cost of capital: used to calculate the NPV of the project models i.e., leasing, buying, and financing (BCB, 2023).
- Airport cost of debt: used to calculate interest expenses and depreciation (BNDES, 2023).
- Airport tax rate: annual tax rate the airport must pay relative to its revenue (ANAC, 2023b).

- Índice Nacional de Custo de Construção (INCC): this indicator determines the evolution of costs in the housing construction sector and was used to estimate the present value of the bridge remodeling costs (IPEA, 2023b).

b. Equipment and remodeling data

To check the feasibility of the economic model, the equipment and remodeling related costs come as an expense. The main values are shown in the table below:

Table 1

Equipment and remodeling related costs.

Item	**Cost (USD)**
Equipment price (HVAC 100/400Hz + 90 kVA[1])	$187,433.60
Maintenance per year (over equip. price)	1.7%
Training cost per bridge	$792.08
Remodeling cost per bridge (C-III)	$19,704.20
Remodeling cost per bridge (C-IV)	$39,408.40
Depreciation per year (over equip. price)	10%

[1] The equipment specification accounts for a narrowbody (e.g., 737-800), with maximum seating capacity, and fully occupied. The analysis considers only narrowbodies due to its relevance to Brazilian aviation scenario.

3. Economic Model

Through the economic model, the financial variables and the project's outcome were assessed using the NPV, IRR, followed by a sensitivity analysis on key variables.

a. Revenue

This value is the money the airport will receive by charging the airlines after their use of AGES service.

$$Revenue = (Number\ of\ bridge\ hours) \times \frac{charge}{hours}$$

b. Expenses

This value represents the money the airport will spend on equipment acquisition, airport remodeling, data collection and billing, energy cost, and maintenance cost.

$$Expenses\ =\ Leasing\ payment\ +\ Data\ Collection\ and\ Billing\ + Energy\ Cost$$
$$+ Maintenance\ Cost$$

c. Depreciation

The depreciation will be the natural value reduction of the equipment or remodeling. Depending on the acquisition model, there will be different types of depreciation.

❖ Leasing:

Leasing depreciation will only be applied during the lease period.

$$Depreciation\ Lease = -\left(\frac{NPVlease}{Period}\right)$$

Remodeling depreciation is applied to the total remodeling cost per bridge during the project period.

$$Depreciation\ Remodeling = \left(\frac{Total\ Remodeling\ Cost}{Period}\right)$$

❖ Purchase/Financing:

In the case of purchase or financing, the period of depreciation for the equipment and remodeling will be the same. Thus, the formula can be simplified.

$$Depreciation\ Purchase = -\left(\frac{Total\ Remodeling\ Cost\ +\ Total\ Equipment\ Cost}{Period}\right)$$

d. Gross margin

Represents the model profitability.

$$Gross\ Margin = Revenue - Expenses$$

e. Selling, General & Administrative Expenses (SG&A)

It was assumed that 4% of gross margin would be spend as general and administrative expenses, such as labor, insurance, materials, etc.

$$SG\&A = 0.4 \times Gross\ Margin$$

f. Earnings Before Interest and Taxes (EBIT)

The difference between gross margin and depreciation.

$$EBIT = (Revenue - Expenses) - Depreciation$$

g. Interest expenses

The interest expenses are the cost incurred by an individual for borrowed funds. In the model, includes airport cost of debt, the investment varying in a period.

h. Taxable income

This variable considers that income is taxable, and it must be accounted.

$$Taxable\ Income = EBIT - Interest\ Expense$$

i. Taxes

Taxes is the multiplication between the negative taxable income and the airport tax rate.

$$Taxes = -Taxable\ Income \times Airport\ Tax\ Rate$$

j. Net income

Represents the gross income with deductions.

$$Net\ Income = Taxable\ Income - Taxes$$

k. Net Cash Flow (NCF)

The NCF represents the gain or loss of this model over a period.

$$NCF = Equipment\ Cost + Remodeling\ Cost + Salvage\ Value + Net\ Income - Depreciation$$

l. Outputs of the model

The product of this economic model is the NPV and IRR with a range of results using sensitivity analysis. The NPV shows how much the airport operator will profit if they implement this service over the 15-year period. Then, the IRR indicates the most attractive alternative for AGES implementation.

The sensitivity analysis will unveil the impact of certain variables in the bottom-line results, facilitating the airport operator risk management. The variables selected were the ones with the greater level of volatility in the author's perspective, being energy price, the range of possible charge prices, and the equipment cost.

Table 2

Different financial tools for equipment acquisition

Leasing	**Purchase in t=0**	**Financing**
• Duration: 72 months • Monthly payment: 2.5% equipment cost • Depreciation: 10% of equipment cost/year • Year 7 to 15 monthly payment: 10% prior monthly payment.	• Purchase in year 0. • Salvage value: 6% equipment cost. • Depreciation: 10% of equipment cost/year.	• 10 Years of Financing with 20% down payment in 2023. • Salvage value: 6% equipment cost. • Depreciation: 10% of equipment cost/year.

Table 3

Assumptions and Examples of Inputs

Congonhas Airport

Number bridges[1]	12
Energy price (kWh)	\$0.13
Energy consumption/bridge.h (kWh)	72.52
Charge per hour	\$50.00
Dollar exchange rate	R\$ 5.05
Airport cost of debt	9.95%
Airport cost of capital	13.25%
Airport tax rate	34%
Lease payment	\$56,230.08
Salvage value (over equip. cost)	6%
Inflation rate	6%
APU fuel consumption (L/h) [1]	94.62
Year	2024
Nº of bridge x hours[1]	135,493
APU Fuel Consumption (L) [1]	12,820,116
CO_2 Emissions (Ton CO_2) [1]	40,512
Carbon Credit Price (Ton CO_2)	\$3.71
Potential CO_2 Credit[1]	\$150,297.91

[1] Variables related to the specific airport, in this example Congonhas.

4. Emissions

In relation to sustainability, aligned with the Paris Agreement, the NET Zero CO_2 program, and as advocated by the Airports Council International (ACI), it is important to evaluate the potential for emission reduction within the scope of this project. As indicated by ACI (2023b), the airport community's commitment to emission reduction has, in certain instances, surpassed the anticipated timelines set by global agreements on climate goals.

The evaluation of aircraft emissions during the Landing and Take-off (LTO) Cycle stages was conducted as part of ANAC's National Inventory of Civil Aviation Atmospheric Emissions in 2019. Following the methodology outlined in ICAO Doc 9889 - Airport Air Quality Manual, the findings reveal that, at major Brazilian airports, the APU usage accounts for 13% of overall fuel consumption, translating to 9.5% of CO emissions for the year 2018. Despite global efforts and initiatives in Brazil, few Brazilian airports are part of the ACI Airport Carbon Accreditation Program, which aims to map, reduce, and optimize actions contributing to emissions reduction. In this context, one of the study's objectives is to highlight the AGES not only as a business opportunity but also as carbon footprint reduction strategy. The aspiration is that the findings will not only contribute to a more sustainable approach but also inspire a heightened environmental commitment that benefits society at large.

Figure 4

Airport Carbon Accreditation Program airports in Latin America and Caribbean Region

Note. By ACI, 2023c, Airport Carbon Accreditation Program airports in Latin America and Caribbean Region.

To assess the cost of replacing the APU with alternative, less polluting solutions, it is essential to evaluate the expense associated with decreasing fossil fuel consumption. Furthermore, the analysis should encompass an evaluation of the reduction in CO emissions, along with an estimation of potential compensation obligations. This estimation should consider the projected market price of carbon credits, providing a comprehensive understanding of the financial implications associated with transitioning to more environmentally friendly alternatives.

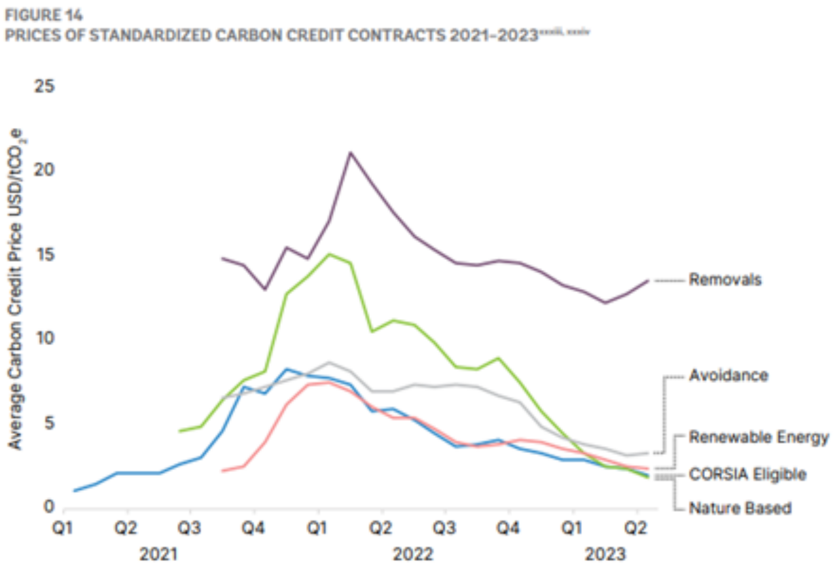
To estimate the volume of CO_2 emitted, a conversion factor of 3.16 was applied to the fuel consumption by the APU. For the airport, a conversion of 0.3406 was applied to the MWh (MCTI, 2023). Estimating the cost of carbon credits proves challenging due to the evolving nature of the carbon credit market, spurred by global emission reduction targets and initiatives such as ETS and CORSIA.

The State and Trends of Carbon Pricing report from World Bank (2023) indicates a trend towards values around USD $3.5 per ton of CO_2. A projection from the 225th ICAO council meeting aligns this value with the median scenario (ICAO CAEP, 2022). Moreover, the annual rate of increase in carbon credit prices is projected at 9.5%. Despite an observed increase in the supply of carbon credits, it is anticipated that this will lead to more moderate growth values in the upcoming years.

Furthermore, in the context of CORSIA, the utilization of Sustainable Aviation Fuels (SAF) plays a pivotal role in reducing compensation obligations. Consequently, this diminishes the necessity to acquire additional carbon credits. Thus, considering the articulated rationale the model considered the price per-ton of CO_2 at USD $3.5, with an assumed annual adjustment of 6% applied to this specified rate.

Figure 5

State and Trends of Carbon Pricing 2023



Note. By World Bank, 2023, State and Trends of Carbon Pricing

Project Outcomes

Results

The application of the methodology enabled the development of a model for the financial feasibility assessment of the project over a fifteen-year project horizon. Within the model, the application of parameters from Table 3, allows for the estimation of revenues, expenses, depreciation, rates, cash flow, NCF, NPV, and IRR. In the selection of factors influencing the model, their impact on the NPV and its dynamic variation over time were considered. in this regard, factors such as airport cost of debt, airport cost of capital, charge per hour, energy price, infrastructure investments and demand were evaluated. The assessment reveals that inflation positively affects the NPV due to the correction of other factors, demonstrating a correlation with the energy price variable. It is also noteworthy that a 1% variation in the cost of capital, cost of debt, and inflation variables results in an average NPV change of 8%, -2%, and -8%, respectively.

Among the several factors influencing the project's outcome, four stand out. The four factors are: demand, service charge, and energy price and infrastructure investments. Considering the charge and energy price factors, limits within the model were assessed for each variable and airport.

Demand – For the feasibility study, one important input is the number of bridge hours at each airport. A reduction in this input can impact negatively on the NPV of the implementation. To comprehend it, a margin of uncertainty can be calculated. The margin of uncertainty is the percentage of demand that can be reduced to maintain the project feasible, within the range of $0.10-$0.16 for the energy cost and $ 22 - $ 27 for the charge fee. For some airports, the margin of uncertainty can be significantly different, as we can see in the table below:

Table 4

Margin of uncertainty on the demand for feasible outcomes

ICAO	**Margin of uncertainty**
SBBE	50%
SBBR	50%
SBCF	10%
SBCT	30%
SBCY	60%
SBEG	30%
SBFL	10%
SBFZ	30%
SBGL	0%
SBGO	50%
SBGR	50%
SBKP	40%
SBMO	40%
SBPA	30%
SBRF	60%
SBRJ	70%
SBSG	0%
SBSL	40%

SBSP	80%
SBSV	10%
SBVT	30%

For example, for SBSP, the margin of uncertainty is 80%, which means that even if the bridge hour projection is 80% lower, the implementation would still be financially feasible. On the other hand, for SBFL, the margin of uncertainty to maintain the project feasible is 10%. This margin should be considered a risk for the airport when planning the implementation.

Infrastructure Investments – Through interviews conducted with service providers and airport operators, as well as an analysis of available literature, a wide range of values were identified. The values encompassed both equipment prices and the associated expenses required to modify the terminal for accommodating the increased electrical and air conditioning demands. Consequently, NPV values were simulated across a spectrum of infrastructure investment scenarios, ranging from $150,000 to $600,000.

Energy Price - The current kWh cost in Brazil is $0.13 for airport operators. For this study, the lower limit was set at $0.05/kWh because it will allow airport operators that are willing to invest in cheaper energy sources to understand the effect it will have on the NPV. The upper limit was calculated based on the scenarios with the highest charge value that renders the project feasible.

Charge – For the lower limit, the minimum values to be charged to airline operators were considered in scenarios where energy price assumes the lower limits. The upper limit was defined as the scenario in which there is no financial gain in replacing the use of the APU with AGES. Among the analyzed projects, for feasibility at São Gonçalo do Amarante Airport (SBSG) and Galeão Airport (SBGL), there would be a need for service charges, 79%, and 174% higher than the average charges at other airports. This is partly because in these two locations, it is low compared to the substantial investment required for the adaptation of all boarding bridges. The values for the feasibility ranges can be visualized in the table below.

Table 4

Parameter ranges for feasible outcomes

ICAO	**Energy Price**		**Charge**	
	Min	Max	Min	Max
SBBE	$0.13	$0.57	$19.00	$52.00
SBBR	$0.13	$0.57	$20.00	$53.00
SBCF	$0.13	$0.46	$28.00	$53.00
SBCT	$0.13	$0.52	$25.00	$54.00
SBCY	$0.13	$0.55	$18.00	$49.00
SBEG	$0.13	$0.55	$23.00	$54.00
SBFL	$0.13	$0.46	$27.00	$52.00
SBFZ	$0.13	$0.56	$24.00	$56.00
SBGL	$0.13	$0.16	$48.00	$51.00
SBGO	$0.13	$0.54	$19.00	$50.00
SBGR	$0.13	$0.56	$19.00	$51.00
SBKP	$0.13	$0.51	$21.00	$50.00
SBMO	$0.13	$0.50	$21.00	$48.00

SBPA	$0.13	$0.53	$23.00	$53.00
SBRF	$0.13	$0.57	$17.00	$49.00
SBRJ	$0.13	$0.59	$16.00	$51.00
SBSG	$0.13	$0.35	$32.00	$48.00
SBSL	$0.13	$0.48	$22.00	$48.00
SBSP	$0.13	$0.64	$13.00	$51.00
SBSV	$0.13	$0.52	$27.00	$56.00
SBVT	$0.13	$0.47	$24.00	$49.00

Note. Ranges of energy costs and charge values for feasible scenarios, considering an investment of $250,000.00 on airport infrastructure linked to the project. Despite the simulation value for the Energy price lower limit being $0.05, the actual value for energy price in Brazil is currently $0.13/kWh.

While there exists a spectrum of conditions within which the project is deemed feasible, it is crucial to explore the impact of energy price, charges, and airport investments on the NPV. Table 5 shows the outcomes of the sensitivity analysis for these variables. The ΔNPVs have been computed as the angular coefficients derived from linear regressions for each variable pair, namely, NPV vs. Energy Price, NPV vs. Charges, and NPV vs. Investments.

Table 5

Sensitivity analysis outcome.

ICAO	**NPV**		**Δ NPV / Energy x10** [1,2]	**Δ NPV / Charge** [1,2]	**Δ NPV / Invest** [1,2]
	Min	Max			
SBSP	$36.992,43	$49.415.346,45	$-3.730.621,27	$501.720,00	$-7,47
SBGR	$4.014,46	$53.156.907,84	$-3.213.989,33	$429.989,80	$-14,09
SBBR	$2.918,55	$25.851.968,07	$-1.504.101,45	$203.515,99	$-6,46

SBKP	$1.621,39	$20.689.001,64	$-1.185.927,87	$159.299,54	$-5,02
SBRF	$6.345,01	$15.965.731,66	$-1.032.893,74	$138.890,48	$-4,20
SBGL	$316,32	$6.738.185,91	$-790.081,83	$100.333,07	$-16,22
SBRJ	$842,91	$12.107.825,77	$-789.519,22	$106.125,61	$-3,18
SBCF	$592,89	$10.274.742,94	$-572.548,27	$77.565,14	$-5,00
SBPA	$111,98	$9.218.547,71	$-516.563,33	$69.571,06	$-2,48
SBFZ	$931,15	$8.316.190,91	$-466.551,14	$62.075,64	$-2,53
SBSV	$1.482,15	$8.090.123,91	$-460.197,04	$59.601,57	$-3,54
SBCT	$5.602,82	$7.570.329,95	$-417.542,09	$57.011,56	$-2,38
SBBE	$2.097,64	$5.679.988,07	$-338.973,03	$44.918,85	$-1,47
SBCY	$1.561,94	$4.427.662,81	$-271.351,24	$36.145,00	$-1,17
SBEG	$1.254,99	$4.633.412,18	$-261.817,04	$34.957,12	$-1,38
SBFL	$1.940,60	$3.709.365,01	$-215.138,90	$28.421,91	$-2,08
SBGO	$319,48	$3.602.547,87	$-212.020,51	$28.659,49	$-0,92
SBVT	$103,81	$2.998.253,55	$-167.458,48	$22.398,40	$-1,08
SBMO	$147,55	$2.915.503,01	$-165.882,21	$22.353,04	$-0,73
SBSG	$534,45	$2.009.076,54	$-132.991,05	$17.969,43	$-1,73
SBSL	$60,47	$1.878.435,38	$-105.309,42	$14.324,00	$-0,52

Notes. The table presents the minimum and maximum NPV values considering the variables variance (energy price, charge, and infrastructure investment).

Per the table, the energy price range is $0.05/kWh to $0.60/kWh. Price of energy for simulation purposes was considered the actual price in Brazil of $0.13/kWh. The charge range is $12.00/hour to $56.00/hour, considering pay-per-hour use of the equipment and energy. Infrastructure investments ranges from $150,000.00 to

$600,000.00, including equipment prices, airport electrical and air conditioning adaptations. [1]ΔNPV/Energy, ΔNPV/Charge and ΔNPV/Invest are the angular coefficients of the linear regression equations considering the average NPV as dependent variable and energy price, charge, and infrastructure investment as independent variables. To ease comprehension, the values for ΔNPV/Energy are expressed on the table for each $0.10 cents variation.

[2]ΔNPV/Energy, ΔNPV/Charge and ΔNPV/Invest per hour are calculated by dividing the values for each airport by its total bridge hours for the 15-year period of the project.

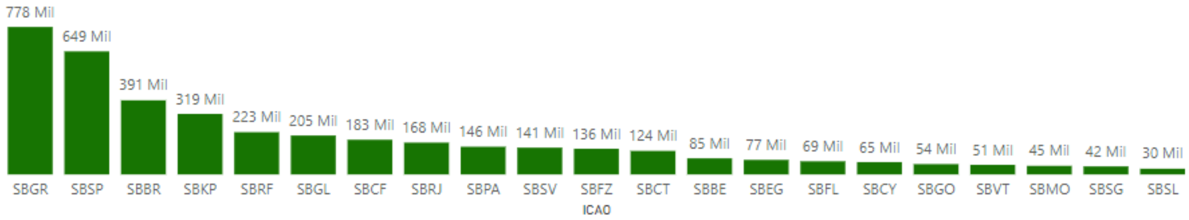
Table 5 clearly reveals that even minor fluctuations in energy prices can exert considerable influence on the NPV. This, in turn, signifies a notable risk factor, as energy prices are inherently susceptible to various dynamic factors, including climate conditions and external events such as conflicts. Conversely, the substantial effect on profitability places considerable pressure on the airport to enhance its operational efficiency and explore alternative, cost-effective energy sources, such as solar power.

A similar pattern emerges when examining variations in the Charge and Infrastructure Investment variables. For instance, let us consider Brasília Airport (SBBR), where a $0.10 fluctuation in the energy tariff leads to a substantial reduction of approximately $1.5 million in NPV over the 15-year project duration. Similarly, following this rationale, a $1.00 increase in Charges results in an increment of over $200,000.00 in SBBR's NPV, while a $1.00 increase in investment yields a nearly $6.00 reduction in NPV. The service's financial viability depends on the amount charged by the airport. The analysis shows that some scenarios can make the service financially viable by charging amounts close to $13.00, while others require four times that amount to achieve positive NPVs.

In terms of the environmental impact, an estimated reduction of up to 3,983,000 tons of CO_2 was projected with the reduction of APU usage, if all twenty-one airports would adopt the solution from 2024 to 2038. On the other hand, the energy from the AGES would emit around 447,000 tons of CO_2. To put this into perspective, if we consider that a mature tree can absorb approximately 22 kilograms of carbon dioxide from the atmosphere in one year (EEA, 2011), this reduction equates to the environmental benefit equivalent to that of 181,045,455 trees. In 2024, for example, the implementation could reduce by around 208,954 tons the CO_2 emission. According to ANAC, in 2022 the Brazilian Aviation Domestic market was responsible for emitting 8.56 million tons of CO_2. So, the implementation has the potential to reduce around 2.4% of the Brazilian Aviation Domestic Emissions. In the figure below, we can see the total amount of CO_2 reduction per each airport:

Figure 6

CO_2 reduction per airport



Note. Own work.

In addition to the environmental impact, the prevention of CO_2 emissions could result in significant savings, estimated at around $23.5 million. This amount represents potential compensation expenses for the prevented CO_2 emissions once market-based measures are regulated in Brazil. Considering that the implementation could lead to a reduction in airline costs by $861 million, factoring in the reduction in fuel expenses over the entire period, this translates to an additional 2.7% in cost avoidance for the airlines.

Limitations

The project is specifically geared towards serving narrow-body aircraft. In this context, the suitable equipment for this type of aircraft was defined for the model (HVAC 100 - 400Hz +90 kVA), and the projection of demand did not include the movement of flights with wide-body aircraft. It was assumed that the median turnaround time for each airport would be the same as their historical data. It's important to note that the model does not account for costs associated with APU maintenance. Furthermore, when calculating the remodeling cost for each airport, it was assumed that all airport bridges would have the equipment installed. However, it's worth noting that the airport has the flexibility to opt for the installation of AGES in only select bridges, thereby reducing the required investment.

The potential gain from emissions reduction was not included in the model since, to date, there has been no regulation in the domestic or international market for carbon offsetting. However, when the domestic model is regulated in the future, it should be considered in further studies. To estimate the charge values, the hourly APU fuel consumption was calculated while parked at the bridge.

Risks

The interviews conducted by the team with airport operators and service providers and given the absence of any current regulatory barriers hindering this initiative, it can be confidently asserted that the underdevelopment of the market in Brazil is not rooted in technical or financial constraints. While the market structure exhibits characteristics of a natural monopoly, the concession contracts prevent the establishment of entry barriers by the operator. Consequently, service providers may be vulnerable to the potential entry of a new player at the airport, a concern evident from the interviews conducted.

The primary risk stems from the inherent volatility of the Brazilian aviation market. A decrease in the volume of flights can lead to a reduction in bridge hours, potentially affecting the financial viability of the project. To address this risk, this paper has introduced a margin of error for each airport. Furthermore, this risk can be effectively mitigated through negotiations between airports and airlines. Airports may consider including a minimum guaranteed number of hours within the contract or exploring the possibility of implementing an additional charge. This extra margin does not adversely affect the cost-saving measures of the airlines and can provide a safeguard against uncertainties in the market.

Another risk identified pertained to fluctuations in energy prices. Over the last eight years, factors such as droughts in 2012 and 2013, among others, led to tariff increases surpassing annual inflation rates. Our sensitivity analysis indicates that, on average, the NPV decreases by approximately $0.7 million for every 10-cent rise in the energy price per kilowatt-hour.

Conclusions and Recommendations

Conclusions

The provision of energy and air conditioning services to airline operators at boarding gates has significant environmental appeal. In Brazil, despite the yet-to-be-implemented regulation for environmental compensation in the aviation sector, there are various ongoing initiatives within the government, airports, and airlines aimed at achieving the decarbonization goals set by each segment of the aviation industry. The findings of this study indicate the financial feasibility of offering services at prices below

$30.00 per hour at 19 out of the 21 airports studied. The primary variables studied that impact the NPV were the price of electricity, service charges, and infrastructure investments. In the sensitivity analysis, it was observed that even if these variables shift unfavorably, there are several scenarios where NPV is still positive for most airports to proceed with the AGES solution.

Recommendations

The recommendation is for each airport operator to utilize this model with internal data to analyze the feasibility of the AGES implementation and the associated environmental benefits. Beyond that, the model could be used to analyze the feasibility of implementing or expanding the number of passenger bridges in the airport, based on the extra revenue that would be achieved. For the sake of streamlining the implementation process, it could be beneficial to simulate the minimum number of airport bridges required for feasibility at each airport.

Another highly relevant aspect to be explored in future studies involves incorporating a model that combines power generation through solar panels at airports. A future study may reveal the need to reduce the energy costs and consequently the cost-of-service provision. Such a model could make installation of AGES feasible in certain locations. Furthermore, to broaden the scope of discussions, it would be beneficial to conduct studies involving service provision for international operations and wide-body aircraft, as well as service provision at remote positions.

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