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Appraising the impact of air transport on the environment: Lessons from the COVID-19 pandemic

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ABSTRACT

The spread of the COVID-19 disease caused by the respiratory syndrome coronavirus 2 (SARS-CoV-2) infection has resulted in unprecedented measures restricting daily flights. Although passenger demand for travel has considerably reduced, the pre-existing impacts of gases generated by aeroplane engines on the environment are still substantial. This paper uses a modelling-based scenario analysis to assess the restriction policies relating to air transport in Argentina, Brazil and Colombia during and after the pandemic and their effects on the environment. The simulation results highlight the need to reduce the negative environmental impact produced by the aviation sector and suggest that policymakers should try to focus on creating ways to reduce the impact made by the aviation industry on the environment, through a coordinated environmental policy between countries, including the three that are the subject of the present case study in order to highlight these issues.

Introduction

Although governments have implemented different measures to mitigate the spread of coronavirus, new contagions and outbreaks have occurred again (Cacciapaglia et al., 2020). Currently, most countries have tried to reduce the spread of the virus by using a massive number of COVID-19 screening tests (Takyi-Williams, 2020). The measures for moderating SARS-CoV-2 has also been characterised by large-scale physical distancing efforts – including the closure of airports – being implemented by a large number of countries despite heavy economic costs (Hotle and Mumbower, 2021). As a result of these measures, restrictions on flights have increased around the world. For instance, the number of domestic U.S. markets served between commercial airports decreased by 32.1% during May 2020 (Hotle and Mumbower, 2021). Certainly, social distancing within airports has been vital in order to moderate the spread of the virus; however, restricting flights in the long term does not likely to reduce their negative environmental impact.

The transport sector is one of the industries that contributes most to CO₂ emissions worldwide (Charabi et al., 2020; Wu et al., 2019; Zambrano-Monserrat et al., 2020). Over the last decade, the contribution by the transport sector in Latin America increased considerably from 35.15% in 2010 until in 2014 it reached 36.3% of the emissions of greenhouse gases (World Bank Group, 2014). At least in the short term, the SARS-CoV-2 virus has inadvertently minimised emissions more than any other individual action, policy or intervention to date (Perkins et al., 2020). Recent studies have reported a decrease in environmental impacts due to the lockdown situation at some airports (Giani et al., 2020; Shi et al., 2020). Zambrano-Monserrat et al (2020) point out that emissions during the pandemic could drop to proportions not seen since before the Second World War. Besides this, Tian et al. (2020) report that the urban air quality throughout Canada have improved notably during the pandemic period. For instance, in six cities of Canada, the CO₂ concentration level dropped from 0.14 to 0.07 ppm (parts per million) in March from 2018 to 2020. Although the lockdown has had a positive impact on the environment, policy intervention in the past has been inadequate for dealing with the high concentration of emissions caused by fossil fuel sources, especially in Latin America (Chêze et al., 2013; Martínez-Jaramillo et al., 2017).

Whilst a number of studies have addressed the COVID-19 issues recently, few studies have reported on the environmental impact in relation to the aviation sector in Latin America. The present paper aims to fill this gap; therefore, the research question that it addresses are: Could restricting flights during the pandemic reduce the negative environmental impact? What lessons can be learned regarding the aviation sector, including the three that are the subject of the present case study in order to highlight these issues.
sector in terms of social and environmental behaviour during the pandemic? To give a response, the paper assessed the impacts of the present pandemic on three South American countries, and it did this through simulation scenarios, including air passenger restrictions and the effects of these on the climate, particularly in terms of CO₂ emissions and temperature.

The pandemic has prompted a reappraisal of existing production systems that have been based on complex, environmentally unfriendly value chains (Perkins et al., 2020). Besides this, empirical data on this issue are scarce due to the newness of the SARS-CoV-2. In this context, simulation is particularly useful when the task of obtaining such data is a challenging one (Davis and Bingham, 2007). This paper shows a simulation model based on system dynamics (SD) in order to achieve a better understanding of the positive effects on the environment of having less air transport since the beginning of the pandemic. SD has been increasingly recognised as a useful method for understanding and addressing complex health systems (Darabi and Hosseinichimeh, 2020), and environmental issues (Nabavi et al., 2016). On the one hand, Darabi and Hosseinichimeh (2020) recently reported on a large number of articles that focus on disease-related modelling. In this category of modelling, the majority of SD models have been traditionally

Table 1
Indexes associated with air transport measuring government response to COVID-19 outbreak.

| Oxford stringency index          | Brazil | Argentina | Colombia |
|----------------------------------|--------|-----------|----------|
| Restriction on internal movement | 100    | 100       | 50       |
| International travel control     | 25     | 75        | 100      |
| Close public transport           | 0      | 100       | 50       |

Source: (Hale et al., 2020).

Table 2
Correlation between air passengers, CO₂ emissions and temperature.

|        | Passengers carried | CO₂ emissions | Temperature |
|--------|--------------------|---------------|-------------|
|        | Pearson Correlation| 0.811**       | 0.357**     |
|        | Sig. (2-tailed)    | 0.000         | 0.017       |
|        | N                  | 44            | 44          |
|        | Pearson Correlation| 0.931**       | 0.827**     |
|        | Sig. (2-tailed)    | 0.000         | 0.003       |
|        | N                  | 44            | 44          |
|        | Pearson Correlation| 0.730**       | 0.827**     |
|        | Sig. (2-tailed)    | 0.000         | 0.000       |
|        | N                  | 44            | 44          |
|        | Pearson Correlation| 0.875**       | 0.491**     |
|        | Sig. (2-tailed)    | 0.000         | 0.001       |
|        | N                  | 44            | 44          |
|        | Pearson Correlation| 0.437**       | 0.491**     |
|        | Sig. (2-tailed)    | 0.003         | 0.001       |
|        | N                  | 44            | 44          |

**, Correlation is significant at the 0.01 level (2-tailed). N = sample size.
mental issues (Benvenutti et al., 2019; Herrera et al., 2017; Orjuela-Castro et al., 2017). In this sense, SD has proved useful for transport policy design (Noto and Bianchi, 2015; Shepherd, 2014).

The present paper is organised as follows. Section 2 provides background information on the current environmental situation for three countries: Argentina, Brazil and Colombia. Moreover, a brief description of policy and practices is presented. Section 3 describes the modelling methodology and also offers a validation and mathematical model. Section 4 presents and analyses the modelling results in two dimensions – social and environmental. Finally, conclusions and policy implications are discussed in Section 5.

Background

Since the time when aviation started with the Wright brothers on 17 December 1903, aircraft and flight numbers have increased continuously year by year and never stopped, until in 2020 the SARS-CoV2 virus caused the COVID-19 pandemic. Although the aviation industry contributes to improving the means of transport, due to the pandemic the number of passengers carried was restricted and flights were limited, in order to maintain social distancing (De Vos, 2020). This situation has provided evidence that engines used by aeroplanes in the long term can cause negative effects, such as the increase in CO2 emissions that cause the temperature to rise: aeroplane engines emit gas that contains contaminants such as carbon dioxide (CO2), carbon monoxide (CO), nitrogen oxides (NOx), and nitric oxide (NO) (Hao et al., 2016; Lozano et al., 1968).

A typical aeroplane engine can generate 3.16 kg per 1 kg of jet fuel burned (ICAO, 2016). However, new alternatives, such as engines powered by biofuel or electricity, are expected to reduce CO2 emissions, although their release is not anticipated until 2030. According to Nair and Paulose (2014), by using biofuel it is possible to regulate CO2 and reduce it by 50%. Thus, if non-petroleum alternatives replaced jet fuel, the CO2 emissions would be reduced by 2050 (ICAO, 2016).

Argentina, Brazil and Colombia reported an increasing level of CO2 emissions between 1960 and 2013 (World Bank Group, 2014), and this paper explores these cases focusing on the aviation sector. The tendency for the future in each territory is directly proportional to their past CO2 emissions and air passenger numbers (Appendix A). In other words, Argentina had 15 m air passengers and 190,000 kilotons of CO2 in 2014. The projected values for Argentina by 2050 are 17 m air passengers and 270,000 kilotons of CO2. Brazil reported a proportionately larger number of air passengers and kilotons over the same years: 95 m and 504,000 respectively, and its projected values for 2050 are 138 m and 710,000. In the case of Colombia, with 32 m air passengers and 89,000 kilotons of CO2 in 2014, the country’s projected values for 2050 are 39 m and 114,000 respectively.

Ibarra Vega (2020) emphasises the importance of policy intervention such as lockdowns for mitigating the spread of coronavirus. Table 1 shows an indicator aim to measure government responses to the coronavirus, as proposed by Hale et al. (2020). These data provide evidence of the policy interventions in terms of the shutdown of air transport for each country. According to the data, Colombia shows better measures for international travel control than Brazil and Argentina.

Fig. 2. Stock and flow diagram to represent the interaction between COVID-19 pandemic and dimensions (Environmental and Social).
do. However, Argentina presents a better process in terms of restricting internal movement and closing public transport. These data are evidence of government control to mitigate the spread of the pandemic by imposing transport restrictions.

**Model simulation**

**Model assumptions and data**

The COVID-19 pandemic has increased exponentially, with nearly two million deaths so far around the world (World Health Organization, 2021). This situation has provoked the countries in the present case study to adopt the measures of locking down airports and restricting flights. For instance, both Colombia and Brazil started lockdown measures on 24 March, while Argentina began 3 weeks earlier, on 3 March. Appendix B shows the confirmed cases taken into account. From 26 February 2020 to 2 January 2021 Brazil registered 7,675,973 confirmed cases of COVID-19 with 194,949 deaths. Colombia, from 6 March 2020 to 2 January 2021, registered 1,642,775 confirmed cases with 43,213 deaths, while Argentina from 3 March 2020 to 2 January 2021, disclosed 1,625,514 confirmed cases with 43,245 deaths (World Health Organization, 2021).

From the behaviour of the confirmed cases, the total confirmed cases per 100 thousand people used in the simulation model is calculated. Fig. 1 shows the total confirmed COVID-19 cases per 100 thousand people – Brazil (3611 people), Argentina (3597 people) and Colombia (3229 people).

Air passenger numbers, CO2 levels and temperature were examined through a correlation analysis. The statistical analysis was computed by using SPSS Predictive Analytics to determine whether there is a relationship between each variable. To do this, the correlation matrix between all the variables in pairs was calculated.

Table 2 shows the Pearson correlation matrix of the variables – passenger numbers, CO2 levels and temperature – in the three countries analysed. The statistical analysis shows a symmetrical correlation matrix for each country. The values above and below the main diagonal are equal to one. Subsequently, the variables were selected, and the analysis of the three correlation coefficients was developed. Air passengers and CO2 emissions indicate a positive and robust correlation: 0.931 for Brazil, 0.875 for Colombia and 0.811 for Argentina. As air passenger numbers increase, so CO2 emissions increase in the same proportion yearly.

Consequently, the significant 2-tailed value of the correlation was 0.000 for all the countries, the null hypothesis was rejected, and the correlation between variables was assumed. The correlation between air passengers and CO2 emissions was significant at the 0.01 level. Air passengers and temperature have a positive Pearson correlation within all three variables, Brazil (0.730), Colombia (0.437) and Argentina (0.357). CO2 emissions and temperature show the correlation between all three variables as positive: Brazil (0.827), Colombia...
Fig. 4. Passengers carried scenarios for each country.
(0.491) and Argentina (0.400). Statistical estimates for temperature are substantially lower. This result reflects the fact that the estimators of autoregressive coefficients are biased towards zero. This bias increases when a variable (i.e., passengers carried) is included, and this makes the estimated value lower. However, previous studies show that the relationship between temperature and CO2 levels have a strong correlation (Kaufmann et al., 2006). In other words, there are results which show that a 1 °C rise in temperature increases the atmospheric concentration of CO2 by 1.5 ppm (MacIntyre, 1978).

The CO2 emissions and temperature are not something that can be managed and changed easily; they are exogenous variables. Meanwhile, ‘air passengers’ is an endogenous variable that can be handled by a policy (Sterman, 2000). A brief explanation of the model structure is presented below.

Model description

This paper simulates the behaviour of the CO2 emissions and temperature, considering whether the air passengers variable changes according to the passenger restrictions by COVID-19. The model simulation used a stock-and-flow diagram to represent the interaction between passengers and coronavirus, as illustrated in Fig. 2. Also, the stock-and-flow diagram represents on the one hand, climate variation – CO2 emissions and temperature – and on the other hand, the epidemic model proposed by Ford (2010).

The simulation model considers two dimensions: social and environmental. In this sense, the passengers can be considered as a social dimension (green line) and CO2 emissions and temperature as an environmental dimension (blue line). The model simulates lockdowns as a delay to regulate the number of passengers from the year 2020 to 2050.

The stock and flow diagram is composed of a system of differential equations, which is solved through a simulation structure. For instance, the carried passengers (Cp) and passenger rate (Pr), were calculated by Eqs. (1) and (2), respectively.

\[
\begin{align*}
Cp(t) &= Cp(t-1) + \int Pr(t) \, dt \\
Pr(t) &= \frac{D - Cp}{\varphi} \cdot FC 
\end{align*}
\]

Where,
\[\varphi = \text{lockdowns due to COVID-19 outbreak}\]
\[FC = \text{Fraction of contacts to susceptible person}\]
\[D = \text{Discrepancy}\]

The stock of atmosphere temperature is based on the interaction of experimental learning using historical data and CO2 in the atmosphere. The contribution within the model is the double loop between the carried passengers and CO2 emissions (Arlbjørn and Haug, 2010). This section was adapted from Fiddaman’s model for analysing the temperature, as illustrated in Fig. 4 (Fiddaman, 1997). The variables used to calculate the temperature of the atmosphere are: i) previous CO2 emission, ii) direct normal irradiance, and iii) the net radiative forcing. The direct normal irradiance (DNI) used in the model is 1177 kWh/m² per year (World Bank Group, 2019). The net radiative forcing (F) to CO2 is calculated from Eq. (3) (Byrne and Goldblatt, 2014).

\[
F = 5.32ln\left(\frac{C}{C_0}\right) + 0.39 \left[ln\left(\frac{C}{C_0}\right)\right]^2
\]

Where C represents the concentration of CO2, while C0 is equal to \(278 \times 10^{-6}\).

Temperature is a physical quantity that measures the warmth and coldness of the environment (Ford, 2010), and atmosphere temperature \((AT)\) depends on the net radiative forcing and the initial temperature, as illustrated in Eq. (4) (Byrne and Goldblatt, 2014).

\[
AT(t) = AT(t-1) + \int F(t) \, dt
\]

This section discusses the results obtained from the simulation model in two dimensions (social and environment) for three types of behaviour (passengers, CO2 emissions and temperature) in the countries selected. The results show two scenarios that represent the policy.
Fig. 5. CO₂ emissions scenarios for each country.
Fig. 6. Temperature scenarios for each country.
intervention aimed at passenger restrictions. The first scenario denotes conditions without passenger restrictions in the aviation sector, while the second presents the terms of lockdowns or passenger restrictions on the flight trips imposed due to the COVID-19 outbreak.

Social dimension

Fig. 4 shows the behaviour of air passengers for two scenarios: with and without the COVID-19 outbreak. The solid lines represent the historical data of the passengers carried, while the dotted lines are determined by the scenarios. The first scenario shows a rapid increase per air passenger from the 2020 to 2050 projections. The second scenario, from 2020, shows the stabilisation period until 2030 that is managed by controlling the number of passengers carried during the COVID-19 outbreak. After 2030, the graph shows a smooth tendency due to the new alternative fuels, influenced by the climate variation that is expected to be released by the aviation sector by that year.

A lesson learned from the COVID-19 outbreak is the need for an environmental policy to regulate the number of commercial flights per year to mitigate the percentage of the CO₂ emissions and temperature from the previous year according to results that will be presented in the following subsection.

Environmental dimensions

Fig. 5 shows the behaviour of the historical CO₂ emissions data from 1970 to 2013. The first scenario shows the increase according to the percentage rate of air passengers between 2020 and 2050. The second scenario shows a smooth tendency between 2020 and 2030, the period managed by controlling the number of passengers carried as a consequence of the COVID-19 pandemic. After 2030, the graph shows a smoother tendency due to the new alternative fuels used as a response to climate change.

The simulation of the temperature for the two scenarios is represented in Fig. 6. The data described in a solid line, and the dotted lines are the projection of the temperature for each country. The second scenario shows a decrease in comparison to the first one.

For 2021, the results of temperature behaviour include controlling the air passengers carried by aircraft and CO₂ emissions variations. The temperature behaviour for scenario 1 shows an increase of around 2.24 °Celsius compared to the actual temperature of Brazil. As a consequence of the rise in temperature, Brazil might not meet the terms of the Paris Agreement (UNFCCC, 2015) nor those of the Intergovernmental Panel on Climate Change (IPCC, 2006). Meanwhile, Argentina and Colombia might not meet the IPCC terms because of reaching 1.6 and 1.5° Celsius in 2050, respectively.

When the COVID-19 pandemic is incorporated into the model for scenario two within the environmental policy and practices dimension, such as social distancing or passenger restrictions, the temperature shows a better behaviour in the case of Argentina and Colombia. In the case of Brazil, there is a lower increase of 2.24 °C in temperature while Argentina and Colombia reached 1.44 and 1.35 °C by 2050, respectively. In all results, the temperature behaviour reaches a measure regarding the IPCC and the Paris Agreement of below 1.5 and 2.0 °C (UNFCCC, 2015), in comparison to the temperature reported without the COVID-19 pandemic.

Conclusion

To analyse what happened with the COVID-19 outbreak and its impact on air transport, it is essential to study the aftermath of this phenomenon, in terms of the social and environmental dimensions. Other studies have demonstrated that the exogenous variables can have adverse environmental effects (Fonseca et al., 2020; Ford, 2010; Little et al., 2019; Lo, 2014). With a pandemic situation, it is clear that policymakers have to include sustainability effects in the long term and minimise the impact by means of strategies for reducing people’s mobility, including through lockdown and social distancing. As mentioned, this paper contributes to the analysis of two dimensions – environmental and social – in the aviation sector for three countries in South America during the COVID-19 outbreak. However, other studies related to the spread of the virus are needed in order to understand better the sustainability effects in the long term.

During the COVID-19 outbreak, the impact on the social, economic and environmental aspects should be given the same priority so as to seek a balance between them. For instance, the pandemic brought a decrease in airline employment which in turn impacted the social and economic dimensions (Sobieralski, 2020). From the simulation, the results show that passenger restrictions between 2020 and 2021 – which is the estimated time of the pandemic – have contributed to the mitigation of CO₂ emissions. The reduction in these emission levels and in temperature helped to improve the air quality in the last quarter or so of 2020. Moreover, the challenges caused by the pandemic, but also the opportunities that have arisen, have contributed to new fuel alternatives being considered to reduce CO₂ emissions as part of dealing with the uncertainty after the COVID-19 pandemic.

In the transport sector, a strategy based on reducing mobility as a way to mitigate pollution is not easy, as it requires an integrated transport policy. In other words, the transport policy design should contemplate the equilibrium between social, environmental and economic dimensions. Thus it is necessary to take urgent action over air transport, based on a more robust transport policy, in order to counteract or mitigate climate variation.

Another lesson learned from the simulation model is that although the pandemic has affected international flights, it has also brought partial benefits to the environment. Furthermore, the model might help to assess resource allocation for linking passenger movements with environmental targets. For instance, policy makers may decide when to schedule new flights in association with environmental goals. These simple insights could help investors and policy-makers in their decision-making process and contribute to reducing emissions in the long term.

For this case study, the economic dimension has been excluded, due to the priority given to the environmental one; however, future works could include it. The case study may also help in the future to assess which measures should be adopted in developing countries to enable them to reach the targets of the IPCC and the Paris Agreement (IPPC, 2000; UNFCCC, 2015).

CRedit authorship contribution statement

Javier Calderon-Tellez: Conceptualization, Software, Validation, Formal analysis, Writing - original draft.
Milton M. Herrera: Conceptualization, Formal analysis, Writing - review & editing, Supervision.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.trip.2021.100351.

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