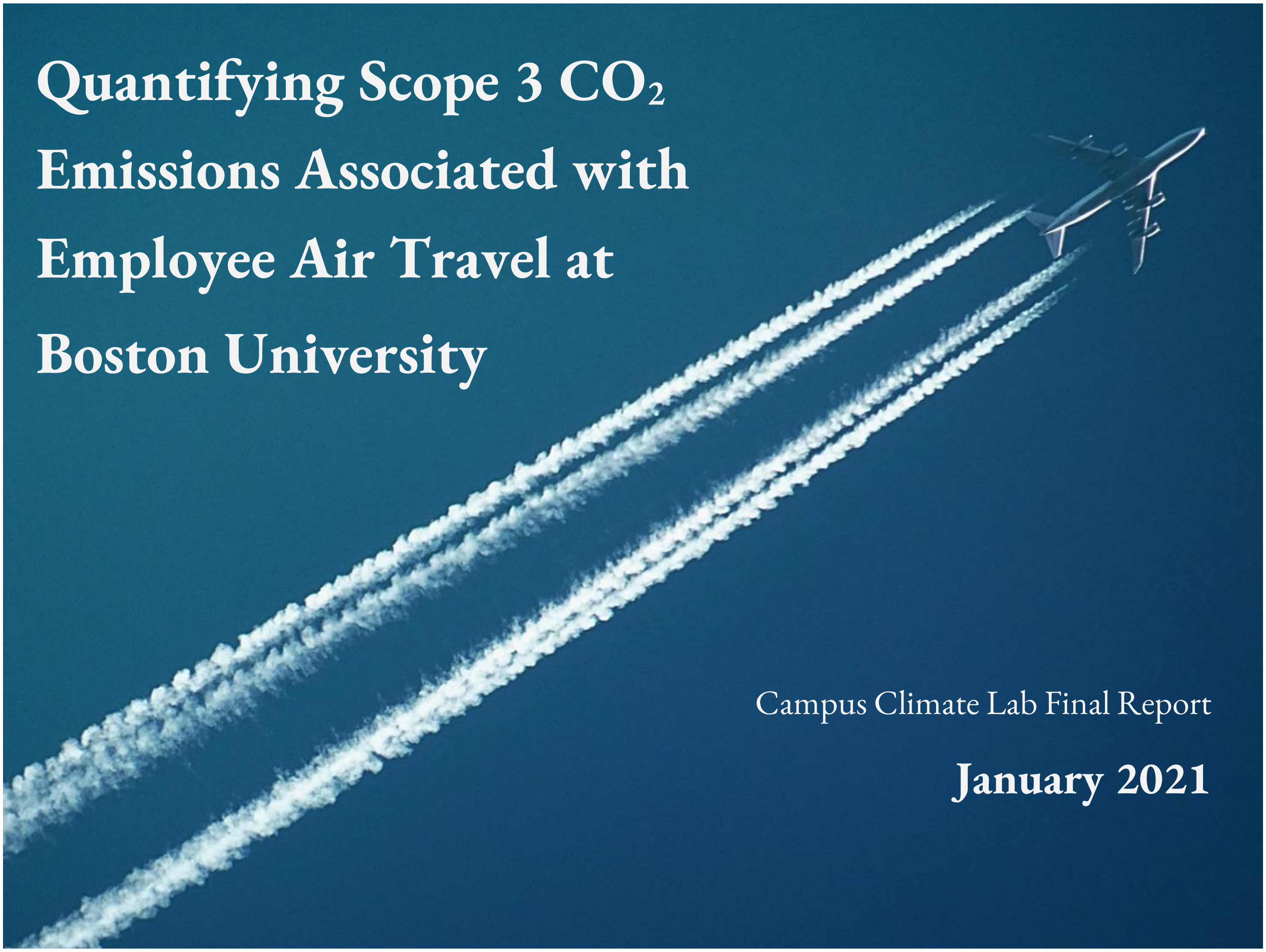

Quantifying Scope 3 CO_2 Emissions Associated with Employee Air Travel at Boston University

Campus Climate Lab Final Report

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Executive Summary

This research was conducted to gain an understanding of the Scope 3 CO_2 emissions associated with employee business travel at Boston University (BU), which could account for a significant portion of the University's total emissions that are currently estimated at about 329,400 MT CO_2e[1]. This work builds on previous research from the Transportation Working Group of Boston University's Climate Action Plan, which investigated flight records from 2015. We analyzed over 46,000 employee flight records from the University's booking platform in the period 2017 through 2020 and distributed a survey to explore the flight behavior of a sample of 118 staff and faculty at BU. Flight records were analyzed using statistical analysis in R and emissions were calculated using the ICAO carbon emissions calculator (ICEC). The survey results were analyzed using Qualtrics.

We found that the flights in our study period emitted a total of 2,368.54 MT CO_2, with an average distance flown of 1,245.44 miles. Both the number of flights and the emissions associated with these flights increased from 2017 to 2018 as well as from 2018 to 2019. More frequent trips to closer destinations had emissions comparable to less frequent trips to further destinations.

The survey results indicated that only about 33% of travel is logged through the University's booking platform, which suggests that our hard data represents just a part of overall employee flight emissions. As such, one of our recommendations is to mandate the use of the booking platform to enable accurate data collection related to travel, which in turn will enable accurate quantification of the carbon emissions from employees flying on behalf of the University.

Although travel habits have drastically changed due to the COVID-19 pandemic, resulting in 79% fewer carbon emissions from flights in 2020, the majority of surveyed employees stated that they expect to travel as much as in 2019 once travel restrictions are lifted. Moreover, survey participants indicated that on average 66% of their business air travel is necessary for their jobs, in that not flying would lead to adverse consequences for professional advancements such as lost networking opportunities, lowered performance reviews, decreased ability to keep up with changing industry standards, or fewer grants.

A portion of respondents also reported that seeing the emissions associated with a flight at the time of booking might change their behavior. These responses suggest that some air travel can be avoided through the alternatives that have been widely adopted since the start of the pandemic, but that attending many events in-person is still important. Therefore we also recommend increased promotion of alternate forms of travel (eg., bus, train, electric vehicle) for shorter-distance business trips, incentive programs for employees who decrease their flight frequency, and continued use of teleconferencing after the risks of the pandemic have passed.

Introduction

As part of its Climate Action Plan (CAP), Boston University (BU) has committed to the goal of reducing its greenhouse gas emissions to net-zero by 2040. Like the U.S. EPA and other institutions, BU classifies its greenhouse gas emissions into three broad categories: Scope 1 or direct emissions, including gas and oil burned on campus and fleet vehicle emissions; Scope 2 or indirect emissions, including those from purchasing steam and electricity; and Scope 3 or induced emissions, including emissions from travel by community members to and from campus, waste disposal, purchasing supplies, and dining services. In 2016, BU's Scope 1 and 2 emissions attributed to its fossil fuel use and electricity purchasing were approximately 129,400 $MTCO_2e$[1]. On the other hand, Scope 3 or induced emissions from transportation, purchasing, and waste disposal have not been formally counted but are estimated to be on the order of 200,000 $MTCO_2e$[1]. The Climate Action Plan Task Force recommended in their 2017 report a series of pilot studies to explore options for reducing these induced emissions, especially considering that they are estimated to be almost double the Scope 1 and 2 emissions combined.

Flights in particular can account for a large proportion of a university's Scope 3 emissions. For example, the University of British Columbia estimates that the carbon impact of university-related air travel (including student travel) represented about 2/3 of the annual impact from operating its main campus and was almost as high as annual heating emissions[2]. As a hypothetical but no less real example, if 20,000 higher education institutions around the globe (of which there are more than 30,000 total) each have 250 active research staff who fly a few times annually to conferences, meetings, and field work, the total impact would be 7 million tons of carbon per year - almost 0.1% of global fossil-fuel consumption which is 10 billion tons of carbon per year[3]. As a globally recognized and active research University, BU could have a very high impact from employee travel alone. As daunting as this prospect is, there is hope in quantifying these emissions and then developing concrete measures to reduce them, which is the goal of this research.

Until now, John Helveston's work in 2015 with the BU CAP Transportation Working Group represented the best estimates of Boston University's flight-related emissions. His initial estimates had not been refined in large part due to the difficulties associated with collecting the data needed to calculate the emissions from flights taken by BU employees on behalf of the University. BU faculty and staff have the option to book travel through the SAP Concur platform[1], which directly provides the University with crucial flight information such as departure location, destination, travel date, and distance traveled. However, the Transportation Working Group estimated that only about 55% of employee aviation trips are booked through Concur[5]. This is because staff are also able to purchase work-related flights through third-party platforms such as Expedia and later be reimbursed through Concur. The reimbursement process currently does not provide enough information about the flight to estimate the resulting emissions.

As such, the primary aim of this research is to further quantify the emissions associated with Boston University employee air travel and to more accurately determine how much travel is accounted for in Concur. Other questions explored include: determining what historical travel data already exist and how complete they are; determining and quantifying the attitudes, flight behaviors, and forecasts for post-pandemic air travel of a subset of BU's employees; and identifying the challenges and solutions to reducing the emissions associated with employee air travel. We hope that with a more precise measurement of these emissions, BU can better understand how to reduce them and get closer to reaching the CAP goals, specifically the aim of net-zero emissions by 2040.

1 https://www.concur.com/en-us/travel-booking

Methodology

Data Collection

We included a survey in our analysis to contextualize the flight records we received from the Concur platform and to gain a better understanding of what drives employee flight behavior. Our questions ranged from *"What percentage of flights do you book through Concur?"* to *"What factors influence your choice of travelling by plane, car, bus, or train?"* with 15 questions in total. To see a full list of survey questions, see Appendix A.

The survey data was collected and analyzed using the program Qualtrics. The questionnaire was distributed via email among an existing list of faculty and staff who have used Concur for travel. This list was provided to us by Emma Bonanomi, Director of Communications at Boston University Office of Research, with connections to the Director of Travel Services at BU. The survey was open for two weeks, after which time we began to analyze the resulting data. In total 118 BU employees completed the survey, 48 of whom were staff members and 69 of whom were faculty members, and one postdoctoral researcher.

The flight data contained Concur logs of flights booked through the years 2017 to 2020, which included fields such as booking date, flight date, departure airport and location, distance travelled, arrival airport and location, and ticket ID number. These data were provided by Ian Poole, the Manager of S&P Systems and Analytics at BU's Sourcing & Procurement department. The data were in .xls format, which we then converted to .csv for working in R and Python, as detailed below. The dataset started with 46,768 rows, where each row represents one direct flight.

Data Cleaning

All code for this project can be found in our GitHub repository, including the Python data pipeline. Initial cleaning included removing rows with values of 0 or None in the Distance (miles) column, values of None in the Ticket ID column, and those rows in which the departure and arrival airports were the same. Additionally, two rows were blank or had values of -1 for almost every field except for the departure airport. After the initial cleaning, our dataset had 46,319 rows. Several more rows had to be removed after calculating the emissions associated with each trip, as detailed below.

Calculations

The Concur dataset does not contain information about the greenhouse gas emissions associated with the flights. To get these numbers, we turned to the International Civil Aviation Organization (ICAO)'s Carbon Emissions Calculator (ICEC)[6]. According to the ICAO, this tool "applies the best publicly available industry data to account for various factors such as aircraft types, route-specific data, passenger load factors, and cargo carried"[7]. Specifically, the calculator takes as input several fields (including trip type, departure and arrival airport codes, ticket class, and the number of passengers accounted for) and outputs the associated carbon emissions in kg CO_2 for the entire flight and on a per-passenger basis. The underlying assumptions and calculations involved in this method are described in detail in the ICAO Carbon Emissions Calculator Methodology report.[8]

While inputting the trips into the ICEC, we discovered that several of our data points were invalid. The calculator raised an error in the browser stating that it couldn't find a trip connecting the two airport codes because a direct flight on that route did not exist. We skipped and later removed these rows, since adding another leg to the journey and arbitrarily choosing a connecting airport would have changed the emissions for that trip and introduced unknown errors. Ultimately, we ended the calculation phase with 46,140 rows with emissions data after skipping 179 rows.

To keep our results consistent with the CAP report and the Transportation Working Group's work, we converted the emissions values from the ICEC for each trip in our data from kg CO_2 (kilograms of carbon dioxide) to MT CO_2 (metric tons of carbon dioxide).

For a more detailed account of the coding process involved in this project, please refer to Appendix B and our GitHub repository.

Results & Analysis

Survey Results & Analysis

There were 118 complete survey responses from BU employees, 48 of whom were staff members and 69 of whom were faculty members, and with one postdoctoral researcher.

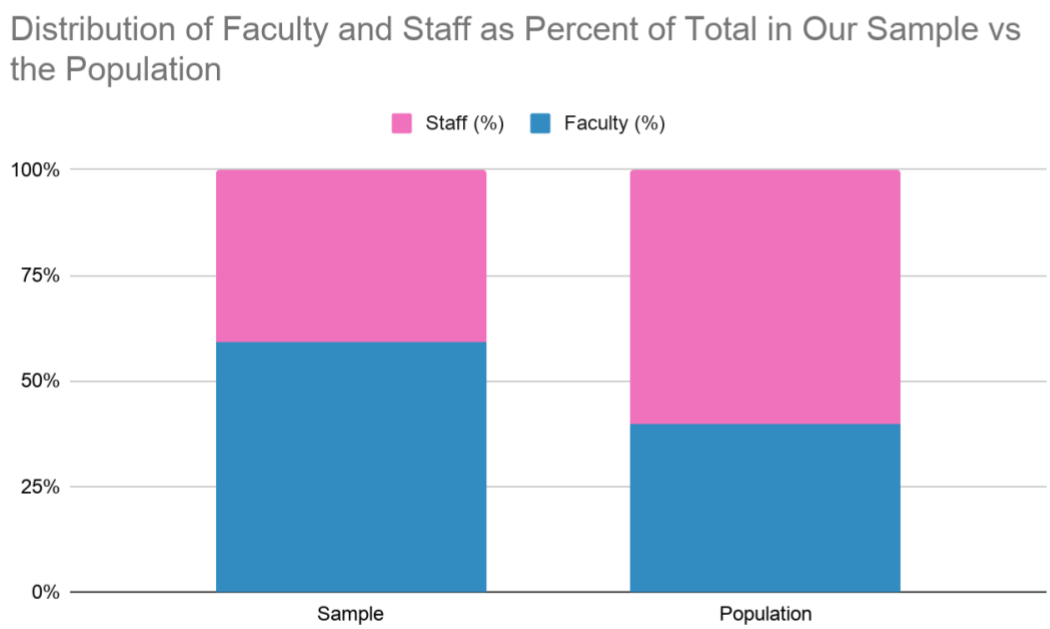

Figure 1: comparing faculty and staff distributions in our sample vs the Boston University employee population. Note that the ratio between the groups is almost flipped in our sample vs the population.

Inaccuracies in this analysis will primarily stem from the relatively small sample size and participant bias. We were not able to randomly select individuals in every department at the University. Instead, we were provided with a list of 1,819 employees to whom to distribute the survey by the Office of Research, which keeps records of employees that travel on behalf of BU. These employees represent Concur users that were on record as having used Concur to book their air travel on or before 1/1/2020.

It is impossible to assess exactly what biases this employee selection process could introduce to our data, although we can make some observations as follows: Only one participant reported no air travel at all, despite that likely being not uncommon in the BU employee population. Further, the majority of participants were faculty, whereas BU has many more staff members than faculty members (see Figure 1). Finally, not every department at the University was represented in our sample, and there was a significant proportion of employees from one department over others (e.g., a large number of responses from the College of Arts and Sciences, Earth and Environment).

Which subset of the employees responded to our survey email may have been influenced by the likelihood that a given individual would check their email regularly, and that our message had not been sent to spam or junk; that the individual would be interested in the incentive we offered; and that they would have the time and desire to take the survey to begin with. Therefore this sample is neither random nor uniformly distributed. Despite this, we believe that the survey provides useful insights into employee booking and travel behavior, which we report on below.

Booking Behavior

On average, the employees in our sample self-reported that only 33% of their flights are booked through the Concur platform, versus through personal payment and reimbursement; the standard deviation being 41%. This is a significant change from the results published by the CAP's Transportation Working Group, which found that 55% of sample employees' flights were recorded in Concur. We believe that this is at least partially a result of the difference in sample size; we surveyed 118 employees, while the Transportation Working Group surveyed only 15.

The main reasons that employees selected for booking air travel outside of Concur were: Ease, followed by Availability (referring to availability of accommodations) and Cost (Figure 2). 8.5% of the open-answer responses to this question included comments about wanting to earn frequent flyer miles or rewards points through a third-party booking service and the users' own credit cards, as well as having greater control over seat arrangements and service quality.

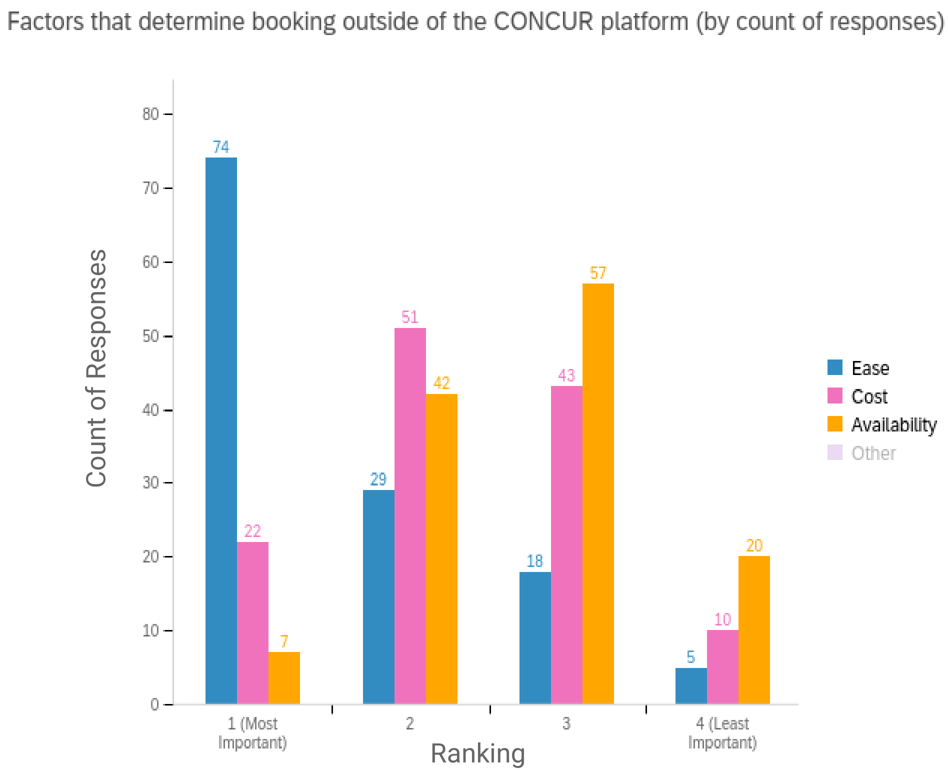

Figure 2: survey results on factors that determine booking outside of the Concur platform.

Interestingly, there were more numerical ratings in the Ease category than in any other, and more responses of "Don't know" or "Don't use" in the other categories. This result, coupled with the relatively low ratings for Ease by both staff and faculty, may suggest that some employees in our sample were turned off from using Concur after initially trying to book travel through the platform and finding it difficult to use. We believe this may partially explain why Ease was the most-selected reason for booking with a third-party service.

When asked to rate the Concur platform in the same categories (Ease, Cost, and Availability), faculty were more critical in all areas than staff. The mean is about 5 in every category across faculty and staff (Figure 3).

Figure 3: survey results on mean ease, cost, and availability ratings by employee type.

When asked if seeing the greenhouse gas emissions produced by their flight when they are booking travel would influence their travel choices, 41% of respondents said yes (see Figure 4).

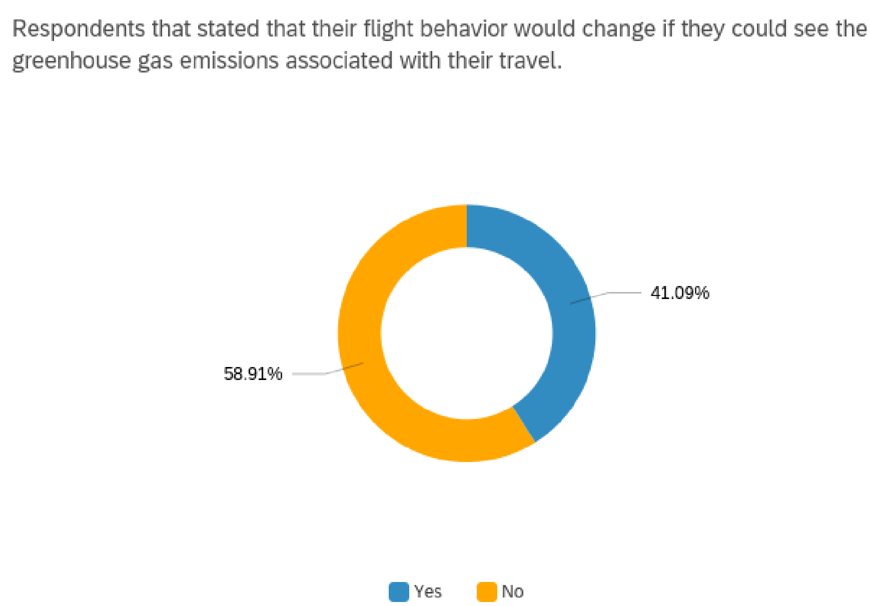

Figure 4: pie chart of responses indicating yes or no, whether seeing the greenhouse gas emissions at the time of booking a flight would change behavior

Travel Behavior

When asked which events were important to attend in person, the most frequent response was large conferences, followed by research-related site visits, small meetings, and one-on-one collaborator meetings (Figure 5).

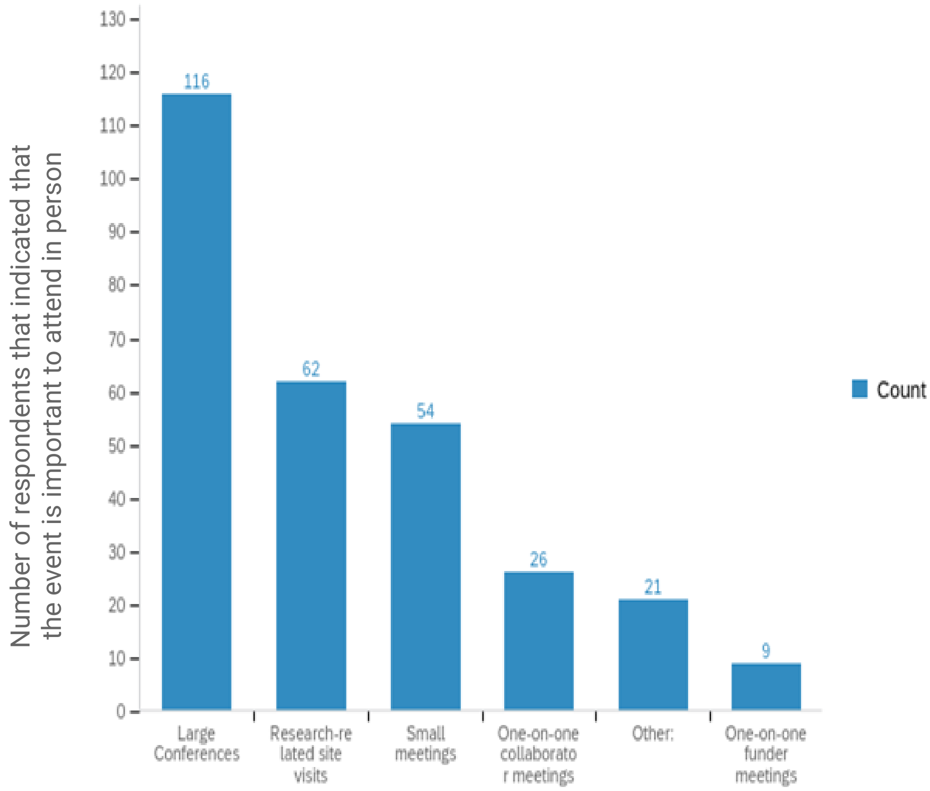

Figure 5: survey results on which events were important to attend in person

On average, our employees thought that 66% of their professional air travel was necessary for their job, but the responses ranged from 0% to 100%. Faculty reported more necessary travel, at about 70% on average, while staff reported less, at 62% on average. On average, employees reported that 73% of their flights are domestic, 27% are international, and that 64% were direct and 36% were indirect. When asked what factors influence an employee's choice for mode of travel (plane, car, bus, train), our survey respondents said that distance was the most important factor, followed by time spent travelling (Figure 6).

Despite the changes that have been made since early 2020 and the start of the COVID-19 pandemic, including transitions to remote and semi-remote events, meetings, and conferences, the majority of our respondents said that they expect to fly as much as before COVID-19 once travel is deemed safe again. This may suggest that there is a quality inherent to in-person communication that is not effectively replicated online, or that perhaps flight habits are more ingrained than we initially expected. In any case, as disruptive as the global crisis has been, it was not sufficient to disrupt our sample travellers' expectations of future travel behavior.

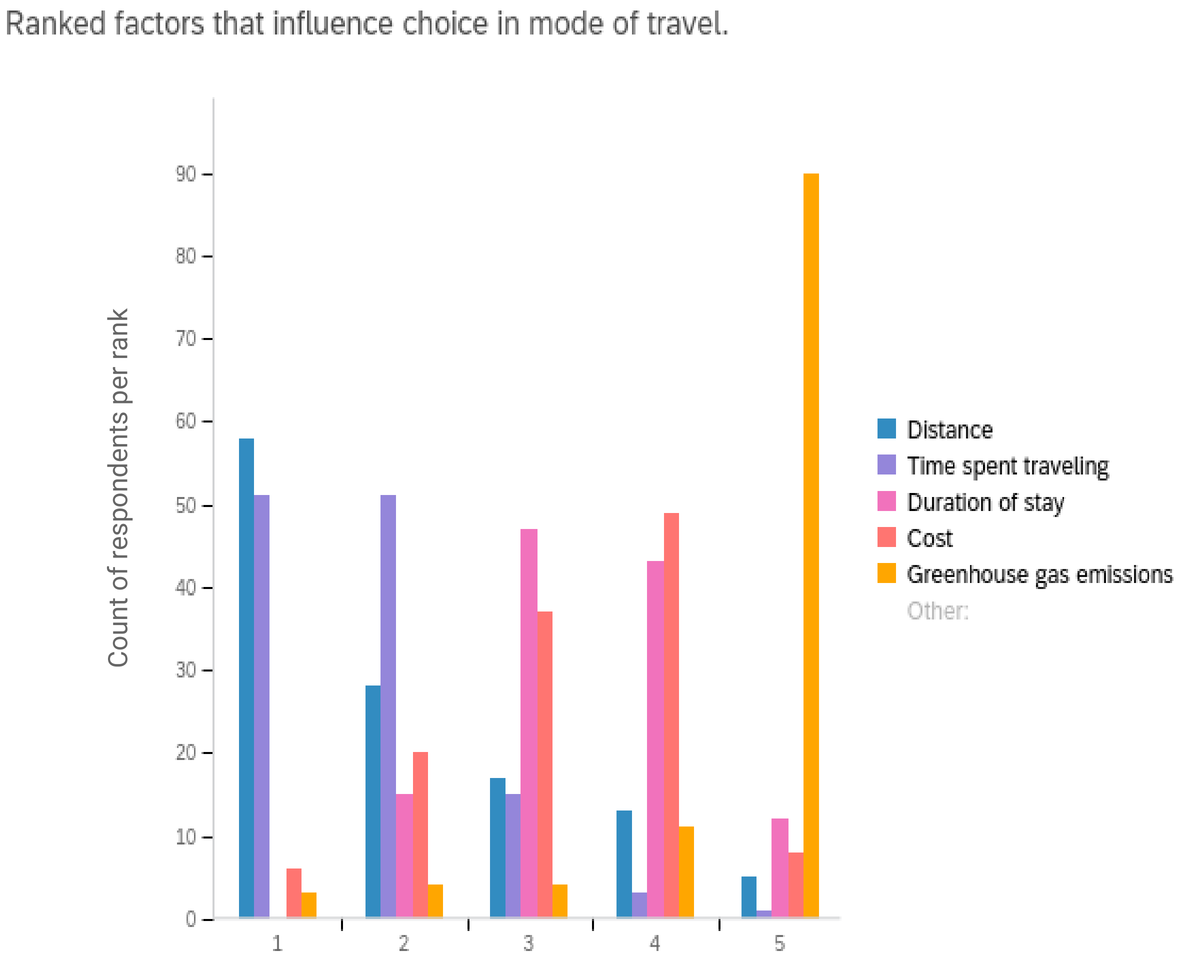

Figure 6: ranking of factors that influence participants' choice in mode of travel, on a scale of 1 (most influential factor) to 5 (least influential factor)

Emissions Data Results & Analysis

Our analysis of flight data from the Concur platform found that the most common domestic destinations from Boston were Washington D.C., New York City, Chicago, and Philadelphia (Figure 7). These cities are all within a 6-hour plane trip from Boston (the longest trip, to Chicago, would take 3 hours on a direct flight and about 4.5 hours on a connecting flight), which qualifies trips to these destinations as short-haul flights[9]. The most common international destinations from Boston were: Toronto, CA;

London, GB; Amsterdam, NL; Montreal CA; and Paris, FR (Figure 8). Two of these, Toronto and Montreal, are within North America and the rest fall in Europe.

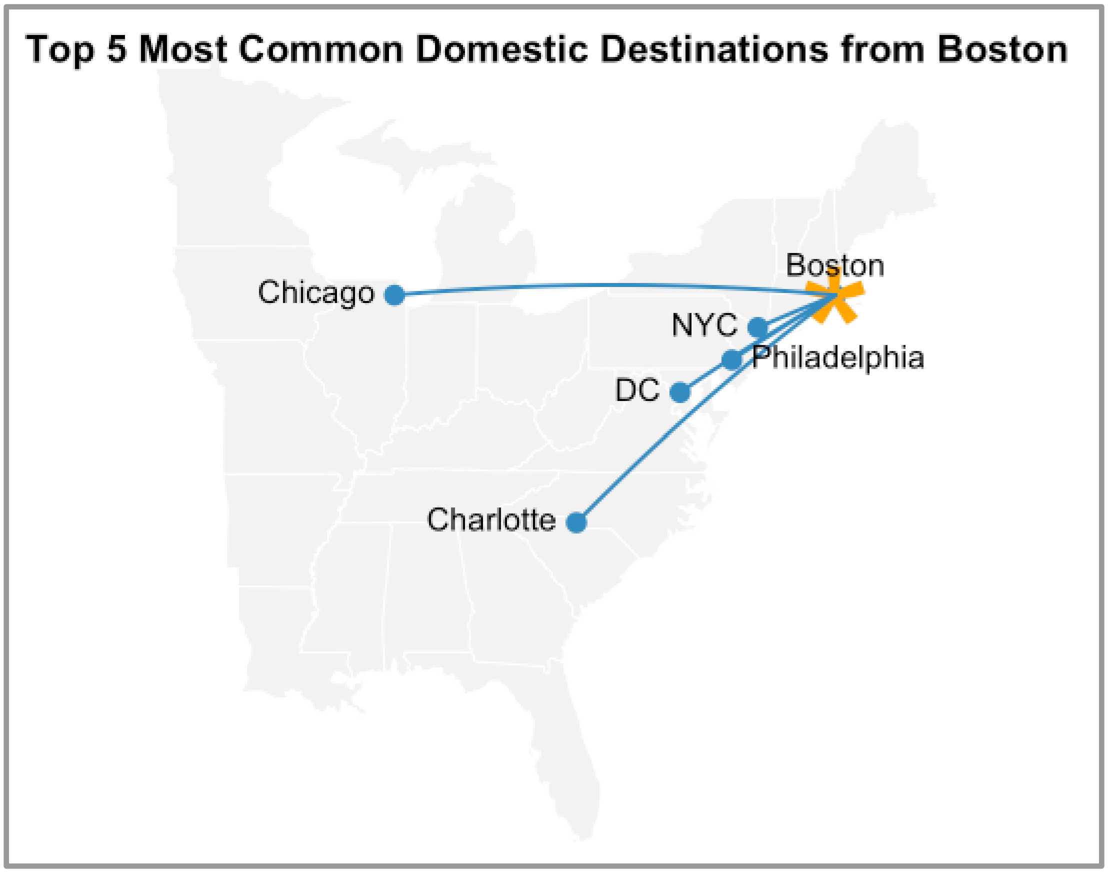

Figure 7: map of the top 5 domestic destinations from Boston.

Figure 8: map of the top 5 international destinations from Boston

In the data reported through Concur, only 20% of flights were international, compared to the 27% that employees self-reported in our survey. This inconsistency could be attributed to the gap in reporting on Concur, especially if a traveler is more likely to earn rewards or miles on an international flight, prompting them to book through an external service.

From data reported in Concur, including the first three months of 2020, there were a total of 46,533 flights, emitting a total of 8,140.86 MT CO_2. The mean distance flown was 1,258.03 miles, and on average each flight emitted 0.18 MT CO_2 (or 176 kg CO_2), with a standard deviation of 0.14 MT CO_2 (or 140 kg CO_2).

As expected, CO_2 emissions during 2020 were much lower than previous years. However, the percent change from 2019 to 2020 was less than expected (just 79%), given that the University suspended all travel in March, just three months into the year. From the flights reported in these early months of 2020, we estimated how many flights and resulting emissions would have occurred had the year been business as usual. Because we had data from January through March, we extrapolated these numbers from the first quarter of the year to an annualized estimate of the entire twelve months (Table 1).

Stats for 2020 Concur Data

	Calculation
Mean Distance Traveled (miles)	1139.62
Total Emissions (MT CO2)	579.73
Total Flights (count)	3598.00
Estimation of 2020 Emissions based on 3-month Data	2318.91

Table 1: the estimate of 2020 emissions in the bottom row is an annualized emissions estimate, based on the 3 months of reported data.

From our Concur data, we were able to see that total CO_2 emissions increased slightly from 2017 to 2018, then more dramatically from 2018 to 2019 (Figure 9). Our estimation of emissions for 2020 indicates that emissions in 2020 might have returned to a level that is more similar to 2017 and 2018 totals.

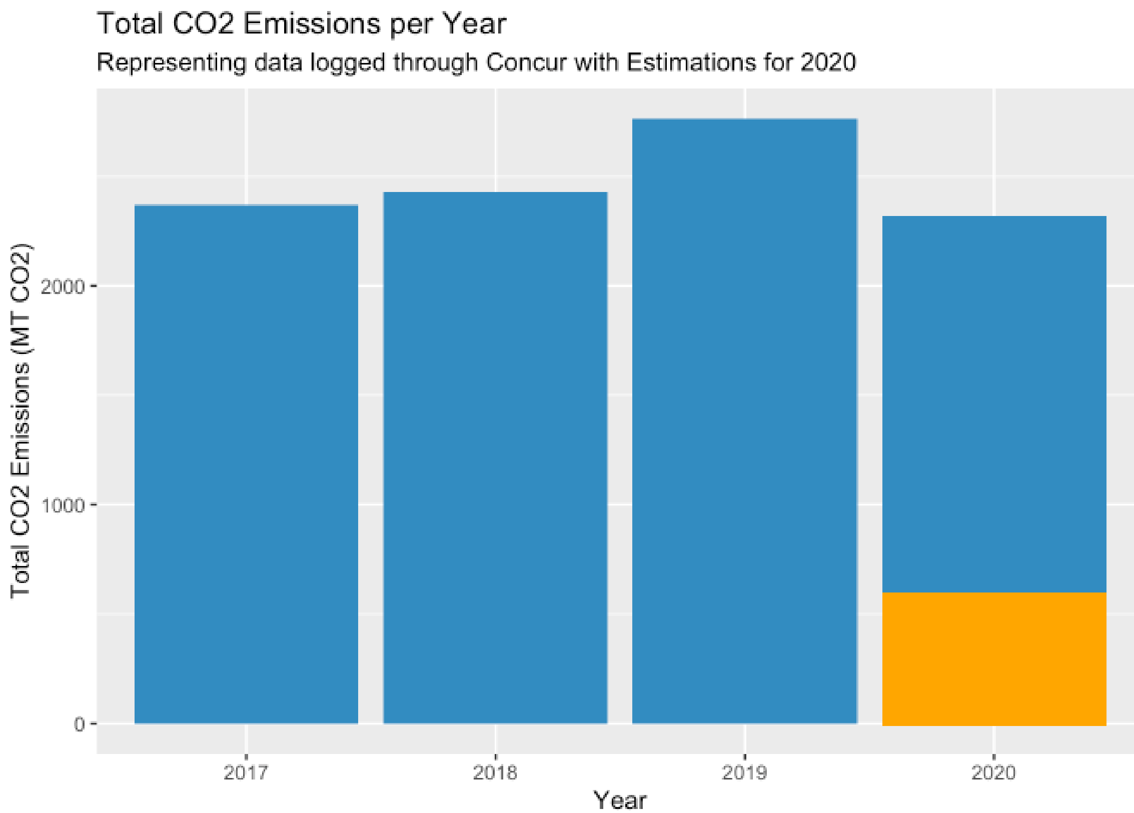

Figure 9: total CO_2 emissions per year, according to calculations from Concur data. Note that the orange bar in 2020 is the emissions from flights recorded in Concur, and the full blue bar is our estimate of a yearly total had it not been for the pandemic.

Interestingly, the two most-traveled months in 2017-2019 were March and October, with smaller peaks in April and September (Figure 10). The drop in business travel in January and December coincides with the American holiday season and Boston University intersession, which is typically the period of December 22 to January 22. Flights also dropped off during the summer season, particularly in May, July, and August.

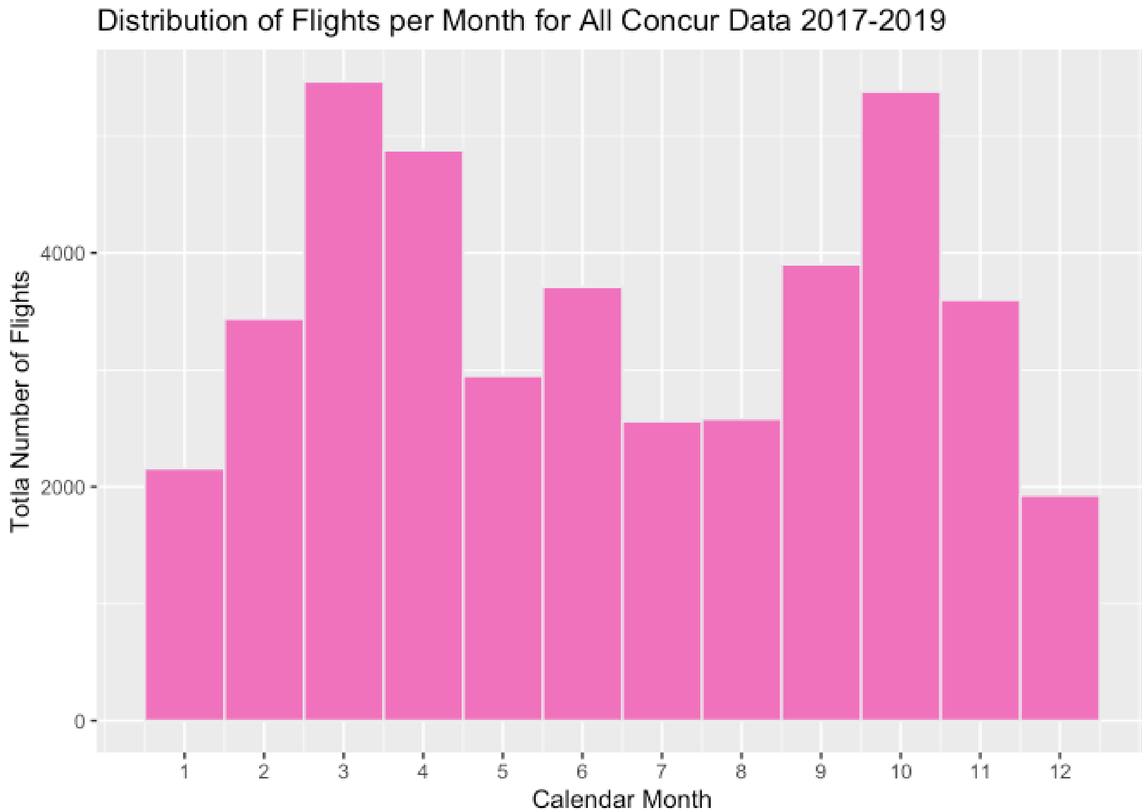

Figure 10: the sum of flights per month over the recorded period

In addition to analyzing travel behavior and emissions by year and month, we explored emissions associated with some international destinations. The majority of the 10 most-frequently visited countries from Boston in 2017 through 2019 were in Europe, but also included Canada (pink bubble at the top left), China (yellow bubble in the bottom middle-left), Turkey (pink bubble in the lower right), and Puerto Rico (blue speck in the lower left). Although Canada was visited much more frequently, its share of emissions is comparable to those from flights to China. This makes intuitive sense, since Canada is much closer to Boston than China, and greater distance travelled generally means more fuel burned by a plane. We also noted that emissions from flights to Germany (green bubble in the bottom-middle) and the United Kingdom (pink bubble in the bottom middle-left) were greater than those from flights to other countries, including China and Canada, despite lying roughly in the middle distance-wise. In some cases, premium tickets are more likely to be purchased for trips to Europe than China or Canada, since the middle distance makes the extra seat space and accommodations attractive but also not unattainably expensive. This was true for the United Kingdom, for which there were more than twice as many premium flights than China; Germany had just a few more.

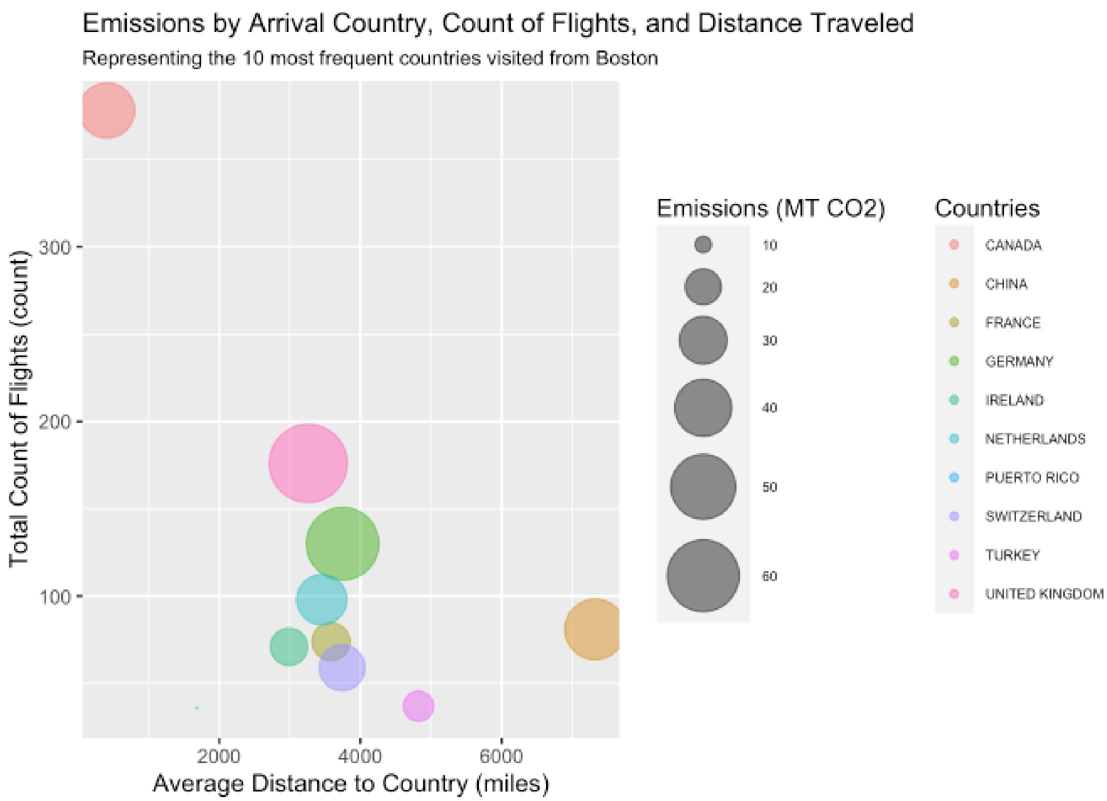

Figure 11: bubble plot exploring the relationship between the emissions associated with flights to the top 10 international arrival countries, the average distance of the flight, and the total number of flights to each country. The sizes of each country's emissions bubble are proportional to the total emissions with all flights to that country from 2017-2020.

Please see Appendix C for additional emissions summary tables.

Emissions Estimates

Since the survey results indicated that there may be many flights which are not booked through Concur, we attempted to estimate what proportion of employee Scope 3 flight emissions we have represented in our research (Table 2). 2020 emissions were projected using an annualized estimate, based on 3 months of recorded data before travel was suspended in March. As stated before, these estimates will come with a large caveat, that the survey sample was not randomly or uniformly distributed. In the best case, the flights reported through Concur account for all employee travel in 2017 through 2020. Then, assuming that the ICEC gave accurate emissions values for each flight in this period, the total emissions from employee air travel was 9,880 MT CO_2. We assume that in the worst case, Concur records account for only 33% of all employee flights as reported in our survey, and the estimated total is 29,940 MT CO_2 (see Figure 12 for a visual comparison).

Emissions Estimations (MT CO2)

Year	Best-Case Estimate	Worst-Case Estimate
2017	2369	7177
2018	2429	7360
2019	2764	8376
2020	2319	7027
Total 2017-2020	9880	29940

Table 2: best- and worst-case estimates of emissions from 2017 through 2020, and the period total 2017-2020 CO_2 emissions.

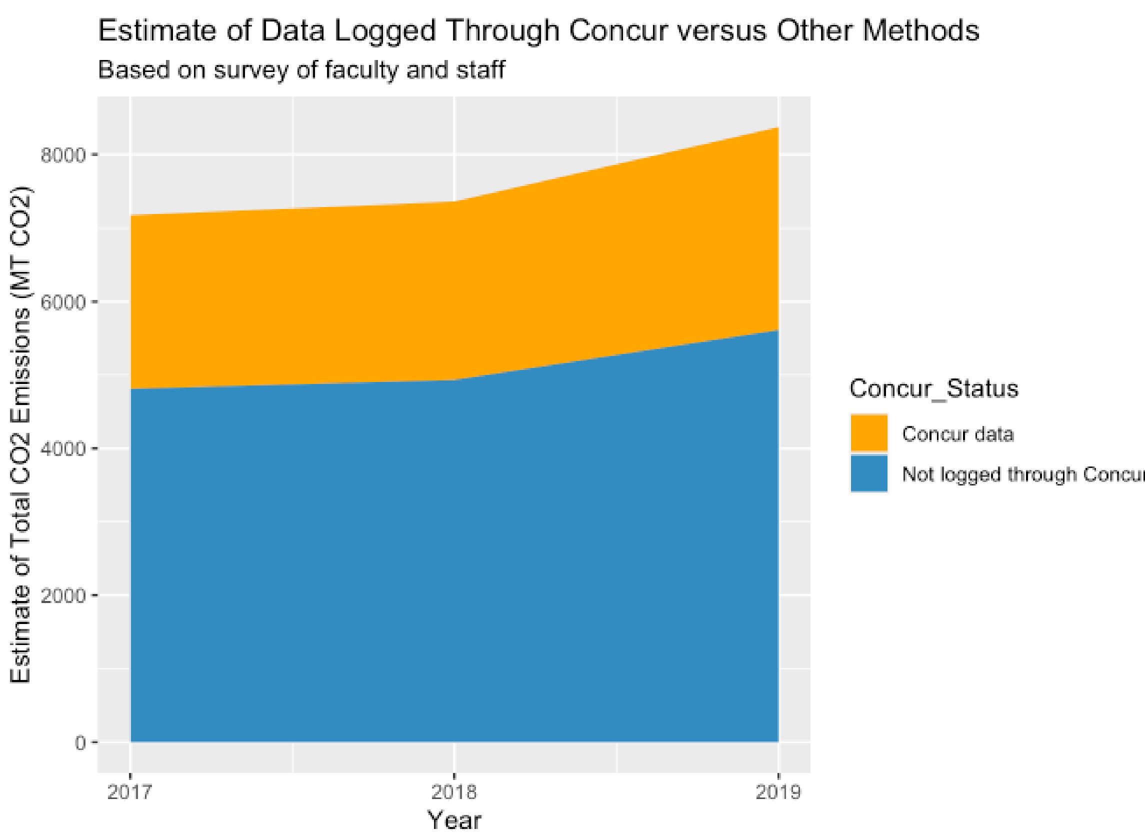

Figure 12: an estimate of emissions from trips not accounted for in Concur.

Discussion

As this work builds off previous research by the Transportation Working Group of Boston University's Climate Action Plan, it is important to note the differences in our findings and how our results compare to this previous analysis. From their 2017 Report, the group estimated the total emissions from 2015 to be 4,000 MT CO_2, with uncertainty bounds of 3,000 - 6,000 MT CO_2[5]. This is fairly similar to our emissions estimates, with our calculations having a wider range between best- and worst-case scenarios. This variability reveals the disparities and inconsistencies with calculating emissions from air travel and with Scope 3 emissions on the whole. These differences in results are also likely influenced by the surveyed faculty and staff in 2015 claiming that they use Concur for 55% of their travel bookings, whereas our survey results showed staff and faculty using Concur for only 33% of their travel bookings.

It is clear nevertheless that emissions associated with flights for University business or study can be a significant contributor to the total greenhouse gas impact of an institution. The University of California, Santa Barbara's estimate, for example, amounts to about one third, "equal to the total annual carbon footprint of a city of 27,500 people in the Philippines". Note that this is more than the individual impact of UCSB's undergraduate, graduate, and faculty populations combined and that many climate scientists recommend that planetary greenhouse gas (GHG) emissions be not much more than the current per capita level of the Philippines, or 1.3 MT CO_2/person/year[10].

The Paris Agreement of 2015 outlined the global commitment necessary to limit the warming of the planet to within 2°C, ideally 1.5°C, to minimize the catastrophic impacts of climate change[11]. In developed countries, such a commitment requires "a reduction of emissions of between 80-95% from the 1990 baseline"[12]. Despite this, emissions from international aviation, an industry overwhelmingly associated with the same developed economies, have increased by 53% between 1990 and 2011. Frequent flyers contribute to the majority of these emissions: 12% of Americans are responsible for two-thirds of all air travel by Americans; 53% take no flights in a given year[13]. It is estimated that fewer than 5 percent of the people of the world have ever boarded an airplane[14], but it is the 95 percent—overwhelmingly vulnerable people of the Global South—who are paying the increasingly steep toll for the jet-setting behavior of affluent consumers, "conferencegoing academics included"[15]. Academic researchers are among the highest emitters as a result of annual trips to conferences, project meetings, and fieldwork.

Some airlines have made promises to reduce their emissions, for example by becoming carbon neutral through offset purchasing[16] or incorporating sustainable aviation fuel (SAF)[17], but significant challenges remain. "Strong policy support…is needed to shift from petroleum-based fuels to sustainable, low-carbon alternatives in the mid-century time frame"[18]. There is a need for government action in the form of mandates, fiscal incentives, and grant programs, as well as direct support for supply chains in the near future. Unfortunately, federal policies have largely included SAF as an add-on to existing policies that are meant primarily to address ground transportation - not flights[19]. For now, the most effective way to address air travel emissions is by not flying. Carbon neutrality commitments by those few sustainably-minded airlines are unlikely to be complete before mid-century, and policy change on SAF is a tumultuous and slow process complicated by special interests.

Besides the climate change mitigation benefits, there are other reasons for academia to investigate alternatives to flying for business and research. The cost of airfare from anywhere in the developing world to anywhere in North America or Europe is often greater than the per capita annual income in these countries. Consequently, scholars from most of the world's countries, and nearly the entire Global South, have long been quietly excluded from international conferences. Even in wealthy countries like the U.S., conference participation is a privilege unequally shared[20]. This is not only limiting for those excluded, but for all of the academic world which has missed out on the opportunity to meet a broad swathe of scholars unable to attend such conferences, meetings, and other collaborations. As Hiltner writes, "Wouldn't it be far better if proximity and time zones were not an issue and we could interact with scholars the world over with interests that intersected with ours?"

The recent IPCC reports have shown that we have very little time left to forge a livable tomorrow, with only a 5% chance of keeping global temperatures from rising above 2°C and just a one-in-a-hundred chance of meeting 1.5°C. "At the moment, academia is, on balance, part of the carbon problem rather than the solution. But it doesn't have to be this way"[21].

Conclusions and Recommendations

General Conclusions

Our data show that the flights in our study period emitted a total of 2,368.54 MT CO_2, with an average distance flown of 1,245.44 miles. The survey results also indicated that only about 33% of travel is logged through the Concur platform, which suggests that the totals we have calculated may only be a fraction of overall employee flight emissions.

We found that a large distance travelled was associated with a comparable amount of emissions on average than a large number of flights, in that flights to farther, less-often visited countries accounted for a similar percentage of overall emissions than flights to closer, more-often visited countries. The most common domestic destinations from Boston in our dataset included shorter-distance trips, such as from Boston to New York City, for which there are other less-emitting forms of travel available.

On a single-year basis, both the number of flights and the emissions associated with these flights increased from 2017 to 2018 as well as from 2018 to 2019. We were surprised to learn that emissions in 2019 were significantly greater than in 2018 (14% change), as was the number of flights recorded (15% change). One possible reason for this is the fluctuating landscape of federal research funding at the time. Federal funding for BU in the 2019 fiscal year (July 1st, 2018 through June 30th, 2019) increased by 14% from 2018 fiscal year values.

Although travel habits have drastically changed due to the COVID-19 pandemic, resulting in 79% fewer carbon emissions in 2020, the majority of our surveyed faculty and staff stated that they would return to traveling as much as in 2019 once travel restrictions are lifted. With the onset of the COVID-19 pandemic, many systems have been altered to accommodate our new way of life. This is a pivotal time in which we should take the opportunity to make systematic changes in how we approach mitigating climate change, including reevaluating the need for frequent business travel. As travel restrictions are lifted, we should strive to avoid simply returning to business as usual for air travel and instead encourage the pursuit of new strategies that have been established during the COVID-19 pandemic.

Recommendations

We recommend that Boston University mandate more consistent travel logging through the Concur platform. One benefit to employees for purchasing travel outside of the Concur platform is the ability to earn credit card points when using their personal cards for booking travel. Concur currently has a feature to add frequent flyer miles rewards to a trip booked through the service, which employees should be made aware of and trained to use. This could reduce the frequency of trips that are booked through a third party to accrue points, and increase the amount of reliable flight data available to researchers and decision-makers. More consistent travel logging and data collection will in turn allow the University to more accurately calculate its Scope 3 emissions associated with employee air travel. 41% of respondents also reported that seeing the emissions associated with a flight at the time of booking might change their behavior, which is encouraging for considering programs aimed at reducing these emissions. This could be another adaptation to the Concur platform that may assist in decreasing air travel.

We recommend increased promotion of alternate forms of travel (eg., bus, train, car) for shorter-distance business trips and incentive programs for employees who decrease their flight frequency. There is evidence that advertising and improving the ease of using alternative forms of transportation for short-distance travel could assist in decreasing frequent flyers' air travel and the associated emissions[21]. BU can use these results to inform behavior change programs for employees. From our data, all of the most frequent domestic flights are short-haul trips, with destinations to which there are many alternate forms of travel such as Amtrak trains that would have significantly fewer associated emissions. This pattern plays out nationally as well: the ICCT reports that flights departing from airports in the United States and its territories emitted about one-quarter (24%) of global passenger transport-related CO_2. Two-thirds of these emissions came from domestic flights, and flights in the U.S. to destinations within a short distance, 500km (or about 311 miles), accounted for 5% of the global CO_2 total - nearly twice as many emissions per passenger as longer flights[22]. Two out of the five most frequent international destinations for BU employees, Montreal and Toronto, are also accessible by Greyhound. By increasing awareness and rewarding the use of alternate forms of travel, employees will be able to make more informed and emissions-conscious travel choices.

We also encourage the use of teleconferencing, especially with the recent innovations in online communication due to COVID-19. Survey participants indicated that on average 66% of their business air travel is necessary for their jobs, in that not flying would lead to adverse consequences. It will require a major culture shift to reduce the perception of necessity around business travel, but in light of the COVID-19 pandemic and the widespread use of telecommunications, it may be possible to maintain systemic change. Incentive programs for employees who decrease their flight frequency may also encourage this change.

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Appendix A: Survey Questions

Demographics:

1. Which category best classifies your position at Boston University?
    i. faculty member
    ii. staff member
    iii. Other: ___________
2. What department is your primary appointment associated with?
    i. _____________

Booking Flights:

1. Approximately what percentage of your flights do you book through CONCUR versus through personal payment (ie with your own funds) and reimbursement/other pathways?
    i. _____ %

    b. If you do book travel accommodations outside of CONCUR, what is your main reason for doing so? Rank the following choices:
        i. Ease
        ii. Cost
        iii. Availability
        iv. Other: _________
2. How would you rate the functionality of CONCUR?
    i. Ease of use: ___/10 (1=extremely difficult, 10=very easy)
    ii. Cost of travel accommodations: ___/10 (1=very expensive, 10=very inexpensive)
    iii. Availability of travel accommodations: ___/10 (1=very few options, 10=many options)

Behavior:

1. What events are important for you to go to in person?
    i. Large conferences
    ii. Research-related site visits

   iii. Small meetings
   iv. One-on-one funder meetings
   v. One-on-one collaborator meetings
   vi. Other: ______________

2. Approximately what percentage of your professional air travel is necessary for your job (i.e., if you chose not to take a trip, could it have adverse effects on your professional standing with the university?)
   i. ____%
3. If you were able to see the greenhouse gas emissions produced by your flight when booking travel accommodations, would that influence your travel choices?
   i. Yes
   ii. No

Flight Habits:

1. Roughly how many round trips did you take by plane in 2019 for professional reasons?
   i. ______ trips
2. Compared to an average year over the window 2015-2018, would you consider your amount of professional travel in the 2019 calendar year to be:
   i. More than average
   ii. About average
   iii. Less than average
3. What percentage of your flights are domestic versus international?
   i. Domestic: ____%
   ii. International: ____%
4. What percentage of your flights are direct versus those that include one or more layovers?
   i. Direct: ____%
   ii. Indirect: ____%
5. What factors influence your choice of traveling by plane, car, bus, or train? Rank the following:
   i. Distance
   ii. Time spent traveling
   iii. Duration of stay

iv. Greenhouse gas emissions
v. Cost
vi. Other: ________

6. What amount of out of town travel for professional reasons do you anticipate doing post-COVID-19 compared to before COVID-19?
   i. None
   ii. Less than half as much
   iii. Half as much
   iv. As much
   v. Twice as much
   vi. More than twice as much

   b. Counting trips involving air travel and trips that do not involve air travel, how do you expect the proportion of your trips that involve air travel in the future to change?
      i. I expect to fly less than in 2019
      ii. I expect to fly the same as in 2019
      iii. I expect to fly more than in 2019

Appendix B: Programming Methodology

Please find the code for this project in our GitHub repository[2]. We have organized our code in the following directories: analysis, clean, and scraper. All of the code can be run from a command-line terminal using 'python run.py' in the appropriate directory (i.e. at the level of each run.py file). Each run.py file runs the program using our flight logs dataset from BU. Please update the paths in this file according to your system. We recommend running the R code in RStudio for best results.

Please note that we have not made the flight and survey data from this research publicly available, but each program can be run on other datasets. Before attempting to replicate this project on your own machine, please read the Use Instructions and requirements files in the repository.

The analysis directory contains all R code for analysis and scripts for plots, charts, and calculating statistical values.

In the clean directory, the Python program does the following:

1. Deletes rows with values of 0 in the Distance (miles) column, or in which the departure and arrival airport codes are the same.
2. Deletes rows in the data with values of None in the Ticket ID column.
3. Creates new columns for the Departure Month and Departure Year, from the original Departure Date column.

In the scraper directory, the Python program will read a data.csv file and input the relevant trip information in each row to the online ICEC, then scrape the emissions value calculated and add it to the CSV file. It requires the Selenium library for Python and the chromedriver by Google. The "PyScraper" class is used to control the browser and scrape the data. The functions.py file contains all auxiliary functions used in the run.py file, including those to extract the unique trips and back-fill the remaining data after scraping the emissions calculations.

[2] https://github.com/ghostpress/employee-travel-emissions

Appendix C: Emissions Summary Tables

Top 5 Domestic Destinations from Boston

City	Number of Flights
Washington, DISTRICT OF COLUMBIA, US	2449
New York, NEW YORK, US	1086
Chicago, ILLINOIS, US	1032
Charlotte, NORTH CAROLINA, US	792
Philadelphia, PENNSYLVANIA, US	792

Table 4: Top 5 domestic destinations from Boston, with count

Top 5 International Destinations from Boston

City	Number of Flights
Toronto, CA	272
London, GB	175
Amsterdam, NL	98
Montreal, CA	91
Paris, FR	74

Table 5: Top 5 international destinations from Boston, with count

Stats for All CONCUR Data

	Calculation
Mean Distance Traveled (miles)	1258.03
Standard Deviation of Emissions (MT CO2)	0.14
Minimum Emissions (MT CO2)	0.01
Maximum Emissions (MT CO2)	2.77
Total Emissions (MT CO2)	8140.86
Total Flights (count)	46140.00

Table 6: Summary of flight data from Concur in the years 2017 through early 2020. Note that the minimum and maximum values in each table are for one flight.

Stats for 2017-2019 Concur Data

Year	Mean Distance Traveled (miles)	Total Emissions (MT CO2)	Total Flights (count)
2017	1245.439	2368.535	13400
2018	1294.840	2428.659	13546
2019	1264.202	2763.934	15596

Table 7: Summary of flight data from Concur in the years 2017 through 2019, including emissions calculations.