

Carbon Emission - Blue Marble Institute

Yishi Wang¹ and Dayana Mishel Zhigüe Alvarez²

¹*Civil Engineering, School of Engineering, Virginia tech, Blacksburg, Virginia, United States*

²*School of Mathematical and Computational Sciences, YachayTech, Urcuquí, Ecuador.*

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This study aims to calculate the carbon emissions for business travels of the BMSIS (Blue Marble Space Institute of Science) between the years 2019 and 2020. In this report, We introduce details about how we develop the carbon calculator, including both the mathematical formulas and rules behind it. Besides, our team initialize a carbon offset policy based on the calculated annual carbon emissions and offer some recommendations to mitigate carbon emissions of BMSIS community in the future.

Keywords: carbon footprint, sustainability, environmental policy

I. INTRODUCTION

The influence of aviation on climate change is expected to increase significantly, it is the one of the fastest-growing sources of GHG (greenhouse gas) emissions today. Over the past four decades, the number of passenger-kilometers flown in global civil aviation has increased at an annual rate of 5%.³ Thus, air journeys can contribute a tremendous share of an individual's carbon footprint, even though aviation emissions are small compared to different sectors of the economy.⁴ One group of people with an exceptionally high air travel footprint are academics.⁵ Indeed, many researchers are frequent travelers due to the importance of workshops, conferences, visiting positions, international collaborations, etc. The interest of different institutions worldwide in these issues has increased. In that case, an exhaustive quantitative analysis of the air travel data is required.⁵ Hence, in this project, we quantify the carbon footprint of the BMSIS members by year, and we identify mitigation strategies and suggestions to make the organization more sustainable. However, due to the difficulty of having quality datasets, this work is limited to air travel and the connected ground transportation performed by BMSIS members between 2019 and 2020.

II. METHODOLOGY

In order to describe the professional travel habits of BMSIS staff, the air travel data and the ground traffic data of the years 2019 and 2020 are retrospectively collected. The dataset comprises all travel made by BMSIS researchers during the specified time period. The dataset is anonymized and includes information on the city of departure, city of arrival, layover city (if exists), ground transportation types, and ground travel distances for every trip. The total carbon emissions for the year include the carbon emissions from the flight and the connected surface transportation. The carbon emissions during the air travel are calculated using the International Civil Aviation Organization (ICAO) methodology of the

year 2017¹. This methodology estimates the amount of carbon dioxide generated by one of the total passengers (PAX) in a flight. The main formula of this methodology is

$$CO_2 \text{ per pax} = 3.16 \frac{(\text{total fuel} \cdot \text{pax to freight factor})}{(\text{n}^\circ \text{ of y-seats} \cdot \text{pax to load factor})}$$

where:

- 3.16: is a constant that represents the number of tons of CO_2 produced by burning 1 ton
- Total fuel: The weighted average of the fuel used by all flights of a specific aircraft model departed from the original airport to reach the destination airport.
- Pax-to-freight factor: it is a proportion calculated from the ICAO statistical database based on the number of passengers and the tonnage of mail and freight, transported in a given route group.
- Number of Y-seats: the total number of economy equivalent seats available.
- Pax load factor: the proportion of the number of passengers transported and the number of seats available in a given route group (ICAO data-based).

The carbon emissions from the ground transportation are estimated using the greenhouse gases equivalencies calculator from United States Environmental Protection Agency. Based on the travel distance and the vehicle size, we develop carbon emission calculating equations for fuel vehicles, electric vehicles, and hybrid vehicles based on the technical information page with the greenhouse gas emission calculator.⁶ The following equation gives the result of carbon emission of fuel vehicles:

$$CO_2 \left(\frac{g}{mile} \right) = 8887 \left(\frac{g}{gal} \right) * \frac{1}{MPG \left(\frac{mile}{gal} \right)} * 1.25$$

where:

- 8,887: with unit $\frac{g}{gal}$, is the constant carbon emission value given by the EPA, which means 1 gallon of fuel could generate 8,887 grams of carbon dioxide.
- MPG: represents mile per gallon, is the fuel efficiency parameter for the each vehicle.
- 1.25: is the national average factor to account for emissions associated with gasoline production, including refining, transportation, etc.

For electrical vehicles:

$$CO_2(\frac{g}{mile}) = R(\frac{lbs}{MWh}) * MPGe(\frac{KWh}{100miles}) * \frac{1}{1000}(\frac{MWh}{KWh}) * 453.6(\frac{g}{lbs}) * \frac{1}{100} \quad (1)$$

where:

- R: is the carbon dioxide emissions rates for 26 United States regions based on the eGRID2020 (Emission Generation Resource Integrated Database).⁷
- MPGe: represents miles per gallon of gasoline-equivalent for electric and hybrid vehicles.

For plug-in hybrid vehicles:

$$CO_2(\frac{g}{mile}) = (1-EUF)*8887(\frac{g}{gal}) * \frac{1}{MPG(\frac{mile}{gal})} * 1.25 + EUF * R(\frac{lbs}{MWh}) * MPGe(\frac{KWh}{100miles}) * \frac{1}{1000}(\frac{MWh}{KWh}) * 453.6(\frac{g}{lbs}) * \frac{1}{100} \quad (2)$$

where:

- EUF: is the utility factor, represents percentage of share of electricity for the specific vehicle.

For developing the carbon calculator: we create three codes, the details is discussed below:

- CODE1: Calculates the carbon emissions for a single trip.
Input: Departure and arrival city. Optional: layover city.
Output: Carbon emissions in kilograms.
- CODE2: Calculates the carbon emissions for all the travels in the year.
Input: the data from the travels of Blue Marble Members (2019-2020)
Output: Total of carbon in kilograms.
- CODE3: Calculates the equivalent trees need to be planted to fully offset the total carbon emission produced by business travels in the year.
Input: The total of carbon in kilograms.
Output: The equivalent in planted trees of the carbon produced in the year.

A. Considerations

In CODE1, the primary consideration is that only one layover city could be entered in the code. Besides, we classify all types of flights into short-haul, medium-haul, and long-haul based on their flight distances. The CRJ 700 is the aircraft for travels less than 550 kilometers; Airbus A320 is used for travels between 550 and 5500 kilometers and Boeing 777-300ER for travels greater than 5500 km.

B. Versions

To improve the accuracy and update some factors, the second version of CODE1 is created with some changes. The changes on variables can be viewed below.

- The constant representing the number of tons of CO_2 produced by burning 1 ton of fuel. The constant 3.16 is replaced with 3.6 because the constant provided by ICAO methodology does not include the factor for pre-production used of fuel (0.538 kg CO_2e/kg jet fuel).⁸
- The Pax load factor (plf) and the pax-to-freight factor(ptff). The data provided by ICAO of these two parameters corresponds to the year 2015¹, hence we update the plf and ptff values to the year 2016.²
- In CODE1, the plf and ptff used correspond to 36 values and include routes between Europe, North America, South America, Africa, Asia and Oceania. The values of plf and ptff increase to 98 and the sub-regions used are Africa, South Asia, West Asia, North Asia, East Asia, Central Asia, Pacific, Middle East, North America, Central America, Caribbean, South America, Middle East and Europe.

The software python is used to create the program and calculate the carbon emissions. The quantitative analysis is performed using the Python language and the os, sys, pycountry, numpy, pandas and geopy packages. The data is loaded from a .csv file.

III. RESULTS

As mentioned earlier, our data is compiled by business travel records of BMSIS researchers in 2019 and 2020. 34 valid travel data from the year 2019 and 13 valid travel data from 2020 are recorded in the .csv file format. In 2019, the total carbon emission is 6912.24 kg with the first version of the code and increases to 10283.84 kg with calculation of our revised version. The difference in carbon emission is 949 kg. In 2020, the total carbon emission is 2993.17 kg with the first version of the code and

will increase to 3428.55 kg after revising. The difference is 435 kg.

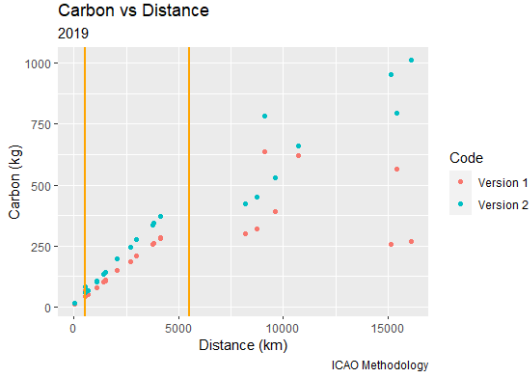


Figure 1: (CO_2 of 2019) Relation between distance and carbon emissions with the two versions. The orange lines separates the short-haul, medium-haul and long-haul.

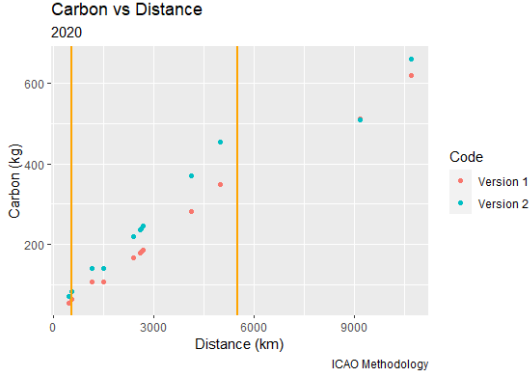


Figure 2: (CO_2 of 2020) Relation between distance and carbon emissions with the two versions. The orange lines separates the short, medium and long flights

On the other hand, in the year 2020, a linear relation is obtained in both versions. According to the graphs 4-2, a linear relationship between the distance and carbon emissions can be observed in the section between two orange lines. From the x-axis, the travel distance of this section is approximately from 0 to 5500 km. This distance includes all the short-haul and medium-haul flights, the carbon emission from the aircraft is proportional to its travel distance. However, for long-haul travel, due to the yearly changes in the loading coefficient and freight coefficient by different continents and subcontinents, the relationship between travel distance and carbon emissions is still linear with different slopes and many outliers.

To verify the piecewise linear relationship between travel distance and carbon dioxide emissions. Fifteen random groups of cities' distance data are tested through the ICAO calculator. In the relationship graph, from 0 to 6000 km travel distance, a linear relationship can be observed. For the flight travel distance further than 6000 km, another linear relationship can be found with outliers. The shape of the relationship line for these test

groups is close to what we get from the code. Thus, our code has been proved that it is effective and can be used to estimate the carbon emissions. In addition, as a supplement to the above speculation, except the factors of loading and freight coefficients, the piecewise linear relationship with outliers that may be also caused by different types of aircrafts and airlines between the short-haul, medium-haul flights and the long-haul flights.

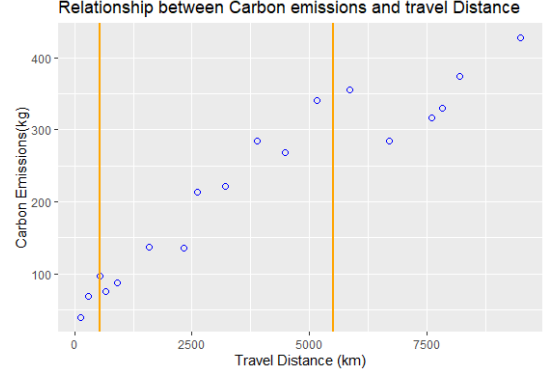


Figure 3: Relationship between Carbon Emission and Travel Distance for Reference Group⁹

Furthermore, we validate equations used to calculate carbon emissions from ground transportation based on 266 hybrid plug-in vehicle carbon emissions records from the EPA database from 2000 to 2020¹⁰, our calculator shows a high accuracy, with the average error less than 5 percentage. The plot shows the comparison between the actual carbon dioxide emissions and calculated emissions based on our formula. But because the vehicle carbon emissions in the real world are related to local power plants, fuel generation and transportation efficiency, among other factors, the results of our formula above, while highly accurate, are comparable to the average emissions calculated by the EPA. Therefore, calculating the exact carbon emissions should take into account the margin of error of $50 \frac{g}{mile}$ of the value calculated by our equations.

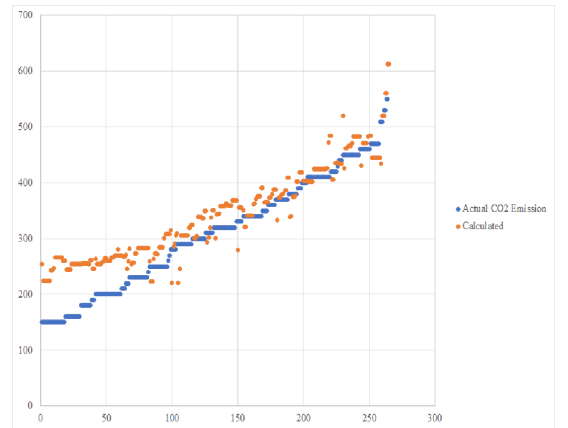


Figure 4: Difference between actual carbon emissions and calculated carbon emissions using our calculator

Regarding the results obtained with the CODE3, it is essential to mention that we need a system to get the equivalent of carbon emissions in American dollars. Hence, we decided to use the concept of emission trading. Emissions trading is a market-based strategy to control pollution through providing economic incentives for reducing the emissions of pollutants.¹¹ EU Emissions Trading System provides the fundamentals for the Carbon Emission Trading, which works on the principle of cap-and-trade. It establishes an annual absolute limit or 'cap' on the total amount of particular greenhouse gases that the entities covered by the system can emit. This cap is reduced over time so that total emissions fall.¹¹ ETS currently uses an equivalent of 28.28 American dollars per ton of carbon dioxide¹². To complete the transformation of carbon-trees, we use the website One-TreePlanted. This webpage offers to plant a tree for every dollar donated.¹³ Using the carbon obtained with our revised version, we obtained a total of 321 and 107 planted trees in 2019 and 2020, respectively. Since the Emissions trading systems use different considerations for the price of emissions, this value of planted trees varies depending on the system to be used.

IV. DISCUSSION

In 2015, Representatives from 195 countries gathered at the United Nations Framework Convention on Climate Change's 21st Conference of the Parties. They negotiated and made agreements on the future of climate, resulting in the Paris Agreement. Main goal of the agreement is to limit global temperature rise to 1.5 Celsius Degree by 2100 and gradually achieve carbon peak and carbon neutrality.¹⁴ Since then, the Paris Agreement has provided the best example for businesses and individuals to achieve carbon sustainability. Air travel is one of the most significant factors of carbon emission. According to the EPA, transportation accounts for 29 percent of total U.S. carbon emissions. For most companies and organizations, business travel accounts for more than 50 percent of the company's total carbon emission. However, fewer than 30 percent of companies have restrictions on their business travel.¹⁵ According to Professor Sanjoy, CEO of BMSIS, business travel accounts for most of BMSIS total carbon emissions. It is critical for us to develop effective environmental strategies to reduce future carbon emissions. On the one hand, we are developing recommendations for researchers to effectively reduce carbon emissions, on the other hand, we are trying to find ways to offset the carbon generated by our business travel.

According to the data, the relationship between travel distance and carbon dioxide can be observed. It is in a piecewise linear relationship with little points out of the line. The linear relationship means that taking the flight with more miles leads to higher carbon dioxide emissions. Generally, miles directly relate to the flight price and flying time. Thus, the carbon emissions will

decrease if the BMSIS community can reduce the number of miles, the number of representatives, and the total amount of money invested in business travel. Our environmental policy is based on Dr. Thomas Crowther from ETH Zurich's research. He found 900 million hectares of land are still available for reforestation so far. This area with trees will be able to capture two-thirds of total carbon emission by human-beings from the industrial revolution to today.¹⁶ In addition, because time is also an important factor for our consideration. Nowadays, tree planting is the most available and effective way for us to start carbon offsetting as early as possible. Therefore, reforestation is our environmental strategy. According to the European Environment Agency,¹⁷ 48.5 pounds of carbon dioxide will be absorbed by a mature tree and release oxygen in exchange each year. Considering 1600 trees in one hectare area, 38.8 tons of carbon dioxide will be absorbed by a one-hectare forest each year. And these newly planted trees will continue to absorb carbon dioxide for years to come. To realize this idea, we decided to use the donation website, OneTreePlanted, shared by Dr. Sanjoy.¹³ Which offers a convenient and economic way to realize our goal.

Based on the previous findings, we recommend limiting the carbon footprint of business travel by reducing total miles, amount of money, and size of travelling group. Online meetings are one of the most effective ways to reduce carbon emissions. There may be a problem that many people consider online meetings less likely than regular meetings. But in the future, according to data from the zoom company, 10 million people used zoom meetings daily in December 2019 and this number increased to 300 million in April 2020.¹⁸ So far to 2024, only 25% of meetings will be hosted in-person.¹⁹ Our second recommendation is to minimize the size of the group in travel, one or two meeting representatives can be selected to attend the meeting while the others assist them virtually. It is effective to save carbon by avoiding first and business class business travel. The business class flight has carbon footprints 3 times that in economy class. In addition, the first class flight has carbon footprints 9 times that in economy class.²⁰ Another effective way to reduce carbon emissions is to select an alternative transportation, especially for short-haul distance. From the graph 3, As the result, short-distance air travel contributes more to carbon emissions than long-distance air travel. Besides, on average, 285 grams of carbon dioxide will be generated for each person per mile who travels by aircraft. This number will decrease to 68 grams for the bus, 55 grams for the medium vehicle, and 14 grams for the train.²¹ Thus, replacing the short-haul flights with alternative transportation methods efficiently leads to the reduction of carbon emissions. Consider that air business travel is unavoidable under some conditions. Recommendations on what kind of flights can be helpful to minimize the carbon emission has also been initiated by us. Based on an analysis of approximately 30 different aircraft models, we ranked aircraft fuel efficiency for each kind of

aircraft based on their common travel distance: short-haul (figure 5), medium-haul (figure 6), and long-haul (figure 7). Since fuel efficiency is directly proportional to carbon dioxide emissions, the aircraft model with the most fuel-efficiency means it emits the lowest amount of carbon dioxide. Not only for aircraft type, but we also made recommendations on airline selection based on Atmosfair Airline Index 2018.²² Each airline's fuel-efficiency and the technology used are two main evaluation criteria of the index. We made a recommendation chart for international airlines according to the carbon-friendly ranks of the airlines and their destination continents from the United States. In addition, considering that most researchers in BMSIS are living in the United States, the rank of airlines are also based on the number of flights they have in the United States and the number of choices of departure cities in the United States. The result is shown in the table below. (Table 1) Another recommendation chart is made for researchers to select carbon-friendly airlines for their domestic travels (Table 2). All the above recommendations will be printed as the format of the brochure. And the brochure will be distributed to every researcher in the BMSIS community. The sample brochure is shown below.

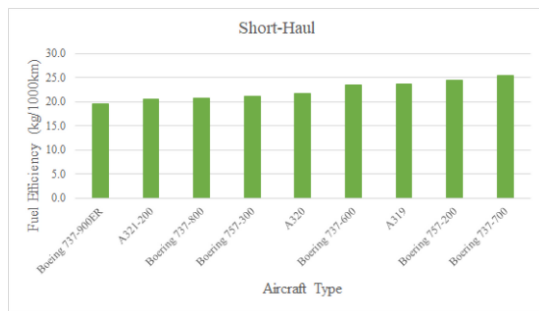


Figure 5: Carbon-Friendly Comparison between Most Common Short-Haul Aircraft Types

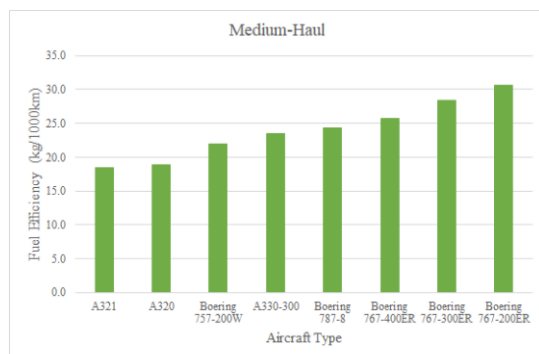


Figure 6: Carbon-Friendly Comparison between Most Common Medium-Haul Aircraft Types

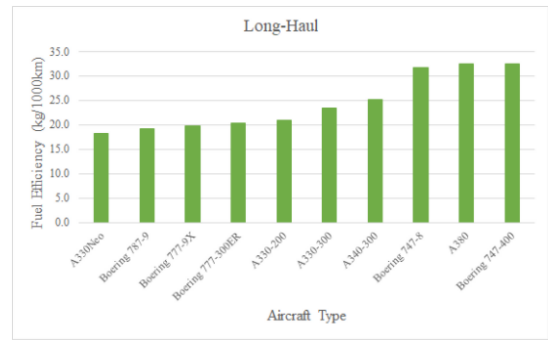


Figure 7: Carbon-Friendly Comparison between Most Common Long-Haul Aircraft Types

Table 1 - International Airline Recommendation based on Carbon-Friendly

Destination Continent	First Choice based on Carbon-Friendly	Second Choice based on Carbon Friendly
Africa	Air Canada	El Al Israel Airline
East Asia	KLM	Xiamen Airline
Europe	Air Europa	KLM
Middle East	Air Canada	Finnair
South America	LATAM	Avianca

Table 2 - Domestic Airline Recommendation based on Carbon-Friendly

1	Alaska Airlines
2	Delta Airlines
3	United Airlines
4	Hawaiian Airlines
5	American Airlines

V. CONCLUSION

In this project, our team develop a calculator to estimate the total carbon dioxide emissions from busi-

ness travel for the BMSIS community. We also develop recommendations to help researchers in or community build their carbon-friendly business travel. In the future, we are planning to design more applications to extend our calculator, including calculating carbon emission for more transportation ways and designing personalized recommendations based on the carbon data and even more. Besides, we find that the data is important for our study in this project. More data can help us make horizontal and vertical comparisons and come up with better suggestions and solutions. In the future, we hope that more researchers in BMSIS can help us with providing their travel data. A greener BMSIS awaits us!

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