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Evaluation and Mitigation Analysis of Carbon Footprint for Nepal Airlines Corporation

by

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ABSTRACT

This research deals with evaluation and analysis of carbon footprint of an airline operator, Nepal Airlines Corporation (NAC) by using its actual flight and maintenance data from 2016 to 2019. NAC is a multi-fleet operator, of both turboprop and turbofan aircrafts. Carbon footprint in terms of Carbon Dioxide (CO_2) emission has been calculated for NAC's airline operations per individual aircraft, fleet-type and operating sector (i.e., international and domestic), and also from its total ground handling operations.

Actual flight data including fuel burn, flight time, city pairs, take-off weight and engine life data has been used for NAC's aircrafts. Using jet fuel emission factoras per ICAO emission methodology, CO_2 emission of NAC's flight operations has been evaluated. Excel add-ins i.e. Correlation and Regression analyses and Crystal Ball toolshave been used to analyze the cause and effect of CO_2 emissions by NAC.

In each of the study years, contribution to NAC's total CO_2 production from its domestic fleet was found out to be very small *(below 6% of yearly total),* even though its fleet number outnumbered that of the international fleet. This indicates better optimization opportunities for turbofan aircrafts used in international sector than turboprop aircrafts used in domestic sector. As an airline operator, and also a ground handling service provider, total CO_2 emission from ground handling operations is less than 1% of the total carbon emission from direct combustion of fuels. As such, mitigation strategies in its airline operations optimization could be more beneficial.

Reductions in fuel on-board as per prescribed Original Equipment Manufacturer and operator levels, better airport slot management, reductions in existing route distance and selection of long-haul flights in case of new destinations have been identified as potential mitigation strategies for CO_2 emission from international sector. Also, equal amount of carbon taxing per ticket irrespective of aircraft type or destination could be invested in carbon neutral programsto offset the existing produced CO_2 emission.

Smaller aircrafts operating in domestic sectors are more prone to variations in occupancy rate and as such, NAC could focus on optimizing its commercial strategy to improve its CO_2/passenger rate in domestic sector.

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A320	Airbus A320-200 Ceo aircraft
A330	Airbus A330-200 aircraft
AFL	Aircraft Flight Log
APU	Auxiliary Power Unit
AOG	Aircraft on Ground
B757	Boeing 757-200M aircraft
CAAN	Civil Aviation Authority of Nepal
CAEP	Committee on Aviation Environmental Protection
CO_2	Carbon Dioxide gas
CO_2e	Carbon Dioxide gas equivalent
DHC-6	De Havilland Canada-6/300 aircraft
EASA	European Aviation Safety Agency
FAA	Federal Aviation Administration
FOB	Fuel on Board
GHG	Green House Gas
ICAO	International Civil Aviation Organization
MA60	Modern Ark 60 aircraft
NAC	Nepal Airlines Corporation
OEM	Original Equipment Manufacturer
OEW	Operational Empty Weight
PAX	Passengers
RF	Radiative Forcing
STOL	Short Take-Off and Landing
TFL	Technical Flight Log
TOW	Take-off Weight
PIC	Pilot in Command
Y12-E	Harbin Y12-E aircraft

CHAPTER ONE

INTRODUCTION

1.1 Background

Air transportation has developed a long way from the 20th century with the first controlled flight of Wright Brothers in 1903. Until 1930s, piston engines were majorly used while the induction of turbo-machinery for mainstream power plant in aircrafts by Frank Whittle in 1930 formed a base for the modern aircraft engines used today.Burning of jet fuel in induces production of emissions, like carbon dioxide (CO_2), carbon monoxide (CO), nitrogen oxides (NO_x), Sulphur oxides (SO_x) and hydrocarbons (HC).

Carbon footprint is defined as the total greenhouse gas (GHG), primarily carbon dioxide (CO_2) caused by an individual, event, organization or product expressed as carbon dioxide equivalent (CO_2e) (Carbon Trust, 2020). There are two types of carbon emissions: direct and indirect (Carbon Trust, 2020). Within the direct emission type, scope 1 emissions are of interest in aviation sector because it measures direct emissions from the source, like burning of fuels. Scope 2 emissions, which are from use of utilities like electricity and heat, and Scope 3 emissions which are from upstream and downstream of the end use are secondary emissions. CO_2 emission account for the majority of effects from fuel burn in the atmosphere due to aviation due its high power to increase temperatures whose effects remain constant for a long period of time.

Aviation sector accounts to 2% of the total human induced CO_2 emissions(Yang, et. al., 2020) and around 12-18% of emissions of all types of transportation sectors. The active global commercial fleet as of 2017 stands at above 25,000 aircrafts. The next 10 years will see 3.4% net annual growth, increasing the number to around 35,500 (Penner, et. al., 1999). This projection though is hampered by the COVID-19 situation, will have a net growth in the coming years to come.This clearly signifies the increase in fuel consumption by airlines and thus, more CO_2 emission in future.

Most of today's operational aircrafts are either of newest technology or old ones which are incorporated with at least minimal modifications to be at par with the existing regulatory requirements. For instance, from 2013, all aircraft engines produced had to comply with ICAO/CAEP6 NOx limits but all aircraft engines in production since then are already performing better than this regulatory limit (EASA, 2020).

While there are opportunities to reduce CO_2 emissions from the OEM and aviation authorities' level through design changes or modification incorporation, airline operator themselves can contribute to reducing CO_2 emission via increase in operational efficiency and mitigation tactics which can help to reduce the cost in implementing emission trading scheme (Scheelhaase, 2019).

Nepal being a landlocked country, means of aviation for transportation is an important life line for the country apart from land transport. Moreover, the fact that Nepal's terrain is mountainous means that air transport is the only means of transport for some very remote places. Tourism has been recognized as one the major business and economic activity of Nepal due its abundance in natural beauty. Thus, tourism also attributes to a lot of aviation business in Nepal.

As of recent times, there are more than a dozen airline operators in Nepal, like Buddha Air, Yeti Airlines, Tara Air, Shree Airlines and Saurya Airlines on the domestic forefront and Nepal Airlines and Himalaya Airlines on the international forefront. Also, there are around three dozen foreign airline operators whose aircrafts land at Nepal's TIA airport ondaily basis. Operations of multiple aircrafts from all these airlinesflyover Nepalese air space and thus accounts to partial or full CO_2 emissions in Nepal.

Nepal Airlines Corporation (NAC) is the national flag carrier of Nepal and is operating multiple fleets of aircrafts. Over the period of 2016-2019, NAC has had significant changes in its fleet size and types: some being decommissioned, while some being added.

All aircrafts except the DHC-6/300 aircraft are new in a sense that they are less than a decade old. The two Boeing 757-200M aircrafts of NAC have now been phased out while the MA60 and Y12-E aircrafts have had operational and maintenance hurdles which has caused irregular flights over the years. The aircraft operation data for NAC for 2016-2019 are shown as follows:

Table1.1: Aircraft operation data for 2016-2019

Aircraft Type	**Call Sign**	**Operational Years from 2016-2019**	**Operating Sector/ Aircraft Type**	**Non-operational after:**
DHC-6/300 Twin otter	9N-ABT	2016-2019	Domestic / Turboprop	-
	9N-ABU	2016-2019		-
Modern Ark 60	9N-AKQ	2016-2018		2018
	9N-AKR	2017-2019		2019
Harbin Y12-E	9N-AKS	2016-2018		2018
	9N-AKT	2017-2019		2019
	9N-AKU	2018-2019		2019
	9N-AKV	2018-2019		2019
Boeing 757-200	9N-ACA	2016	International / Turbofan	2016
	9N-ACB	2016-2018		2018
Airbus A320-200	9N-AKW	2016-2019		-
	9N-AKX	2016-2019		-
Airbus A330-200	9N-ALY	2018-2019		-
	9N-ALZ	2018-2019		-

In this present scenario, there are regulations are on effect by international aviation regulatory bodies like Federal Aviation Agency (FAA), International Air Transport Association (IATA) and International Civil Aviation Organization (ICAO). Both FAA and IATA have set targets of carbon neutrality till 2020, while FAA has stated for net reductions by 2050 and IATA has set net reductions by 50% till the same year (taking 2005 as base year).

Airlines can reduce the net carbon footprint by adopting better operational practices like using more direct routes with newer forms of navigation, exploring better fuel-efficient aircraft and their related technologies (choice of engines in particular). These are arbitrary mitigation analyses, based on generic information available mainly from different assumptions provided by independent organizations like ICAO and IPCC. Specific research like that of an airline operator with real-life data could provide underlying causative parameters of CO_2 emission, which can be pin pointed for reductions in net carbon emission.

1.2 Problem Statement

Aviation in Nepal though small in respect to the global arena, is growing, and is in its development phase if we compare it with the international aviation operations. There have been various researches attributed to finding the CO_2 emissions with respect to specific airline, geographical region and in relation to policy making changes. Almost all of these researches are based on theoretical framework of approximating the fuel consumption and passenger flux either from technological facts, empirical formulae or some form of historical data.

The ICAO calculator methodology(ICAO, 2017) for calculating CO_2 is based on various assumptions and technological findings. For example: it has used the historical data for type of aircraft movement between two destinations and provided a weighted average of fuel consumption based on the number of types of aircrafts generally flying between those destinations. It has also used the airline database to predict the seat occupancy rate for the flight between two places. However, the problem lacking here is that real data is not being used.

The “Carbon Neutrality Report 2018” by Yeti Airlines has done some research specific to its airline operation: finding out the actual factual data and feeding into the calculator to find how much tons of CO_2 emissions have been produced by the airline. However, the report is limited to finding out the emissions but short of in-depth analysis of why the results are so. Yeti Airlines has indeed attributed the results to change in its aircraft fleets and some other reasons, but the detailed analysis of correlation of different factors such as Take-off weight, APU and engine use have not been studied. Detailed study of this type of relations would quantify the methods of carbon footprint mitigation, of which only qualitative discussions have been made so far.

Thus, this calls for a detailed research of factual data of an airline operator with its relevant parameters to get correlation between prospective causative factors of CO_2 emission due to flight operations. There is a need as well as an opportunity to study the trend of CO_2 emission of aviation from an airline operator viewpoint. In essence, the obtained results could provide recommendations which an airline could implement in practical use for demonstrating the capabilities of changing operational styles on reductions of carbon emissions.

1.3 Objectives

1.3.1 Main Objective

The main objective of this research is to evaluate carbon footprint of Nepal Airlines Corporation (NAC) from its airline operations amounting to direct emissions, and examine its different facets, including analytical reasoning for the obtained results.

1.3.2 Specific Objectives

The specific objectives of the thesis are:

1. To evaluate CO_2emission on the basis of aircraft fleet type, operating sector and destinations for a specific time-frame (i.e. four years) for availability of historical data.
2. To analyze fleet and sector-wise CO_2 so as to point out causative parameters which could be changed to mitigate CO_2 levels.
3. To studyeffect of aircraftengine utilization on CO_2 emission over time.
4. To look into the effect of aircraft occupancy rates of various fleets on CO_2 emission.
5. To forecast CO_2 levels of NAC pertaining to future scenarios.
6. To compare CO_2emission from NAC's airline and ground handling operations.

CHAPTER TWO

LITERATURE REVIEW

2.1 Carbon Footprint andtheir effects

Carbon footprint is the total greenhouse gas (GHG), primarily carbon dioxide (CO_2) caused by any entity expressed as carbon dioxide equivalent (CO_2e).Carbon emissions are classified as direct and indirect emissions. Direct emissions include the most visible modes of emission i.e., from the sources like burning of fuel. This is known as scope 1 emissions. Direct emissions also include scope 2 emissions which are caused by activities not directly linked to the end use, like electricity consumption along-side fuel consumption. The indirect emissions, called scope 3 emissions which are attributed to emissions caused up- stream and/or down-stream of any end. For example: for the use of aircrafts in aviation, the up-stream carbon emissions may be from its manufacture and its down-stream emissions maybe from its end of use stage, like scrapping process. These three scopes of emissions sum up to the life cycle emissions of a product.While the life cycle emission of a household use of product or service, or industrial process of importance, in aviation, scope 1 effects are more important because of the relatively high quantity of emission from its scope 1 sources.

Green House Gases are the gases which create the "green-house effect", primarily causing heating effects by creating a blanket in the atmosphere. This blanket initially allows the radiant heat with high energy to enter the atmosphere through it. Some heat radiation gets reflected from the earth's surface, which having lower energy than its initial precedent form gets blocked by the blanket of GHGs.

Carbon dioxide gas, which is emitted as the by-product of combustion of any hydrocarbon fuel is the major GHG. Even though the predominant effect of GHG gas is to increase temperature, there is a term called "Radiative Forcing (RF)" which attributes to either heating or cooling effect of a gas measured in terms of W/m^2(Watt/ square meter). Carbon dioxide gas producesa heating effect in the atmosphere.

Water vapor is another by-product of fuel combustion and although its exact effect i.e., heating or cooling is not determined exactly(Scheelhaase, 2020), water vapors have been known to form jet contrails and interfere in formation of clouds in the region where aircrafts fly.Oxides of nitrogen (NO_x) are also one of the GHGs and cause a positive radiative forcing by ozone in the atmosphere.There are hydrocarbons and aerosols which are taken underGHGs, but their effects are minimal in comparison to the discussed first three. These all gases in summation contribute to GHG emissions.

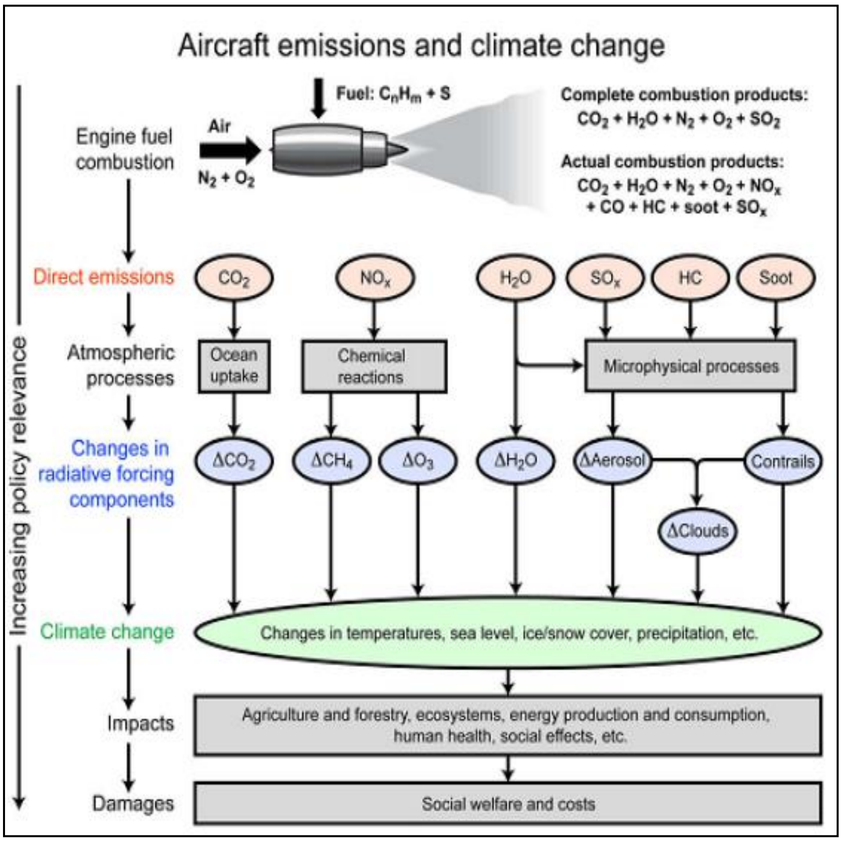


Figure 2.1: Aircraft emissions and climate change (ICAO, 2013)

It is worthwhile to recall that carbon footprint is the carbon dioxide equivalent of greenhouse gases emitted and as such, the calculation of CO_2 alone would form only a part of the carbon footprint. A method to find out the emissions of other GHGs would be to first calculate the CO_2 and then to multiply it with a factor, which is related to the radiative forcing of net GHGs in comparison to the carbon emissions alone. One can see from the diagram below the radiative forcings of different GHGs of which, a large representative fraction of GHGs is carbon dioxide gas alone(Fahey, et. al., 2020).

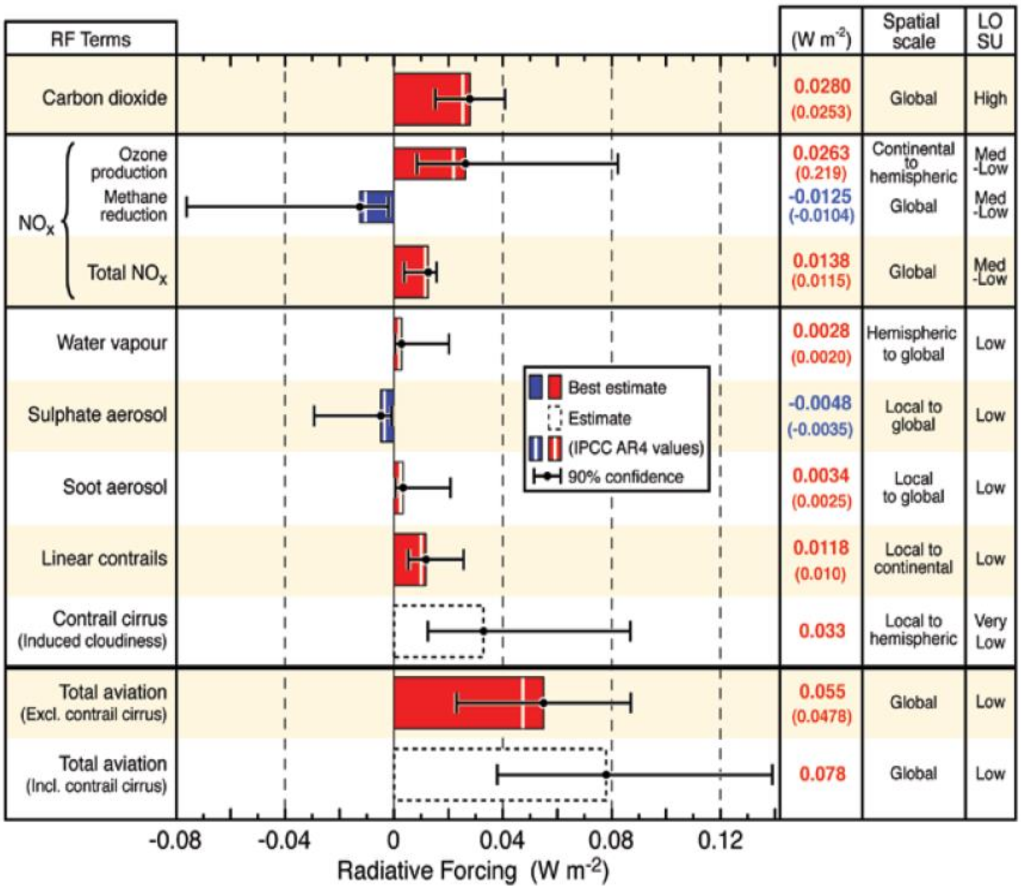


Figure 2.2: Radiative Forcing of Aircraft Emission Gases (ICAO, 2013)

Even though the full impact of aviation always results in larger climatic effects than considering CO_2 alone, the emission ratio: (CO_2 + non-CO_2) per CO_2 is not a constant but rather depends on the individual flight and on the flight length (Scheelhaase, 2019).There have been ambiguous claims to the value of this factor: some define it to be 2.7, some to be 1.7 and some approximate it to 2. It is also worth knowing that this factor, which shows the relative RF of other GHGs in comparison to CO_2, will change over time, but that from CO_2 will remain same(Fahey, 2020). It is due to this changing nature of RF of other GHGs over time, no consensus has been made to factor it in total carbon footprint(IPCC, 1999; Fahey, 2020). Also, shown in Figure 2.2., the LOSU (Level of Scientific Understanding) of RF from GHGs other than $CO_2$is low or medium-low. As such, ICAO's carbon emissions calculator(ICAO, 2017) has only focused on calculating only the CO_2 emissions and left the matter of other GHGs. This method is justifiable to show that the CO_2 emissions are a representative of the total carbon footprint of aviation and an airline company in particular, because on one hand, CO_2 is the major GHG, and the net value of carbon emission can be presumably represented by carbon emissions as the total carbon footprint would just be a multiple of the carbon emissions as a whole.

Within an airline company, only the carbon emission could suffice as this value would be compared within the sphere of the aviation company itself to analyze the underlying cause and effect of carbonemissions summing up to carbon footprint as a whole.

2.2 Reviews on CO_2 Calculation

The ICAO carbon emissions calculator is a tool that calculates the carbon dioxide emissions using the start and destination airports as the input parameters. The methodology used includes technological data from aircrafts' fuel consumption, airline history data for type of aircraft flow and industry-based averages that contribute to calculating the emissions from airline operation.

The ICAO calculator has been explicitly used by many researches like by Yang et.al. and Debbage et.al. including CAAN's CAAN Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) which takes 3.16 tonnes of CO_2 emission produced per tonne of aviation fuel being burnt. Any mention of different values of CO_2 emission resulting from use of different types of aviation fuel is not mentioned. (Yang, et.al., 2020)

The primary calculation methodology used in ICAO emissions calculator uses technological data of various aircrafts in operation (majority of the commercial aircrafts in operation currently) to determine the average fuel consumption for the distance flown between destinations. It has used a database of 312 aircrafts showing the fuel consumption for specific interval of air distance. From the matrix, one can find the fuel consumption from one type of aircraft for a specific air distance through interpolation. The calculator takes into consideration the types of aircrafts usually in operation between the specific pair of airports. For example, for a short to medium haul flight in Asia Pacific region, the usual commercial aircrafts in operation are A320 and B737 variants. The aggregate fuel emission between two airports can be then found via pro-rata basis from the ratio of aircraft type in operation between the two airports.

Great Circle Distance (GCD), which is found by intersection of latitudes and longitudes at the airport's location is used. But, as GCD is not the actual distance, because an aircraft uses its fixed route between airports owing to its operational needs, a correction factor has been used to make the distance between the airports more realistic. For a GCD less than 550km, the correction factor used is +50km while for GCD in the range of 550-5500km, a correction factor of +100km has been used.

To get a realistic grasp of the estimated passengers on board during any flight between two airports, a concept of 'load factor' has also been used, which corresponds to the passenger occupancy rate of the particular flight between two places. Then, there is a term called "y-seats" which is the total number of economy seats that can be fit inside an equivalent aircraft. ICOA has made use of a standard cabin layout along with the positioning of galleys, toilets and exits and it is according to this layout, the "y-seat" numbers have been assumed. The passenger (pax) load factor can thus be found out by the following formula:

$$Pax\ Load\ Factor = \frac{Actual\ pax}{y-seats} \quad (2.1)\ \textit{(ICAO, 2017)}$$

According to ICAO, it is essential to relate the fuel burn to only the passengers, and not the freight and other pay loads of a flight. As such, term called "passenger to cargo factor" has been devised to find the fuel burn by the passengers alone.The passenger to cargo factor could be calculated from the following formula:

$$Pax\ to\ cargo\ factor = \frac{Pax\ weight}{Pax\ weight + Cargo\ weight} \quad (2.2)\ \textit{(ICAO, 2017)}$$

ICAO uses a standard 80 kg per passenger regardless of passenger gender or ratio while FAA uses a 60:40 male to female ratio at 83 kg and 73 kg respectively. EASA established weights of 95 kg and 75 kg for male and female respectively. An additional estimation of passenger baggage (WBAG) is added to the overall payload, assuming that each item of luggage is 25 kg and that 70% of the passengers take one bag and 30% take two bags. Also, study show that in Indian region (which is closest example for Nepal) the standard weight of passenger is 75 kg (Mellis, et. al., 2019). This provides us a standard weight with hand luggage standing at 100kg.

A cabin class correction factor has been used to account for the number of business/premium class seats for distances longer than 3,000km. It has been presumed that the space used by business class could accommodate twice the economy class seats. It is due to this reason that a correction factor would have to be used to accommodate for the equivalent economy seats in an aircraft. Thus, the total carbon emission from a premium-class seat is taken to be twice than that of an economy-class seat.

In gist, the carbon dioxide emission per passenger can be calculated by using the following formula:

$$CO_2\ per\ pax = \frac{3.16 * Total\ fuel\ burn\ per\ flight * pax-to-freight\ factor}{number\ of\ y-seats * pax\ load\ factor} \quad (2.3)\ (ICAO,\ 2017)$$

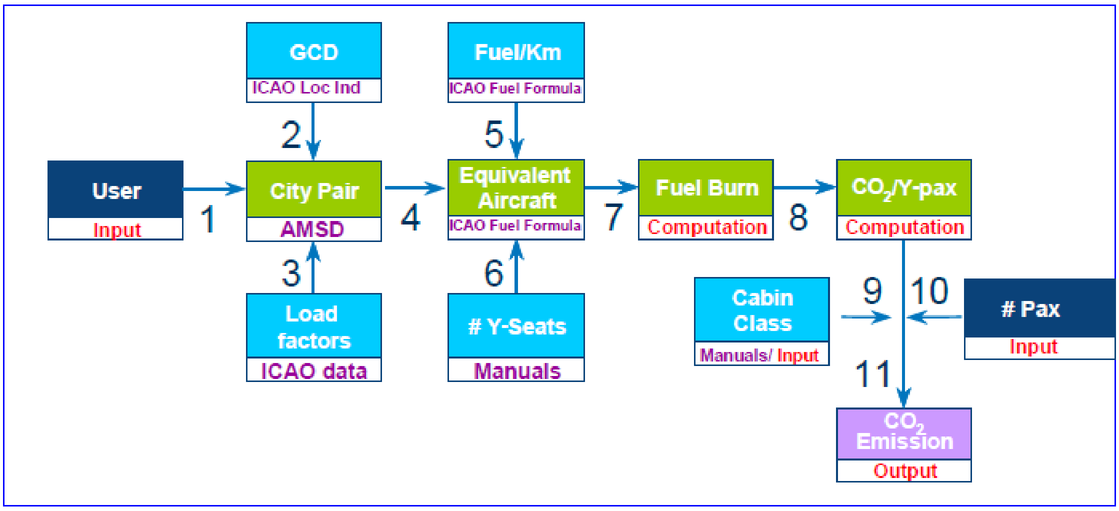


Figure2.3: Calculation Procedure as defined in ICAO Calculator Methodology, (ICAO, 2017)

Because the cargo weight is not documented in AFL, for each flight, it can be calculated as follows:

$$Freight = Take\text{-}off\ Weight - FOB\ (Tons) * 0.8 * 1000 - pax * 100 - Operational\ Empty\ Weight \quad (2.4)$$

An average specific gravity of 0.8 is assumed for the aviation fuel used (CAAN, 2020). Because the actual number of passengers per flight is used, there is no requirement of pax-load factor. The operational empty weight (OEW) and passenger capacity for aircrafts of NAC have been obtained from OEM's manuals as follows:

Table2.1: OEW and Pax capacity for NAC's aircraft

Aircraft	OEW	Pax capacity
B757	43,670 kg	190
A330	124,870 kg	274
A320	58,800 kg	158
DHC-6/300	3,674 kg	19
MA60	13,720 kg	56
Y12-E	3,800 kg	17

While the ICAO carbon emissions calculator provides a very close approximation from scientific data and weighted averages, the carbon emission values produced by this methodology will not provide an exact value. On the contrary, ICAO has mentioned that airlines can use their own data documenting their credible sources and provide a much closer approximation of the CO_2 value (ICAO, 2017). Thus, there is an opportunity for specific airlines to use its own documented data using the exact fuel consumption, passengers and route distance unique to its operations to calculate a more accurate value of the carbon emission. Another major drawback in this methodology is that the total carbon footprint cannot be calculated because only the CO_2 part of GHGs is calculated and the other gases are not accounted for because ICAO is still not in resolution to what amount of radiative forcings would other GHGs produce in comparison to CO_2 alone.

2.3 Review on CO_2 mitigation

Both FAA and IATA have set targets of carbon neutrality till 2020, while FAA has stated for net reductions by 2050 and IATA has set net reductions in 2050 by 50% (taking 2005 as base year). Also, there are requirements established by Civil Aviation Authority of Nepal (CAAN) applicable to an aeroplane operator that produces annual CO_2 emissions greater than 10,000 tons from the use of an aeroplane(s) with a

Maximum Take-off mass greater than 5,700 kg conducting international flights on or after 1st January, 2019 (Hofer, et. al., 2010).

Carbon accounting is the process by which organizations quantify their GHG emissions, so that they may understand their climate impact and set goals to limit their emissions (Schaltegger, et. al., 2012). Carbon accounting has been done for NAC by compilation of comprehensive flight and maintenance data of aircrafts operated by NAC over the period of 2016-2019.

There are many ways by which an airline operator can mitigate and offset is carbon emission. Induction of new fleets with most modern aircraft can reduce carbon emission. Carbon offsetting through purchase of carbon credits and supporting projects dealing in sustainable development goals has enabled Yeti Airlines to be carbon neutral as of 2018 (Rai, et. al., 2018). Yeti Airlines Pvt. Ltd. has in partnership found its greenhouse inventory from the airline operation, vehicular use and office use for a period of three years. It has been verified that Yeti Airlines has been successful in reducing its CO_2e emissions per flight per kilometer by 20%, and by 12% per passenger after expanding its fleet with more efficient ATR72-500 aircrafts over the years.

Also, for offsetting the carbon emissions produced, Yeti Airlines has purchased credible and certified offsets from United Nations Framework Convention on Climate Change (UNFCCC) Climate Neutral Now Platform to offset 100 % of emissions from its 2018 business operation. This is how Yeti Airlines has gained carbon neutrality in its 2018 operations.

The report also states the following as possible ways to reduce the carbon emissions through operational reforms:

- Examining take-off, ascent and landing operations for feasibility to adopt angle of ascent adjustments and tailored arrival: this could be challenging as operational safety usually precedes over efficiency.
- Training and education initiatives for more efficient piloting of aircraft: this can work out as a means to make the crew aware of efficient flying.

- Use of pushback vehicles, possibly electric for taxiing: pushback vehicles used around the world use internal combustion engines and it would take time for electric technology to get penetration into ground handling equipment.
- Monitoring of passenger demand patterns to ensure flights to ensure high occupancy rate. (This has been achieved as there was an increase in 3% occupancy rate going from 2017 to 2018).

While emissions from specific air travel sector, year, month per passengers flown and kilometers run have been evaluated in the report, detailed causative factors' analysis have not been carried out. Varying the controllable causative factors (like: FOB, routes and flight time) of CO_2 emission over a future tenure provides insight into operational efficiencies NAC can add to reduce its CO_2 emissions.

CHAPTER THREE

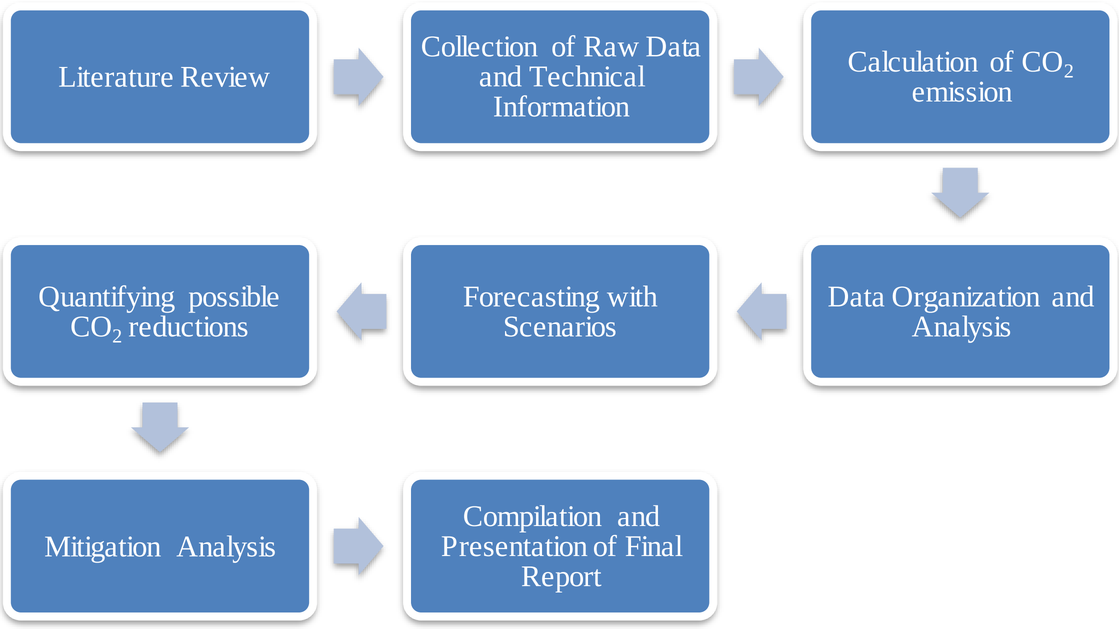
METHODOLOGY OF RESEARCH

This research is an applied research, which aims to derive explanatory results for carbon emission from an airlines operator: NAC. An inductive approach has been used wherein an established set of theory has been used to produce analytical reasoning for the results obtained.

This research has aimed to answer the major research questions:

1. What is the CO_2 emission trend of NAC?
2. How different are CO_2 emission from different aircrafts?
3. What are the causative variables for CO_2?
4. How can the CO_2 emission be reduced?
5. How will the carbon emission change in future?

The following methods have been carried out to meet the objectives of the research:



The above steps have been explained in detail below:

3.1 Literature Review

Literature review on related topics, research papers, thesis reports, books, citations in relevant materials have been studied to get an insight into what the topic is about, and where the research gap, and how to address it. The issue of value addition to the existing research will be searched as a result. Findings, theoretical background has been looked into to develop the research work. Mainly, the following will be studied under literature review:

- Effect of GHGs and CO_2 on climate
- Method to find CO_2 emission
- Study of how underlying factors affect carbon emissions.
- Regulations regarding aircraft emissions from international and local aviation authorities.
- Research on what has been done to mitigate the carbon footprintand possible ways to mitigate CO_2 emission.

3.2 Collection of Raw Data and Technical Information

Raw data have been collected from the individual Aircraft Flight Log (AFL) which includes the departure and arrival airport pair, date of flight, air time (time during which aircraft is in flight, or time between take-off and landing),fuel on board (FOB), fuel burn, passengers on board (pax), Take Off Weight (TOW) and Auxiliary Power Unit (APU) and engine use. Other information, like aircraft empty weight, Maximum Take-off Weight (MTOW) and average fuel consumption have been obtained from flight and maintenance manuals of respective aircrafts.

Also, additional information, like the operational data, APU fuel consumption, route distance for NAC have been obtained from the data provided by Original Equipment Manufacturer (OEM), maintenance/operation manuals, independent research and the operator data itself.

3.3 Calculation of CO_2 emission

As per the ICAO carbon emissions calculator, CO_2 emission (as a good representation of carbon footprint)has been calculated using the obtained raw data. CO_2emissionfor individual flights, individual aircraft, aircraft fleet type and also flying sector has been evaluated. Specific CO_2 per passenger and per kilometer of travel have also been calculated for analysis of different facets of carbon emission.

The ICAO carbon emissions methodology has been used in this research,recalling equation (2.2) from literature review as follows:

$$CO_2\ per\ pax = \frac{3.16 * Total\ fuel\ burn\ per\ flight * pax-to-freight\ factor}{number\ of\ y-seats * pax\ load\ factor} \quad (3.1)\ \textit{(ICAO, 2017)}$$

As the actual number of passengers have been used in this research, pax load factor will not be necessary. However, we would need to find the passenger-to-cargo factor, which is the ratio of passenger weight to passenger plus cargo weight. This factor is necessitated to account the carbon emissions to passengers alone and not to the cargo freight carried by the aircraft, which is not of the passenger. As discussed earlier, the average passenger weight along with their baggage would be taken as 100kg (considering 80kg for male and 70kg for female and an average of 25kg baggage per passenger).

The freight weight can be calculated by the following formula:

$$Freight = TOW - FOB - Passenger\ weight - Empty\ weight \quad (3.1)$$

There are two types of empty weight, Manufacturer's Empty Weight (MEW) and Operational Empty Weight (OEW). MEW is total weight of structure, power plant, systems, furnishing and other items of equipment that are an integral part of the aircraft configuration including fluids contained in closed systems. OEW, on the other hand also include other weights which are specific to airlines operator like documents and tool kits, potable water, catering and galley equipment and the crew along with their hand baggage also.In this research, all seats are taken as economy seats, as there are limited business class seats in NAC's international sector aircrafts while the domestic sector aircrafts are of all-economy class configuration. Moreover, as the occupancy rate of business class seats is fairly low, this assumption can provide good approximation without any complex calculations.

3.4 Data Organization

The collected data have been sorted per aircraft type with the data being compressed into yearly averages for different air routes. Corresponding information like air time, fuel on board, passenger number and take-off weight have been arranged in this format. The total CO_2 emissions by international and domestic sector were evaluated. The CO_2 emissions by total ground handling operations was also calculated for the most recent year, i.e., 2019 and compared with the total aviation operations' emissions.

Correlation and regression analyses have been done for international sector aircrafts to point out relation between carbon emission and causative factors. Graphical representations of the obtained result have showed the variation in CO_2 and specific CO_2 over the years, 2016-2019. Also, carbon emission per engines and APU use have been evaluated to look into the aircraft ageing effect on carbon emission over the years.

3.5 Forecasting with Scenarios

Total CO_2 emission from NAC as a whole has been evaluated and forecasted over ten years' period using Crystal Ball Predictor add-in in MS-Excel. Two scenarios have been considered: the first one, using historical data for 2016-2019, which does not include effects of COVID-19 crisis and another one, using historical data of 2016-2019 plus approximation of data for 2020, which includes effect of COVID-19 on air travel.

3.6 Quantifying possible CO_2 reductions

From correlation analysis, parameter pairs with R^2 value greater than 50% were taken to create a regression equation between CO_2 emission and most influencing causative factors. Monte Carlo Simulation was then carried out with CO_2 as the decision variable, while the causative variables were taken as assumptions with appropriate distribution type and statistical values as per historical data. The probability distribution obtained thus from the simulation of appropriate number of iterations gave an insight to mitigation opportunities from changes in controllable variables in quantitative way.

3.7 Mitigation Analysis

Further to the quantitative analysis for CO_2 mitigation, some qualitative analyses were also done from the obtained results.

3.8 Compilation, Discussion and Presentation of Final Report

This is the last phase, which includes compilation of all information derived and presenting them in a formal report. From the results obtained, analytical discussions were made for critical reasoning and the same have been filed in the report.

CHAPTER FOUR

RESULT AND DISCUSSIONS

4.1 CO_2 emission of Nepal Airlines Corporation Airline Operation

Using theoretical background and data processing, the total CO_2 emission of NAC segregated into aircraft fleets and domestic/international sector has been presented.

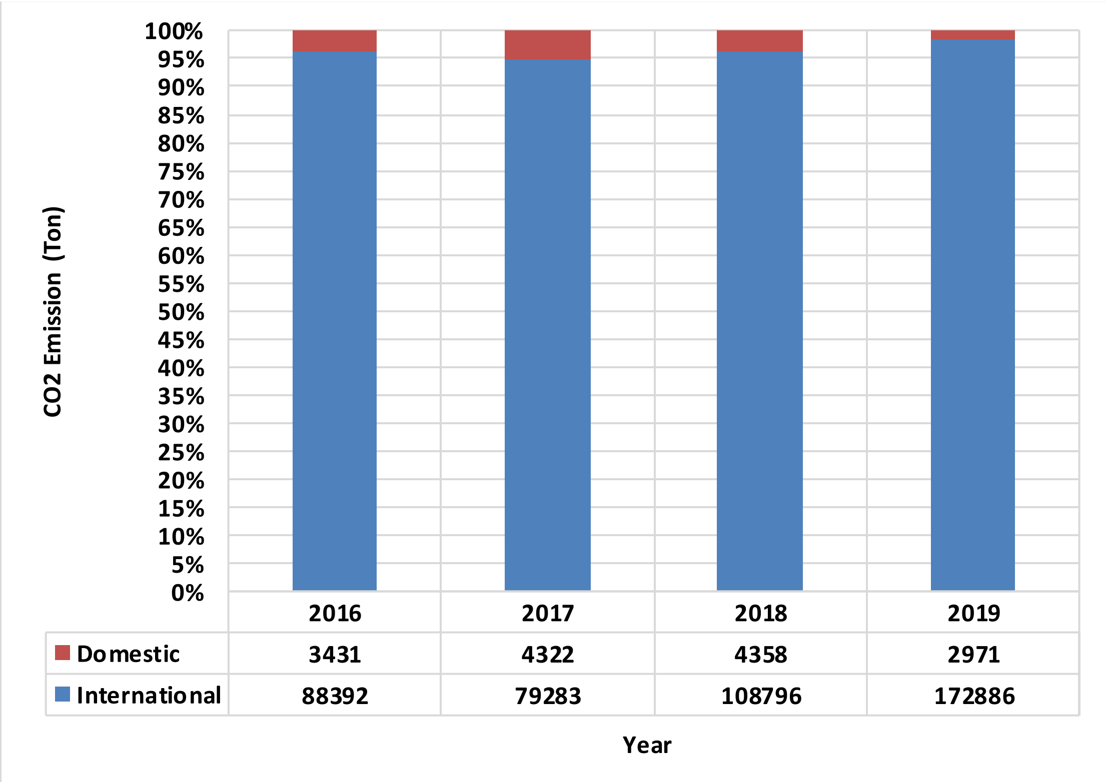


Figure 4.1: CO_2 emission of NAC from Domestic and International flight operations (2016-2019)

Figure 4.1 clearly depicts that the CO_2 emission contribution from domestic flights operations is very low in comparison to the yearly carbon emission. The yearly CO_2 production from domestic operations are (as % of total production): 3.7%, 5.2%, 3.9% and 1.7% for 2016, 2017, 2018 and 2019, respectively. The carbon emission by domestic sector increased in year 2017 because new Y12-E aircrafts were introduced into the fleet and other domestic fleets were also operating in full capacity. During the same time i.e., 2017, one of the Boeing 757 aircraft was removed from NAC's fleet which explains the increase in contribution in carbon emission by domestic sector. In the year 2018, the remaining Boeing 757 aircraft was also decommissioned while two new Airbus A330 aircrafts were added to the fleet. During the same year, one MA60 and several Y12-E aircraft suffered AOG (Aircraft on Ground) situations which explains to the drop in contribution of emissions from domestic sector flights.

Lastly, in 2019, many of MA60 and Y12-E aircrafts have experienced irregular operations while the DHC-6/300 seemed to be the sole aircraft fleet operating regularly in the domestic sector. Also, the newly inducted A330 aircrafts were being operated in full fledge by 2019 which resulted in sudden drop of carbon emission contribution by domestic sector. The following diagram better explains the phenomenon of CO_2 production share of each aircraft over the years.

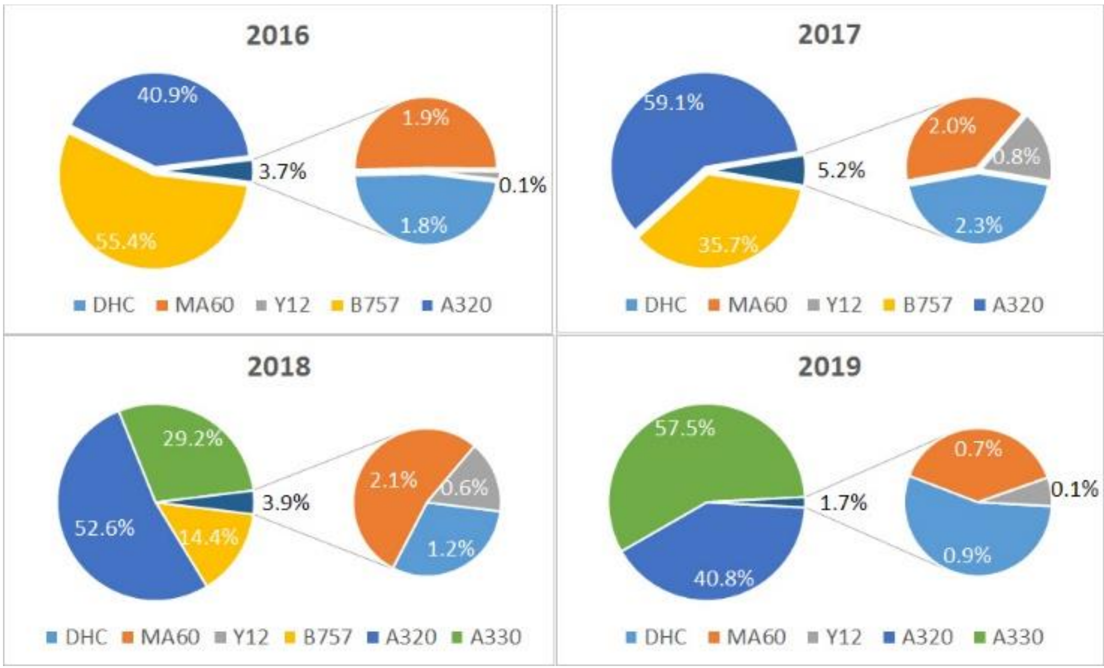


Figure4.2: CO_2 emission share of NAC aircrafts (2016-2019)

Since the CO_2 emission generated by domestic sector aircrafts is much lesser than international sector aircrafts, detailed analysis of causative factors have been done for only the international sector aircrafts (i.e., turbofan aircrafts).

4.2 CO_2 emission of Nepal Airlines Corporation Ground Handling Operation

NAC provides ground handling service to majority of foreign airline operators operating at TIA, Kathmandu. The services provided majorly include: Ground Power Unit (GPU), Fork Lifts, Baggage Tractors, Passenger Steps, Catering Trucks, Conveyer Belt Loaders, Air Starter Units, Lavatory Service Trucks, Pushback Tractors, Ramp Movement Vehicles, Maintenance Platforms, Potable Water Trucks, Passenger Ramp Buses, Air Conditioning Units and Ambulifts. An average emission factor of 2.66 kg of CO_2 emission/diesel (liter) fuel burn and 2.29 kg of CO_2 emission/petrol (liter) fuel burn(Natural Resources Canada, 2014) has been used to compute the total CO_2 emission from ground handling operations of NAC for the year, 2019. A comparison of the carbon emission between aircraft operations and ground handling operations are shown below:

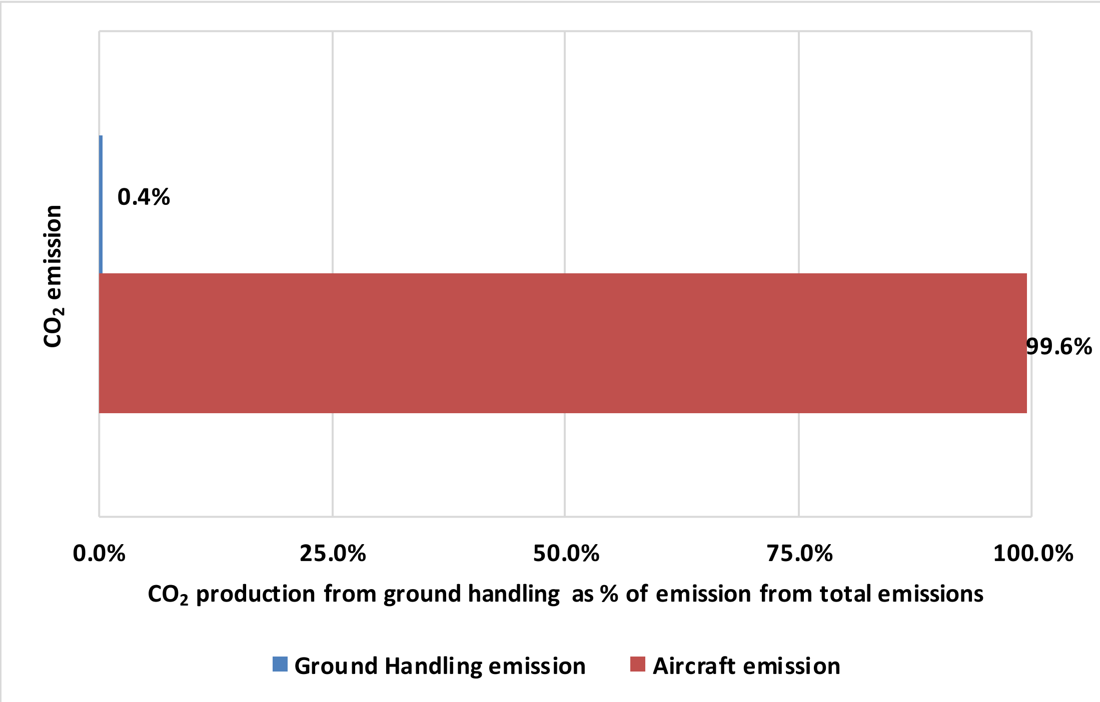


Figure 4.3: CO_2 emission share of NAC airline and ground handling operations (2019)

As seen in Figure, 4.3, the total CO_2 emission from ground handling operations accounted to only 0.4% of the total operational emissions. As, such, international flight operations have been focused on for mitigation analysis.

4.3 Driving Factors of CO_2 Emission

Scatter plots between different parameters were obtained from the available and calculated data. The correlation parameter, R^2 provides us how much of a resultant parameter is affected by a causative parameter.

Here, individual, one on one correlation analysis has been done to determine how much effect a causative factor (like: flight time, route distance, take-off weight, fuel on board and number of passengers) has on the resultant output (in this case, CO_2, and its derivatives being subject of interest).

Similarly, trend line corresponding to the scatter plots were made and its equations were generated from Excel Data Analysis Add-in: Correlation. The gradient value of the simple straight line thus lets us quantify sensitivity of output parameter with respect to changes in the input parameter.

4.4 Variations in CO_2

Table4.1: R^2 and gradient values for correlation with CO_2

CO_2 (Tons) vs.	**Correlation R^2 value**			**Regression Line Gradient**		
	A330	**B757**	**A320**	**A330**	**B757**	**A320**
Flight Time (hr.)	0.970	0.977	0.973	15.637	12.105	7.788
Route Distance (km)	0.897	0.923	0941	0.018	0.014	0.009
Fuel on Board (Tons)	0.626	0.445	0.604	1.776	1.807	2.628
Take-off Weight (kg)	0.418	0.540	0.463	1.136	1.516	1.615
Occupancy(%)	0.013	0.070	0.007	14.794	22.922	-5.951

The above table summarizes the R^2 value for correlation between the given parameters and respective intercept values for each turbofan aircraft, which are sorted in order of their Maximum Take-Off Weight (MTOW).

The results seen in the table infer that there is strong statistical significance between CO_2 emission and the flight time (R^2= 0.970 to 0.970) and route distance (R^2= 0.897 to 0.941). Thus, one hour of flight time corresponds to 7.79, 12.11 and 15.64 tons of CO_2 emission for A330, B757 and A320 aircraft.

Even though the CO_2 emission is directly proportional to the route distance, the CO_2/km value (as will be discussed later) decreases with respect to increase in route distance, and this decreasing rate also increases with the aircraft MTOW.

Fuel on board the aircraft is a parameter of particular interest, because there is good statistical significance of FOB on CO_2 emission. One ton of FOB in average corresponds to 1.78 to 2.63 tons of CO_2 emission produced. Here, it is to be noted that smaller aircraft (A320) has much potential to carbon reductions through more efficient fuel planning than the larger aircrafts (A330 and B757). Also, the CO_2 production is more sensitive to TOW in smaller aircrafts than the larger ones in turbofan aircraft category.

As seen in the table, the R^2 value of correlation between CO_2 and number of passengers ranges from 0.007 to 0.070 for different aircrafts, which is not enough to establish any credible relation between the parameters' pair. The most notable reason for this uncertainty in the relationship is the fact that airline operators do not measure the exact weight of passengers on board their aircraft, but rather use a predefined average value accepted by regulatory bodies and the operator itself. While the actual passenger weights may vary to a large extent, this general rule uses one constant value for passenger weight which is in fact not very accurate in real-life scenario.

4.5 Variations in CO_2/km

Table4.2: R^2 and gradient values for correlation with CO_2/km

CO_2/km vs.	Correlation R^2 value			Regression Line Gradient		
	A330	B757	A320	A330	B757	A320
Route Distance(km)	0.359	0.440	0.553	-0.0017	-0.0016	-0.0012

The CO_2/km with respect to the route distance (km) has a decreasing trend, implying that with increase in route distance, the CO_2 emission per kilometer flown decreases. This rate of decrease is more prominent in larger aircraft than the smaller ones as depicted by the gradient value of regression for the respective aircrafts. This statistical proof is in line with the theoretical basis that longer flight routes offer more of cruising time, (which utilizes lesser fuel than take-off and climb stages of flight), which thus reduces the per km emission for the whole flight.

4.6 Variations in Take-off Weight

Table4.3: R^2 and gradient values for correlation with TOW

TOW (Tons) vs.	Correlation R^2 value			Regression Line Gradient		
	A330	B757	A320	A330	B757	A320
Fuel on Board (Tons)	0.687	0.813	0.640	1.058	1.184	1.140
Route Distance (km)	0.231	0.450	0.342	0.005	0.005	0.002
Occupancy(%)	0.273	0.175	0.075	38.56	17.33	8.50

Data for all three types of fleet show that the fuel on board is a major variable playing role in variations of TOW. That is also why FOB is a major contributing variable of CO_2 emission as depicted in Table 4.3. Route type (represented by route distances) have average role to play in variations of TOW. Also, as seen in the data, number of passengers has as much more driving force in changes in TOW. Also, the gradient for A330 aircraft for TOW vs. pax has the largest value, which means that number of passengers is also an important factor for TOW even though as a whole, the pax doesn't have much driving force on CO_2 emission.

4.7 Effect of Engine Utilization on CO_2

Graphs of CO_2/engine utilization hour were plotted for individual aircraft to look into the effect of engine aging on the carbon emission. Representation of the data per aircraft along with the fleet type also helped find out maintenance status of the aircraft pertaining to its engines.

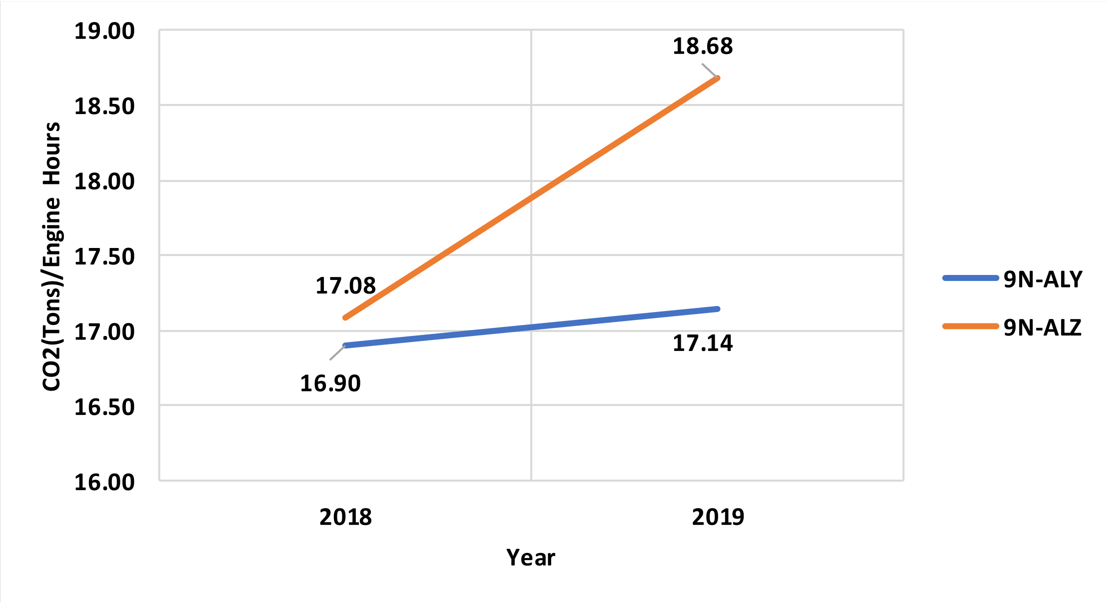


Figure4.4: CO_2 emission with respect to Engine Utilization for A330 aircrafts

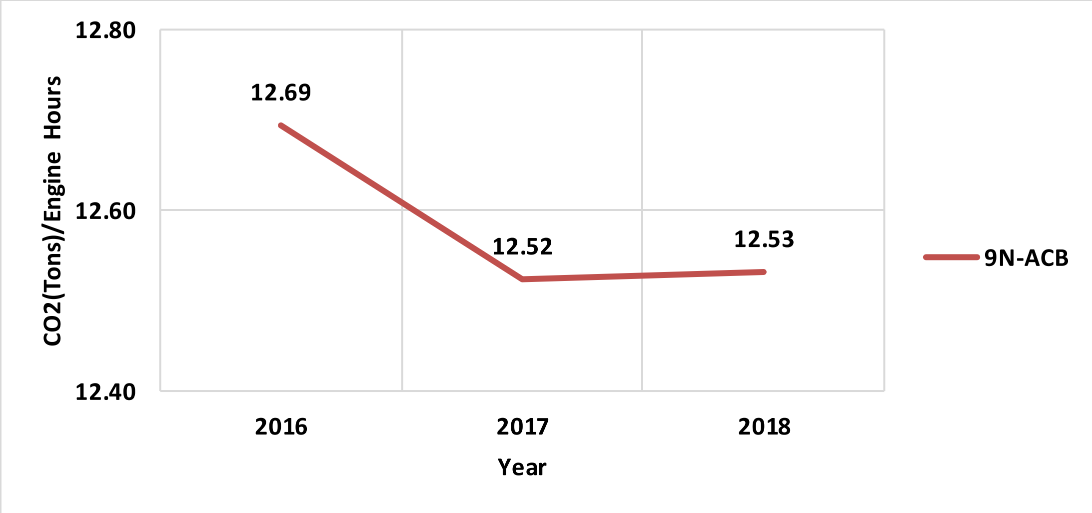


Figure 4.5: CO_2 emission with respect to Engine Utilization for B757 aircraft (9N-ACB only)

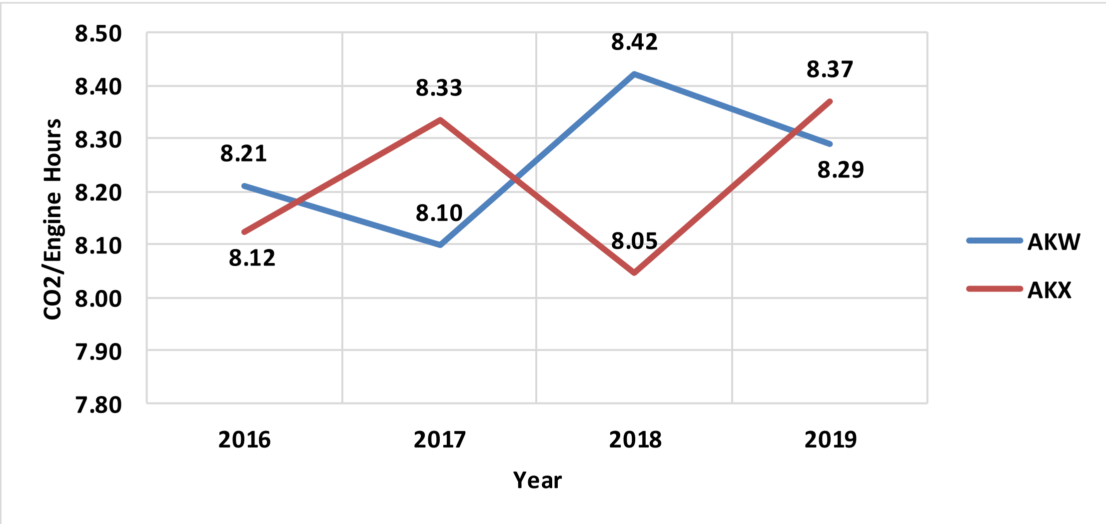


Figure4.6: CO_2 emission with respect to Engine Utilization for A320 aircrafts

The figures for CO_2 emission with respect to engine utilization for all aircraft (except 9N-ALZ) show that the CO_2 emission variation over time is in the range of ±0.35 tons of CO_2/engine hour utilization. This shows that there isn’t significant change in carbon emissions with respect to the engine utilization, or aging. However, the data for A330 aircraft, 9N-ALZ, carbon emission increase by 1.6 tons/engine hour from 2018-2019. This could be some on-going engine-related problems, hard operation, or lapses in maintenance practices. Even though the CO_2/engine hour fluctuates over the years, there is a slight increasing trend for both A320 and A330 aircrafts. The subtle increase in CO_2 emission is attributed to engine wear and tear as amidst compliance to maintenance requirements laid out by aviation authorities or OEMs.

Until such time comes when allowable engine parameters are met, the rate of carbon emission may increase. After that, the engine must go under inspection/overhaul under hard time use or overhaul as per its predefined life (called Life Limited Parts or LLPs), the objective of which is to restore back the performance of engines. Study of engine emission before and after such shop visit could put light on the effect of engine maintenance on performance of an engine.

4.8 CO_2 emission by APU

An APU (Auxiliary Power Unit) is commonly provided in large aircrafts to provide power during in-flight engine failure, engine starting, electrical power and, air-conditioning on ground. Sometimes the maintenance staff or cockpit crew also use APU as a means of lighting and electrical power during maintenance or flight preparation when Ground Power Units (GPU) are not available.

Graphs were prepared to find out the contribution of APU use in carbon emission and its variation over time that can give insight into operational use. For B757 aircraft, APU data has not been well documented and as such, this paper analyses the data for A330 and A320 aircrafts.

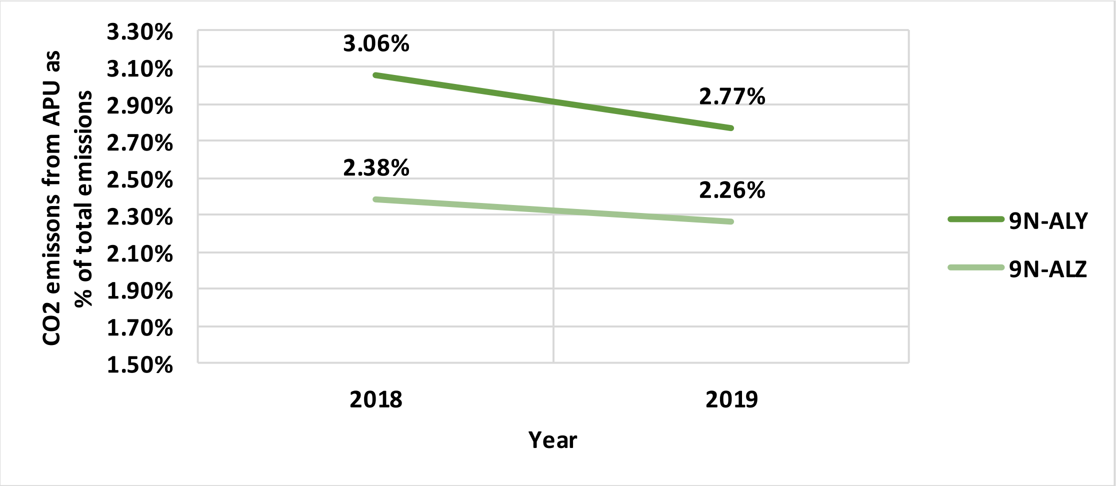


Figure4.7: CO_2 emission from APU as % of total emissions for A330 aircraft

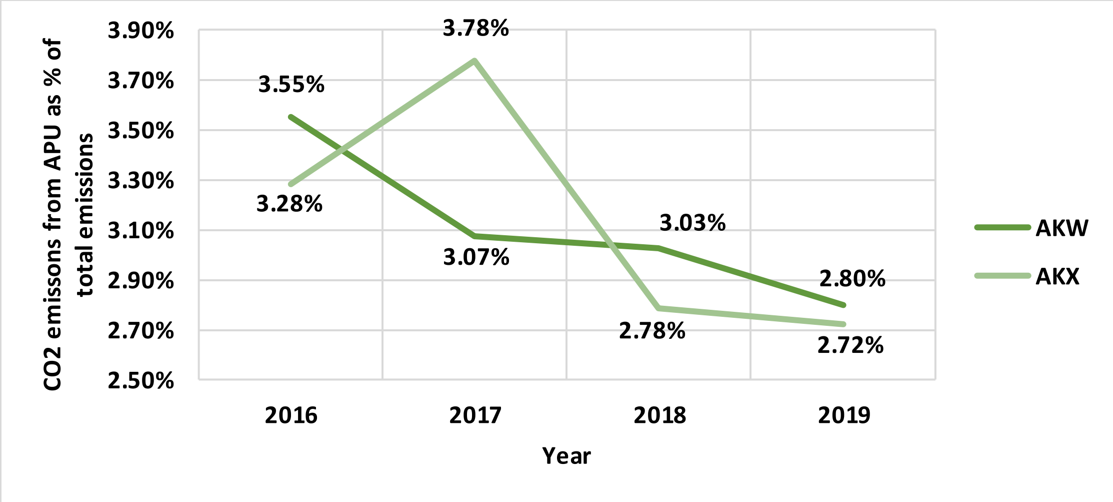


Figure4.8: CO_2 emission from APU as % of total emissions for A320 aircraft

APU used in NAC's A330 aircraft is Honeywell GTCP331-350 whose fuel consumption per hour with maximum electrical and air conditioning load is taken as 210kg as per Airbus (Airbus, 2004). The APU used in NAC's A320 aircraft is Pratt and Whitney APU APS 3200 with fuel consumption rate of 142kg/hr as per P&W (Pratt and Whitney, 2020).

Industry standards puts APU fuel use as around 3% of the total fuel burn. This fact is proven by the statistical data presented in figure 4 and 5. If we look at the yearly variation, we can see that there is a slight declining trend in APU emission with time. Even though the APU use hours are increasing over time, the ratio of APU emission per total emission is reducing.

4.9 Comparison of Aircrafts Based on Specific CO_2 Emission

A standard parameter used to measure the carbon emission efficiency of different aircrafts is CO_2/pax-km, which removes the passenger and distance factor, which are different for different fleet configuration and individual flights. Thus, this parameter can be used to compare CO_2 emission among different aircrafts with aggregated data per year.

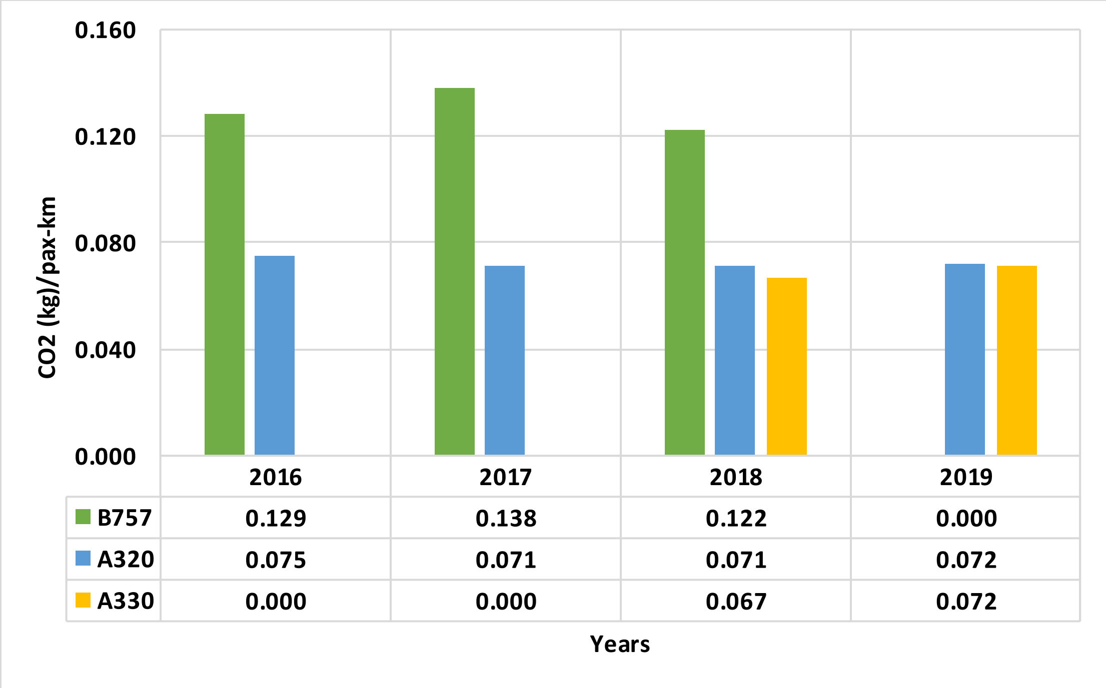
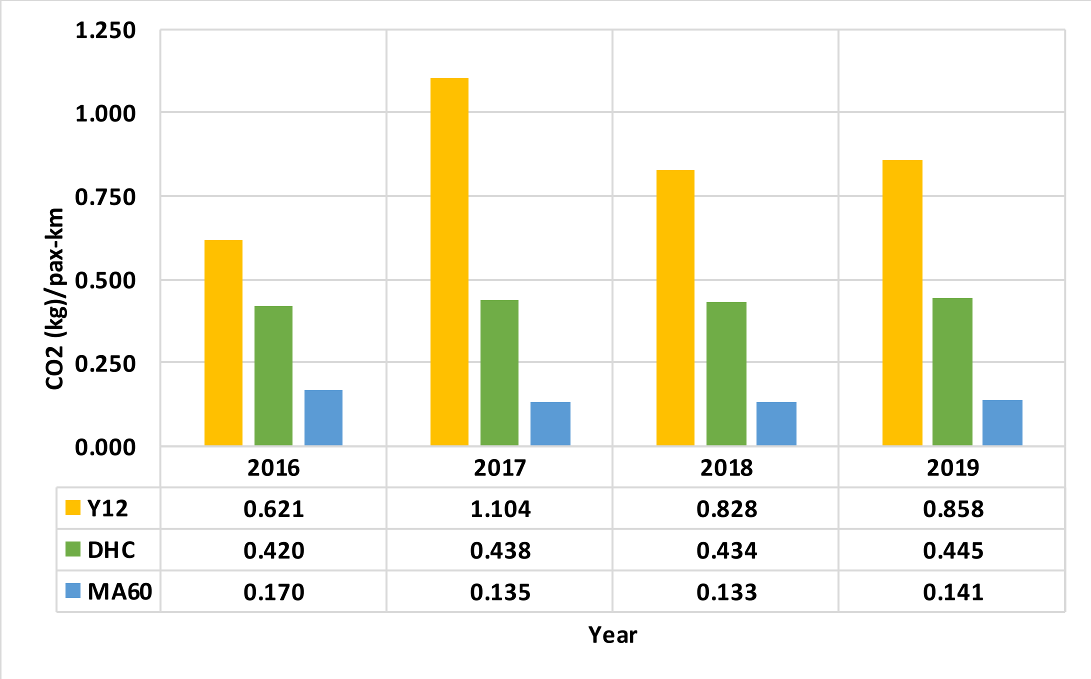


Figure4.9: CO_2/pax-km for turbofan aircrafts

As seen in Figure 4.9, the carbon emission per passenger and kilometer of flight travel depicts that newer aircraft contribute to lesser carbon emission. B757 aircraft is actually an older aircraft which is no longer in extensive commercial use in the world. This aircraft type is more than 35 years old and NAC's B757 aircrafts were in fleet for more than 30 years.

In contrast, NAC's A320 aircrafts are just over 4-5 years old while the A330 aircrafts are only over 1 years old as of 2019. A320 and A330 are one of the leading commercial aircrafts used for short and long-haul flight respectively. The statistical data thus shows that the older, B757 aircraft emits more specific carbon emissions than its newer counterparts i.e. A330 and A320. Also, A330 aircraft demonstrates better emission efficiency probably because it is newer than A320 aircraft.



	2016	2017	2018	2019
Y12	0.621	1.104	0.828	0.858
DHC	0.420	0.438	0.434	0.445
MA60	0.170	0.135	0.133	0.141

Figure4.10: CO_2/pax-km for turboprop aircrafts

Figure 4.10 shows the same parameter for NAC's turboprop aircrafts which are operated in domestic sectors. As seen, Y12-E aircraft has the highest per passenger per km carbon emission capacity among the turboprop aircraft, followed by DHC-6/300 and MA60 aircraft. The chart is arranged in increasing number of seat capacity. The results obtained could be so because of the large sensitivity of passenger numbers per flight of respective aircrafts. Lower seat capacity means that even one passenger has capacity to differ the carbon emission per person by a large extent. The rule of newer aircraft being more efficient does not apply much to turboprop aircrafts as seen from the obtained results.

The information also shows that turboprop aircrafts in summation is less efficient in terms of carbon emission. This could be due to the inherent characteristics of turboprop aircrafts which have less seat capacity, less MTOW or their cruise altitude being lesser than their turbofan counterparts. Another major cause of this high carbon emission could be attributed to the fact that full passenger occupancy is not obtained probably due to shortcomings in commercial planning (NAC being national flag carrier of Nepal flies to many destinations in Nepal, a good portion of which, have poor passenger load, but NAC opts to operate in these sectors as a gist of service rather than commercial business).

Also, there is underlying factor that NAC's turboprop aircrafts, DHC-6/300 and Y12-E are operated in STOL (Short Take-off and Landing) sectors which often are in higher altitudes, downgrading the maximum passenger carrying capacity for some high-altitude flights. Also, in case for MA60, trunk routes are operated which are mostly in Nepal's Terai region where during summers, the hot, humid climate plays an evil role in decreasing the maximum allowable passenger capacity.

4.10 CO_2 Forecasting for NAC

Crystal Ball Predictor with iterations of 5,000 was carried out to predict the CO_2 emissions till 2030 with two scenarios: taking historical data from 2016 to 2019 and taking historical data from 2016 to 2019 plus approximate values for 2020 considering no flights in first half of 2020 and corresponding flight schedules (commercial only) pertaining to COVID-19 situation.The approximate values of CO_2 emission were calculated by counting the number of prospective flights in different routes in 2020 from flight schedules prepared by NAC.

- Flights in 2020 were affected in the following ways due to COVID-19:
- Commercial flights upto March 1st were opertaing normally.
- From March 2nd to September 1st, all commercial flights were suspended, only repatriation and charter flights were being operated.
- From 2nd September, flights started to resume, but as of end of 2020, flight operations were operating at only 25-30% of the previous normal level.
- Assumption: Flight opeations will be 25% of normal level till March 15th, 2021 which will gradually grow to 100% by end of 2021.

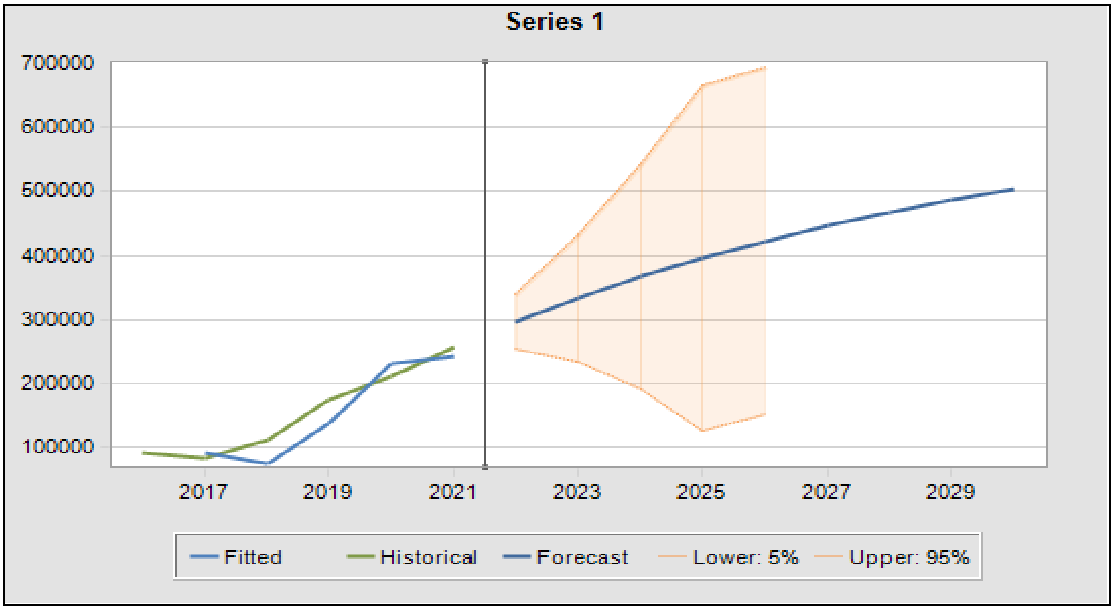


Figure4.11: CO_2 emission forecast for NAC till 2030 including data for 2020 with base data from 2016-2019(historical data only)

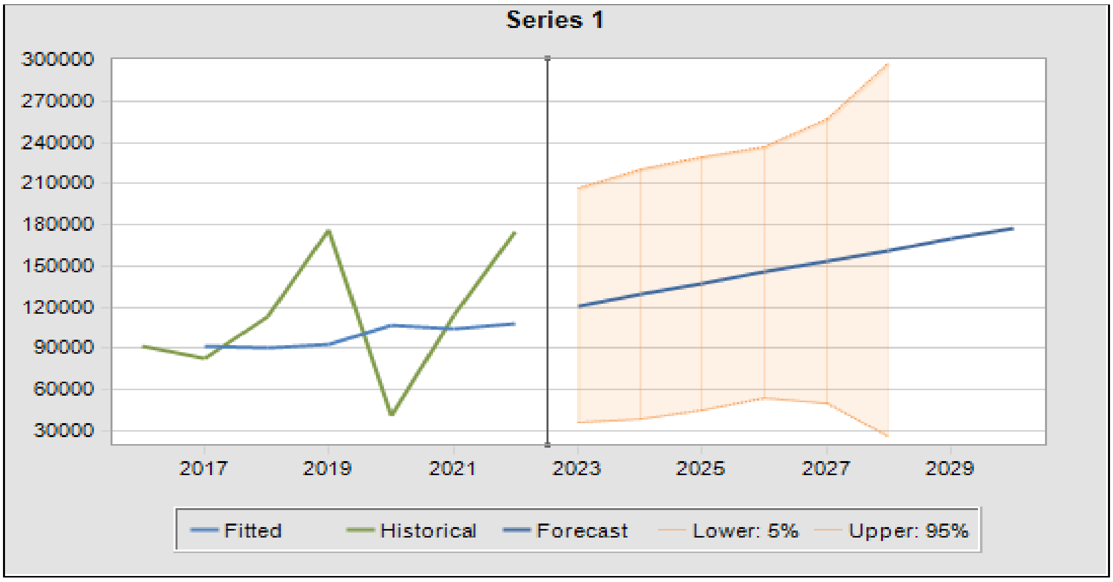


Figure4.12: CO_2 emission forecast for NAC till 2030 including data for 2020 with base data from 2016-2020 including effects of COVID-19 on flights

As seen in the figures, there is substantial effect of COVID-19 in the annual CO2 production rate along with the effect of decommissioning of Y12E and MA60 aircrafts. The best fitted forecast model was Damped Trend without seasonality which brought the CO_2 emission to 178,025 tons in year 2030. This value is almost equal to that of the value in 2019. The possible variations in this value for the year, 2025 stands at 45,420-229,555 (i.e., 26%-131% of total 2019 emission with 90% confidence interval.

The prediction model for CO_2 emission without taking flight reductions due to COVID-19 showed that the CO_2 value in 2030 would be 503,584 tons, which is nearly thrice the value of 2019 production. The possible variations in this value for the year, 2025 stands at 45,420-229,555 (i.e., 26%-131% of total 2019 emission) with 90% confidence interval.

This shows that the COVID-19 situation has caused a drop in flight operations which could affect the CO_2 emissions till 2030, after which the net production may increase from 2019 values. Detailed data for the results obtained from CB predictor are presented in Appendix B.

4.11. Development of Mitigation Scenarios

From the regression and correlation analyses between different CO_2 emission parameters and flight parameters, mitigation analysis has been able to be done. Possible mitigation and offsetting measures for turbofan aircrafts have been discussed here.

4.11.1 Route Optimization

The correlation and regression analysis between CO_2/km and route distance show that longer distances offer lower carbon emission per km flown. On average, A330 and A320 can have deduction of 1.7 tons and 1.2 tons respectively of carbon emission per 1000 km flown. As such, short haul flight sectors like Kathmandu-Delhi, Bangalore, or Mumbai are not feasible sectors for A330 aircraft. Even for A320 aircraft, the Kathmandu-Delhi is not a good sector owing to the high carbon emission per km in this sector. However, the occupancy rates for Delhi flights are very good and is important from economic standpoint. In this backdrop, existing Kathmandu to Indian city pair flights are best fitted for A320 aircraft, and not A330 aircraft.

Mid-to-long range destinations like Bangkok, Kuala Lumpur, Hong Kong, Dubai and Doha are fairly good for both A320 and A330. However, since A330 is a wide body aircraft and has longer range, it is best suited for existing Osaka/Narita flights which are long-haul flights. NAC could reduce its carbon emission values by flying narrow body aircraft in short-haul and wide-body aircraft in long-haul aircraft. Also, in future, if aircrafts are added to the existing fleet, newer (already proposed) destinations like Incheon and Riyadh should be allocated for A330 aircraft. For A320 aircraft, new proposed sector like Guangzhou could be more emission -friendly.

Apart from improving the carbon emission per km, NAC could reduce the carbon emission greatly if it applies ETOPS (Extended Twin Engine Operations) for its international sector aircrafts. ETOPS, as the name implies, is a rule that allows aircrafts to fly longer distances away from airports (like seas and deserts). The existing routes of NAC are non-ETOPS which means that flight routes are prepared in such a way to fly very near to existing airports.

Even though Airbus A330 and A320 aircrafts are ETOPS certified by the OEMs, they still need the operator (i.e., NAC)'s preparations in terms of fulfilling regulatory requirements (related to flight operations and maintenance) to be able to fly on ETOPS routes. If NAC is approved to carry ETOPS flight, destination airports can be flown to via more direct routes than on the paths defined by availability of airports, as shown in the figure below. As the route distance itself decreases, CO_2 emission also decreases.

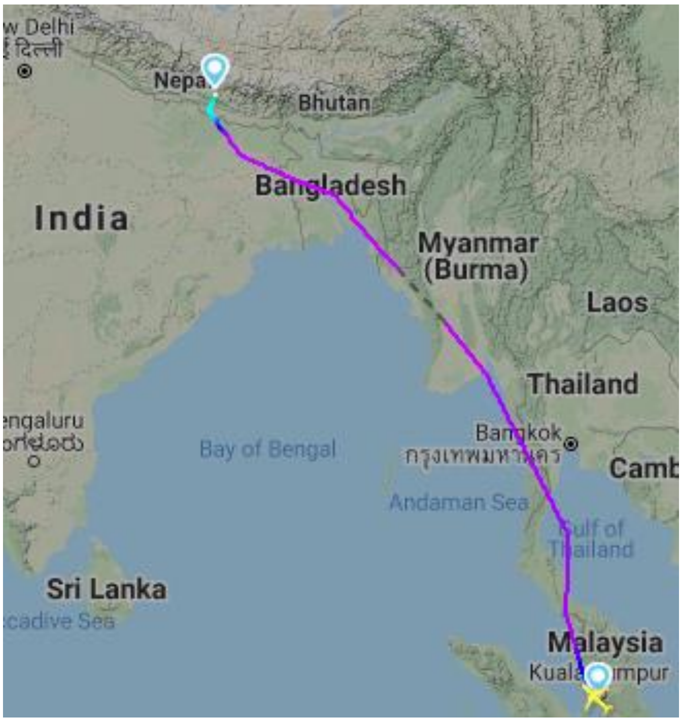


Figure4.13: A Flight Radar flight path for Flight No: RA416 for a flight of 2020 via NAC's A320 aircraft for KUL-KTM flight (Source: www.flightradar.com)

As an example, Figure 5.1 shows the actual flight path from Kuala Lumpur to Kathmandu is such that the aircraft flies very less time over the oceans. This is because NAC cannot yet operate ETOPS flight. If NAC could operate this flight based on ETOPS rules, flights routes would allow aircrafts to fly directly to Kathmandu over the Bay of Bengal which could substantially reduce the route distance and thus CO_2 emission also.

4.11.2 Optimum Fuel Planning

The fuel carried on board has a prominent effect on the take-off weight and in turn the CO_2 emission. As discussed earlier, one-ton addition of FOB could increase the carbon emission by 1.78 tons for A320 and 2.63 tons for A330 aircraft. The study of fuel required per sector as per fuel policy of NAC and general airlines operators versus the actual FOB show that there is additional fuel carried on board than is required for the sector. Additional fuel than the required quantity is carried on board mostly on discretion of the Pilot in Command (PIC) with a mindset of preparation for on-route weather conditions or other safety reasons. However, we can demonstrate safe values for FOB in different sectors through the historical data of actual fuel burn. By this way, we can safely reduce the FOB and also reduce the carbon emissions to a good extent.

4.11.3 Carbon Taxing

Carbon tax is a concept wherein, taxes are included in air fare that gains revenues for the airline operator which can be used to buy carbon credits from credible sources in order to offset the carbon emission that it makes. Moreover, the airline operator can also invest independently in non-carbon emitting projects like clean energy infrastructures to offset the carbon it produces during flight operations.

Table4.4: R^2 and gradient values for correlation with CO_2/pax

CO_2/pax vs.	Correlation R^2 value			Regression Line Gradient		
	A330	**B757**	**A320**	**A330**	**B757**	**A320**
Route Distance (km)	0.404	0.326	0.719	0.00006	0.00006	0.00005

A correlation and regression analysis of CO_2/pax versus the route distance shows that there is fair correlation between the route distance and CO_2/pax. The gradient value of regression line shows that the CO_2/pax value is almost constant with number of passengers. This implies that a constant rate of tax could be added to air fare of all air routes irrespective of the route distance.

Even though the main agenda of carbon taxing is to gain extra revenue for the airline operator to invest in carbon friendly projects, effects of carbon tax could be negative, like decrease in air travel or shift towards automotive transportation which could increase automotive carbon emission while decreasing aviation emission on one hand. But it is pointed that there will be net CO_2 reductions in aggregate as per Hofer et. al.

4.11.4 Slot Management

Slot management refers to planning of flight departure and arrival times. Many-a-while, flight delays occur, or flight times are extended because there is much traffic on ground for take-off, taxiing and landing. In case of Kathmandu airport, the problem lies in airport bays for aircraft turn around which leads to holding while arriving at the airport. In case of foreign airports, large volume of on ground aircraft movement and in some cases, weather conditions cause the flight time to be stretched especially during taxiing phase. As the flight time directly affects the CO_2 emissions, proper slot management of departure and arrival at different airport according to their least traffic timings could provide carbon emission reductions. This is easy to say, but to implement, there is need for cooperation between airlines and the airport authorities/service providers to cater to reduction in flight hours as each airline wants least air time for itself and planning with cooperation can create a win-win situation for all airlines. Wherever possible, slot planning should be done keeping in mind to reduce the flight's air time.

4.11.5 Shift towards newer aircrafts

As is discussed in Figure 4.8, newer aircrafts produce lesser per capita CO_2 emissions than the older counterparts. Thus, if NAC were to expand its fleet, it should opt for buying aircrafts of newer technologies.

It should be borne in mind that when selecting newer aircrafts, the mainstream aircrafts should be of choice because of its proven performance and easy access to OEM's operational and maintenance support for airline operators.

4.11.6 Monte Carlo Simulation for Quantification of CO_2 Reductions

Monte Carlo simulation allows independent variables to change with a certain number of trials so that the total variations in dependent variables can be obtained. In cases where real data are not available, a pre-conceived distribution type and limits for the independent variables are set. However, in the case of this research, actual historical data are available, which is very helpful in automatically generating the limits and probability distributions for the independent variables.

Table 4.1 summarizes the correlation parameter, R^2 value between CO_2 and parameters which are deemed causing factors of the carbon emission. Considering only R^2 values which are greater than 50%, we have flight time, route distance and FOB as the major contributing factors of CO_2 emission. A multiple regression equation was formed using these variables, whose equation is as follows:

$$CO_2 = -0.00039 * Route\ Distance + 7.241 * Flight\ Time + 0.5288 * FOB - 3.448 \quad (5.1)$$

Flight time and FOB have been identified as the controllable variables here while changes in route distance need more planning with wider scope of efforts. As there is a trend of increase in flight time over the years, the flight time has been considered to be kept to the level of 2016 values. The required FOB has been calculated from fuel policies of different airline operators whose main contents are:

- Taxi Fuel – Fuel required for engine start, taxi and APU use => 200kg for A320 aircraft
- Trip Fuel – Fuel required for normal flight from take-off and landing => taken average from historical data
- Reserve Fuel – Includes contingency fuel, alternate fuel, final reserve fuel and additional fuel => Fuel for 5-10% of trip fuel, go-around to cruising altitude and landing and holding of 45 minutes at holding speed at 1500 ft.
- Extra Fuel => Extra fuel on discretion of PIC (Pilot in Command)

Using this theory, the required FOB for different sectors has been calculated. A320 is a mid-range aircraft and in case for NAC, KTM-DEL-KTM (Distance = 926/928 km) is considered a short-haul flight and KTM-DOH-KTM (Distance = 3669/3724 km) is considered a long-haul flight for A320 aircraft.

The following is an Excel screenshot of actual vs. recommended fuel on board requirements for different sectors of A320 aircraft during 2019:

Table4.5:Excel screen with calculation of ideal FOB and its difference with actual FOB as per NAC's fuel policy

From	To	Distance (km)	Mean CO_2(Tons)	FOB (Tons)	Ideal FOB (Tons) as per Historical Data/Fuel Policy						Ideal FOB (Tons)	Extra Actual FOB (Tons)	Extra CO_2 (Tons)
					Fuel Burnt (Taxi+Trip)	Fuel Burn per Hour (Tons/hr)	Alternate Fuel	Contingency Fuel	Final Reserve Fuel	Add-itional Fuel			
KTM	DEL	926	13.72	11.07	4.34	2.83	0.71	0.24	2.60	0.71	**8.60**	**2.47**	**7.80**
KTM	BLR	2145	22.06	13.07	6.98	2.66	0.66	0.37	2.44	0.66	11.12	1.95	6.15
KTM	BOM	1902	21.41	18.41	6.78	2.68	0.67	0.36	2.46	0.67	10.93	7.48	23.63
KTM	KUL	3595	33.31	14.41	10.54	2.47	0.62	0.55	2.27	0.62	14.59	-0.18	-0.57
KTM	BKK	2363	25.93	14.37	8.21	2.64	0.66	0.43	2.42	0.66	12.38	1.99	6.27
KTM	HKG	3493	27.84	16.30	8.81	2.43	0.61	0.46	2.23	0.61	12.72	3.58	11.31
KTM	DOH	3669	41.20	17.71	13.04	2.67	0.67	0.68	2.44	0.67	**17.49**	**0.22**	**0.70**
KTM	DXB	3341	35.75	15.54	11.31	2.41	0.60	0.59	2.21	0.60	15.31	0.23	0.72
DEL	KTM	928	14.50	10.19	4.59	3.14	0.78	0.26	2.88	0.78	**9.29**	**0.90**	**2.85**
BLR	KTM	1993	21.79	13.69	6.90	2.92	0.73	0.37	2.67	0.73	11.40	2.29	7.24
BOM	KTM	1778	20.25	14.72	6.41	2.83	0.71	0.35	2.59	0.71	10.76	3.96	12.50
KUL	KTM	3537	39.00	17.55	12.34	2.72	0.68	0.64	2.50	0.68	16.84	0.71	2.25
BKK	KTM	2391	27.24	14.85	8.62	2.78	0.70	0.46	2.55	0.70	13.02	1.83	5.79
HKG	KTM	3519	38.67	17.72	12.24	2.69	0.67	0.64	2.47	0.67	16.69	1.04	3.28
DOH	KTM	3724	34.68	17.95	10.97	2.73	0.68	0.57	2.50	0.68	**15.41**	**2.54**	**8.03**
DXB	KTM	3150	32.65	17.98	10.33	2.78	0.70	0.54	2.55	0.70	14.81	3.17	10.01

As such, Monte Carlo simulation was carried out to find the possible CO_2 reductions in these flights. Probability distribution and limits for independent variables were generated from historical data of 2016-2019 while the formula for forecast value for CO_2 is: (Route distance and constant terms cancel out.

$$\Delta CO_2 = 7.241 * \Delta Flight\ Time + 0.5288 * \Delta FOB \quad (5.2)$$

Where,

Δ Flight Time = Actual Flight Time –Optimum Flight Time

Δ FOB = Actual FOB – Optimum FOB

The actual values will be changed by the simulation while the optimum values have been obtained from the methodology explained above. Carrying 5,000 iterations, the results obtained are as follows:

Table4.6: Monte Carlo Simulation Results for CO_2 reductions

Sector	**From**	**To**	**Certainty of CO_2 reductions**	**Maximum possible CO_2reduction with 50% certainty**
Short-haul	KTM	DEL	75.47%	1.69 Tons
	DEL	KTM	93.74%	2.19 Tons
Long-haul	KTM	DOH	85.78%	3.35 Tons
	DOH	KTM	93.87%	3.55 Tons

As seen in the table above, out-bound flights from Nepal have lesser certainty of CO_2 reductions than the in-bound flights. This could be due to economic value of fuel in Nepal being more expensive than foreign countries, which might have opted pilots to carry more fuel during in-bound flights.

Another finding is that short-haul flights have lesser opportunity for CO_2 emission than long-haul flights. In average, with reductions in flight time (through better management strategies) and FOB, reductions of up to 2.19 tons in short-haul sector and 3.55 tons in long-haul sector could be achieved with 50% certainty. The simulation results have been attached in Appendix B.

CHAPTER FIVE

CONCLUSIONS AND RECOMMENDATIONS

Carbon footprint in terms of CO_2 emission of Nepal Airlines Corporation has been evaluated for its flight and ground handling operations from 2016 to 2019 using actual flight data.Results of data analysis using Excel tools show that CO_2 emission from a multi-fleet airline like NAC has most of its carbon emission coming from larger aircrafts and should concentrate to emission mitigation based on its large aircraft fleet.

The results from correlation and regression analysis for international fleet show that CO_2 emissions are primarily affected by the flight time and route distance. Also, the fuel on board an aircraft for specific flight is also a parameter of interest since there is statistical relation between CO_2 emission and FOB, mostly due to the fact that more FOB increases TOW, which has effects on CO_2 emissions too. In most of the cases of international flights, more FOB is seen to be taken aboard on a flight than what is required for that particular flight as per the calculations of fuel policy. Reductions in FOB could be suggested for operating flights of NAC to demonstrate practical reductions in net CO_2 emission of NAC.

Air time of various city pairs are fluctuating over time most of which are increasing. Even a small amount of increase in flight time such as 5 minutes can increase CO_2 to a great extent incase of large aircrafts. The problem seems to lie in destination and departure airports being congested. This could be mitigated by doing planning of airport slots for minimal flight and turn-around time.

Through reductions in FOB(by adhering to company fuel policy), and air time (by keeping air time constant as 2016 levels), Monte Carlo Simulation shows that NAC could possibly reduce carbon emission amounting to an average of 1.94 tonnes and 3.45 tonnes of CO_2 per flight operation of A320 aircraft in its short and long haul destinations respectively in future.

There isn’t a good statistical relation between the number of passengers (for larger aircrafts) and thus, passenger number is out of equation for mitigation analysis in international-sector fleet. One of the main underlying reasons to this type of relation being non-existent might be because of the fact that airline operators do not explicitly measure each passenger's weight, which could have affected the TOW for different flights in a randomly varied way.

Engine utilization has some effect on the net CO_2 emissions (i.e., increasing effect) mostly because of gradual wear and tear of engine parts, components, and aerodynamic structures.

In case for domestic-sector operating smaller aircrafts (turboprop aircrafts), reduction in carbon emission could be obtained from increasing its passenger occupancy rate through better commercial strategies while for internationally-operating larger aircrafts, there are various possible methods by which an airline operator like NAC could make net reductions in its CO_2 inventory.

The emission from ground handling operations of NAC for 2019 is equal to 0.4% of the total emission from flight operations of NAC alone. As such, NAC's mitigation measures concentrated on international fleet aircraft operations rather than in other areas could generate large impact in carbon emission reductions for NAC as a multi-fleet airline and ground handling operator.

With the existing fleet in operations with normal flight, for NAC, the carbon emissions levels for NAC in 2030 could be 2.9 times the 2019 levels. If the COVID-19 effects on flight operations are considered, the 2030 levels would be around the same as of 2019 levels. This forecasting being presumed under the conditions as considered would most likely render values for 2030 within 1-2.9 times of the 2019 values considering NAC would add aircrafts to its fleet and that it will take some years to increase air travel subsequent to COVID-19 pandemic.

With the above conclusions at hand, a most valid recommendation for Nepal Airlines would be to account its CO_2 emission inventory as per CAAN's CORSIA program and carry out detail study on fuel requirement for each city pair and its effect on take-off weight as well as fuel consumption. NAC should strongly begin considering to carry out its international flights using ETOPS rules to make possible reductions in fuel consumption and fuel to be carried. The Commercial Department of NAC could also play an important in reducing CO_2 emission by planning transit in airports with lesser congestion and during times where congestion is least. For this, an optimum time and airport location should be selected considering both, costing plus revenue collection and emissions. It is also high time to impart a small percentage (constant for all types of destinations and aircraft type) of ticket price with detailed study that would generate revenue for gradual investment/support for green energy systems. This will ensure a gradual carbon emission offsetting along with mitigations in the coming years.

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APPENDICES

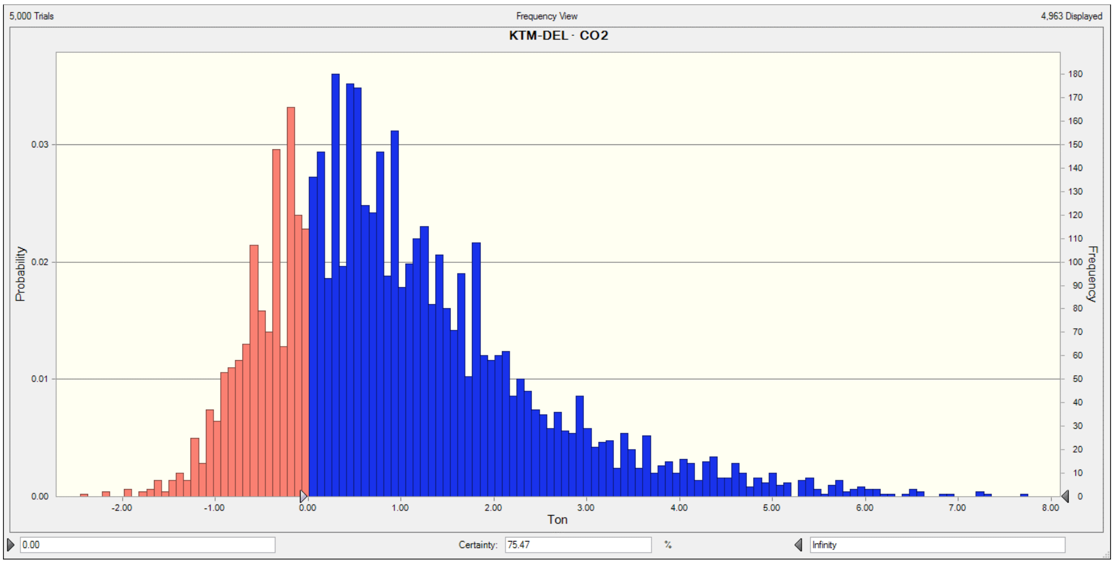
Appendix A1: *Route distance between city pairs for international sectors*

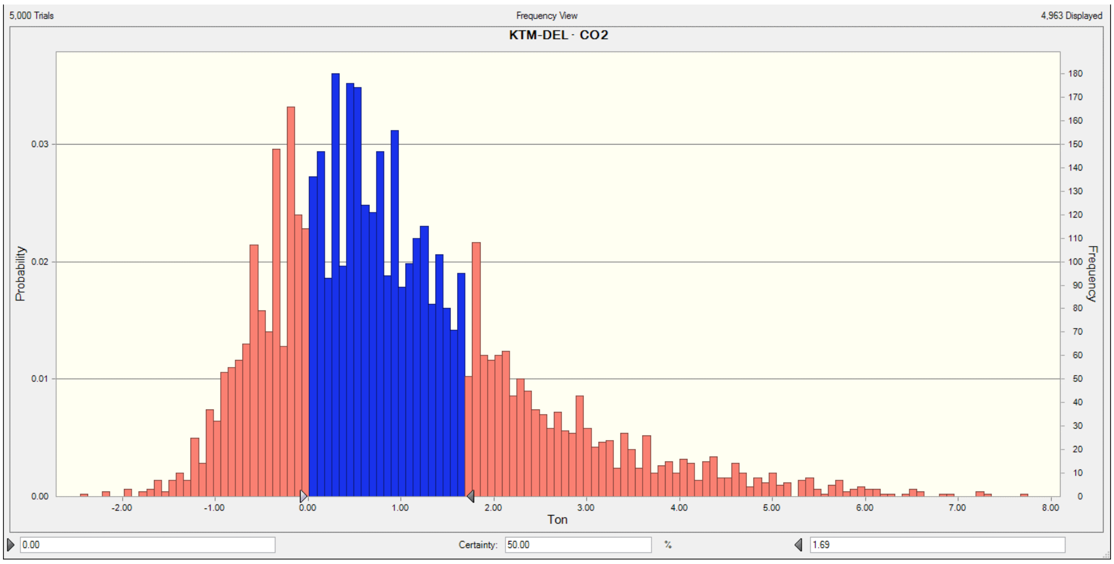
IATA Code for Airports		From	To	Route Distance (km)	From	To	Route Distance (km)
KTM	Kathmandu						
DEL	Delhi	KTM	DEL	926	DEL	KTM	928
BLR	Bangalore	KTM	BLR	2145	BLR	KTM	1993
BOM	Mumbai	KTM	BOM	1902	BOM	KTM	1778
KUL	Kuala Lumpur	KTM	KUL	3595	KUL	KTM	3537
BKK	Bangkok	KTM	BKK	2363	BKK	KTM	2391
HKG	Hongkong	KTM	HKG	3493	HKG	KTM	3519
DOH	Doha	KTM	DOH	3669	DOH	KTM	3724
DXB	Dubai	KTM	DXB	3341	DXB	KTM	3150
KIX	Osaka	KTM	KIX	5495	KIX	KTM	5484

Appendix A2: *Route distance between city pairs for domestic sectors*

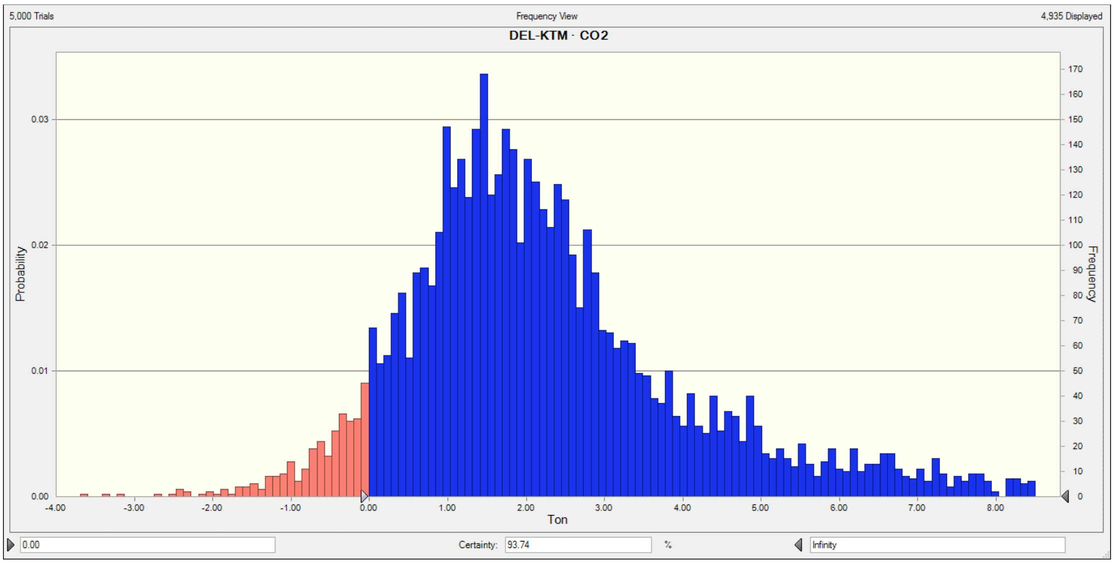
IATA Code for Airports		From	To	Route Distance (km)	From	To	Route Distance (km)
KTM	Kathmandu	KTM	PPL	133	PPL	KTM	133
PPL	Phaplu	KTM	TPJ	254	TPJ	KTM	254
TPJ	Taplejung	KTM	BGL	181	BGL	KTM	181
BGL	Baglung	KTM	BHP	172	BHP	KTM	172
BHP	Bhojpur	KTM	LUA	144	LUA	KTM	144
LUA	Lukla	KTM	HRJ	80	HRJ	KTM	80
HRJ	Chaurjhari	KTM	RUK	96	RUK	KTM	96
RUK	Rukum	KTM	LDN	119	LDN	KTM	119
LDN	Lamidanda	KTM	RUM	102	RUM	KTM	102
RUM	Rumjatar	KTM	TMD	183	TMD	KTM	183
TAL	Talcha	KTM	TAL	152	TAL	KTM	152
IMK	Simikot	KTM	HRJ	80	HRJ	KTM	80
FEB	Sanfebagar	KTM	IMK	215	IMK	KTM	215
DOL	Dolpa	KTM	FEB	133	FEB	KTM	133
BJR	Bajura	KTM	DOL	156	DOL	KTM	156
BIR	Biratnagar	KTM	BJR	157	BJR	KTM	157
DHI	Dhangadi	KTM	BHP	78	BHP	KTM	78
KEP	Nepalgunj	KTM	BIR	232	BIR	KTM	232
BDP	Bhadrapur	KTM	DHI	489	DHI	KTM	489
PKR	Pokhara	KTM	KEP	370	KEP	KTM	370
SIF	Simara	KTM	BDP	294	BDP	KTM	294
BWA	Bhairahawa	KTM	PKR	146	PKR	KTM	146
DNG	Dang	KTM	SIF	67	SIF	KTM	67
LUA	Lukla	KTM	BWA	194	BWA	KTM	194
		KTM	DNG	124	DNG	KTM	124
		KTM	LUA	191	LUA	KTM	191

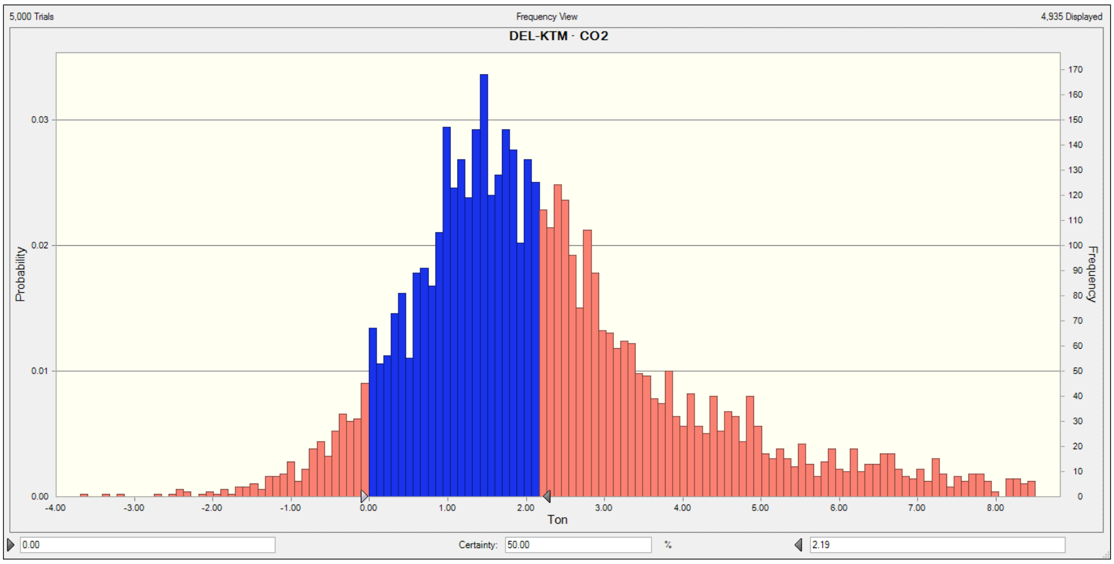
Appendix B1: *Simulation Results for CO_2 reductions in KTM-DEL sector*



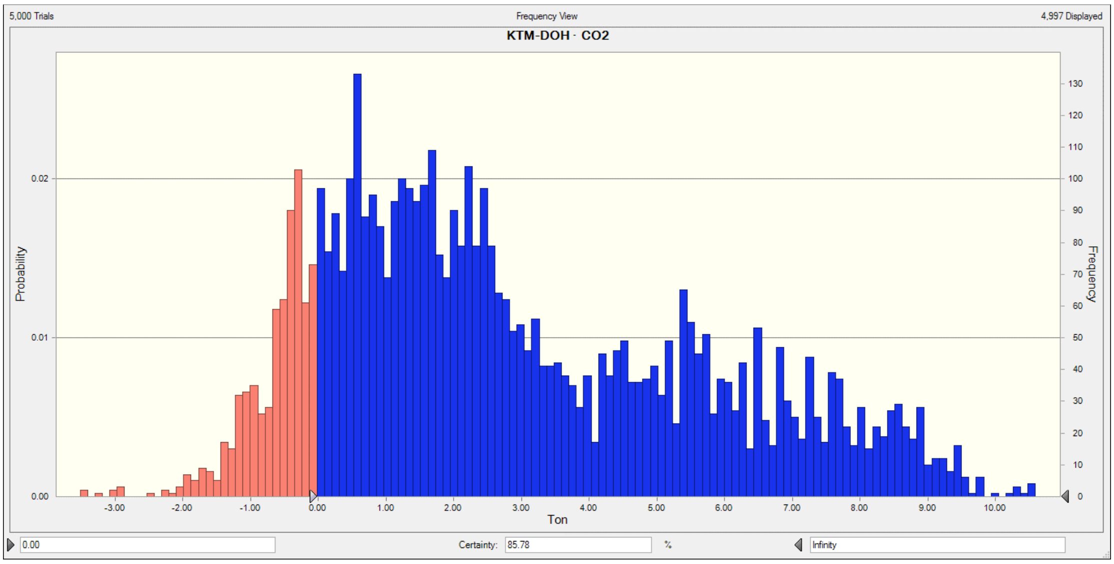


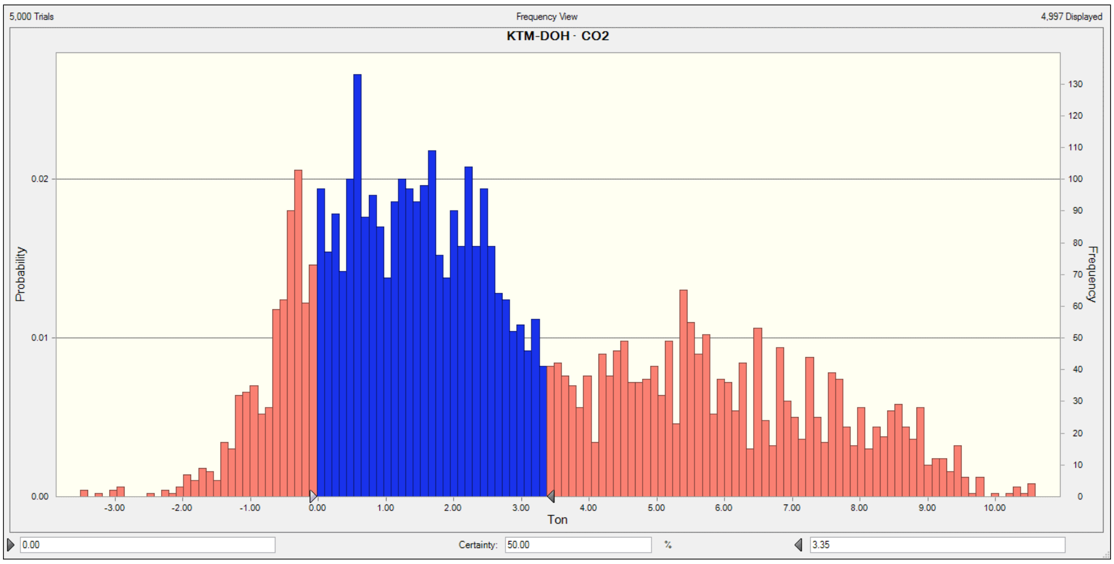
Appendix B2: *Simulation Results for CO_2 reductions in DEL-KTM sector*



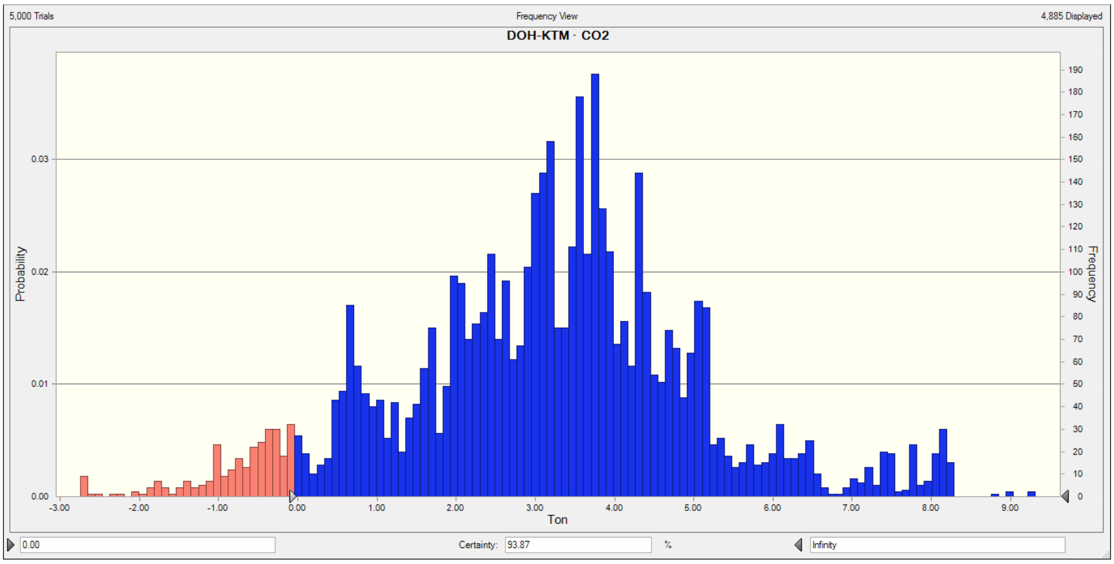


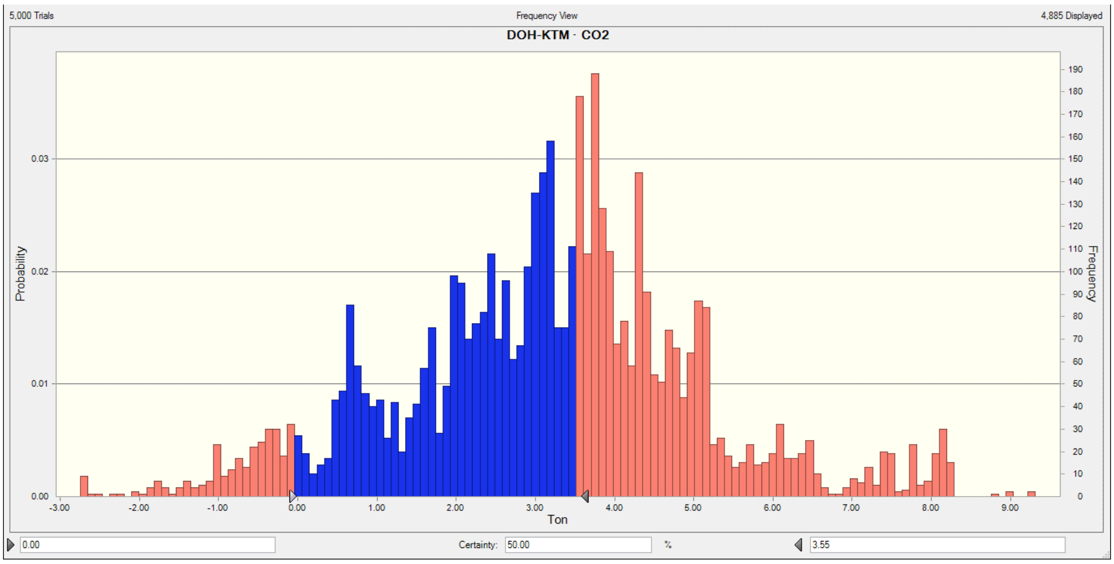
Appendix B3: *Simulation Results for CO_2 reductions in KTM-DOH sector*





Appendix B4: *Simulation Results for CO_2 reductions in DOH-KTM sector*





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INSTITUTE OF ENGINEERING
PULCHOWK CAMPUS

Department of Mechanical Engineering

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Institute of Engineering
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Our Ref. :-

Date:- 22/11/2018

Tribhuvan University
Institute of Engineering
Center for Energy Studies
1999

To:
The Director,
Continuing Airworthiness Management Department
Nepal Airlines Corporation
TIA, Kathmandu Nepal.

Subject : Availing of Necessary Data for Thesis

Dear Sir,

With reference to the above subject, a graduate student of our campus, Mr. Sandeep Tuladhar studying M.Sc. in Energy Systems Planning and Management and working in your corporation, is doing his dissertation on "Evaluation of Carbon Footprint and Mitigation Analysis for Nepal Airlines Corporation" under the department of Mechanical Engineering. As such, he requires historical data (preferably of more than five years) essential for the completion of his thesis, such as Technical Log Page (TLP) parameters of aircrafts in your corporation which includes aircraft type, route, date, fuel consumption, number of passengers (PAX)/load, airframe/engine hours and any other necessary data.

Thus, in this regard, I kindly request you to assist him in his thesis by providing permission to use the required data as mentioned, as this is for scholarly purpose. Your support is highly anticipated in this regard.

Permission granted for the use of data for scholarly purpose only & provided that a copy of thesis proposal is submitted to NAC

Dr. Shree Raj Shakya (PhD)
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Nepal Airlines Corporation
Operations Department
Regd. No. 741
Date: 2077-11-16
2021-02-28

To:
The Director,
Operation Department
Nepal Airlines Corporation
Kantipath, Kathmandu, Nepal

Subject: Availing of Necessary Data for Thesis

Dear Sir,

Pertaining to the above subject, I am a graduate student of M.Sc. in Energy Systems Planning and Management at IOE, Pulchowk Campus and am doing my dissertation on "Evaluation and Mitigation Analysis of Carbon Footprint for Nepal Airlines Corporation" The dissertation work requires Fuel Policy data stipulated in Operating Procedure of NAC, which would be beneficial to quantify carbon mitigation methods in my thesis.

Thus, in this regard, I kindly request you to assist me in my thesis by providing permission to use and cite the required data as mentioned, as this is for scholarly purpose. Your support is highly anticipated in this regard.

Yours Sincerely,
Sandeep Tuladhar,

(M.Sc. in Energy Systems Planning and Management)
IOE, Pulchowk Campus
Lalitpur, Nepal.

Approved as requested.
28/02/2021
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DIRECTOR OPERATIONS