Aviation and Climate Change: A Focus on Zambia's International Aviation Emissions

By

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Declaration

I, Lawson Hang'ombe Mapiki, declare that this dissertation which I hereby submit for the award of the Masters of Science Degree in Environmental and Natural Resource Management at the University of Zambia, is my own work and has not previously been submitted for any other degree at this or another institution.

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Certificate of Approval

This dissertation of Lawson Hang'ombe Mapiki has been approved as partial fulfilment of the requirements for the award of the Masters of Science Degree in Environmental and Natural Resource Management by the University of Zambia.

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Abstract

The aviation industry is one of the fastest growing sources of greenhouse gases (GHGs) emissions and accounts for about two percent of the global GHGs emissions. This study therefore endeavoured to assess on how a low carbon aviation industry could be enhanced in Zambia. Thus the study estimated the levels of international aviation emissions attributed to Zambia over a period of 10 years (2010 - 2019). It also examined the compliance levels of the aviation sector in Zambia against the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Standards and Recommended Practices (SARPs). In line with this, a mixed methods approach was used. Secondary data sets on emissions and the number of active aircraft over the 10-year period were used. Key informant interviews using interview guides were also used to collect qualitative data. Trend analysis was used to show trend in the international aviation emissions attributed to Zambia for the period under investigation while a simple linear regression analysis was used to show the effect of active aircraft on the emissions observed. A comparative analysis was used in examining compliance levels of Zambia's aviation sector against CORSIA SARPs. This was augmented by content and thematic analysis of key informant interviews. A best fit trend line showed a positive and a significant increase (P-value < 0.05) in the international aviation emissions attributed to Zambia at a rate of 2.5 metric tonnes per year over the period assessed. The observed increase in the emissions was attributed to inefficiency in ground handling operations, inefficiency in aircraft operations and increase in the number of aircraft. Results further showed that the compliance levels against CORSIA SARPs were low to medium. This is owing to the absence of an electronic platform to capture data relevant to determine emissions, absence of an independent emissions monitor, poor records keeping among the operators and non-operationalization of the Zambia's Action Plan for the Reduction of Carbon Dioxide Gas Emissions in Aviation. Based on these findings, the study concludes that, enhancing a low carbon aviation industry in Zambia requires improvement in ground handling operations, increase efficiency in aircraft operations, modernize navigation aids, shift from manual to electronic systems and increase access to data for monitoring purposes in meeting CORSIA requirements and appoint an independent emissions monitor to enhance transparency and credibility in the collection and analysis of data relevant to CORSIA requirements.

Key Words: *Aviation industry, Carbon emissions, Climate change mitigation, Zambia*

Dedication

To my lovely wife Muchindu Ng’andu Mapiki

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I would like to sincerely thank my supervisor, Dr. P.H. Nyanga for his insightful comments and guidance on my work.

My field work would not have been possible without the help of the staff at Zambia Airports Corporation Limited (ZACL) and Zambia Civil Aviation Authority (ZCAA); Engineer Cuthbert Lungu (Carbon Offsetting and Reduction Scheme (CORSIA) country representative, ZCAA), Engineer Patrick Phiri (Inspector Airworthiness, ZCAA), Mr. John L. Tembo (International Civil Aviation Organisation (ICAO) representative on the International Federation of Air Traffic Controllers' Associations (IFATCA) panel, ZCAA) and Ms. Phallesy Ngoma (Environmental Officer, ZACL). My special appreciation goes to Mr. Gabriel Lesa (Director General, ZCAA).

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List of Abbreviations and Acronyms

AIS	Aeronautical Information Systems
ANSP	Air Navigation Services Provider
CNG	Carbon Neutral Growth
CORSIA	Carbon Offsetting and Reduction Scheme for International Aviation
GDP	Gross Domestic Product
FAA	Federal Aviation Administration
IATA	International Air Transports Association
ICAO	International Civil Aviation Organisation
IFATCA	International Federation of Air Traffic Controllers' Associations
IMO	International Maritime Organization
IPCC	Intergovernmental Panel on Climate Change
KKIA	Kenneth Kaunda International Airport
SARPs	Standards and Recommended Practices
UNFCCC	United Nations Framework Convention on Climate Change
ZACL	Zambia Airports Corporation Limited
ZASTI	Zambia Air Services Training Institute
ZCAA	Zambia Civil Aviation Authority

CHAPTER ONE: INTRODUCTION

1.1 Background

Transportation is an essential contributor to the health and well-being of every nation's economy. Within the transportation sector, commercial aviation has evolved into the fastest, safest and most far-reaching transportation mode in little more than a century (González and Hosoda (2016). In this regard, the aviation industry is a vital feature of our modern, globalised world, connecting people and businesses across oceans and continents. It plays a major role in supporting poverty reduction, economic growth, as well as social development (Oxford Economic Forecasting, 2003; IATA, 2018). It enables a flow of tourists and trade, including flows of skilled labour by linking global resources and ensuring availability of these resources to areas of need (Brault and Nilausen, 2010). The world economy benefits greatly from its ability to move people and products all over the globe quickly and safely. Over three billion people, nearly half the global population, currently use the world's airlines (FAA, 2015).

Further, the aviation industry supports over 63 million jobs and accounts for 3.5 percent of global Gross Domestic Product (GDP) ($2.7 trillion – based on the 2014 data) (Brault and Nilausen, 2010; IATA, 2018). The industry underpins and enhances the productive capacity of any given economy, supporting long-term economic growth and development (Button, 2017). Thus, people's livelihoods worldwide have in one way or another been affected by the aviation industry. For instance, estimates indicate that over 40 percent of all international tourists travelled by air in the year 2006 (Gössling, et al, 2008) and the number increased to 54 percent in 2014 (Spasojevic, et al., 2018).

Oxford Economic Forecasting (2003) argues that, development of the commercial aviation industry in Africa is instrumental in reducing the cost of trade and movement of goods and people as the industry attracts new investment to locations with good air transport links to the rest of the world. Therefore, infrastructure development in general

and air services in particular, is paramount for the future of African countries, Zambia inclusive, as part of economic integration with the rest of the world.

Nonetheless, while the aviation industry has made positive contributions towards economic and social developments, the industry is one of the fastest growing sources of greenhouse gases (GHGs) emissions and the most climate-intensive form of transport (Lee, 2009; Rothengatter, 2010). Its emissions are responsible for about five percent of anthropogenic global warming at global level (Stern, 2006; Lee, 2009). ICAO asserts that the aviation industry contributes about three percent of all global energy-related Carbon Dioxide emissions (ICAO, 2007). In 2017, global civil aviation industry, as a whole, emitted around 859 million tonnes of Carbon Dioxide, which is roughly two percent of anthropogenic carbon emissions (IATA, 2018).

In view of the foregoing, the aviation industry recognises that its operations were significantly contributing to climate change, hence, it was taking the responsibility to lessen its impact. In 2009, the industry set three global goals to address its climate impact that include: an annual average fuel efficiency improvement of 1.5 percent from 2009 to 2020; stabilise net carbon dioxide emissions at 2020 levels with carbon-neutral growth; and reduce aviation's net Carbon Dioxide emissions to half of what they were in 2005 by 2050 (IATA, 2018). In this regard, the industry intended to achieve these goals through a continued investment in new technologies and strong support mechanisms for the deployment of sustainable aviation fuels.

Pursuant to reducing aviation's net carbon emissions, in 2016, ICAO devised a CORSIA programme (ICAO, 2017). In Zambia, the action plan exists towards the implementation of CORSIA. However, the plan is not yet fully implemented owing to non-appoint of an independent emissions monitor and the absence of an electronic platform to capture data relevant to CORSIA requirements. Additionally, there are few studies that have been conducted in the country to inform the operationalisation of the aforesaid action plan. Therefore, this study is intended to contribute towards baseline data by providing evidence of the international aviation emissions trend and the levels of compliance against CORSIA Standards and Recommended Practices (SARPs) in Zambia.

1.2 Statement of the problem

In 2004, the entire global transport sector was responsible for about 13 percent of all greenhouse gases emissions (IPCC, 2007). Aviation industry alone accounted for about 13 percent of those emissions, arguably among the biggest contributors of GHGs emissions (Reay, 2004; Williams, 2007). In 2018, accordion to IATA (2018) and IPCC (2018), the aviation industry at global level contributed about two percent of the global GHGS. At national level, the contribution to the GHGs from the aviation industry is largely unknown. Thus, baseline data is lacking thereby limiting measures that the country could take towards an informed decision making process in climate change mitigation with respect to the aviation industry. Additionally, aviation and climate change is one area which has previously not been adequately investigated in Zambia. This research therefore attempted not only to estimate the emissions but also explored ways in which a low carbon aviation industry could be enhanced in Zambia.

1.3 Aim

This study aimed at assessing on how a low carbon aviation industry could be enhanced in Zambia.

1.4 Objectives

i. To estimate the levels of international aviation emissions in Zambia.

ii. To examine the Zambia aviation sector's compliance levels against CORSIA SARPs.

1.5 Research Hypothesis

Carbon emissions from the international aviation sector in Zambia have not changed significantly over the last 10 years (2010 – 2019).

1.6 Research Questions

i. What are the annual international aviation emissions in Zambia from 2010 to 2019?
ii. To what extent does the aviation industry in Zambia conform to the ICAO's SARPs for the implementation of CORSIA?
iii. What options are available for promoting a low carbon aviation industry in Zambia?

1.7 Significance of the study

The study will provide baseline data to the Government and ZCAA in particular for the purposes of monitoring of the international aviation emissions trend attributed Zambia in a bid to enhance management and devising control measures to arrest the observed increase in the emissions. The study will also act as guide among the private actors in the aviation sector in the country to enhance their compliance levels against CORSIA SARPs.

In addition, the study would will as well facilitate the full operationalisation of the Zambia's Action Plan for the Reduction of Carbon Dioxide Gas Emissions in Aviation with a view of mitigating climate change on the basis of the lessons provided from the study.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

This chapter defines climate change. It provides an account on the global trends regarding the greenhouse gas (GHG) emissions and highlights the sources and composition of the aviation emissions. The chapter also gives a narrative on climate change and aviation; environmental impact of aviation; and the concept of CORSIA. It concludes by highlighting the context of aviation industry in Zambia.

2.2 The Definition of Climate Change

Climate variability refers to weather variations from season to season (Füssel and Klein, 2006). Persistent change in climatic conditions over a long period of time (not less than 30 years) to a point of shifting the long-term mean atmospheric conditions could entail climate change (IPCC) (2018). Climate change, therefore, with respect to Intergovernmental Panel on Climate Change (IPCC) (2018), refers to a change in the state of the climate that can be identified by changes in the mean in temperature, precipitation, or wind patterns, among other effects, and/or the inconsistency of its properties, and that persists for an extended period, typically decades or longer. Climate change also refers to any change in climate over time, whether due to natural variability or as a result of human activity. Meanwhile, the United Nations Framework Convention on Climate Change (UNFCCC) (2011) defines climate change as change of climate that is attributed directly or indirectly to human activity that alters the composition of the global atmosphere and that is in addition to natural climate inconsistency observed over comparable time periods (minimum of 30 years). Henceforth, Climate Change is any change in climate over time, whether due to natural variability or as a result of human activity. It is clear therefore that, IPCC and UNFCCCC definitions of climate change differ as to the cause of climate change. Nevertheless, regardless of the definition of climate change adopted, this study looked at anthropogenic activities with special attention to the aviation industry's contribution to change in climate.

2.3 Trends in Global Greenhouse Gas (GHG) Emissions

Important GHGs include Carbon Dioxide, Methane and Nitrous Oxides. With a lifetime of 100 years, Carbon Dioxide is the most important one of the GHGs. However, a gradual increase in Carbon Dioxide concentrations in earth's atmosphere is helping to drive global warming, threatening to disrupt the earth's climate as average global temperatures gradually rise. Global atmospheric concentration of Carbon Dioxide had increased from a pre-industrial value of about 280 ppm to about 396 ppm in 2012 (Cloy, et al., 2018). The primary source of the increased atmospheric concentration of Carbon Dioxide from the pre-industrial period results from fossil fuel use. In 2017, the growth rate in global GHGs was estimated a rate of 1.3 percent per year, reaching 50.9 Gigatonnes in Carbon Dioxide equivalent (Olivier, et al, 2017). This was mainly due to emissions of Carbon Dioxide and Methane having increased by 1.2 percent (Olivier, et al, 2017). Global Carbon dioxide emissions associated with aviation industry are estimated to be about 2 percent of the GHGs (IATA, 2018).

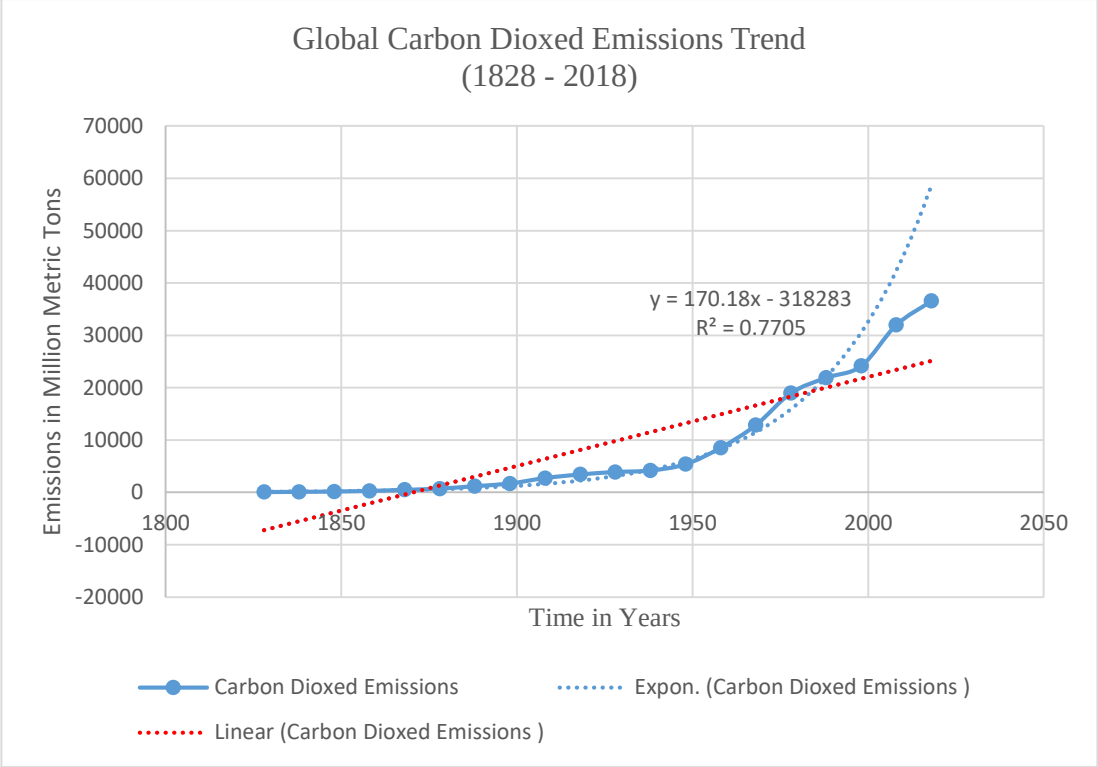

Figure 2.1: Global Carbon Dioxide Emissions Trend
Source: Statista (2020)

2.4 Sources and Composition of Emissions

Gaseous emissions from aviation are not limited to aircraft exhaust. Studies regarding local air quality at airports indicate that aircraft ground handling operations, road traffic accessing the airports and airport infrastructure are some of the major sources that need to be considered (Penman, et al., 2000; FAA, 2015). The main products from the combustion of kerosene-based fuels that include JET A-1 which are widely used in the aviation industry are Carbon Dioxide and Water Vapour, the proportions of which depend on the Carbon to Hydrogen ratio of the specific fuel. An ideal combustion of a one kilogram (Kg) of JET A-1 fuel results in 3.156 Kg Carbon Dioxide and 1.237 Kg Water Vapour (Nelson and Reddy, 2018). In reality, JET A-1 is a complex mixture of hydrocarbons with further additives.

In addition to hydrocarbons, emissions from aircraft engines include particulate emissions also known as Soot, which may contribute to a visible plume. Soot consists of around 2.6

$\times 10^{14}$ carbonaceous particles per Kg of fuel with diameters typically in the range of 10-30nm (Schaefer, 2006; Masiol and Harrison, 2014). Besides, small and liquid particles with diameter in the range of 2-10nm form in the exhaust plume during cruise flight, initially from sulphuric acid, there are some significant amounts of condensable hydrocarbons and water present. Furthermore, due to the sulphur content in the fuel, Sulphur Oxides also form in the aircraft exhaust (Masiol and Harrison, 2014).

2.5 Understanding Climate Change and Aviation

Climate change in the context of this desertion refers to seasonal changes over a long period as a result of the growing accumulation of GHGs in the atmosphere resulting from natural effects and anthropogenic activities, aviation inclusive. It is difficult, however, to separate anthropogenic from natural effects and determine their respective impacts on observable parameters. In order to quantify and compare various influences, the concept of radiative forcing may be used (Schaefer, 2006). Radiative forcing, in units of watts per square metre (W/m^2) may be described as a measure of the effects of perturbations to the planetary radiation balance. More exactly, it is the net radiative flux change at the top of the atmosphere calculated in response to a perturbation such as a change in gas concentration. Usually determined as a global and annual mean value, positive radiative forcing causes a warming of the earth system. An approximately linear relationship may be assumed between the change in radiative forcing and the global mean surface temperature change (Checa, et al., 2018).

In view of the forgoing, IPCC arrived at a radiative forcing for aviation in their report of 1999 “Aviation and the Global Atmosphere” using a ‘three-dimension radiative transfer model’ (Patterson, 2005). Based on the IPPC’s 1999 report, estimates for aircraft related effects were given, with Carbon, Ozone and Contrails being the most influencing factors. Results indicated that aviation caused a radiative forcing of +0.05 W/m^2 in the base year 1992, around 3.5 percent of the global mean radiative forcing from anthropogenic sources (Patterson, 2005). However, uncertainties in such calculations are high because there is limited scientific knowledge regarding aviation’s influence on cirrus clouds and the

atmospheric processes at large. Nonetheless, the IPCC predicts a forcing of 0.19 W/m² in a central scenario for aviation by the year 2050, about four times the value recorded in 1999 and a prospective five percent contribution to the total anthropogenic influence (Myhre, 2017; Avila, 2019).

Brasseur, et al (2016) assert that, in order to understand and predict aviation impacts, process studies must be conducted with a hierarchy of models to improve knowledge of the dynamics, chemistry and microphysics of the upper troposphere and lower stratosphere to support improvements and embodiment of low-carbon technologies in the aviation sector. This will help maintain a sustainable and stable global climate, less there is a great likelihood that the degree of global warming will be significantly above the two degrees Celsius by 2050.

In view of the foregoing, it is worth mentioning that, the transport sector at global level accounts for about 13 percent of global Carbon Dioxide emissions (IPCC, 2007; Lee, et al., 2009). Of these emissions, aviation accounts for 13 percent whereas road transport accounts for about 74 percent (IPCC, 2007). In 2010 the highest share of GHGs emissions had come from the road transport with a record of 72.0 percent, while international and domestic aviation together recorded a share of 10.62 percent (IEA 2012; Stocker, et al., 2013). In comparison to the road transport, aviation emissions may be small. The concern is that, they are emitted directly into the troposphere and lower stratosphere where they influence Ozone and Methane concentrations via chemical processes. For instance, at typical cruise altitudes of between 10 and 12 Km and particularly in the heavily occupied airspace of the northern hemisphere, aircraft emissions alter the concentration of atmospheric gases and influence atmospheric chemistry (Stocker, et al., 2013). Together with anthropogenic emissions from other sources, aviation is believed to disturb the energy balance of the earth and contribute significantly to climate change (FAA, 2015). In this regard, aviation emissions have been in the focus of meteorologists in recent years as they are deemed to contribute significantly to the global warming.

It is also the rapid and continuous growth of air transport that justifies special attention to its adverse effects. Although significant technological progress in the fields of engine and airframe technology has been made, overall emissions of the aviation industry are still on the rise. With sustainability becoming a key word in many fields of society, the environmental sustainability of the aviation industry is not an exception (Lyle, 2018; Larsson, et al., 2019).

Therefore, aviation emissions inventories are a must. This is because they provide input data for the development of scientific models of the atmosphere, out of which, they could be used to analyse the relevant chemical processes. Models would also provide a better understanding of atmospheric reactions to guide technological and political actions to be taken in order to minimise the adverse effects of aviation on the environment.

2.6 Environmental Impact of Aviation

Kousoulidou and Lonza (2016), asserts that, air quality problems are amongst the local concerns resulting from aviation in addition to aircraft noise and the third party risk through potential accidents. They argued that emissions from aircraft engines, aircraft ground handling operations, road traffic accessing the airports and the airport infrastructure were among the major sources of air pollution in the vicinity of airports. Whereas aircraft are the predominant source of emissions at the airport itself, road traffic is usually the largest polluter in residential areas located in the vicinity of large airports. Surveillance of air quality at major airports has shown that Nitrogen Oxides, Carbon Dioxide, Carbon Monoxide, volatile organic compounds and particles (PM10) were the most prominent pollutants. Sulphur Dioxide, Hydroxyl, Nitrous and Nitric Acids may also affect local air quality.

Dickson and Bureau (2014) revealed from their study that, airports as major transport hubs have a negative, though highly localised effect on air quality. However, determining the effects of aircraft emissions amongst other emission sources in the vicinity of airports including domestic flights emissions is a complicated task and beyond the scope of this dissertation.

In light of the above, the United Nations Framework Convention on Climate Change (UNFCCC) and the International Civil Aviation Organisation (ICAO) recognizes the critical importance to implement and support decisions defined to provide financial incentives for the developing countries to implement policies aimed at reducing GHGs emissions (Griscom, et al, 2017). In this regard, the 2016 ICAO General Assembly Resolution established the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA). The scheme encourages member states to develop policies and regulations aimed at limiting aviation emissions in line with the Paris Agreement resolutions regarding the Polluter Pays Principle (ICAO, 2017).

2.7 Understanding the Concept of CORSIA

CORSIA is a global carbon offsetting concept designed by ICAO to address carbon emissions from the international aviation. It is the primary emissions mitigation market-based mechanism tool for the international aviation industry. It aims to reduce carbon emissions from the industry in line with the Kyoto Protocol recommendations (Lyle, 2018; Scheelhaase, et al., 2018). The scheme augments the industry's technology, operational and infrastructure advances designed to reduce aviation emissions. It encourages airlines to compensate for their emissions by financing reduction in the emissions elsewhere in line with the Polluter Pays Principle (IATA, 2018). That is, it does not necessary require the industry to reduce emissions "in house", it provides an environmentally effective option for other sectors where the potential for further emissions reduction is limited by financing projects which could be used as offsets to bring about social, environmental and economic benefits relevant to sustainable development (Cho, et al, 2019).

However, the scheme bears a character of an international soft law. This character makes the scheme less stringent. Hence, it has been received with mixed feelings among ICAO member states. This is because the scheme is a market based mechanism that focuses on offsetting emissions through the process of individual airlines purchasing emissions units

equivalent to their offsetting requirements. In this way, ICAO member states feel that the offsetting processes may tend to divert the focus from reducing emissions to trading on emissions.

> ICAO carefully avoids use of the word 'mandatory' for the period from 2027 onward and with good reason: The Organization has no direct authority over its member States, and so it will be up to each State to decide whether to stay in CORSIA (Lyle, 2018:7).

Further, the Kyoto Protocol excludes international aviation emissions monitoring from individual country targets. This exclusion has to date made it difficult for the individual ICAO member states to serious implement the CORSIA scheme because governments are not held responsible for their international aviation emissions under the Kyoto protocol's recommendations.

> The Paris Agreement, adopted under the UNFCCC, addresses sectors and related greenhouse gas emissions following an approach similar to that of its overarching Convention. Specifically, governments working under the auspices of the UNFCCC have agreed that while all domestic GHG emissions are dealt with under the UNFCCC, GHG emissions associated with international aviation and maritime transport are to be dealt with under ICAO and International Maritime Organization (IMO), respectively. This approach is consistent with similar UNFCCC decisions that also apply to the Kyoto Protocol (ICAO, 2018:10).

Further, CORSIA's coverage is limited. The scheme is planned to end in 2035, with no credible plans at global level to address international aviation's emissions beyond this date (Du Pont, 2017).

2.8 The Context of Aviation Industry in Zambia

The aviation industry in Zambia is an essential sector for its continued support to the economy. The industry is also essential for the tourism industry (Oxford Economic Forecasting, 2003). However, Zambia's aviation sector is relatively underdeveloped. From 1964, the aviation sector in Zambia was dominated by the national airline, Zambia Airways which was declared insolvent in 1994 (Molwelwa, 2011). Since then, a number of privately owned Zambian-registered airlines have been formed. However, only Proflight and more recently Mahogany Air have survived with the former servicing intentional routes in addition to its domestic routes. Traffic has since grown strongly in the past decade largely through an increase in the number of flights by overseas-based carriers facilitated by Zambia's 'open skies' policy in line with the Yamoussoukro Decision (Kazeem, 2018). The Yamoussoukro Decision is a treaty that allows for open skies among most African states. The decision was endorsed by 44 members of the African Union in 1999. It became binding in 2002. It also sought to eliminate restrictions on ownership of airlines and frequency limits on international routes between signatory states (Kazeem, 2018).

Statistics indicate that traffic at the country's four largest airports rose from 1.1 million passengers per annum in 2010 to 1.62 million passengers per annum in 2016, representing an annual average growth rate of 6.9 percent per annum (Forbes and Wilson, 2018). International traffic grew by 7.1 percent per annum over this period while the domestic traffic which comprised 0.27 million passengers in 2016, grew by 6.1 percent per annum (Forbes and Wilson, 2018)

However, the majority of Zambia's international passenger and cargo traffic is carried by non-Zambian airlines. These airlines' emissions are not accounted for in this study as their emissions are accounted for in their respective countries of origin. This is also in accordance with the CORSIA requirements which requires that, the aircraft operators' international flights emissions shall be attributed to their country of origin.

Arising from the above, Zambia Civil Aviation Authority (ZCAA) in 2018 developed the Zambia's Action Plan for the Reduction of Carbon Dioxide Gas Emissions in Aviation in

line with ICAO's 14th General Assembly resolutions during which CORSIA was formulated. Zambia's Action Plan for the Reduction of Carbon Dioxide Gas Emissions in Aviation is a statement by the Zambian aviation industry of its commitment to ICAO explaining ways in which the industry intends to improve operations aimed at offsetting and reducing carbon emissions from Zambia's aviation industry. However, the action plan is yet not fully operationalised.

CHAPTER THREE: THE STUDY AREA

3.1 Introduction

This chapter describes the study area at three different levels; the country context, description of the study area and the general description of the study site.

3.2 The Country Context

Zambia is a land linked Sub-Saharan country sharing boundaries with Malawi, Mozambique, Zimbabwe, Botswana, Namibia, Angola, Democratic Republic of Congo and Tanzania. It has a total surface area of 752,614 square kilometers (Chanda, 2008; WHO, 2014) and a population of about 18 million with a population density of approximately 24 persons per square kilometer (CSO, 2018). Most of Zambia is a high plateau with a flat or gently undulating terrain. It lies between 8 and 18 south latitudes and longitudes 22 and 34 east (CSO, 2018).

Zambia gained its independence from Britain in 1964. The country has experienced three major phases of governance, the multi-party system from 1964 to 1972, one party system from 1972 to 1991 and multi-party system again since 1991 (CSO, 2018). In terms of administration, the country is divided into ten provinces namely; Central, Copperbelt, Eastern, Luapula, Lusaka, Muchinga, Northern, North Western, Southern and Western. These provinces are further subdivided into 105 districts (CSO, 2016).

Zambia's vegetation is mainly savannah type varying from scattered and open forest conditions in the south to tall dense woodlands in the north and northwest provinces. The country has a tropical climate with three distinct seasons; the cool and dry season, the hot and dry season and the hot and wet season. The country has abundant natural resources. It has five main rivers namely; Zambezi, Kafue, Luangwa, Luapula and Chambeshi. In addition to these rivers, the country also has major lakes namely; Tanganyika, Mweru, Mweru Wa Ntipa, Bangweulu and Kariba. A major tourist feature in the southern part of

the country is the Victoria Falls. The falls is one of the seven wonders of the world. Zambia has some of the nature's best wildlife and game reserves affording the country with abundant tourism potential for earning foreign exchange. The magnificent Luangwa and Kafue National Parks have one of the most prolific animal population in Africa. The country is also endowed with various minerals and precious stones such as copper, emeralds, zinc, lead and cobalt (Nyanga, 2006).

3.3 Description of the Study Area

Lusaka is both a province and the national capital city of Zambia (Figure 2). As a province, it has an area of 21, 896 square kilometres with a population of 3.3 million (CSO, 2018). The province is bordered by Zimbabwe along the Zambezi River in the south, Central Province in the north, Southern Province in the southwest and Eastern Province in the north east. In terms of administration, in addition Lusaka District, there are six more districts namely; Chilanga, Chirundu, Chongwe, Kafue, Luangwa and Rufunsa. Kenneth Kaunda International Airport (KKIA) in Chongwe District and Lusaka City Airport in Lusaka District are the two airports in the Province.

As a national capital (Figure 3.1), Lusaka has population of about 2.6 million with a general unemployment rate of 52 percent (CSO, 2018). It is both the national headquarters of central and local governments.

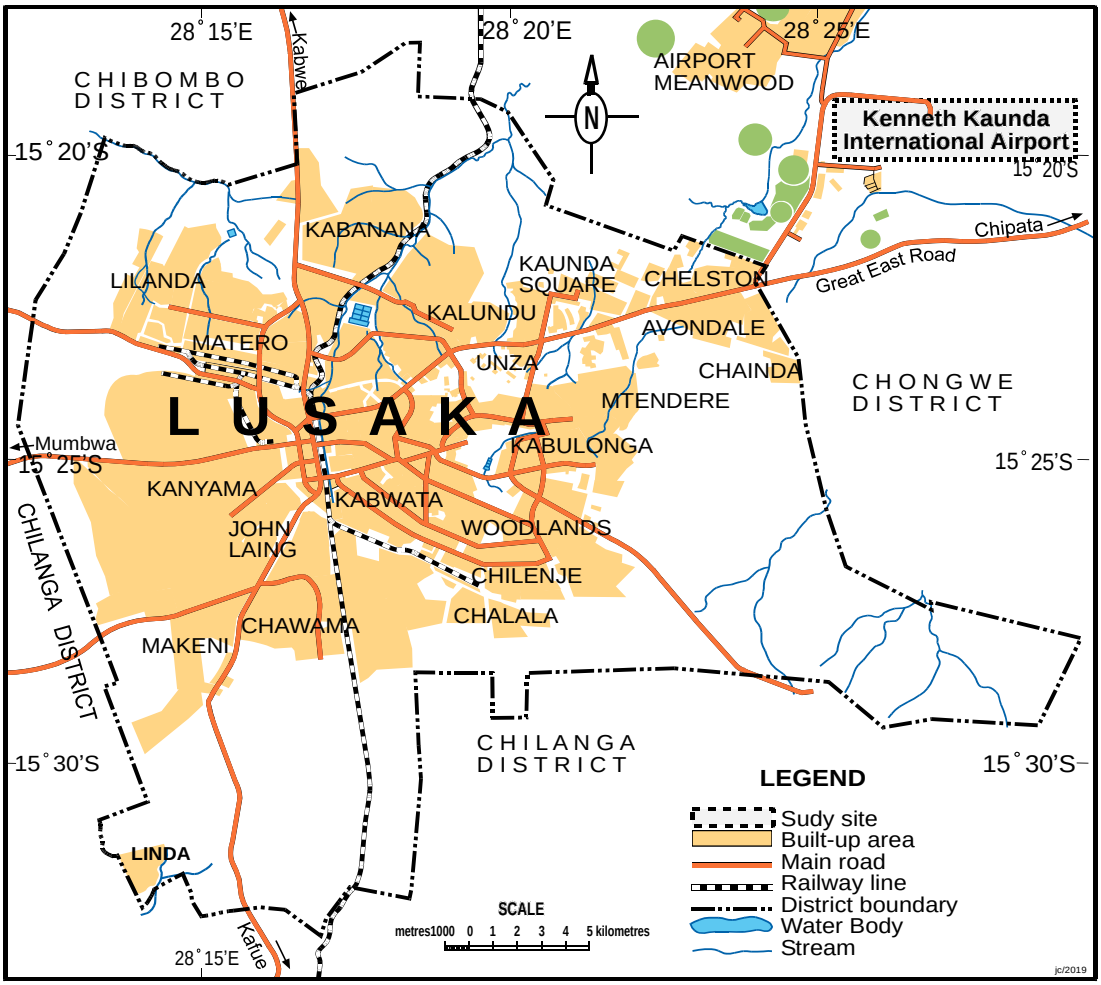

Figure 3.1: Lusaka District Location Map - the Study Area
Source: Generated by Chalila (2019) using ArcGIS

3.3.1 General Description of the Study Site

Kenneth Kaunda International Airport (KKIA) (Figure 3.2) formally known as Lusaka International Airport is the largest International Airport in Zambia located about 27 kilometers from the Central Business District of Lusaka. The Airport was opened in 1967 to provide services for Domestic, Regional and International flights (ZACL,2017a). The Airport was purposively chosen for the study as it is a major centre of the aviation activities in Zambia.

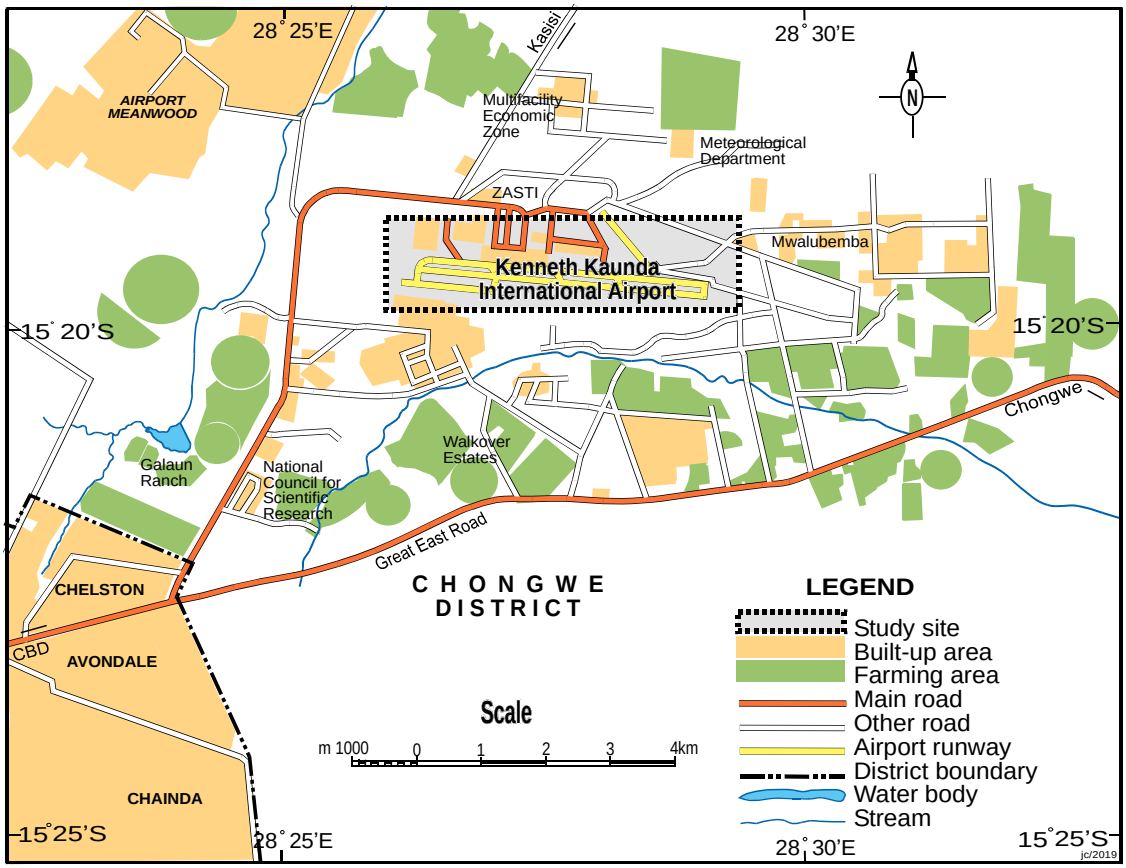

Figure 3.2: Kenneth Kaunda International Airport (KKIA) Location Map - the study site
Source: Generated by Chalila (2019) using ArcGIS

3.3.2 Vegetation and Wildlife

KKIA occupies 3000 hectares which until recently was bound by open savanna grassland on the southern part comprising of few acacia species such as *Acacia Polyacartha and Sieberiana.* Grass species that occur include: *Piptostachya inamoena, Cynodon dactylon, Hyperrhenia filipendula, Rhynchelytrum repens, Elusine indica and Sporoborus pyrmidalis.* The north western and south western parts of KKIA are largely miombo woodlands with predominant trees such as *Brachystegia, Julbernardia and Isoberlinia.* The Airport has a lot of wildlife species that include Common Duikers, Striped Jackals and Pancake Tortoises, Pied Crows, Snake Eagles and White Egrets. These species are attracted to the area by different motives that include among others but not limited to feeding, roosting, nesting and habitation (ZACL, 2017b).

CHAPTER FOUR: METHODOLOGY

4.1 Introduction

This chapter presents the methodology that was used during the course of the study. It begins by explaining the study's research philosophical position. Thereafter, the study gives an account of the research design, sampling procedure, methods of data collection and methods of calculating emissions from the aviation industry. It also outlines the data analysis techniques used on both quantitative and qualitative data collected. The study further explains the ethical considerations which were observed and concludes by giving an account on the limitations encountered during the course of the study.

4.2 Research Philosophical Position

Based on the nature of the study, it follows therefore that the study used a mixed methods approach and took a critical realism philosophical position to interface in between the quantitative data and the qualitative data sets (Wikgren, 2005). The philosophical position here refers to the ontological and epistemological philosophical underpinnings which are key to a clear and a precise research process for they shape the research design and explain approaches taken in supporting the credibility of the research outcomes (Mack, 2010; Jackson, 2013).

Critical realism was used in this study because it is able to combine well the quantitative data with the qualitative data (Archer, 2013). Further that, critical realism was used because it is concerned with aspects of what constitutes explanations and predictions. It also assumes an ontological realism and defends the possibility of causal explanation, but also accepts the notion that knowledge is communicatively (socially) constructed (Wikgren, 2005)

4.3 Research Design

In estimating the international aviation emissions attributed to Zambia quantitatively and in accessing the Zambia aviation sector's compliance levels against CORSIA SARPs qualitatively, the study used a mixed method approach. It follows therefore that the explanatory sequential research design was used. Explanatory sequential research design in this case involves the collection and analysis of quantitative data followed by a collection and analysis of qualitative data for the purposes of using the latter data to explain the outcomes of the former data (Subedi, 2016; Creswell, 2017). It was for this reason as to why the explanatory sequential research design was used. In this regard, the secondary data set (quantitative data) was analysed first before collecting the primary data set (qualitative data). This step informed the designing of the interview guide which was used to collect the primary data set.

4.4 Sampling Procedure

Qualitative data was collected from the field using key informant interviews which were administered to key informants (Table 4.1) who were purposively sampled. Purposive sampling in this study refers to a non-probability sampling technique which is used to select a purposive sample based on characteristics of a population and the objective of the study (Creswell, 2017). In this respect, according to Guarte and Barrios (2006), a purposive sampling was used to enable the study get the expert's knowledge on the basis that the aviation industry is highly specialized and only a few people could have had knowledge about the industry.

Table 4.1: Key Informants

Date	Serial Number	Organisation
24 – Jul - 2019	Key Informant No. 1	ZCAA
25 - Jul - 2019	Key Informant No. 2	ZACL
07 - Aug - 2019	Key Informant No. 3	Zambia ZCAA
09 - Aug - 2019	Key Informant No. 4	Proflight Zambia
09 - Aug - 2019	Key Informant No. 5	ZACL

Source**:** Field Data, 2019

4.5 Methods of Data Collection

Methods of data collection included key informant interviews and collection of secondary data on annual fuel consumptions provided by ZCAA. Firstly, key informant interviews in this study refer to in-depth interviews with people who have great knowledge about the subject under consideration. The principle advantages of the key informant technique relate to the high quality of data which could be obtained in a relatively short period of time (Lincoln and Guba, 1985). In this regard, the method worked well considering that the study had limited time to do the field work which was in this case undertaken to establish factors contributing to the observed increase international aviation emissions attributed to Zambia and also to determine the Zambia aviation sector's compliance levels against CORSIA SARPs. It follows therefore that, a framework based on four CORSIA SARPS (Table 5.5) was used and compared with what was obtaining on the ground with regards to the country's practices. In view of this, the rating of the compliance levels of Zambia's aviation sector against CORSIA SARPs was based on expert judgement. Expert judgement here refers to a technique in which judgment is provided based upon a specific set of criteria and/or expertise that has been acquired in a specific knowledge area (Meyer and Booker, 2001).

Secondary data with respect to Creswell (2017) refers to data which is collected by an individual other than the user. Common sources of secondary data for social sciences include censuses, information collected by government departments, organisational

records and data which was originally collected for other research purposes. In this case, the secondary data set was collected from ZCAA and it constituted time in years, international flights annual fuel burnt, annual carbon emissions and annual accumulated number of active aircraft for the period under investigation. Secondary data in this study was therefore economical as it saved efforts and expenses. It helped the study to make primary data collection more specific.

4.6 Tools of Data Collection

Tools used to collect data included interview guides which were administered to key informants (primary data) and data sheets (secondary data). An interview guide in this study refers to a mechanism to help the interviewer (researcher) conduct an effective interview during data collect data in the field (Kvale and Brinkmann, 2009; Qu and Dumay, 2011) whereas the data sheet in this study refers to a document that provided specifications for the secondary data set as heighted in Section 4.5.

4.7 Methods of Calculating Emissions from the Aviation Industry

The agenda on climate change has in the recent past escalated the importance of monitoring and recording of the Carbon Dioxide emissions to the atmosphere. Globally, governments, business houses and individuals have all become engaged in monitoring the size of their carbon footprints as the first crucial stage towards developing strategies to reduce emissions (Jardine, 2005). In this regard, different calculators have been developed by different environmental agencies, a trend which has resulted into inconsistency among calculators (Holdings 2008).

For the purposes of this work, the formula below informs on how international aviation emissions attributed to Zambia were estimated from the secondary data set that was obtained from ZCAA.

Equation 1: Carbon Emissions = Fuel Burnt × 0.8 × 3.16

Where : 0.8 is the estimated weight of one litre of Jet A-1 in Kilograms; and

: 3.16 is the Carbon Factor.

4.8 Methods of Data Analysis

Data was analysed using trend, simple linear regression, comparative, thematic and content analysis techniques. Trend analysis technique, with reference to Lu and Yang, (2012), was in this study used to analyse secondary quantitative data (Table 5.1) in an attempts to predict the future stock of international aviation emissions from the international flights attributed to Zambia based on the idea that, what would have happened in the past (carbon emissions) will give an idea of what will happen in the future. The simple linear regression was used in this study to analyse the effect of active number of aircraft on the international aviation emissions observed (Table 5.2). On the other hand, content analysis technique was in this research used to make replicable and valid inferences by interpreting and coding textual data set. According to Krippendorff (2018), by systematically evaluating texts, emerging themes could be built to help analyse the data sets). With regards to primary data set, it follows that analysis was by synthesising emerging themes from the texts which were recorded from the key informant interviews. Meanwhile, a comparison analysis was used to determine the levels of compliance of Zambia's aviation sector against CORSIA SARPs. To that effect, four key requirements of CORSIA SARPs were singled out against which the country's practices obtaining on the ground were compared to.

4.9 Ethical Consideration

Ethical considerations refer to norms of accepted conduct in doing research. These norms are an important part of research to adhere to because of several reasons (Resnik, 2011). Firstly, norms promote the aims of study such as knowledge, truth and avoidance of error. Secondly, ethical considerations promote the values that are essential to collaborative

work, such as trust, accountability, mutual respect, and fairness. Thirdly, ethical norms help to ensure that researchers are held accountable to the public. Fourthly, ethical norms in research also help to build public support for research. Finally, norms in research promote a variety of other important moral and social values, such as social responsibility and human rights (Shamoo and Resnik, 2009). It follows therefore that ethical lapses in research could significantly harm the environment, the researcher, and the public (Resnik, 2011). In this study, the following ethical considerations were observed:

i. Informed Consent: Respondents were told the purpose of the study. They were also told that the findings of the study would be used for the academic purposes. In addition, they were also told that, the findings of the study would be shared to the state and that the final dissertation of the study would be published thereby the general public would have access to the document. Based on this, respondents were asked to participate in the study on voluntary basis.

ii. Confidentiality: Respondents were told that all the information that they were to be provide in the interest of this study was only going to be used for the academic purposes and that it was going to be given utmost confidentiality.

iii. Credit to sources of data: The study showed responsibility by giving credit to the respondents and other researchers by acknowledging their ideas through citation and full referencing in the references section respectively.

4.10 Limitations of the Study

The study's main limitation was that of limited time. That is, given the time period for data collection, the nature of the study could not allow the researcher to physically collected data as it would require a longer period for the actual data collection. In this regard, this limitation was taken care of by the used the secondary data set which was obtained from ZCAA.

CHAPTER FIVE: RESULTS

5.1 Introduction

This Chapter presents results of the study. It starts with a presentation on the estimations of carbon emissions from Zambia's international flights over a period of 10 years (2010 - 2019). This is followed by a presentation on the effect of number of active aircraft on the emissions. Then a presentation on the factors contributing to the observed increase in the international aviation emissions attributed to Zambia is made. The chapter then concludes by presenting results on the compliance levels of Zambia's aviation sector against CORSIA SARPS.

5.2 Estimating International Aviation Emissions in Zambia

One of the purposes of the study was to analyse trend in international aviation emissions attributed to Zambia over a period of 10-year period (2010 – 2019). To that effect, secondary data (Table 5.1) was subjected to a trend analysis (Figure 5.1).

Table 5.1: International Fuel Burn and Carbon Emissions (2010 - 2019)

Year	International Fuel(LTR)	CO_2Kg (000,000)
2010	14,339,720.00	36.25081
2011	16,892,970.00	42.70543
2012	17,670,046.62	44.66988
2013	18,482,868.76	46.72469
2014	19,333,080.73	48.87403
2015	20,222,402.44	51.12223
2016	21,152,632.95	53.47386
2017	22,125,654.07	55.93365
2018	23,143,434.16	58.50660
2019	61,197,905.22	61.19791

Source: Zambia ZCAA (2019)

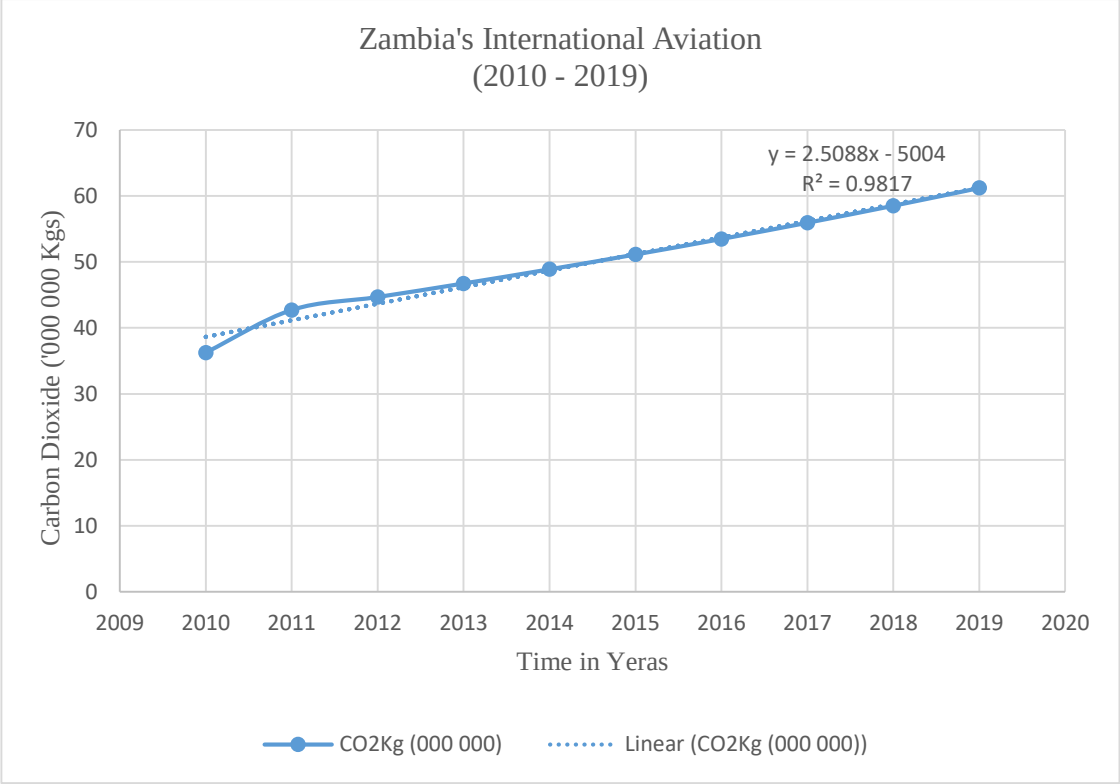

Figure 5.1: Zambia's International Aviation Emissions Trend
Source**:** ZCAA (2019)

Based on the secondary data (Table 5.1), results showed a positive and a significant increase in the international aviation emissions attributed to Zambia as it could be seen from the best fit trend line in Figure 5.1.

The study also sought to analyse effects of active number of aircraft (Table 5.2) on the international aviation emissions observed. To that effect, secondary data (Table 5.2) was subjected to a simple linear regression analysis (y = mx + c) (Figure 5.2), where the predictor variable was the number of active aircraft and the response variable was the carbon emissions.

Table 5.2: Active Number of Aircraft Versus Carbon Emissions

Number of Active Aircraft	Carbon Dioxide Emissions Kgs (000,000)
68	36.25081
79	42.70543
91	44.66988
106	46.72469
118	48.87403
129	51.12223
134	53.47386
134	55.93365
135	58.5066
137	61.19791

Source: ZCAA (2019)

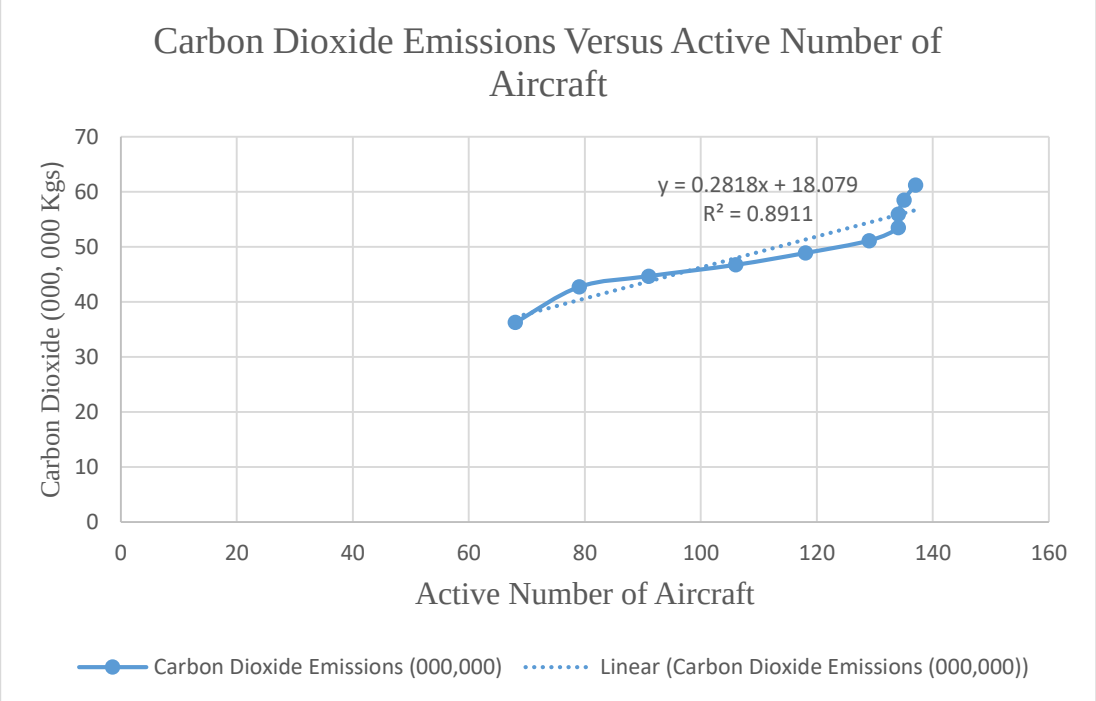

Figure 5.2: Carbon Emissions Versus Active Number of Aircraft
Source: ZCAA (2019)

Based on the data (Table 5.2), results showed that the number of active aircraft had an influence on the amount of international aviation emissions attributed to Zambia (Figure 5.2). A best fit trend line from Figure 5.2 showed a positive increase in the international aviation emissions at a rate of 0.2818 metric tonnes of carbon emissions per aircraft increase.

5.3 Factors Contributing to the International Aviation Emissions in Zambia

Based on the results above (Section 5.1 and 5.2), the study further sought to analyse factors contributing to the observed increase in the international aviation emissions attributed to Zambia for the period under investigation. In this regard, with respect to key informant interviews, the following factors were listed (Table 5.3).

Table 5.3: Factors Contributing to Increased Emissions

No.	**Factors**
1	There are no efforts to reduce aviation carbon emissions among aircraft operators
2	Absence of Area Radar System.
3	Non availability of ground handling power units at the international airports
4	Use of fuels with high carbon content.
5	Non acquisition of new and fuel efficient fleet of aircraft among Aircraft Operators attributed to Zambia
6	Increase in the number of aircraft and flights
7	Inefficiency in aircraft operations and ground handling operations
8	Lack of modern navigation aids
9	Inadequate legislation

Source**:** Field data, 2019

The above factors were further classified into four key themes (Table 5.4); inefficiency in aircraft operations, inefficiency in ground handling operations, increase in the number of aircraft and international flights and inadequate legislation.

Table 5.4: Factors Contributing to Increased Emissions - Key Themes

No.	Theme	Factors
1	Inefficiency in Aircraft Operations	• There are no efforts to reduce aviation carbon emissions among aircraft operators. • Absence of Area Radar System. • Lack of modern navigation aids. • Use of fuels with high carbon content. • Non acquisition of new and fuel efficient fleet of aircraft among Aircraft Operators attributed to Zambia. • Inefficiency in aircraft operations and ground handling operations.
2	Inefficiency in Ground Handling Operations	• Non availability of ground handling power units at the international airports.
3	Increased Number of Aircraft and International Flights	• Increase in the number of aircraft and international flights.
4	Inadequate Legislation	• Inadequate legislation.

Source**:** Field data, 2019

In terms of frequency, inefficiency in aircraft operations accounted for six out of nine factors contributing to the observed increase in international aviation emissions attributed to Zambia, inefficiency in ground handling operations accounted for one out nine factors, increase in the number of aircraft and international flights accounted for one out of nine factors and inadequate legislation accounted for one out of nine factors. In relation to inefficiency in aircraft operations, two of the key informants said:

> *"absence of modern navigation aids both from the airports operator and the airlines which subsequently lead to increased holding time of aircraft on approach" (key Informant No. 4, 2019).*

> *"probable causes for current status could include; absence of efforts to reduce carbon emissions among Aircraft Operators, absence of ground handling power units among Aircraft Operators, use of fuels with high carbon content, limited*

landing and taking off capacity and absence of area radar system" (Key Informant No.5).

5.4 Compliance Levels in Zambia Against CORSIA SARPs

The study also sought to determine the aviation sector's compliance levels in the country against CORSIA SARPs. In doing this, four key CORSIA SARPs (Table 5.5) were singled out against which the country (Zambia)'s practices obtaining on the ground were compared to.

Table 5.5: Compliance Levels in Zambia Against CORSIA SARPs

	CORSIA SARPs	**Compliance Levels**					**Reasons for the Compliance Level Scored**
		1	2	3	4	5	
Documentation	The regulating authority shall develop necessary documents in accordance to the CORSIA requirements					✓	ZCAA has developed the necessary documents which include: Zambia Civil Aviation Requirements Part 21 and the Zambia's Action Plan for the Reduction of Carbon Dioxide Gas Emissions in Aviation pursuant to CORSIA SARPs.
Monitoring of International Flights	The Aircraft Operator attributed to Zambia shall identify international flights that are attributed to it.			✓			Data is not readily available to the authorised persons partly because of the absence of an electronic platform thereby making it difficult to compile and analyse data for the purposes of meeting the CORSIA requirements.
Monitoring of Emissions	The regulating authority (ZCAA) shall appoint an independent emissions monitor to verify records from the Operators.	✓					An independent emissions monitor is yet to be appointed.
Records Keeping	The aeroplane operator shall keep records relevant to demonstrating compliance with CORSIA requirements.		✓				There is a tendency of poor records keeping among Operators.

Notes: 1 = Low, 2 = Low to Medium, 3 = Medium, 4 = Medium to High, and 5 = High

Source: Filed Data (2019)

Based on the expert's judgement, the results above (Table 5.5) show that, two of the CORSIA SARPs were below medium, one was medium and the other one was high, implying that, the Zambian aviation sector's compliance levels against CORSIA SARPs were low to medium.

CHAPTER SIX: DISCUSSION

6.1 Introduction

This chapter discusses the findings of the study with regards to the international emissions trend in Zambia.

6.2 International Aviation Emissions Trend in Zambia

The aviation sector in Zambia has not been doing well in the recent past following the liquidation of the national carrier (Zambia Airways) in 1994. However, the results of the study showed a statistically significant increase in the international aviation emissions attributed to Zambia for the period under investigation (2010 – 2019). This implies that, as time increases, there were more amounts of carbon emissions which were being emitted from the international flights attributed to Zambia at an average rate of 2.5 metric tonnes per year. This could have been because of the inefficiency in aircraft operations. Inefficiency in aircraft operations was as a result of lacking modern navigation aids both on the airport operators and on the aircraft operators attributed to Zambia. Lack of auxiliary power units to support ground handling operations and continued use of old aircraft which had accumulated over time were other factors which were observed to have had contributed to the increase in the international aviation emissions attributed to Zambia. Further that, the other reason for the observed increase in the emissions could be that, the private sector engaged in aviation sector has been consistent in terms of investments.

Meanwhile, these results show that the rate at which carbon emissions were increasing in Zambia were below the average global rate of 740 million metric tonnes per year and that of the average African Region rate of 4.5 metric tonnes per year (IEA, 2012). However, there is potential for Zambia to reach high rates given the low to medium compliance levels of the country's aviation sector against CORSIA implementation which is a global mitigation tool for the international aviation emissions.

It follows therefore that, the general trend of international aviation emissions attributed to Zambia was positively increasing in line with Lyle (2018) and González and Hosoda (2016), whose studies revealed that the aviation emissions were anticipated to increase at the rate of 3.5 percent in the next twenty years despite significant technology progress in the fields of engine and airframe technology. The results were also in line with Hofer (2010)'s findings from his study on "The environmental effects of airline carbon emissions taxation in the United States" which revealed that, the increasing numbers of aircraft would lead to delays in landing (reducing fuel efficiencies), and increased greenhouse gas emissions.

Further, the study revealed that the aviation sector's compliance levels in Zambia against CORSIA SARPs were low to medium. This was largely attributed to poor records keeping among airline and airports operators attributed to Zambia in addition absence of an electronic platform to capture data relevant CORSIA requirements and non-appointment of an independent emissions monitor. However, there is potential for the sector to improve considering that, ZCAA had already developed relevant documents to meeting CORSIA requirements.

CHAPTER SEVEN: CONCLUSION AND RECOMMENDATIONS

7.1 Conclusion

The study revealed that the aviation sector in Zambia for the period 2010 – 2019 had experienced significant positive increase in international aviation emissions. The study showed that there was an annual increase in the international aviation emissions attributed to Zambia at the rate of 2.5 metric tonnes of carbon dioxide per year. This increase in the emissions was largely attributed to; inefficiency in aircraft operations and increase in the number aircraft. The study further revealed that, the compliance levels against CORSIA SARPs in Zambia's aviation sector were low to medium. This was owing to the absence of an electronic platform to capture data relevant to determine emissions, none appointment of an independent emissions monitor, tendency of poor records keeping among operators attributed to Zambia and partial operationalization of the Zambia's Action Plan for the Reduction of Carbon Dioxide Gas Emissions in Aviation.

7.2 Recommendations

In view of the foregoing research findings, discussion and conclusion made above, the following recommendations are made with a view of enhancing a low carbon aviation industry in Zambia in the face of climate change:

i. The Government and the private sector engaged in aviation should acquire modern navigation aids to enhance efficiency in ground handling operations and aircraft operations.

ii. ZCAA need to take a leading role in the setting up of an electronic platform to enhance accessibility of data among key stakeholders in the process of ensuring that CORSIA SARPs were adhered to.

iii. ZCAA need to quickly appoint an independent emissions monitor to ensure credibility and quality in records keeping pursuant to meeting CORSIA requirements.

iv. There is need to incorporate the international aviation emissions attributed to Zambia into the Nationally Determined Contributions for easy monitoring and for the Government to be held accountable.

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Appendices

Appendix A: Interview Guide for Key Informants

A. Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA) Level of Awareness Among Aviation Stakeholders in Zambia

1. Are you aware of the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA), a programme which is intended at reducing carbon emissions from the international aviation?

2. What do you know about Zambia's Emissions Action Plan?

B. The Significance of CORSIA in Zambia

3. How significant do you think is CORSIA to a country like Zambia?

C. Level of Progress in the Implementation of the CORSIA in Zambia

4. What is the level of progress in terms of CORSIA implementation in Zambia regarding:

    i. Identification of the international flights attributed to the Zambian Aeroplane Operators?

    ii. Records keeping relevant to the Aeroplane Operator's carbon dioxide (CO_2) emissions per aerodrome pair?

    iii. Monitoring of the identified international fights CO_2 emissions?

D. Challenges in Implementing the CORSIA programme in Zambia

5. In view of the above (Q4), what are the challenges in:

i. Identifying of the international flights attributed to the Zambian Aeroplane Operators?

ii. Records keeping relevant to the Aeroplane Operator's carbon dioxide (CO_2) emissions per aerodrome pair?

iii. Monitoring of the identified international fights CO_2 emissions?

6. What do you think should be done to address these challenges identified above?

E. Causes of the Current Status with Regards to International Flights Carbon Emissions in Zambia

7. What do you think could have been the causes of the observed steady increase in the international aviation carbon emissions in Zambia for the past nine years?

8. In view of the above, what do you think should be done to improve the situation in an effort to ensure an environmentally friendly aviation industry in Zambia?

9. Do you have any comment over what we have discussed?

Appendix B: Data Sheet

Year	International Fuel(LTR)	CO_2Kg (000,000)	Active Number of Aircraft